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SUMMARY

Ultra High Performance Concrete (UHPC) in case of fire


Fabricio Longhi Bolina

  <https://doi.org/10.56238/sevened2024.004-001>

1-16

Chemical treatment, different conditions and storage periods on the physiological quality of rice seeds



Samara Pedroso Beier, Chaiane Guerra da Conceição, Eracilda Fontanela, Lanes Beatriz Acosta Jaques, Camila Fontoura Nunes and Vinícius dos Santos Cunha

  <https://doi.org/10.56238/sevened2024.004-002>

17-28

Analysis of failures in chemistry-related disciplines and the creation of a leveling discipline



Maria Lucia Teixeira Guerra de Mendonça, Flávia de Almeida Vieira, Carla Bilheiro Santi and Rosana Pefinatti da Cruz

  <https://doi.org/10.56238/sevened2024.004-003>

29-40

Teaching in transport: The use of active methods in the discipline of urban transport



Christiane Lima Barbosa

  <https://doi.org/10.56238/sevened2024.004-004>

41-58

An innovative approach: Agile methodologies for the design of power circuit breakers



Paulo Roberto Duailibe Monteiro, Thiago Trezza Borges and André Fernando Schiochet

  <https://doi.org/10.56238/sevened2024.004-005>

59-72

A real-time computational approach for human facial expression recognition based on landmark feature extraction



Dennis P. Lopez, Felipe Z. Canal, Gustavo G. Scotton, Eliane Pozzebon and Antonio C. Sobieranski

  <https://doi.org/10.56238/sevened2024.004-006>

73-93

The quality of hydrochloric acid produced according to technological routes, contaminants and industrial applications



Fernando B. Mainier, Pedro Ivo Canesso Guimarães and Renata Jogaib Mainier

  <https://doi.org/10.56238/sevened2024.004-007>

94-123

Endophytic bacteria in the biological control of *Spodoptera frugiperda*



Irisléia Pereira Soares de Sousa, Martielle Batista Fernandes, Michelle de Oliveira Santos, Amanda Dayanne Malta Matos, Sabrina Gonçalves Vieira de Castro, Luciele Barboza de Almeida, Marielly Maria Almeida Moura, Helena Souza Nascimento Santos, Jaqueline Pereira Medeiros da Silva and Edson Hiydu Mizobutsi

  <https://doi.org/10.56238/sevened2024.004-008>

124-135

Hydrogen production: The future pillar of energy sector



Hariel Abreu Pereira, Ana Carolina Miranda Magalhães, João José de Moura Vieira, William Magalhães Barcellos and Auzuir Ripardo de Alexandria

  <https://doi.org/10.56238/sevened2024.004-009>

.....136-153

Surface water quality assessment with a fuzzy inference system



Edith Meryluz Claros-Guerrero and Fredy Román Paredes Aguirre

  <https://doi.org/10.56238/sevened2024.004-010>

.....154-164

Analysis of hemoglobin values in prostate cancer patients treated with external radiotherapy



Jéssika Sthephane Crislene Mendes, Larissa Bluma Lopes, Livia de Castro Sbano, Rebeca Pimenta Martins Malvão, Giulia Nogueira Franca, Antonio Belmiro Rodrigues Campbell Penna, Angela Cristina Marinho Moreira, Ana Cláudia Marinho Cardoso, Carla Ribeiro Nogueira Franca, Reynaldo Real Martins Júnior and Carlos Antonio da Silva Franca

  <https://doi.org/10.56238/sevened2024.004-011>

.....165-168

Environmental impact of pollutants and the potential contribution to phytoremediation



Sandra Ávila Gaspar, Denise Nagamatsu, Fábio de Almeida Bolognani, Morgana Teixeira Lima Castelo Branco, Alexandre dos Santos Pyrho, Simone da Silva, Paulo Sérgio Torres Bioso and Marcia Cristina Braga Nunes Varricchio

  <https://doi.org/10.56238/sevened2024.004-012>

.....169-192

Impact of the Charitas-Cafubá tunnel on vehicle travel time



Bernardo Valentim da Rocha, Luiz Afonso Penha de Sousa, Clezio Thadeu de Souza Dutra and Vinícius Araújo de Souza Dutra

  <https://doi.org/10.56238/sevened2024.004-014>

.....193-207

Spectral behavior of tree species of individuals of the families Fabaceae and Myrtaceae, present in the Botanical Garden of the Federal University of Santa Maria (UFSM)



Roberta Aparecida Fantinel, Ana Caroline Paim Benedetti, Claire Delfini Viana Cardoso, Renato Giovani Chaves de Sá, Natália Melos Duarte and Vinícius Henrique Fernandes

  <https://doi.org/10.56238/sevened2024.004-015>

.....208-218

Investigation of the quality of refined soybean oil after the short-term domestic frying process of breading nuggets



Sarah Moura de Oliveira, Ketily Alves Lariú, Carla Gabrielle da Silva de Jesus, Taís Andreza Batista de Jesus and Emília Akil

  <https://doi.org/10.56238/sevened2024.004-016>

.....219-229

Sleep-related movement disorders



Karoline Sias Rocha, Marcele Rodrigues Raphael da Silva Ramos, Nayara Priscila Resende Marinho, Roberta Baldez Verdan, Priscila Saturnino Sousa Lacerda, Maria Esther Silveira Gulberti, Eduarda Beatriz Montenegro de Figueiredo Soares and Natália Carion Haddad

  <https://doi.org/10.56238/sevened2024.004-017>

.....230-247

Potential plastic digester of Euphorbia Tirucalli



Sandra Ávila Gaspar, Rayssa de Macedo Rebelo, Alexandre dos Santos Pyrrho, Simone da Silva, Marcia Cristina Braga Nunes Varricchio and Paulo Sérgio Torres Briosso

  <https://doi.org/10.56238/sevened2024.004-018>

.....248-262

Sustainable use of the pseudostem and rachis of banana Musa sp.



María del Carmen Cuj Chan, Ana Laura Luna Jiménez, Juan Guzmán Ceferino, Nicolás González Cortés and Román Jiménez Vera

  <https://doi.org/10.56238/sevened2024.004-019>

.....263-280

Solid Waste Management of the municipalities of the state of Rondônia in the Western Amazon – Brazil



Lucélia Largura do Vale Vidigal

  <https://doi.org/10.56238/sevened2024.004-020>

.....281-312

Respirable particles, the influence of the tropical climate and the importance of monitoring air quality in the city of Manaus-AM



Ilsa Maria Honório de Valois Coelho, Elizabeth Ferreira Cartaxo, Raquel Salgado Marques and Thiago Mendes de Freitas

  <https://doi.org/10.56238/sevened2024.004-021>

.....313-332

Thermal performance of liquid metal phase heat exchanger used in hydrogen production by thermal efficiency method



Élcio Nogueira and Diniz Felix dos Santos Filho

  <https://doi.org/10.56238/sevened2024.004-022>

.....333-359

Implementation of lean manufacturing in the cake mix production line and its effects on Overall Equipment Effectiveness



Samira Abreu Jamal and Rodrigo Zunta Raia

  <https://doi.org/10.56238/sevened2024.004-023>

.....360-380

Management of urban solid waste in the city of Manaus-AM. Thermal characterization for power generation



Melquizedec Arcos Rodrigues, Kamal Abdel Radi Ismail, Fátima Aparecida de Moraes Lino and Inácia Oliveira de Azevedo

  <https://doi.org/10.56238/sevened2024.004-024>

.....381-407

The prevalence of neck pain, back pain and low back pain among 3RD year medical students at universities in the metropolitan region of Porto Alegre in times of COVID-19



Vivian Pena Della Mea, Carolaine de Oliveira, Marcelo Teodoro Ezequiel Guerra, Carlos Roberto Galia and Samantha Almeida

  <https://doi.org/10.56238/sevened2024.004-025>

.....408-417

Evaluation of the physical-chemical quality of honey without inspection registration sold in municipalities of Itapira and Mogi Guaçu, State of São Paulo



Gabriele Zulato, Renan Augusto Coghi and Mariana Borges de Lima Dutra

  <https://doi.org/10.56238/sevened2024.004-026>

.....418-442


Analysis of busbar arrangements in substations: A methodological approach

Larisa Alves Gomes, Paulo Roberto Duailibe Monteiro and Thiago Trezza Borges

  <https://doi.org/10.56238/sevened2024.004-027>

.....443-458

Ultra High Performance Concrete (UHPC) in case of fire

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Fabricio Longhi Bolina¹

ABSTRACT

Ultra-high-performance concrete (UHPC) has exceptional mechanical properties at room temperature. However, there are no standardized procedures to characterize UHPC in fire. This is due to the lack of research on the subject, leaving gaps for experimental and numerical studies. This study collects a series of parametric data of UHPC at high temperatures. Thermal diffusivity, thermal conductivity, thermal strain and specific heat as thermal parameters were defined for different temperature ranges. The results were compared with other structural concretes proposed in the literature (NSC, HSC and UHSC). The UHPC exhibited a particular fire behavior. Compared to NSC, HSC and UHSC, the thermal expansion and mechanical parameters of UHPC are less affected in fire, but its thermal conductivity and mass loss are higher. UHPC also has the highest specific heat compared to other concretes. The thermal field of UHPC tends to be higher compared to the other concretes.

Keywords: UHPC, Thermal properties, Structures in fire.

Notation:

CA	Coarse aggregate
FA	Fly ash
HSC	High-strength concrete
NSC	Normal-strength concrete
PVA	Polyvinyl acetate
SF	Silica fume
UHPC	Ultra-High-Performance Concrete
UHSC	Ultra-High Strength Concrete
w/b	Water-binder ratio
C _p	Specific heat
k	Thermal conductivity

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INTRODUCTION

Ultra-high-performance concrete (UHPC) is a cementitious concrete with remarkable mechanical properties at room temperature. The specified compressive strength must be at least 120 MPa according to ASTM C1856 (2017) [1]. UHPC has low w/b, high cement content, aggregates, fibers (steel, PVA, glass) and superplasticizer. Its matrix is very dense and has a minimum of interconnected pores, making it an attractive option in chemically aggressive environments.

Buildings are vulnerable to fire. According to Zhu et al. (2021) [2], there is not much research on UHPC at high temperatures. However, UHPC must behave well in fire to be used as a building material. Studies such as Xiong and Liew (2016) [3], Kodur and Khaliq (2011) [4], Li, Qian, and Sun (2004) [5], Poon, Shui, and Lam (2004) [6], Kodur and Sultan (2003) [7], and Shin et al. (2002) [8] already show that high-strength concrete (HCC) does not have the same fire behavior as normal-strength concrete (NSC) due to concrete spalling, as also stated by Ullah et al. (2022) [9] and Akca and Zihnioglu (2013) [10]. According to Liang et al. (2013) [11], spalling occurs more frequently in UHPCs than in NSCs due to their dense structure and limited permeability. Analysis of concrete spalling has been the focus of research that sought to parametrically analyze UHPC under fire conditions [3, 10, 11, 12, 13, 14, 15, 16, 17].

There are no standardized fire design requirements for UHPC structures. Standards such as EN 1992-1.2 (2004) [18], ACI-216 (2014) [19], AS 3600 (2018) [20], NZS 3101-1 (2006) [21], and NBR 15200 (2012) [22] do not provide thermomechanical values for fire design RC structures with compressive strength greater than 100 MPa. There are few studies on this topic, and the fire behavior of UHPC is not well known in the literature. This is a problem in fire design of RC structures. Few studies have attempted to define the thermal properties of UHPC in fire. In this regard, authors such as Ullah et al. (2022) [9] do not suggest any application of UHPC in fire.

There is a discrepancy. Authors such as Du et al. (2021) [23], Willie, Naaman, and Parra-Montessinos (2011) [24], and Habel et al. (2006) [25] believe that UHPC is one of the most promising building materials for the future, but others, including Zhu et al. (2021) [2] and Ullah et al. (2022) [9], question its fire sensitivity. There is a need to do more research on UHPC in fire. According to SFPE (2008) [33], the fire performance of structures depends on the high-temperature properties of their materials.

In contrast, recent UHPC research does not analyze fire behavior. Zhang et al. (2022) [26] studied the mechanical behavior of RC column with UHPC jacket at room temperature; Tian and al. (2022) [27] and Zhou et al. (2023) [28] studied the performance of UHPC under cyclic loading; Zhang et al. (2022) [29] the flexural behavior of UHPC beams; Zhang et al. (2023) [30] the use of UHPC with recycled fine concrete; Li et al. (2023) [31] the mechanical properties of UHPC with

different types of cement, Cui et al. (2023) [32] with expansion agents in the concrete mix, among others.

Kodur et al. (2020) [37] investigated the thermal properties of UHPC. Conductivity, specific heat, mass loss, and expansion were investigated by the authors. The literature review recommended by Zhu et al. (2021) [2] proved to be the only study that suggested thermal parameters for UHPC in different temperature ranges. The UHPC studied by Kodur et al. (2020) with f_c value between 164 and 178 MPa contains SF, silica sand, PP and steel fibers, slag and coarse aggregates (CA). Yang et al. (2019) [38] already show that CA reduces the thermal field of UHPC, i.e., UHPC without CA has a much larger temperature gradient than UHPC with CA. The UHPC in this study does not contain CA, but PVA fibers and a 750-day curing of the concrete, which makes this study a precedent. UHPC without CA has not yet been evaluated in the literature.

In this study, the thermal properties of UHPC without CA were determined. Conductivity, diffusivity, specific heat and thermal elongation were determined as thermal properties. Equations, diagrams, and tables for the use of these parameters in fire design of structures were presented to fill a gap in standard procedures.

METHODS

The methods used to characterize UHPC in each temperature range are shown. The materials used to build the UHPC are shown below.

MATERIALS

The cement used was a high-initial resistance type that contained fewer chemical cement additions. It is a Portland cement used in Brazil classified as CP-V ARI by NBR 16697 [39]. Silica fume (88.5% silicon contained) and fly ash (50.0% of silicon content) were used with, respectively, specific gravity of 350 kg/m³ and 210 kg/m³. Silica fume acts as a microfiller. It also reacts with calcium hydroxide, thus increasing the final strength.

A natural quartz sand with 260 kg/m³ was incorporated. It is a river sand that received a washing process to eliminate impurities. The steel fiber had a length of 25 mm and a diameter of 0.75 mm, with a tensile strength of 1100 MPa and a modulus of elasticity of 210 GPa. The PVA (polyvinyl acetate) fiber had a length of 12 mm and 0.04 mm in diameter, tensile strength of 1600 MPa and modulus of elasticity of 41 GPa. Superplasticizing additive based on polycarboxylates was incorporated to improve the workability of the concrete. The UHPC production and mix was made according to Christ et al. (2022) [40] method.

The concrete mix is presented in Table 1.

Table 1 – Concrete mix

Material	Unit content (kg/m ³)	Ratios of concrete mix
Cement	488	1.00
Silica fume	268	0.55
Fly ash	235	0.48
Natural sand (fine aggregate)	1025	2.10
Steel fiber	120	0.25
PVA fiber	6	0.02
Chemical additive	17.6	0.03
Water	178	0.36

The average compression strength of the concrete at 28, 150 and 750 days were 108.0, 146.4 and 162.4 MPa, respectively. The elastic modulus was 41.4, 44.0 and 46.1 GPa at, respectively, 28, 150 and 750 days. These results were obtained by testing a concrete cylinder with a dimension of 150x300 mm (diameter x length) made according to ASTM C470 [41]. The concrete compressive strength testing was obtained according to ASTM C39 [42] and the elastic modulus in accordance to ASTM C469 (2014) [43] procedures. The concrete samples are produced in accordance to ASTM C31 [44] and ASTM C192 [45].

THERMAL PROPERTIES DEFINITIONS

The thermal diffusivity, specific heat, thermal conductivity and thermal elongation data were determined as shown below.

Diffusivity

The thermal diffusivity of UHPC was obtained according to the Flash Method proposed by ASTM E1461 [39]. The method is used to measure values of thermal diffusivity of a wide range of solid materials. The results were obtained by testing a concrete cylinder with a dimension of 12.7x2.5 mm (diameter x thickness) in accordance to ASTM E1461-13 [46] prescriptions. The UHPC specimens were heating to 100, 200, 300, 400, 500 and 600°C. The test equipment used was a thermal diffusivity analyzer (TDA) with a temperature range from -125°C to 500°C, a thermal diffusivity measurement ranges from 0.01mm²/s to 1000mm²/s and a thermal conductivity range from 0.1W/mK to 2000W/mK..

According to the thermal diffusivity (α) results and with the density in fire (ρ) it is possible to obtain the specific heat (C_p) and thermal conductivity (k) according to Equation (1).

$$\alpha = k/\rho \cdot C_p \quad (1)$$

Specific heat

According to the thermal diffusivity results and according to Equation 1, the specific heat values were defined for the same temperature ranges as in section 2.2.1.

Conductivity

According to the results of thermal diffusivity and Equation 1, the thermal conductivity values were defined for the same temperature ranges as in section 2.2.1.

CORRELATION WITH THE STANDARD PROCEDURES AND REFERENCES

The results (data available in this research) were compared with those proposed by the references. When possible, the data were compared with normal-strength (NSC), high-strength (HSC), ultra-high-strength (UHSC) and, when available, ultra-high-performance (UHPC) concrete similar to this research. Graphs were proposed with the UHPC results of this research. From these, new equations were extracted.

REMARKS FOR TESTING UHPC IN HIGH TEMPERATURES

The first fire tests with UHPC test specimens were evaluated at 28 and 150 days after their construction. However, in these ages, there was explosive spalling of the concrete. In the first case, there was spalling when the specimen was heated to around 100°C. In the second case, when heated to 300°C. After 700 days, the specimens showed no more concrete spalling when heated to 800°C. This justifies carrying out the tests with 750 days.

The low porosity of UHPC prevents internal dissipation of water vapor produced during heating. It is necessary that fire tests be carried out on aged concrete. Due to the high mechanical strength of UHPC, the amount of internal water vapor is high and the concrete spalling is explosive. These results are in agreement with Zhu et al. (2021) [2] and Ullah et al. (2022) [9], who showed that UHPC is more susceptible to spalling in fire than NSC. However, it is important to highlight that the spalling decreases with age, as the internal humidity of the concrete tends to reduce with age, as shown by Manica et al. (2020) [50] and in accordance the previous results of this research.

RESULTS AND DISCUSSION

The results of this research are presented.

THERMAL ELONGATION

Table 1 and Figure 1 a show the thermal elongation ($\Delta L/L_0$) results of UHPC for different temperature ranges. Figure 1b shows the comparison of these results with references.

Figure 1 – Thermal elongation at high temperatures

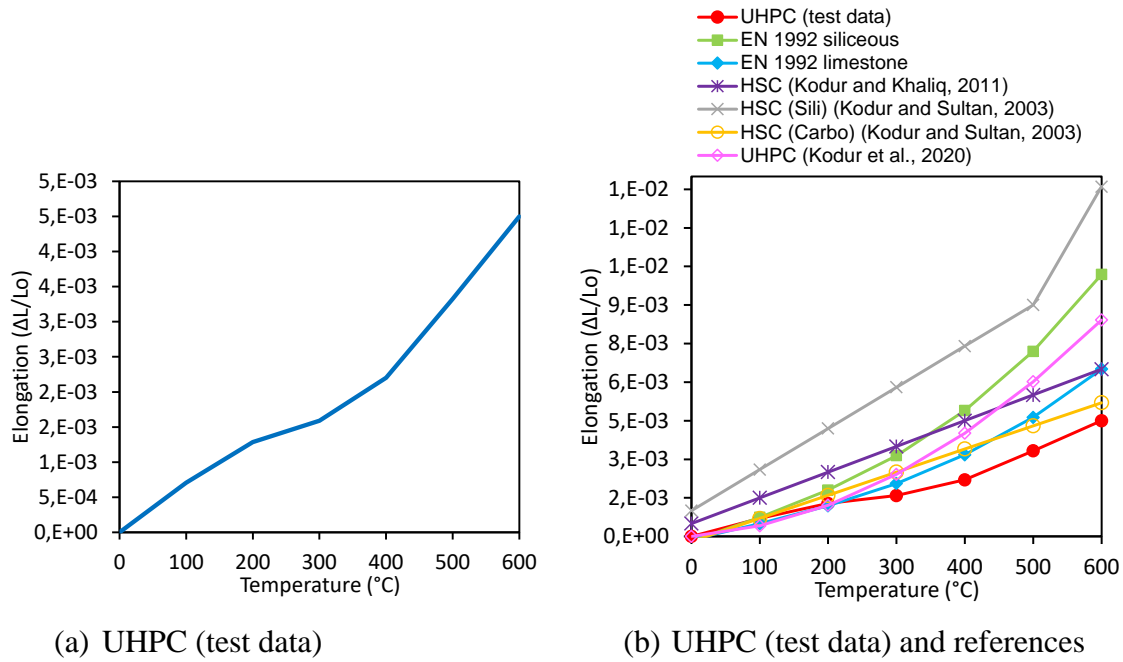


Table 1 – Thermal elongation: correlation between UHPC and references

Temperature (°C)	Thermal elongation $\Delta L/L_0$ ($\times 10^{-3}$)						
	UHPC Test Data	EN 1992 NSC (Sili) (C20/50)	EN 1992 NSC (Lime) (C20/50)	HSC (Kodur and Khaliq, 2011)	HSC - Sili (Kodur and Sultan, 2003)	HSC - Carbo (Kodur and Sultan, 2003)	UHPC (Kodur et al., 2020)
	(a)	(b)	(c)	(d)	(e)	(f)	(g)
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.71	0.74	0.50	1.50	2.60	0.70	0.41
200	1.28	1.80	1.19	2.50	4.20	1.60	1.21
300	1.59	3.14	2.06	3.50	5.80	2.50	2.41
400	2.20	4.89	3.18	4.50	7.40	3.40	4.01
500	3.33	7.20	4.63	5.50	9.00	4.30	6.01
600	4.50	10.2	6.50	6.50	13.6	5.20	8.41

UHPC (Table 1a) has positive thermal elongation when exposed to high temperatures, as with other concretes (Table 1b-g). The UHPC of this research had the lowest $\Delta L/L_0$ value in relation to the others. Up to 100°C thermal elongation can be related to the loss of humidity (free water) in the concrete. Between 200 and 300°C, it can be related to the loss of adsorbed water from hydrated cement compounds and aggregates. Between 300 and 500°C, values may be associated with $C_a(OH)_2$ and CaO dehydration, as reported by Laneyrie et al. (2016) [16]. The lower expansion of UHPC (Table 1a) in relation to the other concretes (Table 1b to f) shows the influence of the coarse aggregate in this aspect. In relation to the UHPC tested by Kodur et al. (2020) [37], in addition to the aggregate, also the experimental procedure (see section 2).

Specific heat

Figure 2a and Table 2 show the specific heat results of UHPC in different temperature ranges. Figure 2b shows the comparison of these results with references.

Figure 2 – Thermal elongation at high temperatures

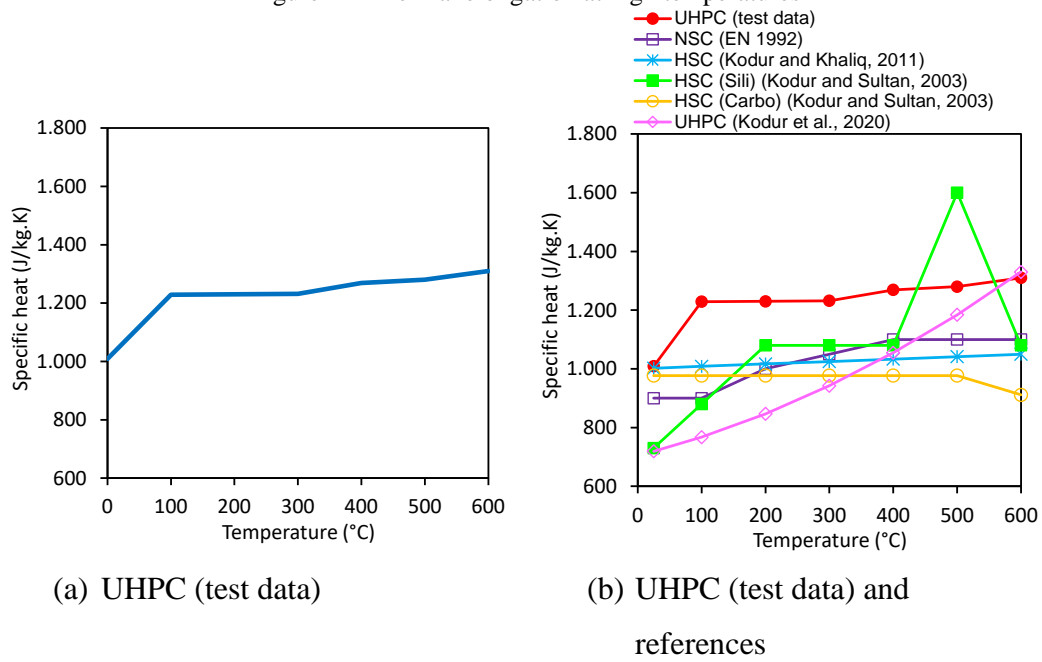


Table 2 – Thermal elongation: correlation between UHPC and references

Temperature (°C)	Specific heat (J/kg.K)						
	UHPC Test Data	NSC EN 1992 (C20/50)	NSC (Shin et al., 2002)	HSC (Kodur and Khaliq, 2011)	UHPC (Kodur et al., 2020)	HSC - Sili (Kodur and Sultan, 2003)	HSC - Carbo (Kodur and Sultan, 2003)
	(a)	(b)	(c)	(d)	(e)	(f)	(g)
25	1009	900	1104	1000	720	730	977
100	1229	900	-	1008	767	880	977
200	1230	1000	-	1016	846	1080	977
300	1232	1050	-	1025	942	1080	977
400	1269	1100	-	1033	1055	1080	977
500	1280	1100	1354	1041	1184	1600	977
600	1310	1100	-	1050	1330	1080	911

Specific heat changes with temperature due to chemical and physical changes that occur in cement past and aggregates when in heating. According to fib Bulletin 38 (2007) [55] and Kodur et al. (2020) [37], specific heat around 100°C increases because of evaporation of moisture present in the form of free water (Figure 2). Between 100°C–300°C, specific heat increases further due to the evaporation of moisture present in the remaining free water, in addition to the adsorbed and bonded water. In 300-500°C range, the C_p value remains almost constant because of the counteracting effects of decrease in moisture due to complete evaporation of free water and the increase in humidity due to $\text{Ca}(\text{OH})_2$ decomposition. There is a small increase in C_p after this temperature due to the release of moisture from the decomposition of the C–S–H gel and significant deterioration of the microstructure within the concrete.

In the case of the UHPC, Figure 2a and Table 2a show that at 25°C its specific heat is 1009 J/kg.k. This means that the amount of energy required to increase the temperature of 1 kg of UHPC by 1K is 1009 J. At the same temperature, these values are similar to those presented by Shin et al.

(2002) [8] for NSC, by Kodur and Khaliq (2011) [4] for HSC and Kodur and Sultan (2003) [7] by HSC with carbonate aggregate. however, the UHPC value at 25°C (Table 2a) was lower than those reported by EN 1992 for the NSC (Table 2b), for the UHPC evaluated by Kodur et al. (2020) [27] (Table 2e), and also for HSC with siliceous aggregates proposed by Kodur and Sultan (2003) [7] (Table 2f).

According to Figure 2a and Table 2a, at 100°C, the C_p of the UHPC tested increased to 1229 J/kg.K. At the end of the tests (600°C) the value was 1310 J/kg.K. For the equations proposed in section 5, the value of the specific heat in the range from 100 to 600°C was defined as the average of the C_p readings in this temperature range (i.e., 1270 J/kg.K). This is a practical simplification of fire design since there is variability between the results, according to Table 2.

In the temperature range 100-600°C, the same interpretation and comparison made at 25°C between researches is preserved (Table 2a-g). However, the research of Kodur et al. (2020) [37] for UHPC (Table 2e) and Kodur and Sultan (2003) [7] (Table 2f) for HSC, which at initial temperatures (i.e., 25 °C) did not converge with the UHPC of this research, tends to converge at the end of analysis. Normally the UHPC of this research (Table 2a) has a specific heat relatively higher in relation to the others concretes. It can be attributed to the lower permeability and dense microstructure of UHPC that requires more heat for evaporation of water.

Conductivity

Figure 3a plots the thermal conductivity of UHPC for various temperature ranges. Figure 3b and Table 3 show the comparison of these results with bibliography.

Figure 3 – Thermal elongation at high temperatures

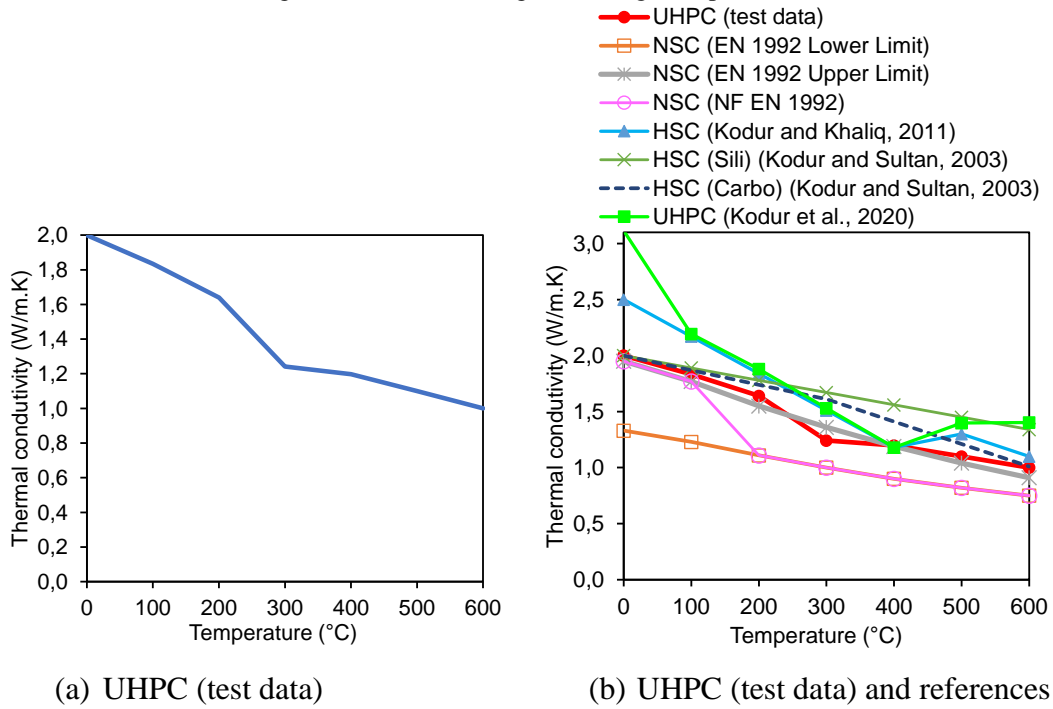


Table 3 – Thermal conductivity: correlation between UHPC and references

Temperature (°C)	Thermal conductivity (W/m.K)								
	UHPC Test Data	NSC (lower limit) EN 1992	NSC (Upper limit) EN 1992	NSC NF EN 1992	NSC (Shin et al., 2002)	HSC (Kodur Khaliq, 2011)	UHPC (Kodur et al., 2020)	HSC - Sili (Kodur and Sultan, 2003)	HSC - Carbo (Kodur and Sultan, 2003)
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
25	2.00	1.33	1.95	1.95	2.19	2.42	3.11	1.97	1.97
100	1.83	1.23	1.77	1.77	-	2.17	2.19	1.89	1.87
200	1.64	1.11	1.55	1.11	-	1.84	1.88	1.78	1.74
300	1.24	1.00	1.36	1.00	-	1.51	1.53	1.67	1.61
400	1.20	0.90	1.19	0.90	-	1.18	1.18	1.56	1.41
500	1.10	0.82	1.04	0.82	1.28	1.30	1.40	1.45	1.21
600	1.00	0.75	0.91	0.75	-	1.10	1.40	1.34	1.00

Thermal conductivity variation in concrete with temperature is governed by the change in moisture levels in fire. Concrete moisture decreases with increasing temperature and therefore thermal conductivity decreases at high temperatures. At temperatures above 100°C, free water starts to evaporate, sometimes causing spalling. When the concrete temperature reaches about 300°C, the adsorbed water from the calcium silicate hydrate (C–S–H) gel and a part of the chemically bound water begin to evaporate. The concrete temperature further to 400°C causes decomposition of $C_a(OH)_2$, converting it into C_aO and H_2O , increasing the moisture content of concrete. Further

increase in temperature beyond 500°C leads to decomposition of C—S—H and further deterioration of concrete and aggregate.

According to Figure 3b and Table 3, it can be seen that the UHPC in this research (Table 3a) are, respectively, 50.4%, 2.6% and 2.6% higher in relation to the NSC proposed by EN 1992-1.2 [18] (Table 3b and c) and NF EN 1992 [53] (Table 3d). Research by Kodur et al. (2020) [37] show that the UHPC had a conductivity 55% higher than those obtained in this research. After 300°C, the values between both researches tend to converge. In relation to the NSC proposed by the EN 1992-1.2, the UHPC tested by Kodur et al. (2020) were 133.8% higher. The notable variability in these results is understandable, and can be attributed to varying moisture content, cement type, aggregate, test conditions and measurements techniques used in each research, as explain by Kodur et al. (2020) [37], Kodur et al. (2019) [52], Bazant and Kaplan (1996) [54].

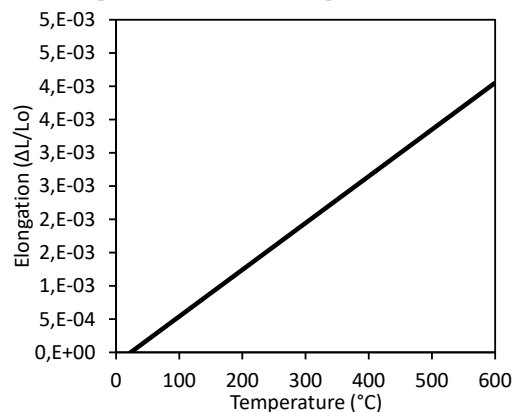
PROPOSAL OF PROCEDURES FOR STRUCTURAL FIRE DESIGN

In this section, due to the absence of the NBR 15200 standard, parametric data are proposed to support the fire-design of UHPC structures in case of fire.

ELONGATION

Figure 4 and Equation 3 show the proposed thermal elongation values for UHPC at different temperature ranges.

Figure 4 – Proposal of thermal elongation values for UHPC

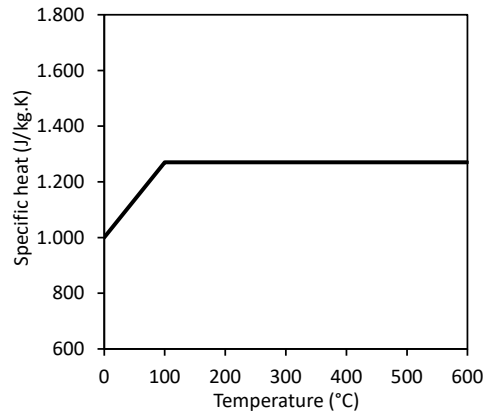


$$\frac{\Delta L}{L_0} = 7 \times 10^{-6} \times T - 2 \times 10^{-4} \quad (R^2=0.96) \quad (3)$$

SPECIFIC HEAT

Figure 5 and Equation 4 show the proposed specific heat values for UHPC at different temperature ranges.

Figure 5 – Proposal of specific heat values for UHPC

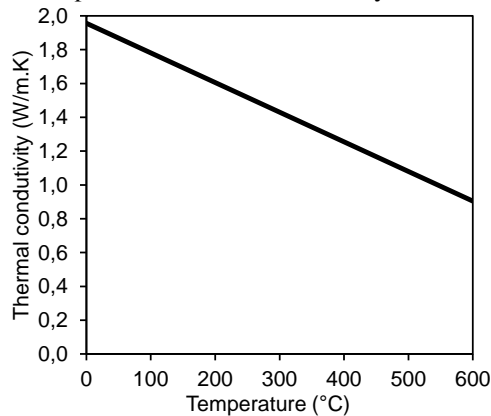


$$\begin{aligned}
 C_p &= 2.7 \times T + 1000 \text{ [J/kg.K]} & 25 \leq T < 100^\circ\text{C} \\
 (R^2=0.99) & & \\
 C_p &= 1270 \text{ [J/kg.K]} (R^2=0.95) & 100 \leq T \leq 600^\circ\text{C}
 \end{aligned}
 \tag{4}$$

CONDUCTIVITY

Figure 6 and Equation 5 show the proposed specific heat values for UHPC at different temperature ranges.

Figure 6 – Proposal of thermal conductivity values for UHPC



$$k_\theta = -1.8 \times 10^{-3} \times T + 1.95 \text{ [W/m.k]} (R^2=0.95)
 \tag{5}$$

CONCLUSIONS

The general conclusions of this paper are:

- This research demonstrated that UHPC specimens tested before 700 days are susceptible to concrete spalling;
- When compared to NSC (according to EN 1992-1.2 parameters), UHPC showed higher thermal diffusivity;



- In this sense, in relation to NSC, UHPC will have a higher average temperature;
- When compared to NSC and HSC, UHPC has the lowest thermal elongation;
- UHPC has a specific heat higher in relation to the others concretes (NSC, HSC). It can be attributed to the lower permeability and dense microstructure of UHPC that requires more heat for evaporation of water;
- Thermal conductivity of UHPC is also higher than NSC. Steel fibers can justify these results;
- New equations were proposed to define the thermal, physical and mechanical parameters of UHPC at high temperatures. These equations are essential for researchers who intend to carry out numerical research with the UHPC;
- As future research, it is recommended to compare the fire performance of UHPC with NSC. In the view of the authors, this comparison should be holistic and from a structural perspective. The combination of mechanical and thermal results are the motivation: in relation to NSC, UHPC has a larger thermal field but is less mechanically affected by temperatures;

REFERENCES


- [1.] ASTM C1856. Standard Practice for Fabricating and Testing Specimens of Ultra High-Performance Concrete. ASTM International, West Conshohocken, United States (2017).
- [2.] Y Zhu, H Hussein, A Kumar, G Chen. A review: Material and structural properties of UHPC at elevated temperatures or fire conditions. *Cement and Concrete Composites*. (2021) V123. <https://doi.org/10.1016/j.cemconcomp.2021.104212>
- [3.] MX Xiong, JTR Liew. Mechanical behaviour of ultra-high strength concrete at elevated temperatures and fire resistance of ultra-high strength concrete filled steel tubes. *Materials and Design* (2016). v. 104, pp. 414-427. <https://doi.org/10.1016/j.matdes.2016.05.050>
- [4.] VKR Kodur, W Khaliq. Effect of Temperature on Thermal Properties of Different Types of High-Strength Concrete. *Journal of Materials in Civil Engineering (ASCE)* (2011) V.15, Issue 2. [https://doi.org/10.1061/\(ASCE\)0899-1561\(2003\)15:2\(101\)](https://doi.org/10.1061/(ASCE)0899-1561(2003)15:2(101))
- [5.] M Li, CX Qian, W Sun. Mechanical properties of high-strength concrete after fire. *Cement and Concrete Research* (2004). V.34, Issue 6, pp.1001-1005. <https://doi.org/10.1016/j.cemconres.2003.11.007>
- [6.] CS Poon, ZH Shui, L Lam. Compressive behavior of fiber reinforced high-performance concrete subjected to elevated temperatures. *Cement and Concrete Research* (2004). V.34, Issue 12. <https://doi.org/10.1016/j.cemconres.2004.02.011>
- [7.] VKR Kodur, MA Sultan. Effect of Temperature on Thermal Properties of High-Strength Concrete. *Journal of Materials in Civil Engineering* (2003). V.15, Issue 2 [https://doi.org/10.1061/\(ASCE\)0899-1561\(2003\)15:2\(101\)](https://doi.org/10.1061/(ASCE)0899-1561(2003)15:2(101))
- [8.] KY Shin, SB Kim, JH Kim, M Chung, PS Jung. Thermo-physical properties and transient heat transfer of concrete at elevated temperatures. *Nuclear Engineering and Design* (2002). V.212, pp.233-241. [https://doi.org/10.1016/S0029-5493\(01\)00487-3](https://doi.org/10.1016/S0029-5493(01)00487-3)
- [9.] R Ullah, Y Qiang, J Ahmad, NI Vatin, MA El-shorbagy MA. Ultra-High-Performance Concrete (UHPC): A State-of-the-Art Review. *Materials* (2022). V15, pp.4431. <https://doi.org/10.3390/ma15124131>
- [10.] AH Akca, NO Zihnioglu. High performance concrete under elevated temperatures. *Construction and Building Materials* (2013). V44, pp.317-328. <https://doi.org/10.1016/j.conbuildmat.2013.03.005>
- [11.] X Liang, C Wu, Y Su, Z Chen, Z Li. Development of ultra-high performance concrete with high fire resistance. *Construction and Building Materials* (2018). V. 179, pp. 400-412. <https://doi.org/10.1016/j.conbuildmat.2018.05.241>
- [12.] S Banerji, VKR Kodur. Effect of temperature on mechanical properties of ultra-high-performance concrete. *Fire and Materials* (2021). V.46, pp. 287-301 <https://doi.org/10.1002/fam.2979>
- [13.] G Choe, G Kim, N Gucunski, S Lee. Evaluation of the mechanical properties of 200 MPa ultra-high-strength concrete at elevated temperatures and residual strength of column. *Construction and Building Materials* (2015). V86, pp.159-168. <https://doi.org/10.1016/j.conbuildmat.2015.03.074>

- [14.] M Abid, X Hou, W Zheng, RR Hussain. Effect of fibers on high-temperature mechanical behavior and microstructure of reactive powder concrete. *Materials* (2019). V.12, pp.1-30. <https://doi.org/10.3390/ma12020329>
- [15.] S Sanchayan, SJ Foster. High temperature behaviour of hybrid steel–PVA fibre reinforced reactive powder concrete. *Materials and Structures* (2016). V.49, pp.769-782. <https://doi.org/10.1617/s11527-015-0537-2>
- [16.] C Laneyrie, AL Beaucour, MF Green, RL Hebert, B Ledesert, A Noumowe. Influence of recycled coarse aggregates on normal and high-performance concrete subjected to elevated temperatures. *Construction and Building Materials* (2016). V.111, pp. 368-378. <https://doi.org/10.1016/j.conbuildmat.2016.02.056>
- [17.] B Luo, C Deng, Y Luo (2022). Mechanical properties and microstructure of UHPC with recycled glasses after exposure to elevated temperatures. *Journal of Building Engineering* (2022). V.62, pp.105369. <https://doi.org/10.1016/j.jobeb.2022.105369>
- [18.] EN 1992-1-2. Eurocode 2: Design of concrete structures - Part 1-2: General rules - Structural fire design. Brussels, Belgium (2004).
- [19.] ACI 216. Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies. American Concrete Institute (ACI). Farmington Hills, Michigan, United States (2014).
- [20.] AS 3600. Concrete Structures. Australian Standard. Sydney, Australia (2018).
- [21.] NZS 3101. Concrete structures standard. The design of concrete structures. Standards New Zealand. Wellington, New Zealand (2006).
- [22.] NBR 15200. Design of reinforced concrete structures in case of fire. Brazilian Standard Association, Rio de Janeiro [in Portuguese] (2012).
- [23.] J Du, W Meng, KH Khayat, Y Bao, P Guo, Z Lyu, A Abu-obeidah, H Nassif, H Wang. New development of ultra-high-performance concrete (UHPC). *Composites Engineering* (2021) V224. <https://doi.org/10.1016/j.compositesb.2021.109220>
- [24.] K Wille, AE Naaman, GJ Parra-Montessinos. Ultra-High Performance Concrete with Compressive Strength Exceeding 150 MPa (22 ksi): A Simpler Way. *ACI Materials Journal* (2011). V.108, pp.46-34. <https://doi.org/10.14359/51664215>
- [25.] K Habel, M Viviani, E Denarié, E Bruhwiler. Development of the mechanical properties of an Ultra-High Performance Fiber Reinforced Concrete (UHPFRC). *Cement and Concrete Research* (2006). V36, Issue 7, pp.1362-1370. <https://doi.org/10.1016/j.cemconres.2006.03.009>
- [26.] X Zhang, X Wu, D Zhang, Q Huang, B Chen. Axial compressive behaviors of reinforced concrete composite column with precast ultra-high-performance concrete (UHPC) jacket. *Journal of Building Engineering* (2022). V.48, pp.103956. <https://doi.org/10.1016/j.jobeb.2021.103956>
- [27.] H Tian, Z Zhou, Y Wei, L Zhang. Experimental and numerical investigation on the seismic performance of concrete-filled UHPC tubular columns. *Journal of Building Engineering* (2022). V.43, pp. 103118. <https://doi.org/10.1016/j.jobeb.2021.103118>

- [28.] F Zhou, Q Su, Y Cheng, H Wu. A novel dynamic constitutive model for UHPC under projectile impact. *Engineering Structures* (2023). V. 280, pp.115711. <https://doi.org/10.1016/j.engstruct.2023.115711>
- [29.] P Zhang, J Shang, Y Liu, J Shao, D Gao, Z Dong, SA Sheikh. Flexural behavior of GFRP bar-reinforced concrete beams with U-shaped UHPC stay-in-place formworks. *Journal of Building Engineering* (2022). V.45, pp. 103403. <https://doi.org/10.1016/j.job.2021.103403>
- [30.] XY Zhang, MX Fan, YX Zhou, DD Ji, JH Li, R Yu. Development of a sustainable alkali activated ultra-high performance concrete (A-UHPC) incorporating recycled concrete fines. *Journal of Building Engineering* (2023). V.67, pp.105986. <https://doi.org/10.1016/j.job.2023.105986>
- [31.] Y Li, X Zeng, Y Shi, K Yang, J Zhou, HA Umar, G Long, Y Xie. A comparative study on mechanical properties and environmental impact of UHPC with belite cement and portland cement. *Journal of Cleaner Production* (2023). V.380, pp.135003. <https://doi.org/10.1016/j.jclepro.2022.135003>
- [32.] Y Cui, Y Li, Q Wang. Engineering performance and expansion mechanism of MgO expansion agent in ultra-high performance concrete (UHPC). *Journal of Building Engineering* (2023). V.68, pp.106079. <https://doi.org/10.1016/j.job.2023.106079>
- [33.] SFPE. *Handbook of fire protection engineering*. Society of Fire Protection Engineers, 4th Ed., Cleveland (2008).
- [34.] JJ Park, DY Yoo, S Kim, SW Kim. Benefits of synthetic fibers on the residual mechanical performance of UHPFRC after exposure to ISO standard fire. *Cement and Concrete Composites* (2019). V.104. <https://doi.org/10.1016/j.cemconcomp.2019.103401>
- [35.] C Kahanji, F Ali, A Nadjai, N Alam. Effect of curing temperature on the behaviour of UHPFRC at elevated temperatures. *Construction and Building Materials* (2018). V182, pp.670-681. <https://doi.org/10.1016/j.conbuildmat.2018.06.163>
- [36.] DX Xuan, ZH Shui. Rehydration activity of hydrated cement paste exposed to high temperature. *Fire and Materials* (2010) V.35, Issue 7. <https://doi.org/10.1002/fam.1067>
- [37.] VKR Kodur, S Banerji, R Solhmirzaei. Effect of Temperature on Thermal Properties of Ultrahigh-Performance Concrete. *ASCE Journal of Materials in Civil Engineering* (2020). V.32. [https://doi.org/10.1061/\(ASCE\)MT.1943-5533.0003286](https://doi.org/10.1061/(ASCE)MT.1943-5533.0003286)
- [38.] J Yang, GF Peng, J Zhao, GS Shui. On the explosive spalling behavior of ultra-high performance concrete with and without coarse aggregate exposed to high temperature. *Construction and Building Materials* (2019). V.226, pp.932-944. <https://doi.org/10.1016/j.conbuildmat.2019.07.299>
- [39.] NBR 16697. *Portland cement - Requirements*. Brazilian Standard Association, Rio de Janeiro [in Portuguese] (2018).
- [40.] R Christ, BF Tutikian, PRL Helene. Proposition of Mixture Design Method for Ultra-High-Performance Concrete. *ACI (American Concrete Institute) Materials Journal*, (2022) V.119, pp.79-89. <https://doi.org/10.14359/51734191>
- [41.] ASTM C470. *Standard Specification for Molds for Forming Concrete Test Cylinders Vertically*. American Society for Testing and Materials, West Conshohocken, United States (2016).

- [42.] ASTM C39. Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. American Society for Testing and Materials, West Conshohocken, United States (2022).
- [43.] ASTM C469. Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression. American Society for Testing and Materials, West Conshohocken, United States (2022).
- [44.] ASTM C31. Standard Practice for Making and Curing Concrete Test Specimens in the Field. American Society for Testing and Materials, West Conshohocken, United States (2022).
- [45.] ASTM C192. Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory. American Society for Testing and Materials, West Conshohocken, United States (2020).
- [46.] ASTM E1461-13. Standard Test Method for Thermal Diffusivity by the Flash Method. American Society for Testing and Materials, West Conshohocken, United States (2022).
- [47.] RILEM TC 129-3 Test methods for mechanical properties of concrete at high temperatures: compressive strength. International Union of Laboratories and Experts in Construction, Materials, Systems and Structures. Cité Descartes, France (1995).
- [48.] RILEM TC 129-5 Test methods for mechanical properties of concrete at high temperatures: modulus of elasticity. Cité Descartes, France (2000).
- [49.] ASTM E228. Standard Test Method for Linear Thermal Expansion of Solid Materials with a Push-Rod Dilatometer. American Society for Testing and Materials, West Conshohocken, United States (2017).
- [50.] G Manica, FL Bolina, BF Tutikian, M Oliveira, MA Moreira. Influence of curing time on the fire performance of solid reinforced concrete plates. *Journal of Materials Research and Technology* (2020). V.9, pp2506-2512. <https://doi.org/10.1016/j.jmrt.2019.12.081>
- [51.] D Zang, Y Liu, KH Tan. Spalling resistance and mechanical properties of strain-hardening ultra-high performance concrete at elevated temperature. *Construction and Building Materials* (2021). V.266. <https://doi.org/10.1016/j.conbuildmat.2020.120961>
- [52.] VKR Kodur, S Banerji, R Solhmirzaei. Test methods for characterizing concrete properties at elevated temperatures. *Fire and Materials* (2019). V.44, pp.381-395. <https://doi.org/10.1002/fam.2777>
- [53.] NF EN 1992-1.2. Design of concrete structures - Part 1-2: general rules - Structural fire design - National annex to NF EN 1992-1-2. France (2005).
- [54.] ZP Bazant, MF Kaplan. *Concrete at temperatures: Material properties and mathematical models*. Essex, UK: Longman Group (1996).
- [55.] FIB Bulletin 38. Fire design of concrete structures – materials, structures and modelling – state of art report. *Fédération Internationale du Béton*, 97p (2007).

Chemical treatment, different conditions and storage periods on the physiological quality of rice seeds

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ABSTRACT

Seed is considered as the main input in agriculture, which must have physiological quality to reach its maximum productive potential. In addition, the germination test is one of the parameters to analyze the viability and represent the emergence in the field when sowing is carried out in ideal soil conditions. Therefore, this work aims to evaluate the germination percentage of rice seeds (*Oryza sativa*) cultivar IRGA 431 CL from the year 2021 with and without seed treatment, stored for different periods in prototypes of vertical silos and big bags. The experiment was carried out at the Post-Harvest Laboratory of the Federal University of Pampa – Alegrete Campus, where they remained for 6 (six) months. The germination tests were set up every 30 (thirty) days throughout the storage period, in the laboratory of the Cooperativa Agroindustrial de Alegrete LTDA. The design to be used was completely randomized (DIC), three-factorial (2 x 2 x 6) for the factors seed treatment levels, type of storage and storage period. There are twenty-four treatments, each with four replications, totaling ninety-six experimental units + initial analysis + final analysis (composed of 4 replications for the use or not of seed treatment). The factors were composed of two seed treatments (T1: with seed treatment; T2: no seed treatment), two storage levels (A1: prototype mini silo; A2: prototype big bag) and six different storage periods (P1: thirty days; P2: sixty days; P3: ninety days; P4: one hundred and twenty days; P5: one hundred and fifty days and P6: one hundred and eighty days). After setting up the germination tests, the counts were performed on the fifth and fourteenth day after insertion in the incubator. The results indicated that there was a reduction in the percentage of vigor and germination throughout the storage period, under the presence of seed treatment, regardless of the type of storage used. Storage in impermeable packaging is less harmful to the physiological quality of the seeds, and the percentage of germination was higher than 80% in all treatments, in accordance with Normative Instruction No. 45 of 2013 for commercialization. From the first 30 days, the portion of treated seeds started to have a decrease in the physiological quality of rice seeds.

Keywords: Germination, Post Harvest, Agricultural Inputs, Store.

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INTRODUCTION

The seed is considered the input with the highest added value, as it carries genetic technology of the varieties, being produced within strict quality standards that provide greater performance in the field, maximizing the action of other inputs, such as fertilizers and pesticides (EMBRAPA, 2021).

The maximum yield potential is a direct result of the physiological quality of seeds, and one of the main parameters for its verification is through the analysis of viability and vigor according to the instructions of the Rules for Seed Analysis – RAS (BRASIL, 2009).

Viability, determined by the germination test, seeks to evaluate the maximum germination of the seed, showing the development of the essential structures of the embryo, demonstrating its aptitude to produce a normal plant under favorable field conditions (BRASIL, 2009). On the other hand, vigor comprises a set of characteristics that determine the physiological potential of seeds, being influenced by the environmental and management conditions during the pre- and post-harvest stages (VIEIRA & CARVALHO, 1994).

In the field, as an alternative to protect the seed in the early stages of the crop, from sowing to seedling emergence, the use of seed treatment has increased due to the greater occurrence of attack by microorganisms and soil pests in the last harvests. Seed treatment is the technique of applying an agricultural pesticide, nutrients (micro/macro) or inoculant on the seeds, with the objective of carrying out phytosanitary control (EMBRAPA, 2013).

The action of insects is one of the main factors that affect rice crops (MARTINS et al., 2004), since the losses caused by them vary between 10 and 35% of production (BENTO, 1999; MARTINS et al., 2000; MARTINS et al., 2004). In addition, according to Costa Lima, in 1936 one of the most harmful insects before the entry of water into the crop is the "rice root worm" or rice weevil (*Oryzophagusoryzae*). As a preventive control measure, rice seed treatment is used.

Although the ambient conditions of the warehouse can be artificially controlled, the cost for such control in large storage areas is generally not economic, which means that almost the entire volume of seeds produced in Brazil is stored at ambient temperature and relative humidity (RAZERA et al. 1986).

The type of packaging used in the packaging of seeds during storage is also of relevant importance to maintain their viability and vigor, seeds preserved in packages that allow exchanges of water vapor with atmospheric air can absorb water under high relative humidity of the air, deteriorating easily (CROCHEMORE, 1993). Therefore, the longevity of stored seeds is also influenced by the type of packaging used for their packaging (POPINIGIS, 1985; WARHAM, 1986).

In this context, the objective of this study was to evaluate the germination and vigor of rice seeds (*Oryza sativa*) from the year 2021 with and without seed treatment, stored for 180 days in prototypes of vertical silos and big bags.

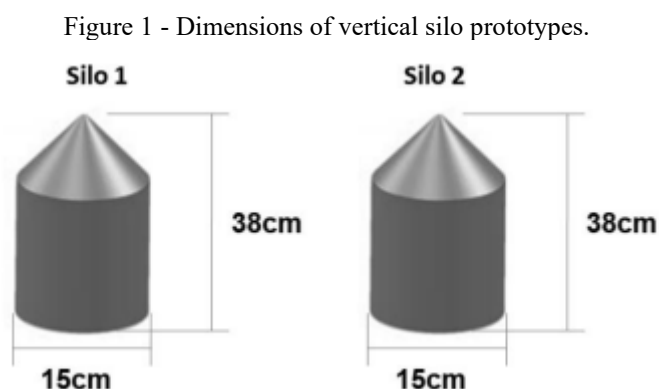
METHODOLOGY

The experiment was carried out at the Post-Harvest Laboratory of the Federal University of Pampa – Alegrete Campus, where they remained for 6 (six) months. According to Köppen and Geiger, the climate of the region is classified as Cfa (humid subtropical climate). The temperature here averages 19.6 °C. The laboratory is located at geographical coordinates 29° 47' latitude, 55° 46' longitude and 95 m altitude.

The design was completely randomized (DIC), tri-factorial (2 x 2 x 6) for the factors seed treatment levels, type of storage and storage period. Twenty-four treatments were used, each with four replications, totaling ninety-six experimental units + initial analysis + final analysis (composed of 4 replicates for the use or not of seed treatment).

The factors were composed of two seed treatments (T1: with seed treatment; T2: no seed treatment), two storage levels (A1: prototype mini silo; A2: prototype big bag) and six different storage periods (P1: thirty days; P2: sixty days; P3: ninety days; P4: one hundred and twenty days; P5: one hundred and fifty days and P6: one hundred and eighty days). The cultivar used for rice seeds (*Oryza sativa*) from the year 2021, used is IRGA 431 CL.

Seed storage was carried out in vertical silo prototypes and big bag prototypes. In the prototypes of vertical silos, the seeds were separated into two batches each weighing 13.5kg (Figure 1). In addition, in Silo 1 lot 1 was packed with seed treatment and in Silo 2 lot 2 without seed treatment.



Source: Adapted from Dubal (2021).

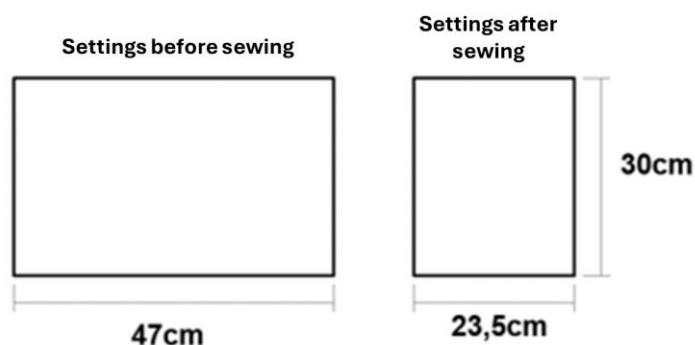
Throughout the time in which the seeds were stored in the prototype vertical silos, temperature and relative humidity readings were taken once a day between 10:30 am and 2:00 pm, every day until the end of the experiment.

For this verification, the MAX-MIN THERMO HYGRO digital hygrometer with an extension cable inserted between the grain mass was used. The device records the minimum and maximum temperature and relative humidity automatically with Accuracy: ± 1 °C (or ± 2 °F) or 5%.

In the big bag prototypes, the seeds were separated into six lots of 1kg each corresponding to each period in which the analyses were performed. Thus, a total of 12 big bag prototypes were obtained between the batch with and without seed treatment.

To make the big bag prototypes, 1 big bag 120x90x90cm with a closed base (raffia) was used, in which 12 pieces of 30x47cm were removed and then sewn (Figure 2). The material of the big bag prototype was prolipropyland with a grammage of 190g/m².

Figure 2 - Dimensions used to make the big bag prototypes.



Source: Authors.

Seed treatment was carried out as recommended by the package insert of the available chemicals: Permit Star = 0.625 at 1 L/100kg of seeds; Cruiser Opti = 0.625 to 1 L/100kg of seeds. An intermediate value of 0.8125 L/100 kg of seeds was adopted, thus, for 20 kg of treated seeds 0.1625 or 162.5 ml. In this way, for

The seed treatment was carried out in two stages, where each 10kg will be used 0.08125 liters or 81.25ml for each of the products.

The estimated syrup for each 10kg of seed was 200 ml, of which 37.5 ml was composed of water for a better coating of the seeds.

The germination tests were set up every 30 (thirty) days throughout the storage period, in the laboratory of the Cooperativa Agroindustrial de Alegrete LTDA.

For the germination test, an initial analysis was carried out, based on the following evaluations. Thus, 1kg of seed was taken for each factor, homogenized and quartered, obtaining a representative sample of work.

The following analyses were performed every 30 days for each treatment on 400 seeds, divided into 4 sub-samples of 100 seeds, for each replication with a total of 16 mounted tests per analysis. The seeds were distributed on germitest paper and moistened with the equivalent of 2.5 times the mass of the paper, then to reduce evaporation, the tests were inserted into plastic bags and, later, directed to the BOD incubator for germination at a temperature of 25 oC.

The seedlings considered normal were evaluated 14 calendar days after the assembly of the test and the results were expressed in %, according to the recommendations of the Rules for Seed Analysis (BRASIL, 2009). The result was expressed as a percentage made by the average of the four subsamples of 100 seeds.

For vigor, the seedlings considered normal were counted, evaluated at 5 calendar days after the assembly of the test, and the results were expressed as percentages, according to the recommendations of the Rules for Seed Analysis (BRASIL, 2009). The result was expressed as a percentage made by the average of the four subsamples of 100 seeds.

The results were analyzed using the Sisvar 4.0 software. Analysis of variance was performed at 5% probability. Subsequently, a joint analysis was performed to identify the presence of interaction between the treatments. Treatments that showed significant interactions were analyzed using Tukey's test.

RESULTS AND DISCUSSION

Table 1 shows the results of the analysis of variance with F-test values for the physiological quality variables of the rice grains examined. The results obtained indicate statistical significance at 5% probability, with coefficients of variation of 5.54% and 3.24%, respectively, for vigor and germination. Thus, it is possible to observe that there was low variability of the statistical data, characterizing their homogeneity.

Table 1 - Analysis of variance for physiological quality of stored grains.

FV	GL	Medium Square	
		SAW	GE
Treatment (trat)	1	26766,76*	900,37*
Storage (arm)	1	133,01ns	2,04ns
Período (for)	5	391,18*	46,61*
trat*arm	1	55,51ns	3,37ns
trat*per	5	477,23*	61,60*
arm*per	5	111,43*	40,86*
trat*arm*per	5	76,63*	24,35*
Repetition	3	8,42	30,29*
Error	69	18,06	8,85
CV (%)		5,54	3,24

*Significant at 5% probability; NS - not significant; VF – variation factor; CV – coefficient of variation; Gl – degrees of freedom; VI – vigor; GE – germination.

Source: Authors.

Table 2 shows the results of the percentages of vigor of rice seeds over 180 days in the different treatments.

Table 2 - Vigor of rice seeds stored for 180 days in prototype silo and big bag, submitted or not to seed treatment. Alegrete, 2023.

Period Stored	With seed treatment		No seed treatment	
	Silo	Big Bag	Silo	Big Bag
Initial	74,75 B a α	74,75 B a α	91.25 A to α	91.25 A to α
30	69,25 B a α	66,00 B a $\beta\alpha$	95.50 A to α	93.25 A to α
60	57,75 B a β	57,75 B a β	92.00 A to α	90.25 A to α
90	42,75 B to \emptyset	40,75 B to \emptyset	94.75 A to α	96,00 A to α
120	67.50 B to α	71.75 B to α	90.50 A to α	96,00 A to α
150	65,00 B a $\beta\alpha$	67.25 B to α	92.75 A to α	93.50 A to α
180	46,50 B b \emptyset	68,50 B to α	92.75 A to α	94.25 A to α
Final	53.25 B to β	53.25 B to β	95.40 A to α	95.40 A to α

Means followed by the same letter do not differ statistically from each other by Tukey's test at 5% probability of error, uppercase letter in the line compares the type of treatment within each type of storage over the stored period, lowercase letters in the line compare the types of storage as a function of the type of seed treatment over the stored period, and, Greek letters in the column compare the periods stored for each type of seed treatment within each type of storage.

Source: Authors.

Analyzing the average results of physiological quality of the grains when comparing the percentages of vigor, analyzing the type of seed treatment (with or without) within the type of storage over the 180 days stored, it can be noted that the treated seeds presented the lowest averages when compared to those without seed treatment.

Statistically for Silo Prototype, the differences were significant, where treated seeds presented averages between 42.75 and 74.75%, while untreated seeds presented higher values in the range of 90.5 to 95.5%.

Similar to the previous results, in the Big Bag Prototype, the differences were also significant, where treated seeds presented averages between 40.75 and 74.75 %, while untreated seeds presented higher values in the range of 90.25 to 96%.

When observing the averages for the breakdown of the type of storage as a function of the seed treatment over the stored period, in both storages only the seeds with storage treatment showed a difference at 180 days, with vigor percentages of 46.5 and 68.5%, respectively for Silo Prototype and Big Bag Prototype.

The seeds stored in the silo prototype obtained lower oscillations throughout storage, and there was no significant difference between the vigor percentages. Krüger et al. 2013, studying the physiological quality of seeds for 10 years, noticed that storage in impermeable packaging is less harmful to the physiological quality of seeds, keeping germination values within the standards required for seed commercialization. Therefore, the longevity of the seeds

stored packaging is also influenced by the type of packaging used for its packaging (POPINIGIS, 1985; WARHAM, 1986).

When analyzing the stored period in relation to the type of treatment as a function of the type of storage, only treated seeds showed statistical differences for both storages, and the variations

observed may have been influenced by the non-homogenization portion of the seed lot when the tests were set up and also a possible mixture of seed lots with different physiological quality.

Although it is considered one of the most efficient methods to ensure the good establishment of the initial seedling stand, research results show that the use of seed treatment can cause a reduction in physiological quality as a function of the time stored (ROCHA et al. 2017).

For Dan et al. (2010), in a study with soybean seeds treated with carbofuran and acephate insecticides for a period of 45 days, they observed that the reduction in the physiological quality of the seeds, conditioned by the insecticides, increases over the storage period of the treated seeds, suggesting that the insecticidal treatment of the seeds be carried out as close as possible to sowing.

In another study developed by Dan et al. (2011), using different insecticides for the treatment of soybean seeds, they showed that there are losses in the physiological quality according to the stored period, reaffirming results already obtained in other studies.

Table 3 shows the results of the germination percentages of rice seeds over 180 days in the different treatments.

Table 3 - Germination of rice seeds stored for 180 days in prototype silo and big bag, submitted or not to seed treatment. Alegrete, 2023.

Period Stored	With seed treatment		No seed treatment	
	Silo	Big Bag	Silo	Big Bag
Initial	94.25 A to α	94.25 A to α	93.75 A to α	93.75 A to α
30	94.25 A to α	86,75 B b ab	96.00 A to α	93.50 A to α
60	91,50 B a α	91.75 A to α	95.75 A to α	94.00 A to α
90	89,50 B a α	91,25 B a α	95.00 A to α	96.75 A to α
120	92.50 A to α	90,75 B a α	90.75 A to α	96.75 A to α
150	83,00 B a β	82,50 B a β	95.50 A to α	94.75 A to α
180	92,50 B b β	89.75 B to α	94.75 A to α	96,00 A to α
Final	86,25 B a $\alpha\beta$	86,25 B a $\alpha\beta$	95.50 A to α	95.50 A to α

Means followed by the same letter do not differ statistically from each other by Tukey's test at 5% probability of error, uppercase letter in the line compares the type of treatment within each type of storage over the stored period, lowercase letters in the line compare the types of storage as a function of the type of seed treatment over the stored period, and, Greek letters in the column compare the periods stored for each type of seed treatment within each type of storage.

Source: Authors.

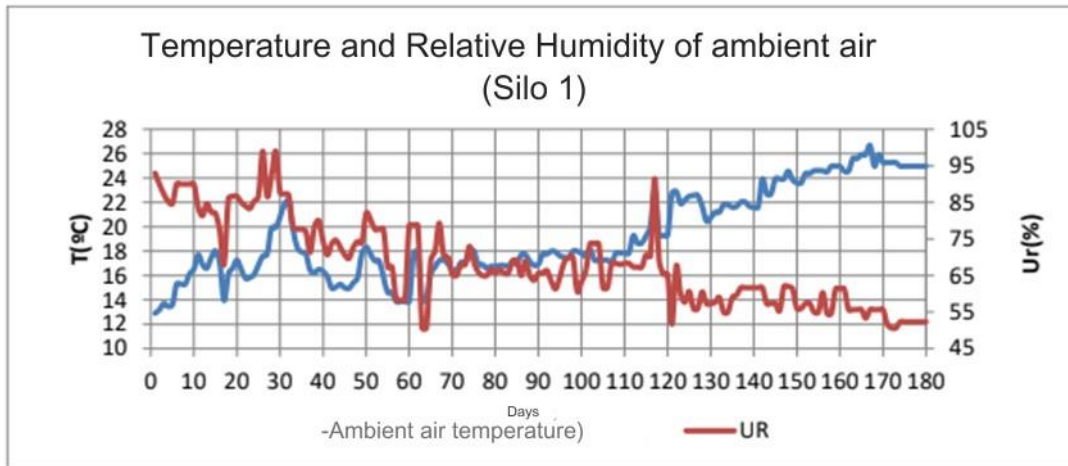
As well as the data obtained for vigor, in germination the averages differed only when the seed treatment was used. However, even with its use, germination averaged above 80% in all treatments. Thus, it is possible to affirm that these seeds germinate in accordance with the provisions of Normative Instruction No. 45 of 2013. In other words, the lot of rice seeds of the 431CL variety is of high quality, which is indispensable to ensure good productivity of the crop in which it will be sown.

In a study, Carraro (2001) showed that the greater the use of certified seeds, the higher the productivity over the years. In addition, according to Embrapa (2013), the guarantee of productivity is a direct result of the genetic, physical, physiological and sanitary quality of the seed.

An example of this, the Seed Analysis Laboratory (LAS) of UDESC in a study analyzed the physiological quality of a total of 81 rice lots produced in Santa Catarina, in the certified and self-use categories, where certified seeds represented 94% of the evaluated lots (CAREGNATO, E. et al. 2019).

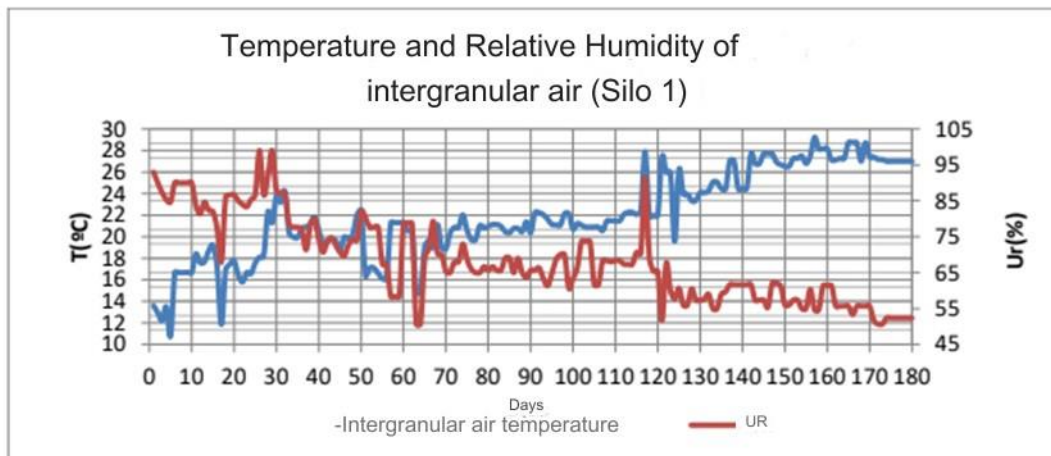
Figures 3, 4, 5 and 6 show the monitoring of the temperature and relative humidity of the ambient air and the intergranular air of the silo 1 and 2 prototypes.

Figure 3 - Monitoring of ambient air temperature and relative humidity Silo Prototype 1.



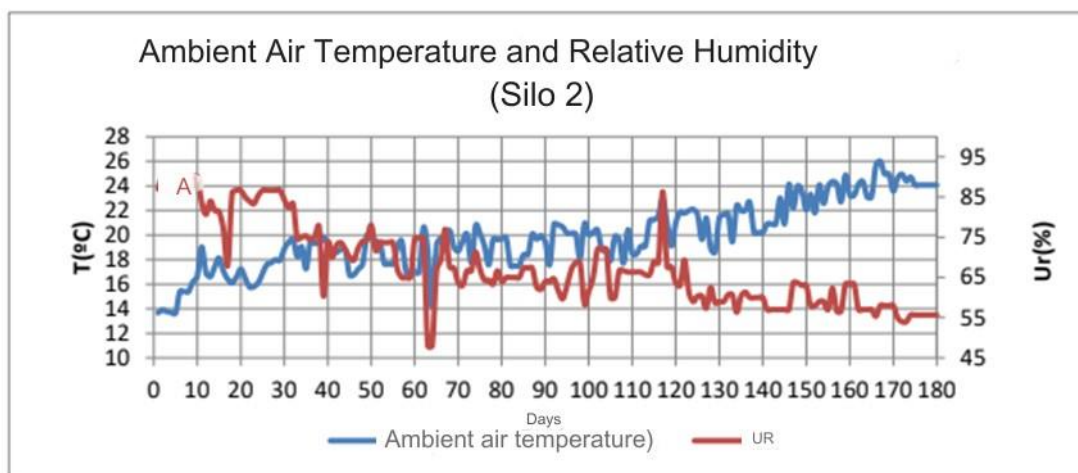
Source: Authors.

Figure 4 - Monitoring of intergranular air temperature and relative humidity Silo Prototype 1.



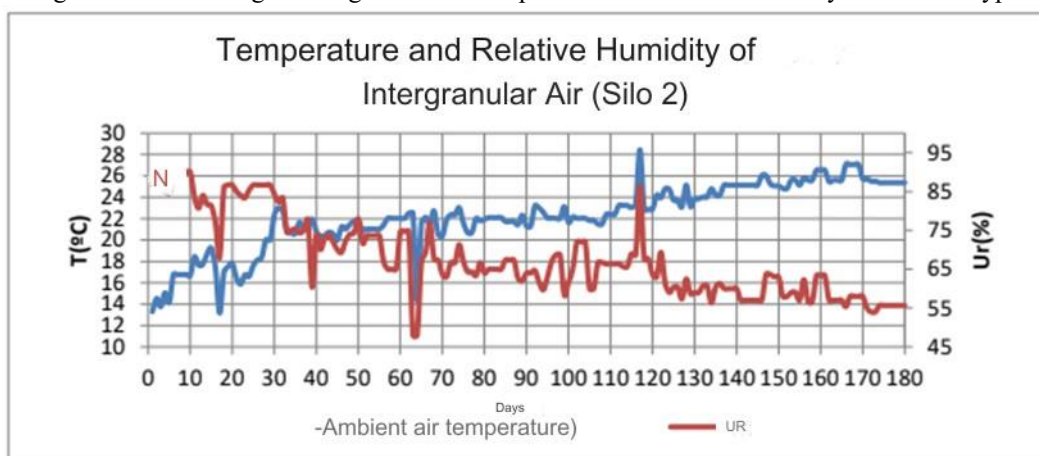
Source: Authors.

Figure 5 - Monitoring of the temperature and relative humidity of the ambient air Silo 2 Prototype.



Source: Authors.

Figure 6 - Monitoring of intergranular air temperature and relative humidity Silo 2 Prototype.



Source: Authors.

In the results obtained, variations in temperature and relative humidity of the ambient air were observed, which influenced the intergranular air conditions. Throughout the storage time, there was an increase in the ambient temperature, which influenced the intergranular temperature, as well as a decrease in the relative humidity, since the two factors have proportionality between them. In addition, such behavior is due to the characterization of the summer season where the experiment was installed, which according to Köppen and Geiger the climate of the region is classified as Cfa (humid subtropical climate) for Alegrete.

Studies indicate that temperature influences the viability and vigor of the seed, interfering with the respiratory process. (MENDES et al., 2009). Thus, Madruga (2010), evaluating the respiratory activity of seeds and enzymatic activity of rice seedlings cultivar BRS 7 Taim subjected to different temperatures for 24 hours, observed that the seeds showed better physiological quality when exposed to 25oC.

According to the results obtained by Nunes (2019), seeking to determine the appropriate conditions to ensure the physiological quality during the storage of soybean seeds, stored for a period of 180 days at temperatures of 15, 25 and 35 °C and packed in different packages, concluded that the temperature of 25 °C kept the germination percentages above the standard, however, it presented lower strength results for all storage systems.

In addition, Marini et al. (2013) studying the changes caused in the physiological quality of rice seeds subjected to different temperatures, relating to seed deterioration, were able to conclude that temperatures higher than 25°C depreciate the physiological quality of rice seeds cultivar Pelota. However, this fact was not observed throughout this experiment, where even with temperatures higher than 25°C there was no significant decrease in vigor and germination percentages.

CONCLUSION

Rice seeds of cultivar 431 CL showed a reduction in the percentage of vigor and germination over the storage period, under the presence of seed treatment regardless of the type of storage used.

Storage in impermeable packaging is less harmful to the physiological quality of the seeds, making it possible to maintain germination within the standards required for seed commercialization.

The seed lot has germination in accordance with the provisions of Normative Instruction No. 45 of 2013, as all the independent averages of the tying presented a value higher than 80%, the minimum percentage required for commercialization.

From the first 30 days, the portion of treated seeds started to have a decrease in the physiological quality of rice seeds.


REFERENCES

1. Bento, J. M. S. (1999). Perdas por insetos na agricultura. **Rev. Ação Ambiental**, Universidade Federal de Viçosa, Ano II(4), Fev/Mar.
2. Ministério da Agricultura, Pecuária e Abastecimento. (2009). **Regras para análises de semente** [Ministério de Agricultura, Pecuária e Abastecimento, Secretaria de Defesa Agropecuária]. Brasília: MAPA/ACS.
3. Caregnato, E., et al. (2019). Sementes certificadas de arroz possuem qualidade fisiológica superior. **XI Congresso Brasileiro de Arroz Irrigado**, Balneário Camboriú SC.
4. Carraro, I. M. (2001). Semente insumo nobre. **Seed News**, (5), 34-35.
5. Crochemore, M. L. (1993). Conservação de sementes de tremoço azul em diferentes embalagens. **Revista Brasileira de Sementes**, 15(2), 227-232.
6. Dan, L. G. M., et al. (2011). Desempenho de sementes de soja tratadas com inseticidas e submetidas a diferentes períodos de armazenamento. **Revista Brasileira de Ciências Agrárias**, 6(2), 215-222.
7. Dan, L. G. M., et al. (2010). Qualidade fisiológica de sementes de soja tratadas com inseticidas sob efeito do armazenamento. **Revista Brasileira de Sementes**, 32(2), 131-139.
8. Dubal, I. T. P. (2021). Influência de teores de impurezas no monitoramento de variáveis indiretas para detecção precoce da qualidade de soja armazenada em silos protótipos verticais. Tese de doutorado, Universidade Federal de Santa Maria (UFSM).
9. Embrapa. (2013). **Colheita, secagem, beneficiamento e tratamento de sementes de arroz irrigado**. Pelotas: Embrapa ClimaTemperado.
10. Embrapa. (s.d.). **Produção de sementes**. Recuperado de <<https://www.embrapa.br/agencia-de-informacao-tecnologica/cultivos/arroz/pre-producao/producao-de-sementes>>.
11. IRGA. (2022). **Cultivares/As 10 cultivares mais plantadas no rio grande do Sul - safra 2021-2022**. Recuperado de <<https://irga.rs.gov.br/cultivares>>.
12. Madruga, P. M. (2010). Atividade Respiratória e Bioquímica de Sementes de Arroz Submetidas a Diferentes Temperaturas. Tese, Universidade Federal de Pelotas.
13. Marini, P., et al. (2013). Indicativos da perda de qualidade de sementes de arroz sob diferentes temperaturas através da atividade enzimática e respiratória. **Inter ciência**, 38(1), 54-59.
14. Martins, J. F. da S., Cunha, U. S., Oliveira, J. V., et al. (2000). Controle de insetos na cultura do arroz irrigado. In: Guedes, J. C., & Costa, I. D. (Eds.), **Bases e técnicas do manejo de insetos**. Santa Maria: Pallotti, p.137-153.
15. Martins, J. F. da S., Grützmacher, A. D., Cunha, U. S., et al. (2004). Descrição e manejo integrado de insetos-pragas em arroz irrigado. In: Gomes, A. S., & Magalhães Jr., A. M. (Eds.), **Arroz irrigado no sul do Brasil**. Brasília: Embrapa Informações Tecnológicas, p.635-675.
16. Mendes, C. R., Moraes, D. M., Lima, M. G. S., & Lopes, N. F. (2009). Respiratory activity for the differentiation of vigor on soybean seeds lots. **Rev. Brás. Sem.**, 31, 171-176.



17. Nunes, C. F. (2019). Qualidade fisiológica de sementes de soja armazenadas em diferentes temperaturas e embalagens. Orientador: Joseane Erbice dos Santos. Trabalho de Conclusão de Curso (Bacharel em Engenharia Agrícola), Universidade Federal do Pampa, Curso de Engenharia Agrícola, Alegrete, 43 p.
18. Popinigis, F. (1985). *Fisiologia da semente* (2ª ed.). Brasília: AGIPLAN.
19. Razera, L. F., et al. (1986). Armazenamento de sementes de arroz e milho em diferentes embalagens e localidades paulistas. *Bragantia*, 45(2), 337-352.
20. Rocha, G. C., Rubio Neto, A., Cruz, S. J. S., Campos, G. W. B., Castro, A. C. O., & Simon, G. A. (2017). Qualidade fisiológica de sementes de soja tratadas e armazenadas. *Revista Científica*, 1(5), 50-65.
21. Vieira, R. D., & Carvalho, N. M. (1994). *Testes de vigor em sementes*. Jaboticabal: FUNEP.
22. Warham, E. (1986). Comparison of packaging materials for seed with particular reference to humid tropical environments. *Seed Science & Technology*, 14(1), 191-211.

Analysis of failures in chemistry-related disciplines and the creation of a leveling discipline

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ABSTRACT

The objectives of this work are: to analyze the low performance in the disciplines of General Chemistry I and Environmental Chemistry, between the years 2012-2 and 2016-2, in the Higher Course of Environmental Management, at the Federal Institute of Rio de Janeiro (IFRJ) of the Maracanã Campus; report the creation of a leveling discipline called "Fundamentals of Chemistry", which aimed to mitigate the low performance in Chemistry-related disciplines, due to the high retention and, consequently, the dropout of students; We also investigate the performance of students after the introduction of this discipline in the course between 2017-1 and 2018-2. The methodology used was the elaboration of graphs that could show the percentage of failures of students in these two disciplines, over the years, before the creation of the leveling discipline, and after. The results were very worrying. The discipline of Environmental Chemistry had rates of more than 60% of failures, from 13% in the year 2016-1 alone. In the discipline of General Chemistry I, the situation was much worse, with the lowest index, in 2014-1 and 2015-1, equal to 59%. After the creation of the leveling course, the results improved significantly for the Environmental Chemistry course, but not for the General Chemistry I course, which still had high failure rates. It is concluded that it is still necessary to investigate more about the conjuncture of failure, retention, probable cause of abandonment of the course, that is, of dropout.

Keywords: Chemistry, Repetition, Retention, Evasion.

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INTRODUCTION

The Law of Guidelines and Bases (LDB 9394/96) provided the authorization and recognition of educational institutions, which caused an expansion of higher education in Brazil, consequently generating a greater influx of students from different social classes (OLIVEIRA *et al*, 2019).

Corroborating this fact, the census of higher education, carried out by the National Institute of Educational Studies and Research Anísio Teixeira (INEP, 2016), reports that, simultaneously with the increase in the number of students entering higher education, the dropout of students has intensified.

This reality leads to negative results in the academic, social and economic spheres. The student starts to spend more time to finish his graduation, postponing the completion of the course, which delays his insertion in the labor market and, therefore, a greater financial expense on the part of the institution, which stays with this student for a longer time than expected (PEREIRA *et al*, 2015).

The retention of the student, due to being failed a few or several times, in certain disciplines considered difficult to understand, especially those of the basic cycle, the initial period of the course, with emphasis on the discipline of General Chemistry (YAMAGUCHI; SILVA, 2019), favors evasion (SARAIVA; DANTAS; RODRIGUES, 2019).

Based on this situation, which attests to the high retention and consequent dropout of students, this paper reports the creation of a leveling discipline called "Fundamentals of Chemistry", in the Higher Course of Environmental Management, at the Federal Institute of Rio de Janeiro (IFRJ) of the Maracanã Campus, in an attempt to mitigate the low performance in the disciplines related to Chemistry (General Chemistry I and Environmental Chemistry).

RETENTION/EVEVASION

In the literature, there are several studies on the subject, such as that of Garcia and Gomes (2022), who carried out a study on the causes of evasion in academic production, verifying a very large number of studies on this theme. The main causes found by the cited authors, in order of relevance, were:

1. Difficulty and academic performance/failure;
2. Lack of time to reconcile work and study;
3. Lack of knowledge in high school;
4. Didactics and methodology of teachers and the institution;
5. Dissatisfaction with the course/did not like it;
6. Financial situation;
7. Vocational;
8. Admission to the course due to lack of option/second option;

9. Lack of time to dedicate to studies;
10. Infrastructure;
11. Low valuation of the profession/teacher (Bachelor's degree);
12. Personal problems;
13. Availability of vacancies/labor market;
14. Institution/quality of the course and
15. Miscellaneous (GARCIA; GOMES, 2022, p.947,948).

The work of Garcia and Gomes (2022) points out that the first three items (difficulty and academic performance/failure, lack of time to reconcile work and study, and lack of knowledge in high school) are presented as a cause of dropout in a large number of studies, revealing the need, on the part of the institution and teachers, to present alternatives for their elimination or, at least, for its minimization.

This is because, to the extent that the student enters the university and starts to belong to a certain institution, the previous failures in the student's education also belong to the institution and the teacher, who have to take responsibility and do their best not to lose this student, who may drop out of the course.

Dropout and/or retention, in addition to causing enormous frustration to the student, which is one of the main factors pointed out by Oliveira *et al* in their work (2019), there is the economic factor, which causes a waste of resources in both the private and public sectors. In the latter, the situation is even worse, due to the scarce resources allocated to education, as mentioned in the work of Silva *et al* (2007):

"Student dropout in higher education is an international problem that affects the outcome of education systems. The losses of students who start but do not finish their courses are social, academic and economic waste. In the public sector, these are public resources invested without due return" (SILVA *et al.*, 2007, p. 642).

The Law of Guidelines and Bases (LDB 9394/96) points out three types of retention: failure due to grade, lack and locking. In the work of Yamaguchi and Silva (2019), retention is associated with low performance and, especially, in the discipline of General Chemistry, which belongs to the initial period of several courses. Compared to failure by attendance, the situation is worrisome, because this discipline is a prerequisite for others in several undergraduate courses.

These authors also concluded in their work:

"Based on the results obtained, it is suggested that retention results fundamentally in the following variables: little affinity with the discipline, socioeconomic difficulty, inadequate study methodology, and deficiency in basic education, especially related to the disciplines of science and mathematics" (YAMAGUCHI; SILVA, p.353, 2019).

The deficiency in basic education can be seen in studies related to high school itself, in which students already present the discipline of Chemistry as difficult to understand.

In the work of Mendonça and Cruz (2008), the authors investigated the difficulties in learning the discipline of Chemistry, from the student's point of view, and found that the majority of the students investigated, 73%, (population of 121 students in total of the first, second and third grades of the various shifts in the morning, afternoon and night) thought that the discipline of Chemistry was difficult or very difficult to understand. This was ratified by the low performance of the students in the assessments. This situation experienced by high school students is reflected in higher education, with gaps in learning and/or lack of understanding.

Rosa and Santos (2018) pointed out basic deficiencies as one of the causes of dropout in undergraduate courses at the Federal University of Goiás (UFG):

[...] "You have to understand what led them to give up on it. Therefore, the number of failures was investigated, with a view to discovering the influence of low academic performance on the option to abandon the course" (ROSA; SANTOS, 2018, p.486).

The authors address the need to provide pedagogical assistance to students who have learning gaps, which have not been remedied in basic education, which is the cause of repetition in certain subjects, especially those in the initial periods, causing them to drop out of the course (ROSA; SANTOS, 2018).

ALTERNATIVES TO SOLVE OR MITIGATE RETENTION/EVASION

As previously mentioned, there are several studies in the literature to investigate retention and evasion, based on the verification of their causes, which point to the need to develop suggestions capable of eliminating or, at least, minimizing the effects of this conjuncture.

The following items can be grouped: lack of time to reconcile work and study, financial situation, and lack of time to dedicate to studies (GARCIA; GOMES, 2022) as a topic related to the student's economic situation; Therefore, it is possible to think about the institution providing scholarships with realistic values, which allow the student to dedicate himself to academic studies and his training without dividing his time with work.

Regarding the item on infrastructure (GARCIA; GOMES, 2022), is related to the institution's environment, which must have comfortable libraries with up-to-date collections, adequate places for meals, and areas reserved for group or individual studies, which does not occur in many institutions, which do not even have convenient classrooms.

Monteiro and Ianuskieztz (2018) address, in their work, the extreme relevance of the environmental factor for the student's sense of belonging to the institution: "The importance of identity construction within the university context for student-school community interaction. The

non-construction of identity in this context can lead to evasion" (MONTEIRO, IANUSKIEKTZ, p. 265, 2018).

It is important to compile topics related to the student's personal identity, such as dissatisfaction with the course/did not like it, the vocational issue and admission to the course due to lack of option/second option (GARCIA; GOMES, 2022). Hence the importance of applying vocational tests in High School, in order to better guide your choices, causing fewer failures:

[...] "as the major factors identified as a cause of dropout precede the student's entry into the University, alternatives were identified to minimize dropout, the application of vocational tests and the insertion of discipline or content on professions in high school, both in public and private education, in order to support the student's choice and decision about his or her professional future" GARCIA; SANTIAGO, p. 49, 2015).

It is noted that the vocational test could be applied thus avoiding evasion and, consequently, economic waste on the part of the government and frustration on the part of the student.

With regard to the topic of didactics and methodology of teachers and the institution (GARCIA; GOMES, 2022), it is necessary to assume that, from the moment the student enters the undergraduate program, he becomes the responsibility of this institution, having the obligation to welcome him as he is. In his work, Silva (2014, apud ROSA; SANTOS, 2018) states: "The educational entity should didactically prepare its faculty to teach the student who receives and not the student who would like to receive" (emphasis added), which shows how important it is for the institution to have knowledge of the student's previous education and create strategies to retain the same in the course chosen by him, so that your training reaches the maximum possible excellence.

The items difficulty and academic performance/failure and lack of knowledge in high school (GARCIA; GOMES, 2022), referring to students' disabilities brought from High School, constitute, in our view, the most relevant for the dropout of students in Higher Education courses. This concern is evident in Veloso *et al* (2018): [...] "of the high rate of school dropout, the Higher Education Institutions, and, in our case, the Faculty created school leveling instruments to try to retain their students" [...] (VELOSO *et al*, p.2, (2018). Among these instruments, leveling disciplines were created with topics of mathematics, general and experimental physics.

The work of Yamaguchi and Silva (2019) analyzes retention in the discipline of General Chemistry, at the Federal University of Amazonas, and the creation of a leveling discipline is proposed to mitigate retention and, consequently, dropout. This fact demonstrates how the difficulty in the disciplines related to chemistry is worrisome and constitutes a large portion of the cause of dropout from some courses.



DEGREE IN ENVIRONMENTAL MANAGEMENT TECHNOLOGIST

The Brazilian Institute of Geography and Statistics (IBGE) (2003) shows that the number of students enrolled in high school is much higher than the number of young people enrolled in higher education, thus pointing to a large number of young people without access to undergraduate education.

In 2007, the Federal Government instituted the Support Program for the Restructuring and Expansion Plan of Federal Universities (Reuni), with the objective of creating conditions for the expansion of access to higher education. Investment in the creation of new universities and/or new campuses has consequently increased the number of vacancies.

In 2009, at the Federal Institute of Rio de Janeiro (IFRJ), Rio de Janeiro campus, there was an expansion of higher education courses and the Environmental Management Technologist (STGA) course was created. The curriculum of this course presents scientific and management bases of higher education, aiming to meet the labor market (PROJETO POLÍTICO PEDAGÓGICO-PPP, 2018).

All this investment, however, did not mitigate the problem discussed. Mazola and Allevato (2016) carried out a study with the objective of verifying, in research published in books, journal articles and annals of events, the approach to the learning difficulties of students entering Higher Education, in relation to the contents of mathematics discussed. They were able to observe a large number of authors concerned with this theme, in the most diverse degrees, indicating that the problem is present not only in the IFRJ, in the CSTGA, but in the entire Brazilian territory.

Regarding the discipline of chemistry, which studies "the composition, structure, properties of matter, the changes undergone by it during chemical reactions, and its relationship with energy" (FNDE, 2023), its definition shows how broad it is and with many contents correlated to mathematical concepts, causing an even greater difficulty in understanding it. The fundamental thing, however, is to try to develop in the student the competence to act critically in the decisions of the community (SANTOS and SCHETZLER, 1996, p. 29).

Em Veras et al. (2010):

"It is known that students have great difficulty in assimilating the chemistry contents covered in the classroom, that is, the classes are mostly only theoretical. This leads to misunderstanding and even a lack of interest in the discipline. It is believed that the teaching of chemistry should contribute to a more comprehensive view of knowledge, emphasizing in the classroom knowledge that is relevant and can interact in the student's daily life. Students understanding this from an early age find that studying chemistry can be easy and fun, especially when this teaching is done in a practical and attractive way. Chemistry is an eminently experimental science; Hence the importance of practical classes. Classes in the laboratory provide a greater approximation of students with the discipline" (VERAS et al, 2010).



Therefore, it is possible to verify the importance for the student of practical classes, which enrich the chemical contents and make comprehension easier. However, although the disciplines of General Chemistry I, II and Environmental of the CSTGA present a reasonable number of practical classes, which try to alleviate the serious situation of these disciplines, it is found that it is necessary to do something more, which makes the understanding more effective, hence the importance of creating a basic discipline, teaching elementary and primordial contents for the understanding of the knowledge of these disciplines.

CONSTRUCTION OF THE FUNDAMENTALS OF CHEMISTRY DISCIPLINE

Regarding the approval of the Environmental Chemistry I course, the situation of the students proved to be serious. The highest failure rates occurred in the semesters of 2012-2, 65%, and 2014-1, 62%, and the lowest was in 2016-1, 13% (Figure 1), thus showing that, on average, the number of failures is high.

Failures in the discipline of General Chemistry I are even higher, with the lowest rate in 2014-1 and 2015-1 equal to 59% and, in all other semesters, the rate was even higher than this value, reaching up to 90% failure in 2015-2 and 2016-1 (Figure 1).

Analyzing the data, it is observed that the situation was alarming in relation to these disciplines, in which the performance was minimal, with the aggravating factor of being disciplines of initial periods of the course, thus causing retention and, probably, dropout. In view of this fact, and after many frustrations from both teachers and students, some action should be taken.

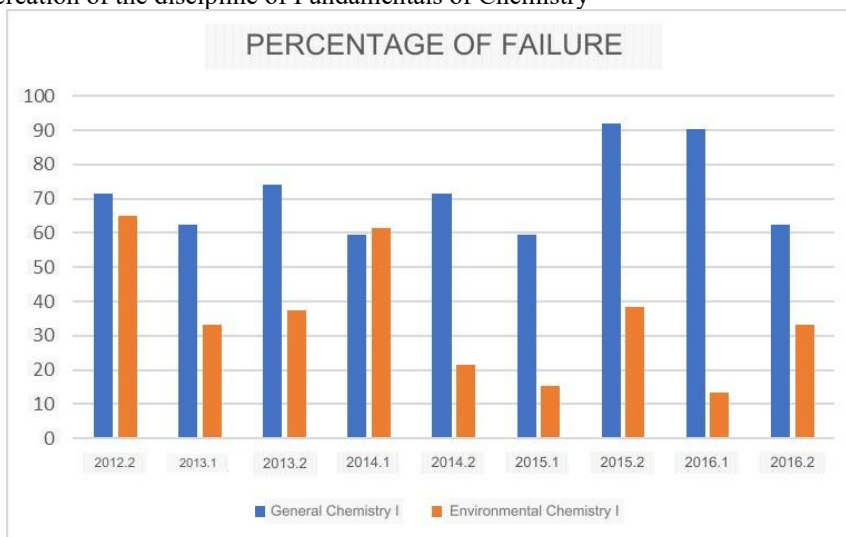
The teacher of Environmental Chemistry I (QGI) observed a great difficulty on the part of the students to understand the basic concepts of chemistry, necessary for their discipline, which caused an obstacle in the understanding of Environmental Chemistry I (IAQ). Observing the number of failures in General Chemistry I (Figure 1), he proved that this cognition was also greatly compromised. The two disciplines belong to the first semester (QGI) and the second semester (QAI) of the STGA course.

Through many discussions among the professors of the course, in the sense of what could be done to mitigate the painful situation for both teachers and students, with regard to the probable causes of the student's failure, retention, frustration, and, consequently, his/her dropout, the collegiate of the STGA course in 2016-2, proposed the formation of the discipline Fundamentals of Chemistry for the year 2016-1, as an elective course, in order to assist in the knowledge and mastery of the basic contents of Chemistry.

The course has been offered since 2016.2. Since then, on the first day of class, a diagnostic assessment is applied to verify that all enrolled students have an indication to attend it and to indicate which contents of the syllabus should be deepened. In odd-numbered periods, the entry of freshmen

in the CST in Environmental Management is in the afternoon shift, while in the even-numbered periods, in the night shift. In the beginning, this discipline was not offered in the shift in which the incoming students were enrolled, which did not promote their adherence.

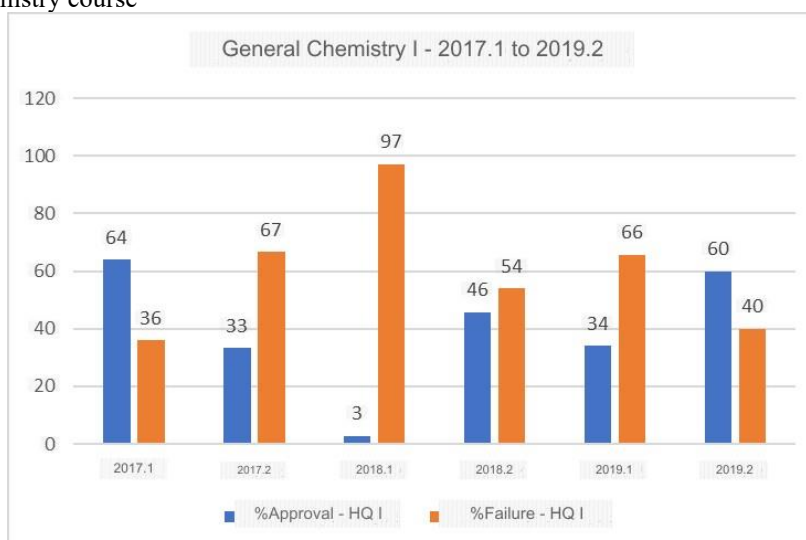
Figure 1 - Percentage of students who failed the disciplines of General Chemistry I and Environmental Chemistry I in the periods prior to the creation of the discipline of Fundamentals of Chemistry



Source: Authors (2023)

With the commitment of the Institute's management, as of 2017.2, a schedule was reached in the schedule for incoming students, who were automatically enrolled during the period of their admission.

Figure 2 - Comparison chart of students who passed and failed the General Chemistry I course after the creation of the Fundamentals of Chemistry course



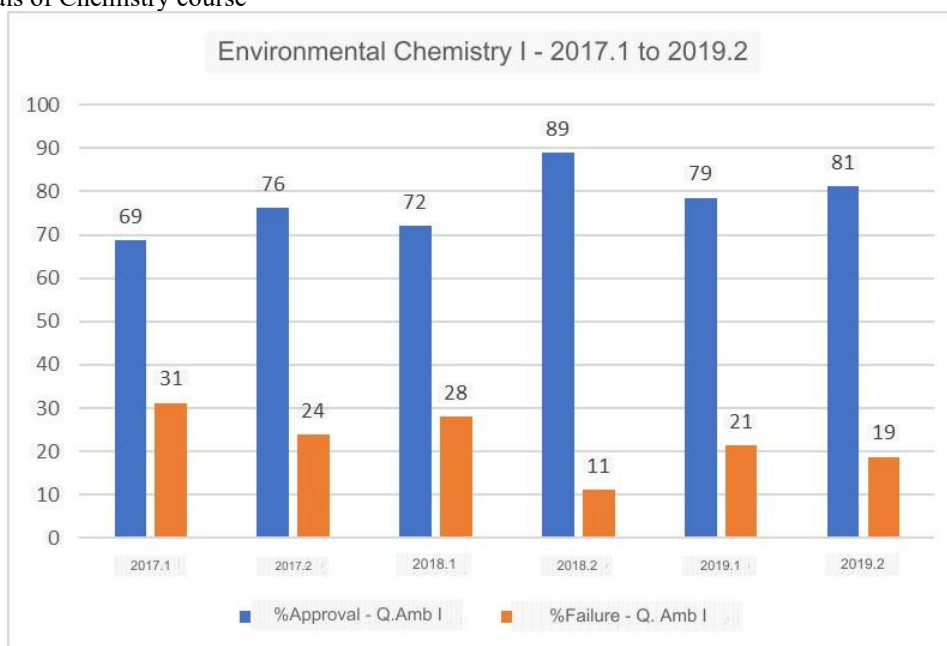
Source: Authors (2023)

Analyzing the number of students who passed and failed in the General Chemistry I course (Figure 2), after the creation of the Fundamentals of Chemistry course, it is concluded that, in 2017-1

and 2019-2, the results were very good, but in the other semesters this did not occur. This finding makes us carefully examine this conjuncture and verify that the discipline of General Chemistry I presents a turnover of teachers who teach it, showing, as previously mentioned, that the didactics and methodology of the teachers influence the student's performance (ASSIS; MELO, 2015).

Examining the percentage of students who passed and failed in the discipline of Environmental Chemistry (Figure 3), after the creation of the discipline of Fundamentals of Chemistry, very good results are observed in all semesters, with the number of approved students being much higher than the number of failures. This result was presumably due to the fact that she was the same professor who taught both disciplines (Fundamentals of Chemistry and Environmental Chemistry). The professor, who taught the basic contents pertinent to Environmental Chemistry, tried numerous times to dialogue with the discipline of General Chemistry I, and the occurrence of this partnership showed reasonable results, such as that of 2019-2, with 60% approved and 40% failed (Figure 2).

Figure 3 - Comparison chart of students who passed and failed the Environmental Chemistry course after the creation of the Fundamentals of Chemistry course



Source: Authors (2023)

FINAL THOUGHTS

The situation investigated was and still remains very worrying, requiring a more detailed analysis of the circumstances. It is perceived that there should be a greater integration between the teachers of the various disciplines, that in the collegiate there would need to be more pedagogical discussions and, also, a follow-up of the syllabus, in the contents in which the students presented more difficulty, so that the leveling discipline (Fundamentals of Chemistry) would address certain



topics in more detail, or that there would be a modification of the syllabi itself. in order to adjust to the needs of the students and the course.

Currently, the possibility of online meetings greatly facilitates the aggregation between teachers and the course coordination, with the opportunity for everyone to stand up and have the floor to address what they think and feel about a given situation.

The role of the teacher is much greater than simply going to the institution to teach. It is necessary for him to commit himself to the student, in an integral way, in order to actually be called a teacher.


REFERENCES

1. Assis, L. M. E., & Melo, A. F. (2015). A evasão sob o olhar dos professores e alunos do curso de licenciatura em matemática do Campus Universitário de Sinop da Universidade do Estado de Mato Grosso–UNEMAT, em 2011/2. *Revista Eventos Pedagógicos, 6*(2), 347-363.
2. Garcia, F. C., & Santiago, E. F. B. (2015). Mecanismo De Enfretamento A Evasão No Ensino Superior Público: Inserção Do Conteúdo Sobre Profissões No Ensino Médio. *Gestão Pública: práticas e desafios, 6*(1).
3. Masola, W. J., & Allevato, N. (2016). Dificuldades de aprendizagem matemática de alunos ingressantes na educação superior. *Revista Brasileira de Ensino Superior, 2*(1), 64-74.
4. Mendonça, M. L. T. G., & Cruz, R. P. (2008). As dificuldades na aprendizagem da disciplina de química pela visão dos alunos do ensino médio. In *Anais da 31ª Reunião Anual da Sociedade Brasileira de Química* (p. T0152-2). Águas de Lindóia. Recuperado de <http://sec.sbq.org.br/cdrom/31ra/resumos/T0152-2.pdf>
5. Monteiro, S. A., & Ianuskiewtz, D. (2018). A evasão escolar nos cursos tecnológicos do instituto federal de educação, ciência e tecnologia de São Paulo-IFSP. *DOXA: Revista Brasileira de Psicologia e Educação, 20*(2), 256-271.
6. Instituto Nacional de Estudos e Pesquisas Educacionais Anísio Teixeira - INEP. (2016). Recuperado de http://portal.inep.gov.br/artigo/-/asset_publisher/B4AQV9zFY7Bv/content/mec-e-inep-divulgam-dados-do-censo-da-educacaosuperior-2016/21206
7. Oliveira, C. H. M., Santos, F. R. T., Leitinho, J. L., & Farias, L. G. A. T. (2019). Busca dos fatores associados à evasão: um estudo de caso no Campus Universitário da UFC em Crateús. *Revista Internacional de Educação Superior, 5*, 1-23. <https://doi.org/10.20396/riesup.v5i0.8652897>
8. Pereira, A. S., Carneiro, T. C. J., Brasil, G. H., & Corassa, M. A. C. (2015). Fatores relevantes no processo de permanência prolongada de discentes nos cursos de graduação presencial: um estudo na Universidade Federal do Espírito Santo. *Ensaio: Avaliação de Políticas Públicas Educacionais, 23*(89), 1015-1039.
9. Projeto Político Pedagógico, Curso Superior de Tecnólogo de Gestão Ambiental do Instituto Federal do Rio de Janeiro (IFRJ). (2018). Recuperado de https://portal.ifrj.edu.br/sites/default/files/IFRJ/PROGRAD/cstga_cmar_projeto_pedagogico_d_e_curso_2018_2_revisado_versao.pdf
10. Rosa, C. M., & Santos, F. F. (2018). Evasão no IME/UFG: O ponto de Vista dos Alunos Excluídos. *Revista Teias, 19*(54). <https://doi.org/10.12957/teias.2018.32421>
11. Saraiva, J., Dantas, V., & Rodrigues, A. (2019). Compreendendo a Evasão em uma Década no Curso Sistemas de Informação à luz de fatores humanos e sociais. In *Proceedings do Workshop Sobre Aspectos Sociais, Humanos E Econômicos De Software (WASHES), 4*. Belém: Sociedade Brasileira de Computação. <https://doi.org/10.5753/washes.2019.6406>
12. Silva Filho, R. L. L. E., Motejunas, P. R., Hipólito, O., & Melo Lobo, M. B. C. (2007). A Evasão no Ensino Superior Brasileiro. *Cadernos de Pesquisa, São Paulo, 37*(132), 641-659. Recuperado de <https://www.scielo.br/j/cp/a/x44X6CZfd7hqF5vFNnHhVWg/?lang=pt&format=pdf>



13. Veloso, C. M. L., Couto, A. C. S. R., & Valentim, M. C. (2018). O nivelamento escolar como instrumento de redução da evasão no curso de engenharia civil–FACEMG. *The Journal of Engineering and Exact Sciences, 4*(4), 399-404.
14. Yamaguchia, K. L., & Silva, J. S. (2019). Avaliação das causas de retenção em Química Geral na Universidade Federal do Amazonas. *Química Nova, 42*(3), 346-354.
15. Santos, W., & Schnetzler, R. P. (1996). O que significa ensino de Química para formar o cidadão? *Química Nova na Escola*(4), 28-34.
16. Veras, E. Y. F., Silveira, F. A., Sousa, A. A., & Paiva, P. E. C. (2010). A importância do laboratório de química no processo de ensino e aprendizagem. *Anais do 8º Simpósio Brasileiro de Educação em Química*. Natal/RN. Recuperado de <http://www.abq.org.br/simpequi/2010/trabalhos/75-7560.htm>

Teaching in transport: The use of active methods in the discipline of urban transport

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ABSTRACT

This research aims to present the pedagogical methodology applied in the discipline of Urban Transport based on the methods of active learning in the teaching of transport of the Faculty of Civil Engineering. The method applies student response mechanisms regarding adherence to the proposed activities and content using team-based and project-based learning, problem-solving, gamification and case study. The results highlight that 60% met the deadline for the delivery of the activities, the students obtained grades close to the maximum limit, whose focus was the relationship with the team, and in the group activities the overall score was higher than the individual one. It is concluded, therefore, that the use of active methodologies in the teaching of transportation in this discipline contributed to an active, participatory, collaborative and interactive pedagogical approach centered on the student, however, the challenge is to stimulate their engagement in group activities, attend to the learning and evaluation processes of the discipline, as well as the student's approval in this curricular component.

Keywords: Active Methodology, Learning Assessment, Higher Education, Urban Transport.

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INTRODUCTION

Continuing education tends to value work by linking knowledge to a given daily reality and to the learning process through educational and integrative actions of an inter- and multi-professional nature (Almeida et al., 2016; Lima et al., 2022). Best practices combine technique or methodology and experience or research, aiming to obtain good results and reliability according to the needs of users (Vendruscolo et al., 2021). Applying best practice requires recognizing and tailoring resources that meet specific situations and contexts.

Continuing Education and Continuing Education are characterized by the continuity of educational actions, develop skills and competencies aiming at professional transformation when worked together, which can strengthen the work process although they present different methodological guidelines (Peixoto et al., 2013; Lima et al., 2022).

The evaluation of teaching is an integral part of the teaching-learning process of the two undergraduate courses and has a formative character and should be conceived as diagnostic, continuous, inclusive and procedural, and prioritizes qualitative and quantitative aspects, considering the verification of competencies, skills and attitudes without losing sight of the labor market in the organic articulation with the trends of the profession in contemporary society. The curricular structure was organized in such a way as to offer learning situations throughout the course that ensure a technical, humanistic and political training of the undergraduate.

Article 70 of the Undergraduate Education Regulation determines that the evaluation of didactic-pedagogical activities must occur at the end of each academic period, and a teaching evaluation questionnaire is made available in the Academic System, which has information and instruments to evaluate the curricular activities and the performance of the professors who taught them, the objectives, the contents, the workload and the material conditions of the pedagogical work. Each professor stipulates his/her evaluation process according to the discipline he/she teaches and can consider continuous evaluations with different strategies in written and oral form, individual and group work, seminars, among others contemplated in the Regulation of Undergraduate Courses at UFPA.

The curricular organization foresees in the Pedagogical Project of the Course (PPC) the articulation of theory with practice, observing the balance between them, allowing, in practice and in the exercise of activities, the learning of the art of learning; seeks an early approach to issues inherent to professional activities in an integrated manner, without losing the knowledge essential to the exercise of the profession; It commits the student to scientific development and the pursuit of technological advancement. In this way, the student gradually acquires knowledge in a greater breadth and depth, with a greater concentration of technical and specific disciplines as the student advances in the course.

This article presents the methodological strategy in undergraduate education at a Federal University, promotes discussions about the results of the application of active methods in the discipline TE08088 Urban Transport offered by the Faculty of Civil Engineering (FEC). The objective is to evaluate the adherence to the proposed activities in relation to the content provided for in the menu. The discipline has a total workload of 60 hours, 45 hours theoretical and 15 hours practical, whose extract is the evening class.

LITERATURE REVIEW

Active learning methodologies stand out as a way of stimulating students' autonomy and independence, modifying the relationship between them and the teacher through instructional techniques and activities of engagement and protagonism of the student in the construction of their own knowledge and professional training. Of the types conceptualized, the following stand out in this study:

- a) Team-Based Learning (*TBL*) – brings together a set of sequenced teaching-learning practices that make the student responsible for the acquisition of their own knowledge, leads them to decision-making through collaborative and effective teamwork. The evaluation includes individual and team tests in the exercises of application of concepts and peer evaluation of the contribution of each of the members to the achievement of teamwork (Correa; Silva, 2022);
- b) Project-Based Learning (*PBL*) – is a method of investigation focused on real-world problems, integrates different knowledge, and encourages reasoning through teamwork, protagonism, and critical thinking (Gouvêa; Days; Cabrelli, 2022);
- c) Problematization – students perform actions that lead them to cognitive, procedural, and attitudinal learning through reflected and transformative theory and practice. The stages are divided into observation of reality, identification of key points, theorization in research sources, hypotheses of solution and application to reality (Rigonato; Cruz, 2022);
- d) Gamification – a technique that brings together strategies, dynamics and game tools in a new non-game context to motivate learning and stimulate problem solving by dividing tasks into phases where the student must complete a challenge to move on to the next;
- e) Case studies – uses real experiences of investigating a phenomenon in its real context, data collection, detailed analysis and discussion of solutions.

The use of active methods establishes a process of continuing education centered on the student. Thus, there is a distinction between Continuing Education and Continuing Education in terms of methodological principles and, similarity, in educational processes characterized by the

continuity of actions that, when combined, allow the transformation of the individual as a professional, of his skills and competencies (Lima et al., 2022). The authors highlight other characteristics of continuing education, such as: the individual seeks knowledge according to his or her personal needs; define your area of knowledge; searches for solutions to a particular problem; individualization of learning, among others. In continuing education, knowledge and learning are directed to the practical needs of an organization, training is continuous, institutionalized and linked to the good practices developed by the institution.

Barbosa et al. (2021) highlight that in this process it is important to distinguish what is known by the individual and the knowledge acquired as a group that works together. In this case, knowledge management is supported by *i)* people, their skills and competencies and *ii)* processes that involve research and investment. In addition to the active methods, there are actions aimed at socialization and group work, motivated and committed teams, validating successful experiences and learning in adverse situations, stimulating the behavioral side, corroborating with the notes of the cited literature and the foreseen in the Pedagogical Project of the Courses in question.

In force, Law No. 8,655 of July 30, 2008 establishes the Master Plan of the municipality of Belém containing guidelines for the transport system aimed at collective public modes of passengers, provides for broad and democratic access through the planning and management of the Urban Mobility System in its section II, art.41 to art.49. The city has an urban public transport system by bus, the *Bus Rapid Transit* (BRT) divided into two stages: BRT Belém (completed) and BRT Metropolitano (under construction). All themes are present in the syllabus of the disciplines and it was up to the groups to choose according to their research interest. The association of active methodologies with teaching in transportation is supported by the legal determinations provided for in the PPC of Engineering and has the possibility of corroborating with the development of studies and research applied and feasible to the reality of the city of Belém.

METHODS AND APPLICATION

The applied method brings together evaluative actions between the proposed activities and the content taught, aiming to obtain results that can direct behavioral changes in the student through empirical and practical provocations. The sample study corresponds to the evaluation process of students regularly enrolled in the discipline TE08088 Urban Transport (night shift) of the Faculty of Civil Engineering.

The teaching strategy brought together lectures, meetings in groups and with each of them, presentation of videos, discussions and consultations with the materials available in SIGAA and in scientific platforms. It was up to the groups to define a topic of interest between Collective Transport (planning and operation, BRT system and buses), infrastructure for urban transport (bus stops and

BRS), bicycles, vehicle rotation, urban tolls, urban cargo transport and logistics. The class schedule was established at:

- TE08088 Urban Transport – 17 face-to-face meetings divided into: eight lectures under the responsibility of the teacher; three face-to-face orientation meetings for the 10 groups; two partial deliverables segmented into delivery 1 (introduction, problem, justification and objectives) and delivery 2 (literature review and methodology); two days of seminar with an average presentation time of 25 minutes; and, two days for delivery of grades and review of concepts.

The evaluation process established the development of a research applied to a given problem chosen by the group/pair to be carried out throughout the course, consisting of *i*) written work delivered in two parts (Deliveries 1 and 2) at the beginning of each month (April and May/2023) via institutional virtual platform (SIGAA) and *ii*) Final seminar with the delivery of the complete written work containing the results and discussions. The strategy for the formation of the groups was random and random using the existing tool in SIGAA, aiming to minimize the formation of groups by affinities.

As for the evaluation criteria defined in the lesson plan: compliance with the deadlines for partial deliveries and the final one in an editable file via the institutional platform (written work); seminar; the monitoring of the practical activities in the supervised form and the determination of the grades (0 to 2.5 points) according to the four criteria thus defined as problematic of a real situation in the metropolitan region of Belém, written work, seminar and compliance with deadlines. This was the way to establish the final grade and concept in the subjects.

The feedback and verification of learning took place in the individual and group assessments, as described below. The method of data collection and analysis followed the planned planning for the teaching and learning process, applying the following types of active methodologies, namely:

- a) TBL, Problematization and Case Studies were applied from the first day of class, following the stages of previous preparation of the student, making materials available on the SIGAA platform for consultation and construction of the conceptual framework of the written work and, application of the concepts, where the team performed several tasks arranged in the forms of deliverables (E1 and E2) ending with the seminar (S) and the final writing (EF). The metric to assess adherence to the stages and engagement considered the completion of Table 1 on a scale of 0 to 2 points per attribute, as well as Table 2, where each group evaluated the others according to the presentations. At the end of each presentation, the other groups should ask a question about what was explained in the seminar and any member could answer. The objective of this evaluation was to capture the different perceptions of the skills required in the proposed activities, as well

as the criticality regarding the content and strategies used by each of them;

Table 1: Evaluation of the individual student in the group.

Group 1	Responsibility and commitment	Relationship with the team	Preparation of the written work	Elaboration of the practical work	Presentation
Student 1					
...					
Student 4					

Table 2: Evaluation between groups.

Criteria	Presentation	Relevance of the topic	Domain of work	Practical application	Answers to questions
Group 1					
...					
Group 10					

- b) In the second application of the TBL, the students answered a questionnaire individually and then in groups. The questionnaire had nine questions about the contents seen in the classroom where, at first, the student answered alone and then in a group they had to agree on an answer to open an option of the template. This feedback contained individual and group scores, with 5 points being counted for individual correct answers and, from 5 on a descending scale for each group error;

Table 3: Evaluation of the student's performance in relation to the content taught

Q1:	The	B	C	D	And
...					
Q9:					
Individual Scoring					
Group Scoring					

- c) Gamification was applied only in the discipline TE08088 Urban Transport and occurred in two ways: *i)* participation in a board game that simulated experiences in transport as a way to help the student to actively mobilize with a view to building their own learning; *ii)* *Quiz* between the groups: each group elaborated five questions on its theme and chose the opponent to answer. In this case, the scoring system per question was defined by the group and in case of error, the chance of answer was passed on to the class at decreasing points.

The results of this process also include project-based learning, as the teacher has established a relationship of guidance and direction, and it is up to the students to search for knowledge and skills to achieve their research objectives. The analyses will be discussed according to the characteristics of the active methodologies applied. It should be noted that the class is mixed, composed of students belonging to the eighth and ninth semester (evening TE08088), whose specificities are students

working in the labor market, as permanent employees in companies or interns, some working in the area of transportation, since the city is undergoing works in this sector.

Table 4: Methodological and evaluative strategy adopted for the course.

Method	Steps	Deliveries	Learning assessment	Evaluation criteria
TBL	* Definition of theme, problem. * Consultation of materials. * Random grouping, no affinities.	E1, E2, EF and S	Individual1 Group2	¹ Responsibility, relationship, written work, practical application, seminar. ² Seminar, definition of the theme, mastery of the content, practical application, answer to questions, compliance with deadlines.
	* Grouping by affinity * Answers to a questionnaire about the contents taught	Issues Template	Individual and group scoring system	Individual: 5 points per hit. Group: on a descending scale from 5 per error in each question.
Gamification	Board Game	Participation	Individual behavioral analysis	Lower cost in group, performance indicator spreadsheets
	Quiz	Five questions	Group Scoring	Hit by question per group Descending scale scoring for the class

RESULTS

The methodology used in the disciplines focused on the development of skills and competencies of the student, encouraging him to think about solutions to everyday problems, with the teacher being the facilitator of the process. In the process of knowledge construction, it was up to the students to define the research problem pertinent to the reality of the city, to seek viable solutions in theory and to document the process (written work). At the end of each activity, the student performed an evaluation of their performance and learning. The results of the application of this methodological proposition will be reported and discussed below.

Considering that evaluation is a qualitative treatment based on subjectivity, the results presented correspond to the inferences arising from the student's perception of the evaluation process of the disciplines and their own performance in the individual scope and in group formation, as well as through the adherence and fulfillment of the proposed activities related to the content taught.

TBL, PROBLEMATIZATION AND CASE STUDIES

The applications of the TBL, the problematization and the case study occurred from the first school day with the subdivision of the class into groups of rooms to five randomly chosen components, which needed to define the theme of study and after the internal discussions expressed the theme of interest and the place of research defined as: one group in urban cargo transport, public

transport by bus, urban toll, bicycles, simulation of urban terminal, BRT, BRS, bus stop and, two groups in specific lines of the traditional bus system. In all groups, the experience of the reality of one of the members prevailed in this process, being accepted by the other members and, in general, the leadership of the team was exercised by him.

The problematization method permeated all the propositions foreseen in the classroom and exposed the student to participate in the dynamics. The distribution of the contents in the course schedule interspersed three or four contents followed by a given delivery. Classes started on 03/14/2023, the first delivery was scheduled for 04/04/2023, the second on 05/09/2023 and the seminars on 06/20/2023 and 06/27/2023. The deadline for the final delivery of *the word and power point* files was extended to Friday of the current week, according to the order in which they were presented.

As for meeting the deadlines, two groups did not make the first delivery and another with a delay of one day. In the second stage, 60% met the stipulated deadline, two were late and one did not make a partial delivery. The remaining 30% justified the delay, delivered the second part, being aware of the evaluative criterion in this regard. Each file was properly read, corrected and returned to the groups containing *feedback* on the content and they could readjust and complement the written work according to the teacher's observations. In the next delivery, it was observed that the file was already updated and with the new placements required in that delivery. According to informal reports from some students, they were waiting for this feedback and few requested an individualized conversation for further clarification.

Table 4: Compliance with the deadline for partial and final deliveries and seminars

Evaluation Criteria	Groups									
	1	2	3	4	5	6	7	8	9	10
Delivery 1 – 04/04/2023	S	S	S	N	N	S	S	1*	S	S
Delivery 2 – 09/05/2023	S	S	S	S	S	NO T	1*	S	21*	14*
Seminar day 01 – 20/06/2023	S	S	N	S	S	ON	ON	ON	ON	ON
Final delivery (day 01) 23/06/2023	1*	S	S	S	S	ON	ON	ON	ON	ON
Seminar on 02 – 27/06/2023	ON	ON	S	ON	ON	S	S	S	S	S
Final delivery (day 02) 30/06/2023	IN	IN	S	IN	IN	S	S	S	S	S

Legend: S (yes), N (no), *Delay in days, NA (not applicable), NE (did not deliver).

As the date of the seminar approached, on the days of orientation of the groups, it was decided to make the last adjustments of content and presentation of the results, as well as changes of teams. Although the change of members was not foreseen, this action occurred naturally due to self-regulation among them, that is, by giving up the discipline at the beginning of the semester or exclusion from the group for not performing the activities. Two of them requested reallocation based

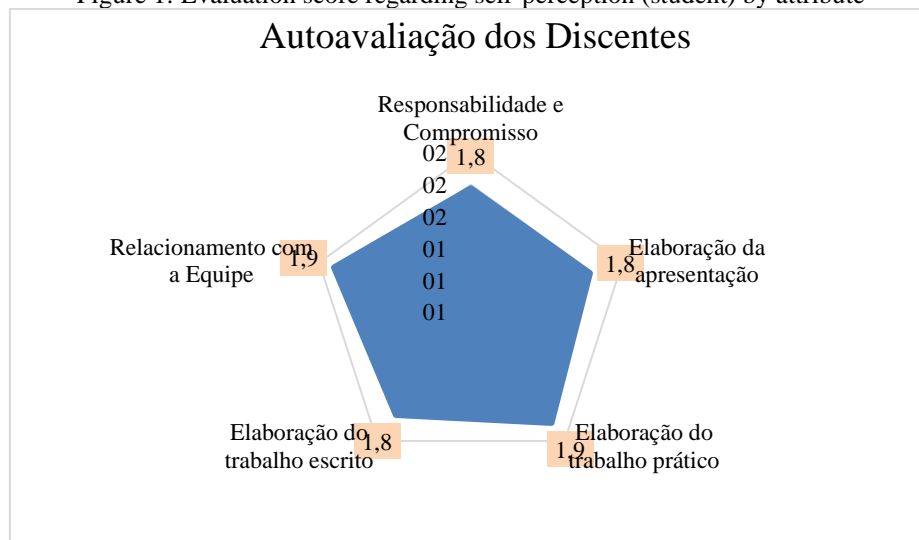
on affinity criteria in order to finish the course in that academic period.

These two students have the highlights: the first student is not a regular in the class, but is enrolled in it, and the other is male belonging to the class. In one of the activities of group 6, the student received the maximum score from her colleagues in three criteria, except for one of them in "preparation of the presentation", contrary to the evaluation of the same, which was given the maximum score in all criteria. The other student belonging to group 7 received the maximum score of three members in all criteria and 1.5 from the other member in "responsibility and commitment, relationship with the team, preparation of written and practical work".

When evaluating the seminar and the posture in the presentation, it was noted a greater engagement of the student to the theme and to the group, a fact that was not observed in the student of group 7, who only presented the conclusion of the work. Another point about this student is the attempt to plead for a formal evaluation via a written test so as not to join another group or perform the evaluation process of the discipline, because the reason for his departure from the original training was the lack of commitment and execution of the work. It was then that he was willing to do a job alone, being accepted by the teacher and then proposed to join another team by affinity to the members, resulting in these scores. It is possible to infer difficulties in assuming responsibility or commitment as a team, although the score indicates different scores given by the new group that welcomed them.

In the results of the evaluation questionnaire, it was found that, on average, the students gave themselves scores close to the maximum limit established of 2.0 points, with emphasis on 1.9 referring to "Relationship with the team" and "Elaboration of practical work" followed by 1.8 in the other criteria (Figure 1).

Figure 1: Evaluation score regarding self-perception (student) by attribute

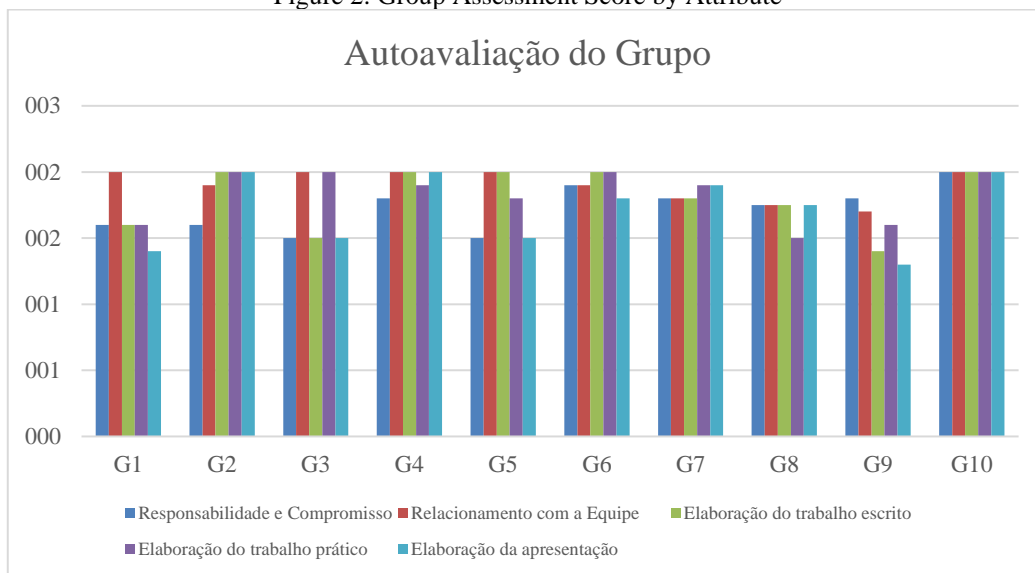


The overall individual evaluation average was 1.8, with the individual score being higher than

the group grade. In the process of assigning grades, the students were aware that it would not imply the definition of the individual concept in the discipline and it was noted that in 66% of the cases the student himself critically self-evaluated, placing his score below that of his colleagues regarding the preparation of the presentation (1.34), the written work (1.43), the practical work (1.61), responsibility and commitment (1.61) and finally, the relationship with the team (1.78).

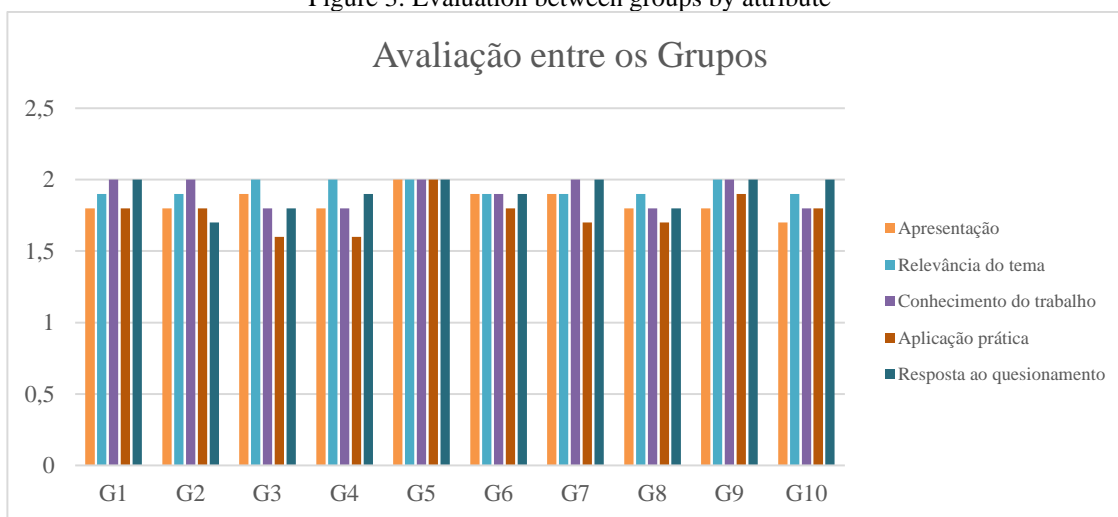
G4 and G9 maintained the original formation, however, the first obtained maximum scores in the individual and group evaluation in three of the items (relationship with the team, preparation of the written work and presentation), unlike the G9, which even with all the members presented variation and scores below the general average. In the others, there was a withdrawal from discipline or a change of group. The curiosity is linked to the G10, which continued to develop the research with 50% of the components, culminating in maximum scores in all analysis attributes (Figure 2).

Figure 2: Group Assessment Score by Attribute



In the next evaluation stage, each team answered a new questionnaire about their perception of the performance of the other groups, following other criteria, on a scale of 0 to 2 points (Figure 3). This score corresponds to the consensus of the group by criterion, with the G5 who obtained the maximum score in everything and this fact reflects the attitude of the members of this team who chose a topic judged as relevant, knew the problem, used theory to find practical solutions and demonstrated such qualities firmly, pleasing the other classmates in the seminar.

Figure 3: Evaluation between groups by attribute



G3, G4 and G9 developed their research on Urban tolls, cycling cities and BRS respectively, topics of interest to the city, proposed viable alternatives and, at the end at the time of the questions (each group answered three questions from the others by lottery) the theme of these teams generated good discussions and controversies in the classroom: the students themselves asked for the floor and used experiences and experiences on that theme to instigate the proposed solutions well as the group without the need for a draw.

When comparing the scores assigned, G3, G4 and G9 obtained the maximum relevance of the theme, however, only the practical solution of G9 was considered to be of greater relevance. This group listed points that imply the effectiveness of the BRS system in the city, not being a practical solution, but a diagnosis, compromising the applicability of the criterion for assigning grades. The solution adopted by G3 regarding the implementation of the urban toll generated questions about the proposition of the tariff to be practiced and whether in fact the benefits to the city and the population would occur and, a curious fact, is that the students applied a questionnaire to the class requesting a position of this feasibility.

The biggest and long-lasting questions occurred in the presentation about G4 bicycles, because in the room were present cyclists, employees of a public agency specific to this approach, as well as other users of this means of transport. In their proposal, the city was zoned in order to study close, central and more populous neighborhoods of the city to create interconnection and new routes using bike lanes and bike lanes since those locations have the medium as an alternative of daily commuting for short distances. However, they obtained a score of 1.6 from the class as an evaluation of the practical application of the solutions.

The second application of the TBL (Figure 4a) verified the content taught in the classroom based on a questionnaire in two phases: individually and in groups. After the end of the dynamics, the highest score was totaled in the group when comparing individually. The criterion of decreasing

the score in the group for each collective error allowed for some addition, which did not occur in the individual, because the correct answer accounted for 5, the error zero. The strategies differed according to their behavior in the execution of the activity: some quickly removed the sticker to find out the correct answer and, in case of an error, stopped for a new consensus since the score had decreased.

In this activity, there are behavioral notes: although the objective of the activity did not include a competition, such action was observed between the groups, because at the end all of them exchanged information about the individual and collective score. As it is a proposal to verify learning, the oral feedback of the students after the completion of the task pointed out the difficulty in reaching a group answer, especially the one who got it right from the beginning (scored 5 in the individual criterion) and did not convince the others, leading them to the wrong alternative and consequent decrease in the group score.

The profile of the class is made up of people who are active in the job market and who study at night, which does not prevent them from maintaining that healthy competition for the best performance when inserted in activities that can generate competition. In a complementary way, the class was active and involved in that activity, they discussed among themselves why it was not a given alternative, questioned the others until they reached consensus and then discovered the correct answer, resulting in *positive feedback*. No one left before the dynamic ended or pressed for frequency.

GAMIFICATION

This method was used in an expository class under the teacher's responsibility (Figure 4b) in the form of a board game that simulated experiences in transportation, inventory and supply chain as a way to help the student to actively mobilize with a view to building their own learning. The game is based on obtaining the lowest cost in the chain by performing the *trade off* between the quantity in stock and the demand forecast, the record of the excess and lack of products were quantified and monetized being accumulated over the weeks. The objective of the application of this game was to provide a simulated experience of a reality that involved several concepts that required decision making and, although it did not aim at competition between teams, again it was the behavior observed among the students. At the end of the activity, they waited for the final result ranked from the highest (the learning champions) to the lowest cost.

At the end of the activity, there was *feedback* on perceptions about the game, the probable causes that culminated in those results, individual behavior under pressure, the indication of the "culprits" for their performance, among other notes. As the answers emerged, concepts were introduced to explain the behavior, mental models, attitude, and decision-making required by the

game.

Figure 4: (a) TBL and (b) Gamification.



The fourth and final gamification method applied was the *quiz*. In this study, the groups had one week to elaborate five objective questions about their research topic. In the execution of the activity in the classroom, the groups were guided on the dynamics:

- * Assign a score to each of your questions using the criterion from easiest to most difficult on a scale of 1 to 5;
- * Challenge a group to answer one of their questions. In case of a wrong answer, the chance would pass to the others at a lower score;
- * In case of success, the challenged group chose another, continuing the actions until everyone had participated in the dynamics.

The *quiz* brought together more than 50 questions prepared by the groups referring to the themes defined for the final work, required consultation of various materials made available or not by the teacher, as well as the formulation of right and wrong answers. In this *quiz* there was a reward revealed at the end of the activity, and the winning group was awarded. It should be noted that there was no extra grade assigned to the final concept of the course.

DISCUSSION OF RESULTS

The construction of the five evaluation attributes considered the evaluation points provided for in the teaching plan of the discipline and directed the individual to his/her perception of the others under the same items. By making a parallel to the theory of active methodologies, it was observed that the student was at the center of the learning process, performing research, reflection, decision-making and autonomy from the problematization of reality, correlating theory and practice in the search for solutions applicable to the reality studied. The results can be extrapolated to the critical and constructive attitude about the themes chosen by the groups, as well as the evaluation of themselves and each other, since along the trajectory there were changes in teams and withdrawals

from the discipline.

There are some inferences in the "relationship with the team": the random formation of the groups aimed at not grouping by affinities; most of the students belong to the same class and do not work together, since each one has the declared preference of their peers; Greater responsibility and commitment to the team was foreseen, which did not prevent the differentiation of scores in the group's internal evaluations.

In order to promote the participation and integration of the class and minimize passivity in the seminar routine, the strategy was adopted by drawing groups to ask questions at the end of each presentation. The pertinent themes or needs that were not visible in the city were the ones that generated the most discussions, such as urban tolls and cycling cities. 80% of the groups opted for themes of collective public transport whose focus was the quality perceived by the user, which was verified during the research, a pertinent fact in the city that is expanding this service offer.

The fact found is that all groups opted for the diagnosis of the problem, the starting point was the perception of their daily experience and the solution outlined from a field research and theoretical recommendations applicable to reality. Therefore, it is possible to affirm that by bringing theory closer to practice and the increase of active learning methods, the student tends to develop critical thinking, inserts himself into the problem and projects the appropriate solutions, and it is not possible to apply and quantify the changes in these propositions of improvements due to the non-intervention of action research.

The second application of the TBL corresponded to the questionnaire containing questions about the contents taught in the classroom, whose student participation was analyzed from two perspectives: the first is individual behavior, since the initial challenge was for each one to answer alone by simulating an individual evaluation; The second was the group discussion. When counting the final individual and group score, the students reported that their grade would be below average (stipulated in the Educational Institution), as they would get most of the answers wrong if that activity was an assessment in the traditional models. In the second round, with the opportunity to interact with their colleague, expose their opinions and exchange ideas, they identified errors and other points that could interfere with the correct answer, being beneficial for a higher final score.

Therefore, the higher scores in the group may explain the improvement in the student's responsiveness, perception and apprehension of the content, as well as their behavior when exposed to different learning stimuli. In the case of the latter activity, the students were not communicated in advance, did not consult the materials or even prepare for it. The strategy of the element of surprise on the day of the activity was a differential in the dynamics of the lectures under the command of the teacher, having the acceptance and adhesion of those present.

As for the continuous evaluation process, segmented deliveries was a strategy accepted by the

student, since most groups respected the dates and made adjustments in the following stages. The non-participation or fulfillment of a member's task were the highlights in the group evaluations, however, they were not decisive in the final concept of the discipline, but caused the reorganization of the group or even its dismissal, and these notes corroborate the strategy of promoting skills and attitudes.

At the end of each academic term, the HEI provides AVALIA: teachers and students answer a questionnaire (scale from zero to five) containing the three dimensions *i*) student self-evaluation, *ii*) evaluation of teaching action, *iii*) evaluation of physical facilities. Table 5 shows the mean of the scores of the first two dimensions, whose analysis is the average of the academic period referring to the evaluated specificities highlighted.

The response from AVALIA highlighted that 78.94% of the students stated that they learned the content taught in the course and remained motivated in the development of the proposed activities. Regarding the teaching action, 92.1% evaluated that the teacher stimulated critical thinking and explained the evaluation process in an objective way. The contextualization of the discipline, its contribution to citizenship and professional training and the diversification of assessment instruments obtained the second highest score in the students' view.

The overall average of the period was egalitarian of 3.68 for the student and teacher action, which allows us to infer that there is no differentiation of importance or division of responsibilities, that is, the construction of knowledge was for the student in the same proportion as the orientation of the teacher. The mean of the AVALIA scores has a high standard deviation (mean of 0.72) and high variation, data far from the mean and requires caution in interpretation, generalizations and inferences.

The grade attributed to the learning assessment in terms of the defined criteria (3.73) and the level of depth of the contents worked on (3.70) alert to possibilities for improvement, as the final concept in the discipline depended only on the grade in the group, and was not differentiated by student by effort learned during the deliveries. Less engaged students obtained grades equal to those more participative, which possibly interfered in the attribution of grades at the end of each proposed activity, as well as in AVALIA.

Table 5: Mean AVALIA scores.

Dimension 1: Student Self-Assessment		
1.1.4	I learned the contents taught in the Discipline/Module	3,61
1.1.5	I was motivated throughout the activities proposed in the Course/Module	3,48
1.1.6	I deepened my knowledge, autonomously, with different sources of studies, outside the classroom	3,45
1.1.7	I carried out the activities of the Discipline/Module meeting the deadlines and criteria established	3,48
Dimension 2: Evaluation of teaching action		
2.2.5	The Teacher taught the concepts/contents in a contextualized way	3,76
2.2.6	The Lecturer encouraged me to develop critical thinking	3,85
2.2.8	The Teacher contributed to my citizenship and professional training	3,76
2.3.1	The Lecturer objectively explained the evaluation process of the Discipline/Module	3,85
2.3.2	The Teacher evaluated learning with objectively defined criteria	3,73
2.2.3	The Lecturer evaluated the learning according to the level of depth of the contents worked in the Discipline/Module	3,70
2.3.4	The Teacher used different assessment instruments (tests, seminars, textual production, etc.)	3,76

As for the active methods, the application of TBL produced good results as it enabled the flexibility and differentiation of the evaluation process, as advocated by Machado et al. (2021) and Luckesi (2022). Interaction and cooperation favor learning, dialogue, and the construction of knowledge together, connecting them to the reality of society.

Gamification has transformed the classroom environment in the days of application, the results of which confirmed the benefits of adopting innovative strategies, in interaction and cooperation as positive responses to learning. The stimulus to self-improvement made the student the very agent of change, of the apprehension of the content and in the construction of their knowledge.

FINAL THOUGHTS

In the discipline TE08088 Urban Transport, the theoretical content (45h) predominates over the practical (15h), having to be adjusted to each reality of the class. The profile of the student belonging to the night period of Civil Engineering stimulated the teacher to search for other means, methods and methodologies of teaching-learning, as he is a student who ends his day in a classroom, enters the facilities with different perspectives and dispositions and, sometimes, makes use of this prerogative as a justification for his performance. It is known that adults need a 5 to 10 minute rest every 50 or 60 minutes of activities to maintain focus. In the classroom, dispersion, side conversations, and the use of electronic devices as ways to stay in that environment are notorious, and attention to content is questioned.



Although these difficulties are recurrent in the analyzed public, the adoption of active methods is promising for making teaching more flexible, differentiating the learning and assessment process, as well as helping the development of competencies, skills and attitudes aimed at humanization and motivation.

Therefore, the use of active methodologies in higher education becomes beneficial, somewhat playful and educational when promoted by activities that, in fact, involve and include students, not being a guarantee of the participation of all of them. The strategy of interspersing the theoretical content with partial deliveries was accepted in this and other disciplines belonging to the area of Transportation and, to a certain extent, fulfilled, because the unforeseen events, the changes of dates in the calendar and the dynamics of each academic period generate new adaptations.


The segmentation of the deliveries, the feedback of the teacher with the correction of the work in all stages of delivery, the execution of group and individual activities were valid notes during the course of the course and to the target audience of the night period. The profile of IES students has a declared preference for the traditional and content-based teaching-learning process with individual written assessment, and negatively labels or greater ease the active teaching practices, especially when the flipped classroom occurs. This feedback occurs in internal evaluations when the student assigns grades in the SIGAA system when asked about the teacher and the discipline at the end of each academic period.

In this discipline and course in particular, the challenge is continuous, the initiatives in active learning are the updates and changes perceived by the student. The results appear in orientations of course completion work, students who express interest in continuing the research and submitting them to congresses or journals in the area, involving the professor and stimulating diverse academic experiences.

REFERENCES

1. Almeida, J.R.d.S., Bizerril, D.O., Saldanha, K.G.d.H., & de Almeida, M.E.L. (2016). Educação permanente em saúde: uma estratégia para refletir sobre o processo de trabalho. *Revista da ABENO*, 16(2), 7–15.
2. Barbosa, C. L., Lima, A. da C., Silva, M. H. T. da, dos Reis, M. E. D. M., & Cosenza, H. J. S. R. (2022). The method of applying knowledge management to Lean in emergency care units. Em *Cases on Lean Thinking Applications in Unconventional Systems* (p. 184–204). IGI Global.
3. Barbosa, C., Lima, A., Sobrinho, A., Calado, R., & Lordelo, S. (2021). Information, communication and knowledge for lean healthcare management guidelines, a literature revision. Em *Advances in Production Management Systems. Artificial Intelligence for Sustainable and Resilient Production Systems* (p. 250–257). Springer International Publishing.
4. Correa, C. B., & Silva, D. C. da. (2022). Aprendizagem baseada em equipes (TBL). In: Luchesi, B. M., Lara, E. M. de O., & Santos, M. A. dos. (org.). *Guia prático de introdução às metodologias ativas de aprendizagem*. Campo Grande, MS: Ed. UFMS.
5. Ferreira, D.S., Ramos, F.R.S., Teixeira, E., Monteiro, W.F., & Aguiar, A.P.d. (2021). Obstacles to the educational praxis of nurses in the family health strategy. *Revista Gaúcha de Enfermagem*, 42.
6. Gouvêa, A. R. de; Dias, A. F. F.; Cabrelli, D. W. M. (2022). Aprendizagem baseada em projetos (ABP). In: Luchesi, B. M.; Lara, E. M. de O.; Santos, M. A. dos. (org.). *Guia prático de introdução às metodologias ativas de aprendizagem*. Campo Grande, MS: Ed. UFMS.
7. Lima, A. da C., Barbosa, C. L., Chaves, S. M. do A., Oliveira, J. G., Queiroz, T. L., & Calado, R. D. (2022). Potential of continuing education in Health of improvement practices in urgency and emergencies in Emergency Care Units – UPA-24h. *IFAC-PapersOnLine*, 55(10), 906–909. <https://doi.org/10.1016/j.ifacol.2022.09.417>
8. Luchesi, B. M., Lara, E. M. de O., & Santos, M. A. dos. (2022). *Guia prático de introdução às metodologias ativas de aprendizagem*. Campo Grande, MS: Ed. UFMS.
9. Machado, A. C., Fernandes, C. D. M., Pereira, A. M. P., Souza, E. de S. e, Rufino, M. V. M., & Oliveira, E. do N. S. de. Avaliação da aprendizagem no ensino superior. *Research, Society and Development*, [S. l.], v. 10, n. 6, p. 1-13, 2021. DOI: <https://doi.org/10.33448/rsd-v10i6.15618>. Disponível em: <https://rsdjournal.org/index.php/rsd/article/view/15618>. Acesso em: 19 jul. 2021.
10. Peixoto, L.S., Gonçalves, L.C., Da Costa, T.D., de Melo, C.M.T., Cavalcanti, A.C.D., & Cortez, E.A. (2013). Educação permanente, continuada e em serviço: desvendando seus conceitos. *Enfermería Global*, 12(1).
11. Rigonato, E. M., & Cruz, K. B. da. (2022). Problematização. In: Luchesi, B. M., Lara, E. M. de O., & Santos, M. A. dos. (org.). *Guia prático de introdução às metodologias ativas de aprendizagem*. Campo Grande, MS: Ed. UFMS.
12. Vendruscolo, C., Silva, K.J.d., Araújo, J.A.D., & Weber, M.L. (2021). Permanent education and its interface with best nursing practices in primary health care. *Cogitare Enfermagem*, 26.

An innovative approach: Agile methodologies for the design of power circuit breakers

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ABSTRACT

During the increasing complexity of electrical systems, the need for more effective and accessible methods becomes evident, seeking to balance technical precision, operational practicality and safety. This article proposes an innovative and simplified method for the sizing of power circuit breakers, aiming to optimize the efficiency of the selection process of these crucial equipment for the electrical infrastructure. The sizing methodology aimed at specifying the main characteristics of power circuit breakers offers a systematic and comprehensive approach, integrating critical considerations ensuring the correct functioning of these equipment in various electrical contexts. The process consists of several steps, covering everything from the initial analysis to the final selection of the appropriate circuit breaker. The modified power method is applied to the definition of the short-circuit characteristics and is introduced in the sizing criteria based on the operation of the electrical system for the analysis in normal operation of the system. A test system of a pumping station consisting of a 69 kV substation is studied. The proposed methodology met its objectives, presenting precision and effectiveness, and can be a very useful tool for project engineers in electricity.

Keywords: Short circuit, Power flow, Power circuit breakers, Circuit breaker sizing, Specification of circuit breakers.

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INTRODUCTION

In the electrical engineering scenario, power circuit breakers play a crucial role in maneuvering, protecting, and controlling electrical power systems (SEE). High-voltage circuit breakers represent a fundamental piece in the global electrical infrastructure, ensuring the reliability and security of power supply in various industrial and commercial applications.

In electrical systems, circuit breakers are required to perform the basic function of controlling the electrical power transmitted by them, either by conducting the load current of the circuits, or by maneuvering the closure of circuits or even the withdrawal of services from circuits under nominal or automatic command. Circuit breakers normally operate in the closed position, conducting the load current, or in the open position in which they operate by exerting insulation. Only in occasional situations are circuit breakers triggered to change position, i.e. to change from open to closed or from closed to open, and only on rare occasions are they triggered to interrupt short-circuit currents [1].

This equipment is designed to interrupt short-circuit currents in very short intervals of time, representing one of the most challenging tasks entrusted to the equipment present in power systems. They must also be able to establish fault currents, to establish and interrupt currents of much smaller magnitudes, and to isolate parts of systems when in the open position. The execution of these tasks, in an absolutely reliable manner, is imperative to prevent damage to other components of the electrical system, positioning the circuit breakers among the most complex equipment installed in the substations [2].

The challenges associated with circuit breakers are multifaceted, ranging from the ability to interrupt short-circuit currents at minimal intervals to the need to operate under harsh environmental conditions for prolonged periods [3]. The complexity of these demands places circuit breakers among the most intricate and critical pieces of equipment in electrical power system (SEP) substations.

Thus, the requirement imposed on power circuit breakers is that of total reliability, and this reliability is the result of a rational design and strict quality control. This process ranges from the careful selection of raw materials to the final stage of the tests, encompassing the input review, materials testing, thorough control of the manufacturing processes, tests on sub-assemblies and, finally, the final tests. Commitment to each phase of this development cycle is vital to ensure not only compliance with technical specifications, but also the durability and operational efficiency required in challenging environments. This integrated and comprehensive approach reflects the relentless pursuit of excellence in power circuit breaker engineering, grounded in sound practices and uncompromising pursuit of quality.

In this context, the precise and efficient performance of circuit breakers plays a strategic role in the stability and safe operation of electrical systems. Their ability to transition between states, from drive to disruption, reflects not only the complexity of their responsibilities, but also the need to

solidly balance operational reliability with efficiency. This scenario serves as a backdrop to the critical importance of innovative advancements and in the sizing and application of these devices.

This paper proposes an innovative approach in the sizing of high-voltage circuit breakers, presenting a simplified method that aims to optimize the selection process of these devices. Understanding and applying sizing procedures is essential to ensure that circuit breakers meet the specific requirements of each electrical system, balancing effectiveness, cost, and efficiency.

The areas of knowledge for the training of electrical engineering professionals include the study of electrical equipment, including circuit breakers. The need to know electrical equipment and experience its actual operation is fundamental [4]. Streamlining the sizing process not only streamlines decision-making but also promotes a more accessible and faster understanding for professionals in the field. This study aims to contribute significantly to the operational efficiency and continuous development of electrical systems, by offering an innovative methodology for the sizing of high voltage circuit breakers.

In the following sections, the fundamentals of circuit breaker sizing are explored, highlighting the importance of considering critical variables such as system load, short-circuit characteristics, and coordination requirements. Next, the proposed simplified method is presented, detailing its premises, applicability and advantages compared to traditional approaches.

FEATURES FOR SPECIFICATION AND DEFINITIONS

Power circuit breakers are the main safety equipment, as well as the most efficient switchgear in use in electrical networks. They have a closing and rupture capability that must meet all established maneuvering prerequisites, under all normal and abnormal operating conditions [5]. IEC 56-1 apud [3], defines a circuit breaker as "a mechanical switching device, capable of establishing, conducting, and interrupting currents under normal circuit conditions, as well as establishing, conducting for a specified time, and interrupting currents under specified abnormal circuit conditions, such as short-circuit conditions."

The main function assigned to circuit breakers is to interrupt fault currents as quickly as possible, in order to minimize the potential damage caused to equipment by short circuits. In addition to dealing with fault currents, it is imperative that the circuit breaker be able to interrupt normal load currents, magnetizing currents coming from transformers and reactors, as well as capacitive currents associated with capacitor banks and no-load lines [2].

Additionally, the circuit breaker must possess the ability to close electrical circuits not only during normal load conditions, but also in the presence of short circuits. The most common functions performed by circuit breakers include, firstly, the conduction of load currents when in the closed position, followed by the function of isolation between two parts of an electrical system [2].

With respect to this function, the circuit breaker being in the open or off state, the insulation distance between the contacts must be able to withstand not only the operating voltage, but also the internal overvoltages arising from maneuvering surges or lightning strikes.

The main characteristics applicable to circuit breakers are listed below, as well as the corresponding definitions, as shown in [5].

- Rated Voltage: It is the maximum operating voltage of the system for which the circuit breaker was provided;
- Rated current: It is the effective value of the continuous regime current that the circuit breaker must be able to conduct indefinitely, without the temperature rise of its different parts exceeding the specified values;
- Rated frequency: It is the system frequency for which the circuit breaker will operate;
- Rated short-circuit interrupting capacity: This is the highest value of the short-circuit current that the circuit breaker is capable of interrupting, under the conditions of use and testing established in the IEC 62271-100 standard. It is characterized by the declaration of the values of the periodic and aperiodic components of the current for which the circuit breaker is to be tested [2];
 - Periodic component value (kA, effective): It is a value chosen among the several defined in the technical standards, higher than the effective value of the highest single-phase or three-phase short-circuit current calculated for the substation where the circuit breaker will be installed;
 - Value of the aperiodic component: The DC component of the fault current, at the time of separation of the circuit breaker contacts, is specified as a percentage of the initial ICCO value, where $ICCO = ICA(\text{peak})$. The percentage value will express the $\%ICCO / ICA(\text{peak}) \text{ ratio} \times 100$. The shortest possible opening time for the definition of this component will consider a protection actuation time of 0.5 cycles. Thus, the value of the CC component varies, over time, according to the exponential (1):

$$I_{CC}(\%) = e^{\frac{-t}{\tau}} \times 100 \quad (1)$$

Let the time constant conform to (2): τ

$$\tau = \frac{1}{\omega} \cdot \frac{X}{R} \cdot 1000 \text{ (ms)} \quad (2)$$

- Nominal short-circuit setting capacity (kA, crest): It is the highest instantaneous value of current that the circuit breaker is capable of establishing, i.e., close and latch when operating at rated voltage. Its value can be calculated by (3):

$$I_{fmax} = I_{CA\ ef} \times f \quad (3)$$

Where f is the asymmetry factor, defined as (4):

$$f = \sqrt{2} \cdot (1 + e^{-\frac{t}{\tau}}) \quad (4)$$

The peak value is linked to the rms value of the rated short-circuit interrupting current, frequency, and time constant (τ). The values specified according to [6] are:

- 2.5 x short-term withstand current rated at 50 Hz at $\tau = 45$ ms
- 2.6 x short-duration rated withstand current at 60 Hz at $\tau = 45$ ms
- 2.7 x rated short-duration withstand current at 50/60 Hz at $\tau > 45$ ms (*)

(*) For all special time constant cases

- Rated Insulation Level: Defines the withstand values of the voltages and overvoltages for which the circuit breaker is designed. It should be chosen from the values indicated in the reference tables [7].
- Nominal Sequence of Operation:

The nominal sequences of operations standardized by ABNT are as follows:

- For circuit breakers intended for rapid reclose:

O-0.3s-CO-15s-CO or O-0.3s-CO-3min-CO

- For circuit breakers not intended for fast reclose:

CO-15s-CO or O-3min-CO-3min-CO

- Rated Interrupt Time:

It corresponds to the longest time that the circuit breaker can take to interrupt a current of any value. This time ranges from 2 to 5 cycles. According to [5], it is recommended to adopt the following interrupting times in the circuit breaker specifications according to the voltage class:

- Voltage class 362, 460, 550 and 800 kV: 2 cycles;
- Voltage class 72.5, 145 and 245 kV: 3 cycles;

- Voltage class 15 kV: 5 cycles.

- Disjunctors Type

A guideline for selecting the type of circuit breakers according to the voltage class presented in [5] is described below:

- Voltage class: 5kV to 38 kV

Vacuum or SF6 circuit breakers. Being the preferred vacuum, although there is a relative equivalence between them, they are competitive.

- Voltage class: 72.5kV to 245 kV

SF6 circuit breakers

- Voltage class: ≥ 365 kV

Compressed air and SF6. SF6 being preferred in most cases.

SIZING METHODOLOGY

Knowing how to size equipment is critical for every electrical engineer, especially for equipment engineers, however, to size them may not be an easy task. The sizing methodology aimed at specifying the main characteristics of power circuit breakers must necessarily offer a systematic and comprehensive approach, integrating critical considerations to ensure the correct functioning of this equipment in various electrical contexts. The process consists of several steps, covering everything from the initial analysis to the final selection of the appropriate circuit breaker. Table 1 shows the main phases of the circuit breaker selection methodology.

Table 1: Methodological phases of the design and selection process.

Phases of the Process	Objective
1-Electrical System Analysis	Evaluation of electrical system configuration and characteristics, including load, short circuit, and coordination requirements.
2- Identification of Parameters	Survey and identification of critical parameters such as rated current, short-circuit current, operating characteristics, and other system-specific factors.
3- Power Flow Analysis	Performing analysis to determine the ability of the circuit breaker to handle the predicted load currents, ensuring that the temperature rise is within the specified limits
4- Short Circuit Analysis	Evaluation of the circuit breaker's ability to withstand and interrupt short-circuit currents, taking into account interrupt times, short-circuit levels, etc.
5- Circuit Breaker Type Selection	Appropriate choice of circuit breaker types, considering the specific characteristics of the system and environmental conditions
6- Documentation and Report	Preparation of detailed documentation, including technical specifications, calculations, and justifications for the final selection of the circuit breaker.

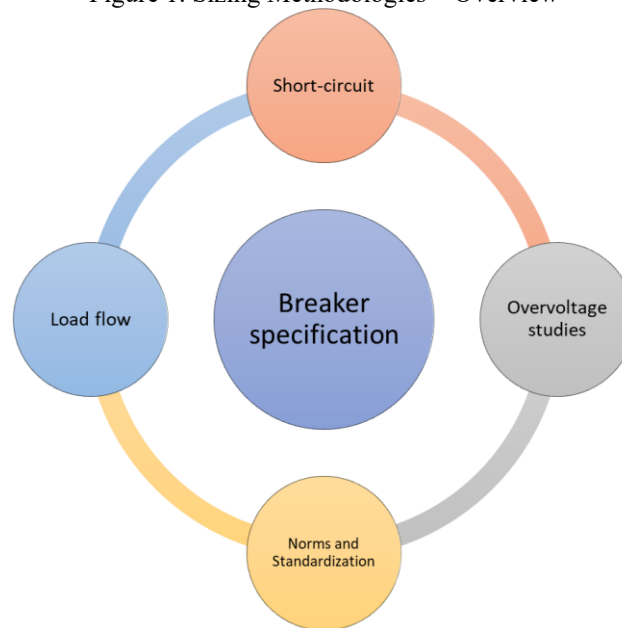
Within the methodological process presented, electrical studies stand out as of fundamental importance. Basically, the studies necessary for the specification of the electrical characteristics of

the circuit breakers are: study of power flow for the determination of the nominal current; short-circuit study to determine short-circuit withstanding and interrupting capacity; study of overvoltages to determine insulation levels and TRT (Transient Restoration Voltage) [8].

To carry out these studies, computational resources are usually used. Computer programs play a key role by providing powerful tools for analyzing complex electrical systems. There are a number of widely recognized platforms for analysis and simulation of electric power systems that include advanced tools and robust capabilities for power flow and short-circuit calculations, as well as stability studies and grid planning.

In view of the above, the challenge is to design and specify power circuit breakers without computational resources. Thus, the proposed methodology for the design of circuit breakers aims to offer a systematic and comprehensive, but simplified approach of direct and objective application, considering premises that allow shortcuts in the execution of calculations. Figure 1 shows the general outlines of the sizing methodologies.

Figure 1. Sizing Methodologies – Overview



Conventional methods for short-circuit calculation involve many formulas, increasing complexity and requiring a lot of time. As demonstrated in [9], the power method has been shown to be quite simple and effective in terms of speed, accuracy, and economy to solve short-circuit problems in industrial electrical systems. Thus, the proposed methodology for the sizing of circuit breakers is based on the modified power method for the calculation of short circuit. The equations used in the short-circuit calculation are as follows [5] and are presented below.

$$Secconc = \sqrt{3} \cdot kVnominal \cdot IccConc \cdot 10^{-3} \quad (5)$$

$$X_{th} = \frac{S_b}{S_{cc}} \quad (\text{PU}) \quad (7)$$

$$X_{pu} = X_{pu} \frac{S_b}{S_{Equip}} \quad (\text{PU}) \quad (8)$$

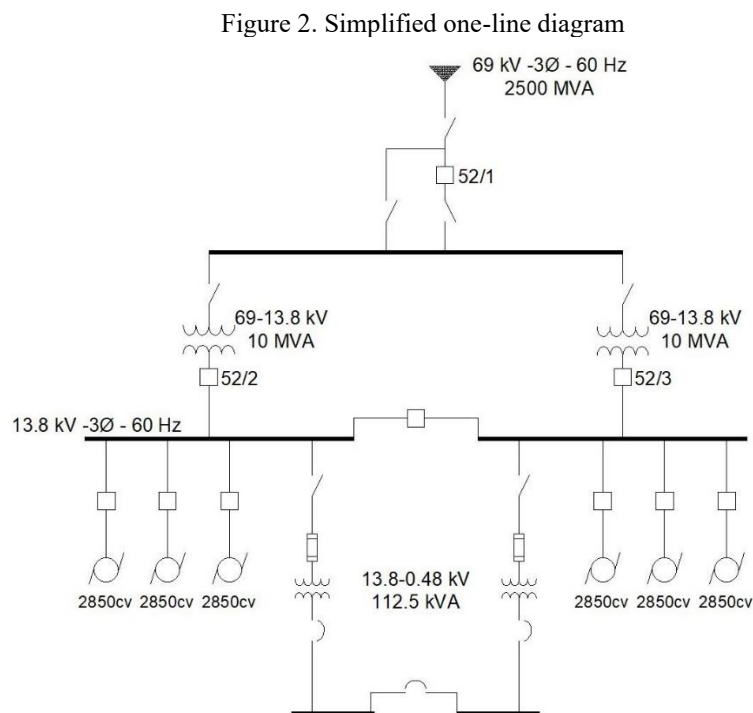
$$S_{k(3)} = \frac{S_b}{X_{pu}} \quad (\text{MVA}) \quad (9)$$

$$I_{k(3)} = \frac{S_{k(3)}}{\sqrt{3} V} \quad (\text{kA}) \quad (10)$$

Regarding the definition of the nominal current of the circuit breaker, it must be considered that it has to be higher than the maximum current that circulates in the section where the circuit breaker will be installed. Normally, the currents that circulate in the stretches are obtained through the study of the power flow with the help of computers. However, the definition of the maximum current that can circulate in a given section of the electrical system for equipment sizing must comply with sizing criteria based on the operation of the system, such as contingency, release flow of the full capacity of the transformers, in the case of the branch under its control, among others.

TEST SYSTEM

The electrical system of a water pumping station consists of a 69 kV substation (SE) with radial and selective secondary arrangement containing two 10 MVA transformers that lowers the voltage to 13.8 kV to power six sets of 1850 hp motor pumps. Two 112.5 kVA transformers are connected to the 13.8 kV bus, as shown in the single-line diagram shown in Figure 2.



The short-circuit power considered at the entrance of the substation to the project horizon was 2500 MVA. An impedance of 6% was considered for the 10 MVA (TF) power transformers. The motors (M) are induction, three-phase with an efficiency of 95%, a power factor of 85% and a subtransient impedance of 17%. The impedance of auxiliary services transformers (TSA) was considered to be 4.5%. The system has no operational restriction, being able to operate both in "L" and "H", that is, it is allowed to operate the transformers in parallel.

SHORT-CIRCUIT STUDY

This topic presents the study that serves as the basis for the definition of the short-circuit currents that are used for the specification of the SE circuit breakers. Initially, the base power should be chosen and all the impedances considered in the studied system should be referred to the chosen base.

In order to simplify and reduce the calculations, the power of the TF was chosen as the basis. Thus, by applying equation (7), the reactance of the source of supply (FS) of the SE in pu in the chosen base is obtained. The reactance of the TF is already at the base of the system, which is the power of the transformer itself, and it is not necessary to change the base. With respect to the induction motor (M) it is necessary to calculate the power in kVA by applying equation (11)

$$S_M = \frac{CV \times 0.736}{\eta \times \cos\phi} \quad (11)$$

Substituting the values gets:

$$S_M = \frac{2850 \times 0.736}{0.95 \times 0.85} = 2598 \text{ kVA} \quad (12)$$

Applying the power of the induction motor in kVA and its impedance of 0.17 pu to equation (8) obtains the reactance of the motor on the adopted base. The same equation (8) is used to transfer the 0.045 pu reactance of the auxiliary services transformer to the new base. Thus, the calculated reactances are presented in Table 1.

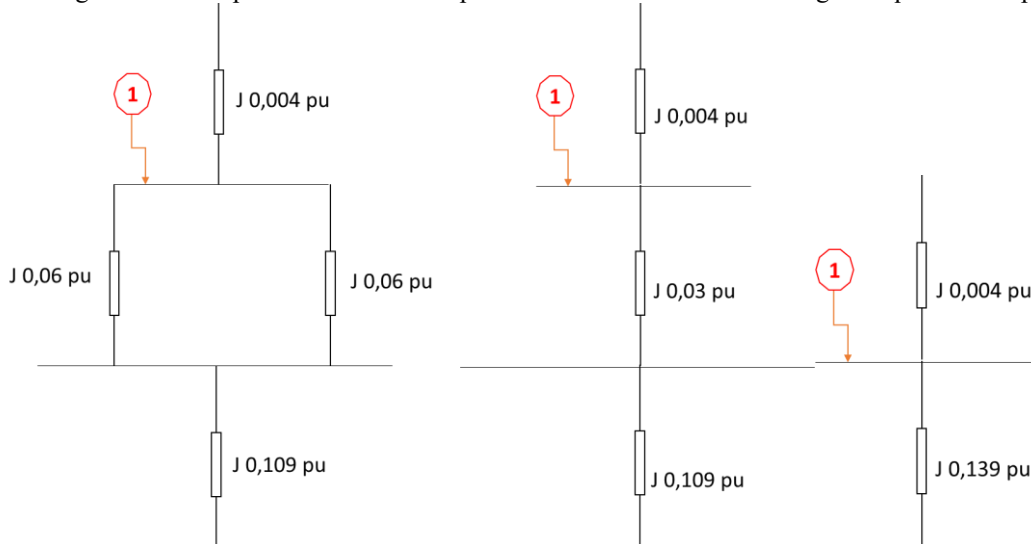
Table 1: Pu reactances at the base of 10 MVA

FS xC	TF (10MVA) xTF	Motor x ["] d	X equivalent (6 M in parallel) x ["] d eq	TSA xTSA	X equivalence (2 TSA in parallel) xTSAeq
J 0.004 pu	J 0.06 pu	J 0.654 pu	J 0.109 pu	J 4 pu	J 2 pu

CALCULATION OF THE SHORT-CIRCUIT SUBTRANSIENT CURRENT IN POINT 1

To calculate the short-circuit subtransient current at point 1, it is necessary to transform the single-line diagram in figure 2 into the corresponding impedance diagram for three-phase short-circuit, as shown in figure 3.

Figure 3. Diagram of the impedances and the simplification method for determining the equivalent impedance



The two impedances in the simplified diagram in Figure 3 are in parallel to the short circuit at point 1. The result of this calculation is the equivalent subtransient impedance at point 1, shown in (13).

$$x_{eq}'' = j0,0039 \text{ pu} \quad (13)$$

Using equations (9) and (10) we get the power and subtransient current at point 1 respectively.

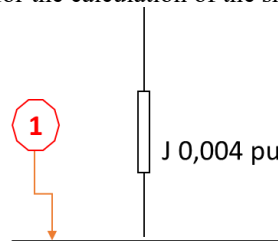
$$S_{k3}'' = \frac{10000}{0,0039} = 2564 \text{ MVA} \quad (14)$$

$$I_{k3}'' = \frac{2564 \times 10^3}{\sqrt{3} \times 69} = 21.5 \text{ kA} \quad (15)$$

CALCULATION OF THE CURRENT AFTER THE ESTABLISHMENT OF THE SHORT-CIRCUIT STEADY STATE IN POINT 1

The impedance diagram for the calculation of the short-circuit steady state current in point 1 is shown in Figure 4.

Figure 4. Impedance diagram for the calculation of the short-circuit steady state in point 1.



$$S_{k3} = 2500 \text{ MVA} \quad (16)$$

$$I_{k3} = \frac{2500 \times 10^3}{\sqrt{3} \times 69} = 20.9 \text{ kA} \quad (17)$$

MAXIMUM LOAD FLOW

For the sizing of the nominal current of the circuit breaker, it is necessary to calculate the highest current that circulates in the section where it must be installed. According to the single-line diagram in figure 2, the calculation of the highest current circulating in the 69 kV input circuit breaker section is determined by the sum of all the loads of the electrical system, that is, the sum of all motors and auxiliary service loads.

However, it should be noted that the two power transformers were dimensioned to meet the demand of all loads and logically their nominal power is higher than the sum of all loads of the pumping station supplied by the substation. Thus, by dimensioning the nominal current of the circuit breaker by the sum of the nominal power of the power transformers, in addition to standardizing the capacity of the substation equipment, the entire capacity in transformers is released to flow through the system, which may eventually supply a certain increase in load. Thus, the maximum current that circulates in the section to be considered in the nominal design of the circuit breaker is calculated by equation (18).

$$I = \frac{2 \times 10000 \text{ kVA}}{\sqrt{3} \times 69} = 167.35 \text{ A} \quad (18)$$

69 kV CIRCUIT BREAKER SIZING (52/1)

The calculations involved for the sizing of the circuit breaker are as shown in figure 1. Regarding the studies related to isolation coordination and TRT, reference [10] presents a methodology for these studies.

From the calculated values of 167.3 A for the maximum current circulating in the normal operating period and the value of the short-circuit steady state current of 20.9 kA, the rated circuit

breaker current and the rated cut-off current can be determined using Table 2 or any coordination table of the rated current values provided by the circuit breaker manufacturers.

Table 2: Coordination of circuit breaker setpoints

Rated voltage kV (effective)	Rated short-circuit breaking capacity kA (effective)	Rated current A (effective)					
		3	4	5	6	7	8
1	2						
72,5	12.5			800	1200		
	16			800	1200		
	20				1200	1600	2000
	31.5				1200	1600	2000
145	12.5	800	1200				
	20		1200	1600	2000	2500	
	25		1200	1600	2000	2500	
	31.5		1200	1600	2000	2500	3000
	40			1600	2000	2500	3000
	50				2000	2500	3000

The rated current to be adopted as well as the rated interrupting current shall be greater than the calculated values of the maximum current in the normal operating regime and the current of the short-circuit standing regime. Thus, using table 2 for the nominal voltage of 72.5 kV, the value of the nominal interrupting capacity immediately higher than the effective value of the calculated periodic component (I_{k3}) is 31.5 kA and the nominal current coordinated with this value is 1200 A, which easily meets the maximum current that circulates in the stretch under normal operating regime.

Thus, the following nominal values are adopted:

- Rated Short Circuit Breaking Capacity (IIN): 31.5 kA (effective);
- Rated current (IN): 1200 A (effective).

In order to determine the nominal short-circuit establishment capacity, it is necessary to know the asymmetry factor (f), which can be calculated by equation (4). Considering the time constant (τ) of 45 ms, the value of f calculated by equation (4) is 2.6, as also established in references [6] and [11].

Thus, by applying f and the short-circuit subtransient current calculated for point 1 in equation (3), the calculated value of the current is obtained for the determination of the short-circuit nominal establishment capacity of the circuit breaker.

$$I_{fmax} = 2.6 \times 21.5 \text{ kA} = 55,9 \text{ kA (crista)} \quad (19)$$

It turns out that the standardized IIN adopted for the circuit breaker was 31.5 kA. Thus, the standardised short-circuit nominal settling capacity shall be the conforming value (20).

$$I_{Cap\ Est\ Nom\ cc} = 2.6 \times 31.5\ kA = 81,9\ kA\ (crista) \quad (20)$$

The following is the specification of the circuit breaker (52/1) at the substation entrance;

- Rated voltage: 69 kV;
- Maximum rated voltage: 72.5 kV;
- Rated Atmospheric Impulse Withstand Voltage (TSNIA): 350 kV;
- Rated withstand voltage at industrial frequency (TSNFI): 140 kV;
- Nominal frequency: 60 Hz;
- Rated current: 1200 A;
- Rated short-circuit interrupting current: 31.5 kA (effective);
- Nominal short-circuit settling capacity: 81.9 kA (crest);
- Type: SF6 disjuncter;
- Live tank disjuncter;
- Drive type: Tripolar;
- Drive mechanism: Spring loaded automatically by electric motor and manual override;
- Nominal Sequence of Operation: O 0.3s CO 3min CO (fast reclose);
- Rated Interruption Time: 3 cycles;
- Installation: On time.

CONCLUSION

An innovative approach in the sizing of power circuit breakers, presenting a simplified method, is proposed to optimize the selection process of these equipments. For the determination of the short-circuit characteristics, the modified power method is used and dimensioning criteria based on the operation of the electrical system are introduced to define the maximum current in the desired branch for the study.


A test system of a water pumping station composed of a 69 kV substation with selective radial and secondary arrangement is studied. It is concluded that the proposed methodology represents a very useful tool for electrical engineers, assisting them in the selection of power circuit breakers.

A methodological structure like the one used in the article can be adopted for the design of other electrical switchgear. The study can also be extended to size equipment at medium and low voltage.

REFERENCES

1. Junior, C. V. (1988). Disjuntores de Corrente Alternada: Especificação e Aplicação em Sistemas Elétricos de Alta Tensão. *Notas de Aula, Universidade Federal Fluminense, UFF*.
2. Frontin, S. O., et al. (2013). Equipamentos de alta tensão—prospecção e hierarquização de inovações tecnológicas. *Brasília: Teixeira, v. 2000,* 934.
3. Colombo, R. (1986). *Disjuntores de alta tensão.* São Paulo: Livraria Nobel S. A.
4. Lima, G. R., Borges, T. T., Baptista, J. M., Monteiro, P. R., & Lima, L. (2018, May). Virtual reality as a tool for electrical substations teaching. In *2018 Simposio Brasileiro de Sistemas Eletricos (SBSE)* (pp. 1-6). IEEE.
5. Monteiro, P. R. D. (2023). *Introdução à subestação e seus principais equipamentos.* Seven Editora.
6. ABB Power Technologies. (2005). Interruptores tipo tanque vivo — Guía del usuario Edição 3.
7. Associação Brasileira de Normas Técnicas - ABNT. (2020). *NBR IEC 62271-1, Manobra e comando de alta tensão – Parte 1: Especificações comuns para equipamentos de manobra e comando em corrente alternada.* Rio de Janeiro.
8. D’Ajuz, A., et al. (1985). Equipamentos Elétricos – Especificação e Aplicação em Subestações de Corrente Alternada. *Furnas/UFF,* 300 p. Rio de Janeiro.
9. Yuen, M. H. (1974). Short Circuit ABC--Learn It in an Hour, Use It Anywhere, Memorize No Formula. *IEEE Transactions on Industry Applications, 2,* 261-272.
10. Monteiro, P. R. D., et al. (2016). Power system stress analysis for main grid substations in Brazil. *Ingeniare. Revista chilena de ingeniería, 24*(3), 377-391.
11. Norma IEC 62271-100 Edicao 2.1 (2012-09). High-Voltage Switchgear and Controlgear – Part 100: Alternating-current Circuit Breakers.

A real-time computational approach for human facial expression recognition based on landmark feature extraction

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ABSTRACT

Real-time human facial expression recognition plays a significant role in many application areas, including human-computer interaction, business intelligence, video surveillance, and robotics. Based on facial expressions, computers can interpret human feelings and psychological stages to provide more realistic approximations in real-world applications. This paper proposes a simple but effective solution for real-time Facial Emotion Recognition (FER), using a mask of the most relevant facial features as input data for a machine-learning approach. For this, a compact Convolutional Neural Network (CNN) classifier associated with a feature extraction layer was used to provide an end-to-end solution that can detect facial expressions from videos with good accuracy rates. The proposed approach was validated using a combination of different facial emotion datasets available in the literature, whose precision rates are considerably better than those provided by the state-of-the-art methods. Score rates of 96.83%, 98.58%, and 98.57% were obtained for the JAFFE, RaFD, and CK+ datasets, respectively, indicating that the presented approach is a promising solution for FER in real-time applications.

Keywords: Real-time facial expression recognition, Emotion classification, Facial patterns extraction, Convolutional Neural network.

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INTRODUCTION

Emotion recognition from facial expressions is a relatively simple task for humans, being part of regular day-to-day non-verbal communication, but complex to be expressed analytically [1]. Humans are capable of inferring emotions through other means, such as body language, tone of voice, and spoken words. However, facial features significantly contribute to the expression of emotions since the face is the main focus of attention during communication. Many studies support the premise that some facial behaviors are universally linked to emotions, regardless of cultural and ethnic differences [2], and can be computationally reproduced.

Although natural for humans, Facial Emotion Recognition (FER) poses a significant challenge for machines since faces can have many attributes such as aging, shape, skin color, beards, and scars [3]. Additionally, faces may include some variability, such as glasses, uneven illumination, and occlusions, and can be visualized from different perspectives. All these challenges can be considered complex for a computational method to discriminate information from the faces and use only the relevant features needed to classify emotion patterns.

A general computational trend for the FER problem is to extract some features from the facial image and pass them through a classifier, thus abstracting its complexity and making predictions possible. Some of the most used feature extraction techniques are the classical approaches, also known as hand-crafted methods. Some examples are (i) the geometric-based features [4, 5], which measure the position and shape of different face components; and (ii) appearance features [5], which involve more complex details like edges and textures. There are also other methods used for specific feature extraction, like the Pyramid Histogram of Gradients (PHOG) [6], Local Phase Quantisation (LPQ) [6, 7], and Gabor Wavelets Features [8]. However, with the recent emergence of Deep Learning techniques, many methods based on Convolutional Neural Networks (CNNs) are becoming general problem solvers in real-world applications. Well-known networks such as AlexNet, GoogLeNet, VGG, and ResNet [9–11] have already been used in several applications and in the FER area.

With CNNs, an end-to-end solution can be provided directly, as the network can learn the most relevant features from the data. However, many samples and considerable computational effort are required to train the model correctly, which leads to better classification results and generalizability. This characteristic is the main difference compared to traditional hand-crafted methods, which are tailored explicitly in advance and designed by an expert.

Nonetheless, many of the FER approaches found in the literature depend mainly on the dataset used to train the models, which in most cases is a single one. Datasets containing face images or videos developed explicitly for FER are no novelty. The first studies date back to 1969 [12], and many facial expression datasets have emerged since then, varying their

acquisition environment, the number of recognizable expressions, and the subject age group, among other features. Some popular datasets include JAFFE, CK+, MMI, RaFD, and AffectNet [13–15]. A too-homogeneous or small dataset can cause overfitting and has little representation for some classes of data, and could lead to some unwanted bias. It can even have mislabeled data and make the learning process more complicated – it was reported that the percentage of correctly labeled data for the FER dataset was about 65% [16].

With these limitations in mind, this paper presents a simple but effective hybrid CNN solution explicitly designed for FER, capable of real-time video processing, and developed considering a mixed dataset. For this goal, the proposed method uses a simple geometric feature extraction technique, combining landmark descriptors from faces and using them to train and test CNN models. The purpose of using geometric features is their invariance to real-world limitations such as skin tones, lighting, and angles. Furthermore, during the training step, the input data (mixed from three databases) combined seven types of emotions: (i) neutral, (ii) happiness, (iii) sadness, (iv) surprise, (v) anger, (vi) fear, and (vii) disgust. The results showed precision rates of 96.83%, 98.58%, and 98.57% for the JAFFE, RaFD, and CK+ datasets, respectively, showing marginally better accuracy rates when compared to the methods found in the literature.

The remainder of this work is organized as follows: Section 2 discusses some highlighted works regarding the FER area. Section 3 describes the proposed method and its implementation aspects in detail, followed by Section 4, demonstrating the obtained results. Finally, the conclusions, discussion, and further works are presented in Section 5.

RELATED WORK

In the literature, it is possible to identify two clear trends regarding the FER area: (i) the classical approaches, also known as hand-crafted features selection methods; and (ii) the Convolutional Neural Network counterpart.

Classical approaches usually involve some technique to obtain a set of features and some metric or classifier to discriminate input vectors for decision-making. Typical examples of classical approaches are the well-known Support Vector Machines (SVMs), decision trees, random forests, or other non-connectionist machine learning techniques to classify the input data. Those methods are said to be hand-crafted since the expert/researcher generally designs the feature extraction method according to the particularity of the problem. Although this tailored approach design can produce a specific method very limited to a subset of input data (used to design the algorithm's model), it generally requires fewer input samples. Some examples of the classical approaches are:

- The method proposed by Happy and Routray [17] performs expression recognition by extracting features from selected facial patches around the face while using an SVM as the classifier. The authors reached 94.09% and 91.8% accuracy rates with this system in the CK+ and JAFFE datasets.
- Using a combination of the oriented FAST and rotated BRIEF features (ORB) and the Local Binary Patterns (LBP) to extract parts from facial expressions, Ben Niu et al. [18] proposed an approach without a CNN, achieving a precision of 88.5%, 93.2%, and 79.8% for the JAFEE, CK+, and MMI datasets, respectively.
- Abdulrahman and Eleyan [19] also proposed a FER approach based on the LBP and the Principal Component Analysis (PCA) algorithms while using an SVM classifier. They performed several experimental tests with the JAFFE and their newly introduced database MUFE (Mevlana University Facial Expression), achieving average results of 87% and 77%, respectively.
- In the paper presented by Salman et al. [20], a new extraction method is proposed based on a geometric approach, where six distances are calculated to measure the different parts of the face that better describe a facial expression, and a decision tree is applied to the JAFEE and COHEN databases. They obtained 89.20% and 90.61% recognition rates for each database.
- Pu et al. [21] proposed a novel framework for FER by recognizing AUs from image sequences using two-fold random forest classifiers. They achieved an accuracy of 96.38% for the CK+ database.

With the emergence of CNNs, several applications were proposed with this technique in mind as a general problem-solver. Their principal aspect is their ability to generalize problems using a generic feature extraction method, paving the way to learn the most relevant characteristics directly from the input data and using them in a neural network classifier. However, training a CNN requires large input data and considerable computational time to provide robust and accurate classifiers. Some works using the CNN counterpart are detailed below:

- Chen et al.'s [10] method calculates the motion of a facial mask for each emotion of the training dataset and uses the results to train a facial mask estimator. The images to be recognized are combined with their facial mask (obtained by passing the image through the estimator) and the classifier to convey the expected emotion. The results obtained showed an accuracy of 98.06%, 82.74%, and 61.52% for the CK+, MMI, and AffectNet datasets.

- Cugu et al. [22] introduced a less than 1MB network with 65K parameters capable of executing at 1851 frames per second on an Intel i7 CPU for lightweight and speed. However, this came with an accuracy penalty cost, achieving 84.8% on the CK+ dataset.
- Burkert et al. [23] proposed a deep CNN with a parallel Feature Extraction block (*FeatEx*), inspired by the GoogleNet network, as the central component. This block processes the input data into two parallel paths with different filter sizes to better capture the varying scales of a face within an image. Concatenating two *FeatEx* blocks and passing the result to a classifier, they achieved 99.6% and 98.63% accuracies in the CK+ and MMIdatasets, respectively.
- Using the recent method of attention networks, Meng et al. [24] created an end-to-end system capable of facial expression recognition from videos. The recognition consists of three distinct steps: (i) frame preprocessing (face alignment and others); (ii) feature extraction; and (iii) classification, which is the same procedure used in the method proposed in this paper. The accuracies reached by this network for the CK+ and AFEW 8.0 datasets were 99.69% and 51.18%.
- Minaee and Abdolrashidi [25] also used attention CNNs to create an end-to-end system that learns the relevant features and focuses on the essential parts of a facial expression. The model was trained using the FER2013, CK+, JAFFE, and FERF databases, reaching accuracies of 70.02%, 99.3%, 92.8%, and 98.0%, respectively.
- The work presented by Kai Wang [11] states that the difficulty in recognizing facial expressions is due to ambiguousness, low-quality facial images, and the subjectiveness of annotators. The solution proposed by the author is based on the *Self-Cure* Network (SCN), a simple but efficient network based on traditional CNNs. According to the author, this approach can suppress uncertainties and prevent CNNs from adjusting excessively to ambiguous facial images. They obtained an accuracy of 88.14% in RAF-DB, 60.23% in AffectNet, and 89.35% in FERPlus.

Although deep learning techniques can be used to have an end-to-end system that learns everything from the features to the classification, that might not always be the best solution. Using traditional features combined with neural networks can yield even better results in some cases. The recent resurgence in the field owes this, given the advances in computing capabilities and the repeated breaking of records using old (e.g., CNNs) and new (e.g., transformers) methods. These techniques can be used not just to create the classifier but also to learn the most relevant features.

Based on the works found in the literature, also summarized in Table 1, it is possible to see that the problems should revolve around the difficulty of recognizing the diversity and ambiguity of the face in the facial emotions. In our approach, we demonstrate that the problem is not related to the complexity of the neural network itself but to the quality of the input data passed to it. We developed a hybrid approach whose features are based on a robust geometric extraction technique that resolves the limitations presented by the authors and provides a fast and practical approach in the FER context, regardless of ethnicity, race, wrinkles, scars, beards, or glasses variations. Additionally, the proposed method is effective against ambiguous or undefined emotions, as will be discussed in Section 4.

Table 1 Comparison of the FER methods found in the literature.

Author	Year	Method	Database	Overall
Happy and Routray	2014	SVM	CK+ JAFPE	94.09% 91.80%
Burkert et al.	2015	CNN	CK+ MMI	99.60% 98.63%
Cugu et al.	2017	Viola-Jones and CNN	Oulu-CASIA CK+	62.69% 84.80%
Meng et al.	2019	CNN	CK+ AFEW 8.0	99.69% 51.18%
Chen et al.	2019	CNN	CK+ MMI AffectNet	98.06% 82.74% 61.52%
Minace and Abdolrashidi	2019	CNN	FER2013 CK+ JAFPE FERG	70.02% 99.30% 92.80% 98.00%
Kai Wang et al.	2020	SCN	RAF-DB AffectNet FERPlus	88.14% 60.23% 89.35%
Ben Niu et al.	2021	LBP and ORB	JAFPE CK+ MMI	88.50% 93.20% 79.80%

METHODOLOGY

The methodology described in this paper can be regarded as a hybrid approach since a Geometric Feature Extraction technique is used to obtain the most relevant features from facial images. These features are then passed through a CNN classifier designed specifically to classify human facial expressions into predetermined categories of emotions. The purpose of using a hybrid solution is to take advantage of its ability to quickly predict the results from a video feed in real-time and continuously.

A general procedure for the proposed methodology is illustrated in Figure 1. First, a data augmentation technique is applied to the input dataset to increase the number of

samples and provide a robust dataset to train the CNN model while avoiding the overfitting effect. Then, a preprocessing step is introduced to standardize the size and the alignment of the faces presented in the images. From there, a Feature Extraction technique is employed to obtain a set of geometric features from the facial image and convert them into a binary mask. Finally, an algorithm is used in the convolutional neural network model to predict facial expressions. These steps are described in detail in the following subsections.



Furthermore, the code implementation is based on the Python3 language

[26] due to its robustness for prototyping and testing, including libraries to support the presented method, such as *OpenCV* [27], *Keras* [28], *TensorFlow* (GPU version) [29], and *Dlib* [30].

INPUT IMAGE

The data augmentation technique applied to every input image consisted of rotating an image at a random angle (between 10 and 30 degrees) in the clock-wise and counterclockwise directions, producing three later mirrored images, and increasing by six times the original size of the dataset. The facial emotion datasets used to validate the proposed methodology are described below:

- **JAFFE** – The *Japanese Female Facial Expression* dataset (JAFFE) is a classical facial expression source from 1998 [13]. It comprises 253 images from 10 female Japanese models expressing seven common emotions: neutral, anger, disgust, fear, happiness, sadness, and surprise. The images are grayscale and have a resolution of 256x256 pixels. Although it is a simple dataset characterized by only a few images, it has been widely used academically worldwide.
- **RaFD** – The Radbound Faces Database (RaFD), presented in 2010, comprises a set of images from 67 models instructed to show eight different expressions (the seven shown in JAFFE plus another one for contempt) and to look in three directions (right, ahead, and left) [15]. For every expression, the subjects' photographs correspond to 5 camera angles (-90° , -45° , 0° , 45° , and 90°), totaling 120 images per model. This paper only used the front-facing images (0°) for the training and testing phases.
- **CK+** – The *Extended Cohn-Kanade* dataset (CK+) is an extension presented in

2010 as a replacement for the already popular at the time Cohn-Kanade dataset (CK) released in 2000 [14]. It comprises 593 images from 123 subjects showing eight emotions (the same as for RaFD) with a spatial image resolution of 640x490 pixels and labeled with the Facial Action Coding System (FACS), apart from the facial expression classification.

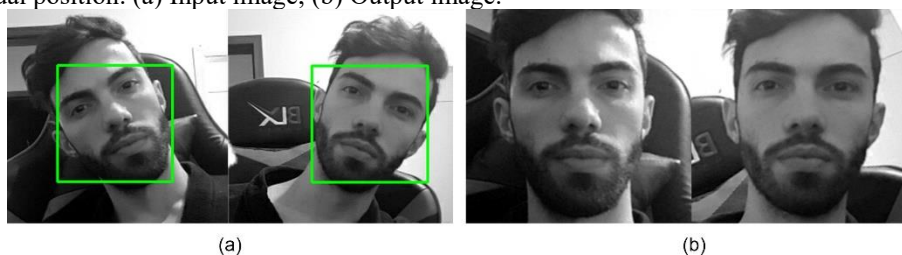
PREPROCESSING

A simple preprocessing stage is introduced to decrease dimensionality and to provide a set of regular images for the feature extraction phase. The result of this procedure is demonstrated in Figure 2, and it is mainly comprised by:

Color simplification – before any extraction, the input image is converted into grayscale, as this color scale has little significance on the facial expression, and the brightness variation is sufficient to detect the features;

- Face regularization – next, a face-centering process is performed by using the coordinates of the nose's center as an alignment reference point;
- Face repositioning – a rigid rotation is then performed to present the eyes in a horizontal line, leaving both eyes on the same y-axis level and ensuring identical aligned images for the dataset;
- Spatial resolution reduction – finally, the input image is resized to normalize the camera's distance (which causes the size of the face in the image to increase or decrease) and to ensure that the faces' sizes are equivalent.

Fig. 2 Regardless of the angle of the face to the camera, the algorithm can align, center, and resize the face to an approximately equal position: (a) Input image; (b) Output image.



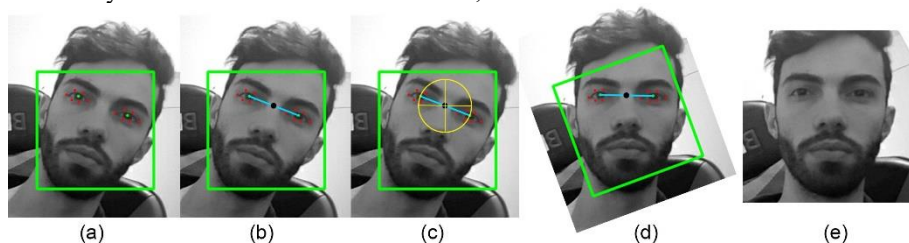
These steps were implemented with the help of the *Dlib* library, a toolkit designed explicitly for machine learning, image processing, and linear algebra applications. Initially, the face detector function [31], which detects a face based on the HOG method and a linear SVM, is used, followed by a proprietary algorithm to calculate the image's required adjustments and alignments. The functioning of this algorithm is detailed in the following subsection.

Alignment Algorithm

The most suitable way to align the face in the image corresponds to positioning the eyes in a horizontal plane register. For this, both eyes' centroids are initially calculated by considering each eye's average points (x and y) and dividing by their cardinality (n). This step is demonstrated in Figure 3a. Next, the difference between the left and right eyes (Δ) is computed in the x and y directions. From there, the eyes' center point is obtained, as shown in Figure 3b. Based on this information, the angle required to rotate the image, and ensure that the y -axis of both eyes is located in the same position, is obtained by computing the arc-tangent for the Δ values in the x and y directions. The result of this step is demonstrated in Figure 3c. Finally, to maintain a standardized dataset, the face image is resized, ensuring that all the images share the same size and, thus, the same input mask size needed by the neural network. This stage is achieved by using the portion of the distance between the eyes (Δ_x and Δ_y) and calculating a scale factor.

Moreover, the image rotation is performed by obtaining the transformation matrix (M) with the help of the `getRotationMatrix2D` and `warpAffine` functions from the *OpenCV* library. The result and the final output of the alignment algorithm are shown in Figures 3d and 3e, respectively.

Fig. 3 Preprocessing alignment algorithm workflow: (a) Location of each eye's centroid shown in green dots; (b) Distance between the two eyes' centroids shown in a blue line;



(c) Image rotation angle shown in a yellow circle; (d) Resulting face image obtained by the alignment algorithm (rotated to the computed angle); (e) Final output of the alignment algorithm (aligned and scaled into a default size).

GEOMETRIC FEATURE EXTRACTION

The Geometric Feature Extraction technique described in this section regards the jawline, mouth, eyes, eyebrows, and nose as the most relevant features during the extraction of facial expressions. These features are extracted from the preprocessed image with the help of the shape predictor function, a *Dlib* library function based on a set of pre-trained regression trees capable of estimating the location of 68 coordinate points needed for mapping facial structures [32]. A general overview of this technique is presented in Figure 4.

Fig. 4 General overview of the Geometric Feature Extraction technique: (a) Coordinate points captured by the geometric feature extractor; (b) Binary Mask created from the feature points; (c) Binary Mask with no jawline.

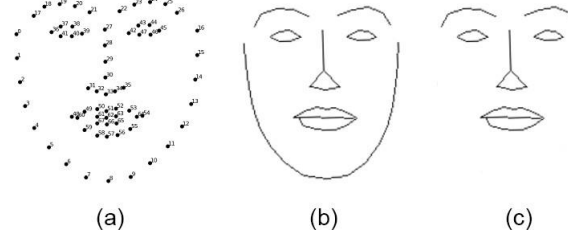
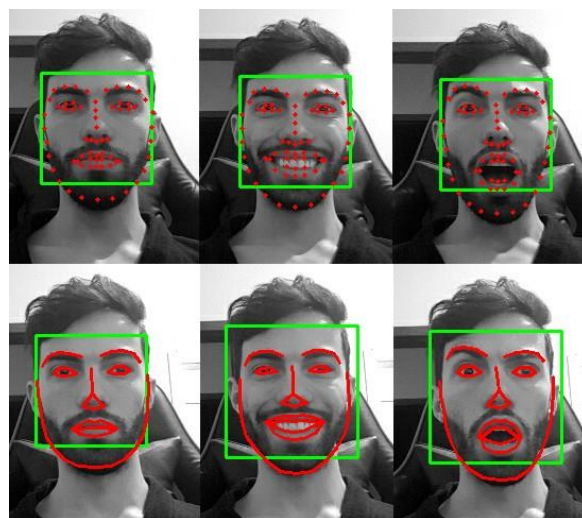


Figure 4a illustrates the 68 most representative points used by this approach. These points are then connected and transformed into a binary mask, Figure 4b, later used by the CNN classifier. This work also aims to compare the jawline's importance and impact during the classification process by evaluating a binary mask with no jawline, as depicted in Figure 4c.

From the image with the facial features, a new frame with a binary mask corresponding to the absolute white and black coloring is obtained by subtracting the pre-drawn image. As a result, for an image with one channel and 8-bit color depth, only values of 0 (black) and 255 (white) with no intermediate gray values can be obtained, simplifying the acquired set of features.

An application of the described Geometric Feature Extraction technique is demonstrated in Figure 5, where the 68 detected coordinate points and the eyes, nose, mouth, eyebrows, and jawline contours are highlighted. The features delimited by the red lines, drawn over the original image, are later processed with the image subtraction function to create the binary mask. Furthermore, the green square marks are used only for face recognition and are ignored when applying the subtraction function.

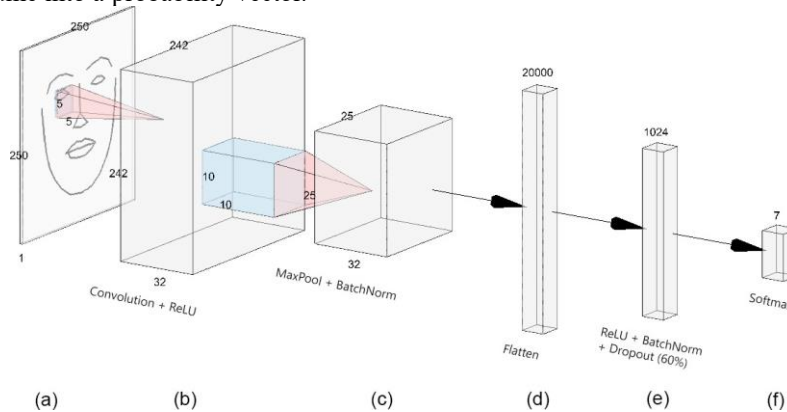
Fig. 5 Application of the Geometric Feature Extraction technique for three distinct expressions: neutral, happiness, and surprise, respectively.



CONVOLUTIONAL NEURAL NETWORK

The configuration and parameters of the proposed CNN architecture are illustrated in Figure 6. The input layer, as shown in Figure 6a, comprises a binary image of the most representative facial features and covers a planar domain of 250x250 pixels. Figure 6b depicts the Rectified Linear Unit activation function layer (ReLU) with network dimensions of 32x25x25 and activation of 10x10x25. Figure 6c displays the MaxPool+BatchNorm layer with network dimensions of 25x25x32. Figure 6d presents the Flatten layer, which reshapes the tensor to a single dimension and yields 20000 units. Finally, Figures 6e and 6f show the 60% dropout and decision output (*Softmax*) layers, which are discussed in detail in the subsequent subsection.

Fig. 6 Configuration of the proposed CCN architecture – The binary mask is inserted into a convolutional layer to extract the obtained features, followed by a max-pooling layer to reduce dimensionality. The fully connected layers then convert the feature volume into a probability vector.



Moreover, implementation details regarding the CNN used in the presented approach are also demonstrated by the source code in Figure 7, which describes the sequence used to build the CNN and the parameter values used as input configuration.

Fig. 7 Source code for the proposed CNN model, including its pipelining.

```
def cnn_modelo():
    modelo = Sequential()
    modelo.add(Conv2D(32, (5,5), input_shape=(250, 250, 1), activation='relu'))
    modelo.add(BatchNormalization())
    modelo.add(MaxPooling2D(pool_size=(10, 10), strides=(10, 10), padding='same'))
    modelo.add(Flatten())
    modelo.add(Dense(1024, activation='relu'))
    modelo.add(BatchNormalization())
    modelo.add(Dropout(0.6))
    modelo.add(Dense(7, activation='softmax'))
    sgd = optimizers.SGD(lr=1e-3)
    modelo.compile(loss='categorical_crossentropy', optimizer=sgd, metrics=['accuracy'])
    callbacks_list = ModelCheckpoint("modelo/expressao.h5", monitor='val_accuracy',
    verbose=1, save_best_only=True, mode='auto')
    return modelo, callbacks_list
```

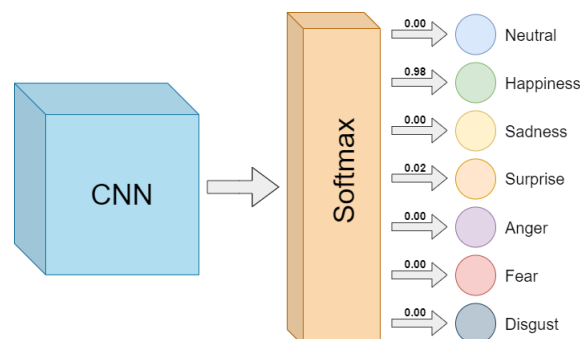

EXPRESSION CLASSIFIER

The final stage of the proposed methodology is related to the expression classifier layer. This layer follows the architecture introduced in Figure 6f, where the ReLU function activates the network and the first dense layer, followed by a 60% dropout and batch normalization procedure (BatchNorm). The final fully connected layer then employs the *Softmax* activation to build a probability distribution associated with one of the seven dataset emotions described in Section 3.1.

The reason for using the ReLU activation is based on self-acquired empirical evidence. This activation function produced the best results for the proposed CNN classifier compared to other activation functions. According to Ian Goodfellow et al. [33], the ReLU is the default recommendation regarding activation functions in modern neural network approaches, as it is appropriately designed to work with images and does not saturate in the positive region, tending to converge much faster than the sigmoid or hyperbolic tangent on images, as well as being not zero-centered.

The dropout stage is used to avoid overfitting since the individual nodes are removed from the network with a probability of 60%, maintaining a reduced network and forcing the nodes of a layer (neuron) to adapt and correct errors from previous layers, making the model more robust and reliable. Moreover, the BatchNorm procedure normalizes the activation of the previous layer, stabilizing and speeding up the neural network while improving the generalization error. Finally, the Softmax function calculates the probability of each input expression, and the sum of the probabilities for each of the seven expressions results in a value of 1. As illustrated in Figure 8, the expression with the highest probability value is the resulting emotion.

Fig. 8 The Softmax function results in the probability of a given facial expression. In this example, the CNN informs that the probability of the expression being happiness is 98%, although there is still a small chance (2%) to be the expression of surprise.



EXPERIMENTAL RESULTS

VALIDATION

Validating a CNN with the same data from the training set can be considered a logical procedural error. After all, a model that checks the images based on previous information would obtain good classification feedback, making the network extremely accurate. However, if the model's efficiency is measured based on data the network has never had access to, then in that case, the model will be completely limited (or useless in the worst case) in predicting new data in a broader set or during real-world applications.

This problem can be solved by conducting a supervised machine-learning phase where the dataset is split into two sets: (i) training and (ii) validation. This way, the network can use the first set to train its predictions and the second one to validate its accuracy, preventing the data used to calculate the accuracy from being seen by both sides (we call this invisible data).

Our approach split each dataset into 80% for training and 20% for validation during the initial supervised training stage. Subsequent training steps ran for 300 epochs using an SGD optimizer with a learning rate of 10^{-3} , a categorical cross-entropy as a loss function, and a batch size of 100. Table 2 shows the experimental results obtained by the presented approach in terms of accuracy compared to some related works found in the literature.

Table 2 Accuracy obtained by the presented method compared to other related works using the simple validation procedure (no cross-fold).

Method	Year	JAFFE	RaFD	CK+
BDBN	2014	93.00%		96.70%
Happy and Routray	2014	91.80%		94.09%
Hamster et al.	2015	95.80%		
DeXpression	2015			99.60%
Zavares et al.	2017		85.79%	88.58%
Mavani et al.	2017		95.71%	
MicroExpNet	2017			84.80%
TeacherExpNet	2017			97.60%
FAN	2019			99.69%
FMPN	2019			98.06%
Minaee and Abdolrashidi	2019	92.80%		98.00%
Kai Wang et al.	2020		88.14%	
Ben Niu et al.	2021	88.50%		93.20%
Our method		96.83%	98.58%	98.46%
Our method (no jawline)		96.03%	97.28%	98.57%

Although effective, this procedure can cause a false sense of overfitting correction that results from the validation set selection volatility and the assumption that the database is not homogeneous. Moreover, its effectiveness is related to the invisibility of the validation set towards the network trained by the training set. Therefore, the randomness applied to the dataset does not guarantee an increase in accuracy, and performing this procedure only once did not

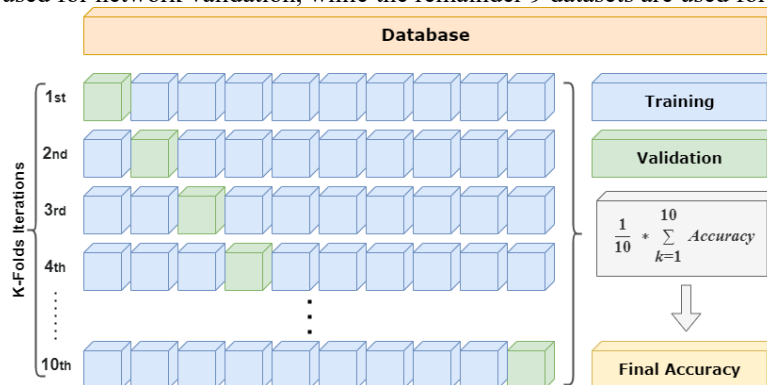
ensure sufficient precision to state whether the network analyzes invisible data efficiently.

CROSS-FOLD VALIDATION

To measure the accuracy of the network’s prediction ability, we used the cross-fold validation method [34], a simple and popular validation technique based on the number of groups (k) that a dataset needs to be divided to avoid biased results. Thus, each dataset was divided into ten subsets ($k = 10$), as this value usually results in predictions with modest variations and low polarization while obtaining approximately equal-sized subsets.

An example of the cross-fold validation method is illustrated in Figure 9, where the data is shuffled randomly and divided into ten subsets, and the model’s precision is obtained by averaging the accuracy values from each iteration, ensuring that the final result is a more accurate estimation in predicting the performance of real-world applications or with invisible data.

Fig. 9 Cross-fold validation method for $k = 10$ resulting in a random separation of 10 subsets of approximately equal sizes. The first subset is used for network validation, while the remainder 9 datasets are used for training.



The individual results of each iteration and the overall accuracy of the network for the two proposed methods (binary mask with and without jawline) are presented in Table 3. These results show that the variation between the two proposed methods is insufficient to state that the jawline provides valuable information for the proposed network in facial expression recognition.

Table 3 Comparison of the cross-fold validation results for the two proposed methods.

Method	JAFFE		RaFD		CK+	
	Normal	No-Jawline	Normal	No-Jawline	Normal	No-Jawline
Fold 1	96.54%	95.90%	97.88%	96.41%	97.93%	98.19%
Fold 2	97.06%	96.11%	98.21%	97.02%	97.74%	97.59%
Fold 3	96.92%	96.17%	98.07%	96.87%	96.91%	97.02%
Fold 4	96.14%	95.83%	98.20%	97.08%	98.49%	98.66%
Fold 5	95.36%	94.75%	98.36%	97.27%	98.58%	98.71%
Fold 6	97.05%	96.38%	97.93%	96.85%	98.07%	98.23%
Fold 7	97.22%	96.61%	98.27%	97.21%	96.95%	97.36%
Fold 8	95.49%	95.74%	97.97%	96.86%	98.39%	98.54%
Fold 9	95.17%	94.99%	98.14%	97.04%	97.43%	97.87%
Fold 10	96.61%	96.06%	97.93%	96.63%	97.82%	97.62%
Average	96.36%	95.85%	98.10%	96.92%	97.83%	97.98%

Similarly, a comparison of the final obtained results between the simple and cross-fold validation techniques is presented in Table 4. As expected, the cross-fold validation method reduced the accuracy of the network since it is a more conservative technique and computationally more expensive.

Table 4 Comparison of the obtained results using the simple and cross-fold validation techniques.

Validation Method	JAFFE	RaFD	CK+
Simple Normal	96.83%	98.58%	98.46%
No-Jawline	96.03%	97.28%	98.57%
Cross-fold Normal	96.36%	98.10%	97.83%
No-Jawline	95.85%	96.92%	97.98%

EXECUTION TIME AND PERFORMANCE

In this subsection, we discuss the method's performance in terms of execution time to provide an end-to-end solution regarding facial emotion prediction. We used the JAFFE dataset as input for the developed algorithm while performing a data augmentation technique to reach the data required in some performance tests, increasing the entries exponentially from 1 to 10000 images.

A comparison of the total time required for the end-to-end algorithm (including the image preprocessing step) and the prediction algorithm (ignoring the preprocessing step) is shown in Table 5. Furthermore, for visualization purposes, the total time of each iteration is also shown in FPS (frames per second) and PPS (prediction per second).

Table 5 Algorithm performance test based on processing time using an input data variation.

	Total processing time		Processing time per image		Metrics per second	
Images	End-to-End Prediction		End-to-End Prediction		FPS	PPS
e0	1s 077ms	1s 065ms	1s 77ms	1s 65ms	0.92	0.93
e1	1s 309ms	1s 189ms	130ms	118ms	7.63	8.40
e2	3s 737ms	2s 505ms	37ms	25ms	26.75	39.91
e3	27s 374ms	15s 291ms	27ms	15ms	36.53	65.39
e4	268s 808ms	143s 789ms	26ms	14ms	37.20	69.54

The setup configuration used for the performance tests was comprised of a desktop computer with a Windows 10 Pro operating system (version 20H2), an AMD Ryzen 7 3700X processor (8 cores with 3.59 GHz per core), 32 GB of RAM (3200 MHz), an NVIDIA GeForce RTX 2070 graphics card (8GB of dedicated video memory), and a Samsung 970 EVO Plus M.2 NVMe SSD.

CPU usage during image previews ranged from 7.8% to 9.1%, while GPU usage ranged from 0.3% to 1.1%. On the other hand, RAM usage was at most 2GB since the dedicated video memory was fully utilized. It is important to consider that these results were observed only for the process in which emotions were predicted, while the system and secondary processes were ignored.

These results show that a bottleneck is created during image loading and that the GPU processes in the batch execute faster than the CPU ones. A possible solution to this problem (not adopted in our approach) is based on distributing the image loading to a new thread to perform the preprocessing, causing the GPU to wait for more data during idle time and mitigating the higher CPU usage compared to GPU usage for the presented configuration.

Since the CPU loads more images at once (avoiding redundancy of operations), it makes the GPU access a greater amount of data, reducing idleness and consequently increasing the algorithm's performance. However, there is still a memory bottleneck for the GPU, being necessary to wait for the loading and unloading of new data from the dedicated memory of the GPU.

The results show that the proposed solution can be executed in real-time while continuously providing facial image decision-making with its corresponding emotion. In a continuous video feed provided by a webcam limited to 30fps, the algorithm was able to process 27 fps, where the fps loss could be related to the latency between the webcam input, loading data, and frame separation. This additional step is necessary to obtain the input image for the end-to-end network while performing an extra operation that was not necessary for the test performed with the JAFFE database, as the image was already captured, being only necessary

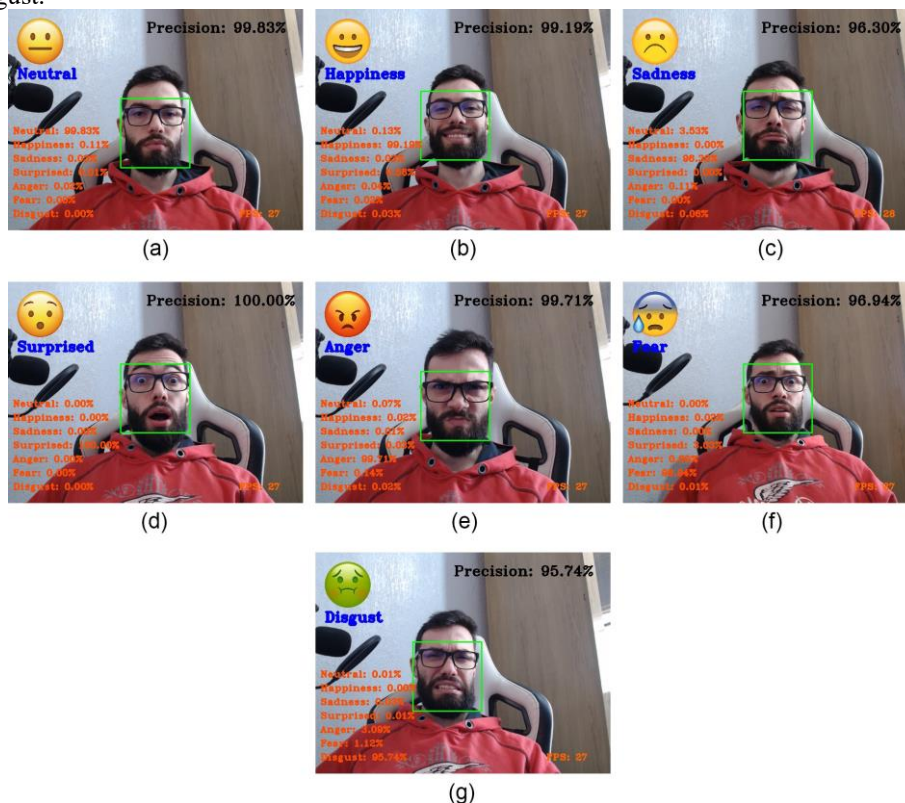
to load the image into the memory. The application of the proposed approach for a video sequence is demonstrated in Figure 10.

FINAL REMARKS

This work presented a real-time computational approach for facial image and video emotion recognition based on a geometric feature extraction technique associated with a CNN. The experimental results were compared against state-of-the-art methods, providing marginally better results for a mixed dataset. Accuracy rates using simple validation were 96.83%, 98.58%, and 98.57% for the JAFFE, RaFD, and CK+ datasets. On the other hand, through cross-validation, we obtained 96.36%, 98.10%, and 97.98% accuracy rates for the same datasets, indicating that the presented approach can be considered a promising solution for FER, especially for real-time applications.

Our method offers competitive results in the three datasets tested, achieving higher accuracies for the JAFFE and RaFD datasets. Using cross-fold validation, we can compare the accuracy between the normal and no-jawline method, whose conclusions are that using the jawline in the binary mask created can help the network to have an additional point of reference with the other facial landmarks. However, it does not directly influence the expression performed. Choosing to use or not use this landmark as input to the network.

Fig. 10 Facial emotions results for the proposed methodology: a) neutral, b) happiness, c) sadness, d) surprised, e) anger, f) fear, and g) disgust.



is a relatively insignificant decision in terms of precision. When comparing the results obtained with the simple and cross-fold validation, we see a decrease in accuracy in a range of approximately 1% since the cross-fold validation procedure tends to be more conservative with its percentages. Thus, it reinforces the thesis that the results obtained with this method are not a consequence of the overfitting effect.

In terms of execution time, the performance speed of the presented method is also encouraging, executing it in real-time with enough precision, paving the way for many real-world applications. Further works consider implementing some mechanism able to mitigate the time invariance of the system. We take each frame as its separate entity without regarding its relationship with the previous ones. This can cause some flickering effecting during the predictions, and taking into account temporal information related to the past few frames can be used to provide a soften classification and prediction.

DECLARATIONS

Conflict of interest: All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

DATA AVAILABILITY

The code generated during and/or analyzed during the current study is available in the GitHub repository <https://github.com/gustavogino/Facial-Expression-Recognition>. Furthermore, a demonstrative video of a real-time application can be found at <https://www.youtube.com/watch?v=fFOldbHtHQU>.

REFERENCES


1. Mellouk, W., Handouzi, W. (2020). Facial emotion recognition using deep learning: review and insights. *Procedia Computer Science*, 175, 689–694.
2. Ekman, P., Friesen, W.V. (1971). Constants across cultures in the face and emotion. *Journal of personality and social psychology*, 17(2), 124.
3. Orgeta, V. (2010). Effects of age and task difficulty on recognition of facial affect. *The journals of gerontology. Series B, Psychological sciences and social sciences*, 65B, 323–7. <https://doi.org/10.1093/geronb/gbq007>
4. Jung, H., Lee, S., Yim, J., Park, S., Kim, J. (2015). Joint fine-tuning in deep neural networks for facial expression recognition. In: *Proceedings of the IEEE International Conference on Computer Vision*, pp. 2983–2991.
5. Sun, N., Li, Q., Huan, R., Liu, J., Han, G. (2019). Deep spatial-temporal feature fusion for facial expression recognition in static images. *Pattern Recognition Letters*, 119, 49–61.
6. Dhall, A., Asthana, A., Goecke, R., Gedeon, T. (2011). Emotion recognition using PHOG and LPQ features. In: *Face and Gesture 2011*, pp. 878–883. IEEE.
7. Ojansivu, V., Heikkilä, J. (2008). Blur insensitive texture classification using local phase quantization. In: *International Conference on Image and Signal Processing*, pp. 236–243. Springer.
8. Zhang, Z. (1999). Feature-based facial expression recognition: Sensitivity analysis and experiments with a multilayer perceptron. *International Journal of Pattern Recognition and Artificial Intelligence*, 13(06), 893–911.
9. Barsoum, E., Zhang, C., Ferrer, C.C., Zhang, Z. (2016). Training deep networks for facial expression recognition with crowd-sourced label distribution. In: *Proceedings of the 18th ACM International Conference on Multimodal Interaction*, pp. 279–283.
10. Chen, Y., Wang, J., Chen, S., Shi, Z., Cai, J. (2019). Facial motion prior networks for facial expression recognition. In: *2019 IEEE Visual Communications and Image Processing (VCIP)*, pp. 1–4. IEEE.
11. Wang, K., Peng, X., Yang, J., Lu, S., Qiao, Y. (2020). Suppressing uncertainties for large-scale facial expression recognition. In: *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*.
12. Sakai, T., Nagao, M., Fujibayashi, S. (1969). Line extraction and pattern detection in a photograph. *Pattern recognition*, 1(3), 233–248.
13. Lyons, M., Kamachi, M., Gyoba, J. (1998). The Japanese Female Facial Expression (JAFPE) Dataset.
14. Lucey, P., Cohn, J.F., Kanade, T., Saragih, J., Ambadar, Z., Matthews, I. (2010). The extended cohn-kanade dataset (CK+): A complete dataset for action unit and emotion-specified expression. In: *2010 IEEE Computer Society Conference on Computer Vision and Pattern Recognition-workshops*, pp. 94–101. IEEE.

15. Langner, O., Dotsch, R., Bijlstra, G., Wigboldus, D.H., Hawk, S.T., Van Knippenberg, A. (2010). Presentation and validation of the radboud faces database. *Cognition and emotion*, 24(8), 1377–1388.
16. Goodfellow, I.J., Erhan, D., Carrier, P.L., Courville, A., Mirza, M., Hamner, B., Cukierski, W., Tang, Y., Thaler, D., Lee, D.-H., et al. (2013). Challenges in representation learning: A report on three machine learning contests. In: *International Conference on Neural Information Processing*, pp. 117–124. Springer.
17. Happy, S., Routray, A. (2014). Automatic facial expression recognition using features of salient facial patches. *IEEE transactions on Affective Computing*, 6(1), 1–12.
18. Niu, B., Gao, Z., Guo, B. (2021). Facial expression recognition with LBP and ORB features. *Computational Intelligence and Neuroscience*, 2021.
19. Abdulrahman, M., Eleyan, A. (2015). Facial expression recognition using support vector machines. 2015 23rd Signal Processing and Communications Applications Conference, SIU 2015 - Proceedings, 276–279. <https://doi.org/10.1109/SIU.2015.7129813>
20. Salmam, F.Z., Madani, A., Kissi, M. (2016). Facial expression recognition using decision trees. *Proceedings - Computer Graphics, Imaging and Visualization: New Techniques and Trends, CGiV 2016*, 125–130. <https://doi.org/10.1109/CGiV.2016.33>
21. Pu, X., Fan, K., Chen, X., Ji, L., Zhou, Z. (2015). Facial expression recognition from image sequences using twofold random forest classifier. *Neurocomputing*, 168, 1173–1180. <https://doi.org/10.1016/J.NEUCOM.2015.05.005>
22. İlke Çıĝu, Şener, E., Akbaş, E. (2017). Microexpnet: An extremely small and fast model for expression recognition from face images. arXiv:1711.07011 [cs.CV]
23. Burkert, P., Trier, F., Afzal, M.Z., Dengel, A., Liwicki, M. (2015). Dexpression: Deep convolutional neural network for expression recognition. arXiv preprint arXiv:1509.05371.
24. Meng, D., Peng, X., Wang, K., Qiao, Y. (2019). Frame attention networks for facial expression recognition in videos. In: *2019 IEEE International Conference on Image Processing (ICIP)*, pp. 3866–3870. IEEE.
25. Minaee, S., Abdolrashidi, A. (2019). Deep-emotion: Facial expression recognition using attentional convolutional network. arXiv preprint arXiv:1902.01019.
26. Van Rossum, G., Drake, F.L. (2009). *Python 3 Reference Manual*. CreateSpace, Scotts Valley, CA.
27. Itseez. (2015). *Open Source Computer Vision Library*. GitHub. <https://github.com/itseez/opencv> Accessed 2021-06-26
28. Chollet, F., et al. (2015). *Keras*. GitHub. <https://github.com/fchollet/keras> Accessed 2021-06-26
29. Abadi, M., Barham, P., Chen, J., Chen, Z., Davis, A., Dean, J., Devin, M., Ghemawat, S., Irving, G., Isard, M., Kudlur, M., Levenberg, J., Monga, R., Moore, S., Murray, D.G., Steiner, B., Tucker, P., Vasudevan, V., Warden, P., Wicke, M., Yu, Y., Zheng, X. (2016). TensorFlow: A system for large-scale machine learning. In: *12th USENIX Symposium on Operating Systems Design and Implementation (OSDI 16)*, Savannah, GA, pp. 265–283.



30. King, D.E. (2009). Dlib-ml: A Machine Learning Toolkit, 10, 1755–1758.
31. King, D. (2015). Face Detection with Python using OpenCV. Retrieved from http://dlib.net/face_detector.py.html. Accessed on: March 5, 2023.
32. Kazemi, V., Sullivan, J. (2014). One millisecond face alignment with an ensemble of regression trees. In: 2014 IEEE Conference on Computer Vision and Pattern Recognition, pp. 1867–1874.
33. Goodfellow, I., Bengio, Y., Courville, A. (2016). Deep Learning. MIT Press, Cambridge, Massachusetts. Retrieved from <http://www.deeplearningbook.org>
34. Refaeilzadeh, P., Tang, L., Liu, H. (2009). In: Liu, L., ÖZSU, M.T. (Eds.), Cross-Validation, pp. 532–538. Springer, Boston, MA. https://doi.org/10.1007/978-0-387-39940-9_565

The quality of hydrochloric acid produced according to technological routes, contaminants and industrial applications

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ABSTRACT

Hydrochloric acid (HCl), the object of this work, was chosen due to the fact that it has several industrial routes and its use, directly or indirectly, allows contamination in final products. The main industrial processes, the raw materials related to each process, the main contaminants and their consequences were highlighted. To prove some contaminations, experiments were carried out in order to demonstrate that contaminants present in hydrochloric acid can affect the quality and performance of a process where their participation is paramount. Finally, the objective of this work is to form a critical technical awareness to evaluate and use hydrochloric acid for purposes compatible with its industrial quality.

Keywords: Hydrochloric acid, Contaminants, Organochlorines, Industrial processes.

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INTRODUCTION

According to Salager *et al.* [1], although the concept of formulations is still used, it is a fact that obtaining chemical and metallurgical products cannot be considered as a modern concept, as it is directly related to the advancement of ancient civilizations, such as the Roman Empire, in which various utensils of lead, copper and bronze (copper and tin alloys) were manufactured in primitive casting, quite common at that time [2]. The formulations were also employed in the paints used in fresco paintings, in the fermentation of wines, in the processing of olive oils, and in the treatment of leather.

At the end of the eighteenth century, when Alchemy became the Science called Chemistry, as well as from the development of the principles of Electrochemistry and Organic Chemistry in the following century, the second period of the development of formulations began. This enabled the emergence and production of new chemical substances and, consequently, new combinations or formulations. However, at that time research and development were still carried out through experiments based on trial and error [1].

Between 1856 and 1880, Organic Chemistry and the textile industry evolved considerably, and dyes of plant and animal origin were replaced by products synthesized in the laboratory. It is essential to show that this fact resulted in the development of theories and procedures, giving rise to thousands of new molecules, which were used in various industrial segments.

Finally, the third period in the history of formulations began in the 1950s after the Second World War, when there was the junction, integration and interdisciplinarity of the knowledge of the various sciences already consolidated. From this interaction, which ranged from biotechnology to nuclear energy, from toxicity to sustainability, new products were created and developed on an exponential scale, whose advantages and disadvantages currently stand out [1].

Today, it is practically impossible to determine the number of substances and/or chemical formulations present in the various products available to people, such as: disinfectants, paints, personal hygiene products, perfumes, alcoholic and non-alcoholic beverages, pesticides, pharmaceuticals, fertilizers, additives, plastics, rubbers, aerosols, solvents, greases, lubricating oils, metallic or non-metallic alloys, batteries, etc.

Environmental and public health agencies estimate that there are currently more than 800,000 formulations that originate, directly or indirectly, from plants, animals, or synthesized. Also to be considered is the great advance in chemical process technologies, which annually launch more than 8,000 new chemical formulations on the market. Often, several of these products have not been analyzed with a view to compromising the quality of life of the man himself. It is observed that many companies do not pass on to society the degree of quality of their products.

Currently, there are more than 10,000 drug formulations available on the market for doctors to prescribe and for patients to use. The environmental pollution caused by these pharmaceutical formulations and their transformation products has become a growing concern in environmental changes regarding the potential toxic effects on human health. Environmental risk assessments are primarily based on one active component, which causes different ecotoxicological effects, although the specific component is present in the environment as part of a mixture of different pharmaceuticals and excipients [3, 4].

The International Free Market is very large and the low price of products dominates and sabotages quality. Rich countries create obstacles, norms and procedures, while poor countries are left adrift and without a clear direction. The power of industrial civilization is advancing rapidly, imposing its guidelines on commercial and industrial transactions.

Figure 1 shows an example of products sold over the *internet* in the International Free Market, where, for example, sodium nitrite (NaNO_2) can be used in various food products [5, 6], as well as as a corrosion inhibitor [7]. The toxic contaminants present in this substance can compromise the lives of human beings, but on the other hand, it does not pose a danger to the integrity of the equipment to be protected.

Figure 1 - Examples of commercial sodium nitrite found in the International Free Market (*internet*)

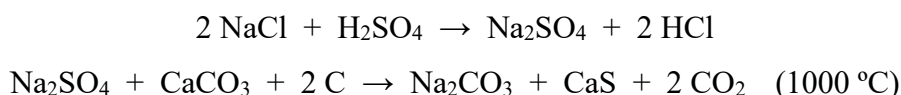


In the area of chemical processes, the obtaining of substances that may be used directly or indirectly, as chemical intermediates, must meet a series of fundamental factors, such as: origin of raw materials, preservation of the environment, efficiency of equipment and materials, control and monitoring, automation, costs, internal and external market, types of packaging used, competitions, patents, contaminants, etc.

In the case of contaminants, there is an important factor to consider, as it is not always possible to identify or visualize, throughout the industrial process, the problems that may be caused

by accidental contamination or contaminants already present in the raw material or originating from the manufacturing processes. In other words, a simple standardized analysis is not always able to identify the contaminants present, especially if they are toxic.

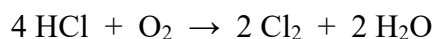
Going back to the past to exemplify the study of hydrochloric acid, it can be seen that one of the industrial objectives of the late eighteenth century was the production of the barrel (sodium carbonate, Na_2CO_3) for the manufacture of soap, glass etc. The first industrial process was developed by Leblanc in 1791 and was based on the reactions:



The first soda ash was installed in France in 1792 and all the hydrogen chloride (HCl) produced was released into the atmosphere, creating a major environmental problem at the time. Based on the stoichiometry of the reaction, it can be seen that for one ton of sodium carbonate produced, 688 kg of hydrogen chloride were released into the environment [8].

In England, it was only around 1823 that this gaseous by-product began to be marketed in the form of aqueous solutions (dilute hydrochloric acid) and, probably, production increased due to the enactment of a law prohibiting the release of HCl into the atmosphere. In 1823, the limit for the release of HCl (g) into the atmosphere was set at 5%. It was considered the first pioneering legislation on air pollution. The disposal problem was partially solved, at that time, on the basis of three solutions:

- Use of chimneys of about 30-40 m for dispersion of polluting gases.
- Absorption towers with water for HCl production.
- Chlorine production from burning HCl (g) with air, based on the reaction:

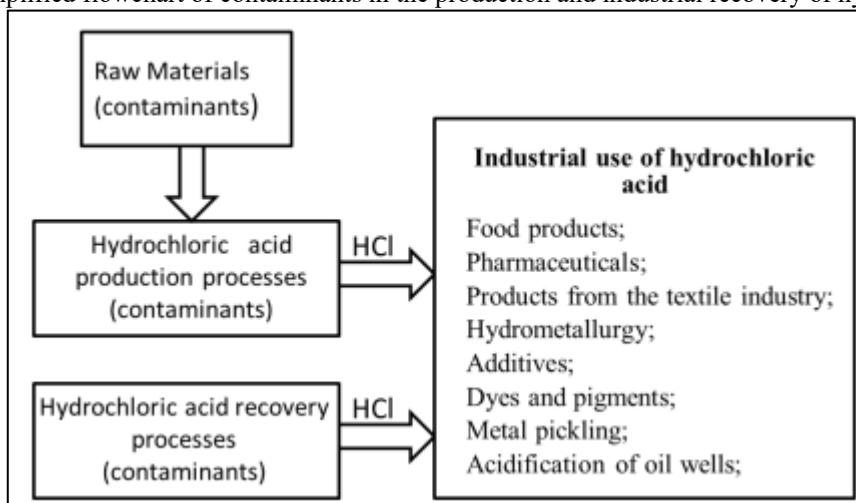


Later, this prohibition was set at 0.03% of HCl in the air stream, requiring the use of the HCl produced. All this effort has led hydrochloric acid manufacturers to look for new processes, new markets and new applications.

To highlight the problems arising from these premises, hydrochloric acid was chosen, as shown in Figure 2, because it is a substance used, directly or indirectly, in various industrial processes, such as: in the petroleum industry, in petrochemicals, in food manufacturing, in hydrometallurgy of various ores, in the pharmaceutical industry, etc. In addition, the contaminants

present in the raw material, in the production of hydrochloric acid and in its recovery processes are also highlighted.

Figure 2 - Simplified flowchart of contaminants in the production and industrial recovery of hydrochloric acid



Thus, the present study is divided into the following parts:

- Description of the industrial processes for obtaining hydrochloric acid and its main contaminants.
- Analysis of contaminants from hydrochloric acid production processes.
- Use of hydrochloric acid to obtain other chemicals.
- Examples of experiments that show the influence of some contaminants.
- Conclusions.

DESCRIPTION OF THE INDUSTRIAL PROCESSES FOR OBTAINING HYDROCHLORIC ACID AND ITS MAIN CONTAMINANTS

SALT-ACID PROCESS

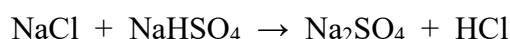
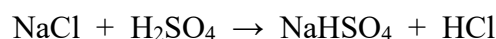
Conventional salt-acid process

As already reported, this is one of the oldest industrial processes for the production of hydrochloric acid, and in the past it was aimed at the manufacture of sodium sulfate (Na_2SO_4), called Glauber's Salt [9].

The salt used for industrial purposes comes from solar evaporation of seawater or the mining of rock salt. Rock salt can be removed by two methods. The first using procedures similar to coal mining; As the salt is mechanically removed, tunnels are formed supported by columns of the salt itself. The other method of production consists of drilling wells up to the salt dome and, by means of a chosen well, hot water is injected, in such a way that the brine is continuously removed from other producing wells [10-13].

The purity of the salt obtained by evaporation is in the order of 98 to 99%. The cations and anions present are: Ca^{2+} , Mg^{2+} , Sr^{2+} , Ba^{2+} , K^+ , Fe^{2+} , Cu^{2+} , SO_4^{2-} , F^- , Br^- , I^- , SiO_3^{2-} , CO_3^{2-} , HCO_3^- , BO_3^{3-} , depending on the location and charge releases.

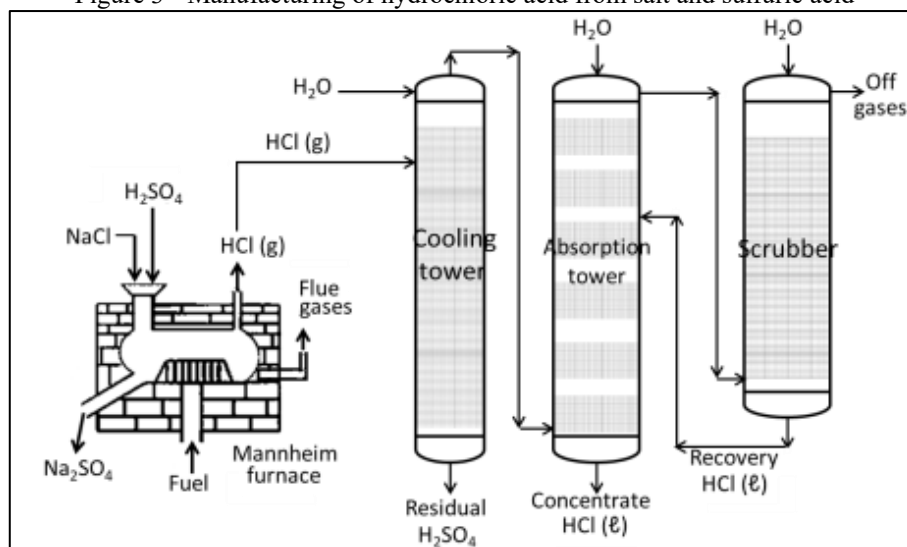
In this process, the reaction of sodium chloride with sulfuric acid takes place in two steps:



The reactions are endothermic, with the first reaction taking place at a temperature of 150°C and the other in the range of 550 to 600°C . Sulfuric acid and sodium chloride are heated in a furnace to form sodium sulfate and hydrogen chloride. Hydrogen chloride contaminated by sulfuric acid droplets and sodium sulfate particles and air pass through coolers, scrubbers and finally is absorbed in absorption towers with water to then form a hydrochloric acid solution as shown in the simplified flowchart in Figure 3.

The furnaces used are of the Mannheim type, consisting of a furnace made of cast iron or iron-silicon alloy, consisting of two plate-shaped parts, one at the top and the other at the bottom, equipped by a melting system in such a way that the molten sodium sulphate is discharged continuously, to measure, that gaseous hydrogen chloride is expelled.

Figure 3 - Manufacturing of hydrochloric acid from salt and sulfuric acid



The purified hydrogen chloride is absorbed in absorption towers lined internally with material resistant to attack by concentrated hydrochloric acid.

Salt-Acid Process with Fluidized Bed

In order to improve the performance of the process, acid salt is proposed to inject sulfuric acid vapor into a fluidized bed reactor with sodium chloride injection in the range of 500°C, according to the following reactions:

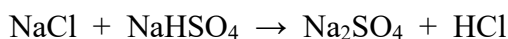
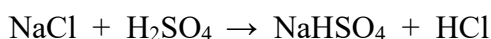
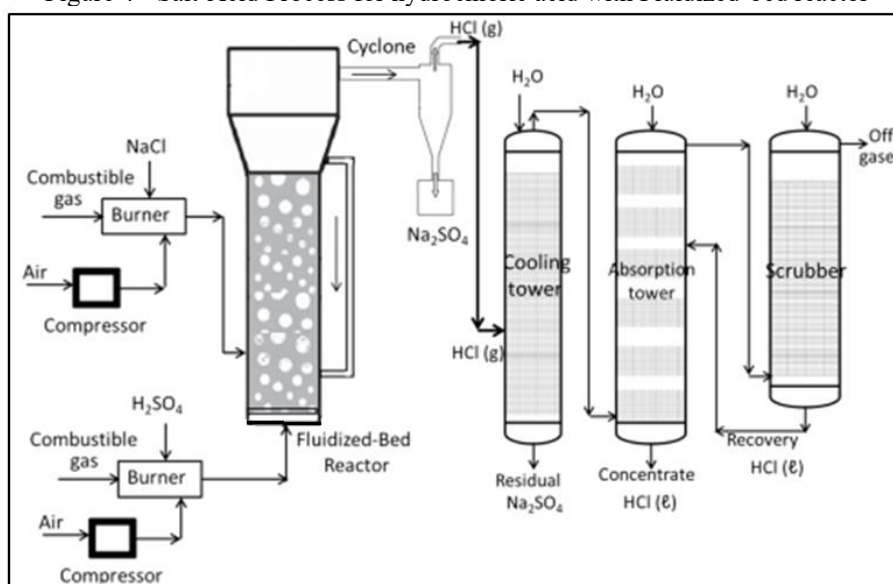


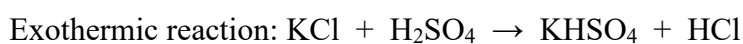
Figure 4 shows the fluidized bed reactor where hydrogen chloride and sodium sulfate formation occur. The cyclone separates the hydrogen chloride from gaseous hydrogen and sends it to the absorption towers for the formation of hydrochloric acid, while the sodium sulfate is recovered in solid form.

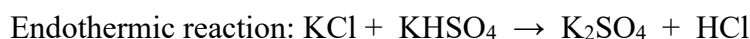
Figure 4 - Salt-Acid Process for hydrochloric acid with Fluidized-bed reactor



PROCESS FOR THE PRODUCTION OF POTASSIUM SULPHATE FROM POTASSIUM CHLORIDE AND SULPHURIC ACID

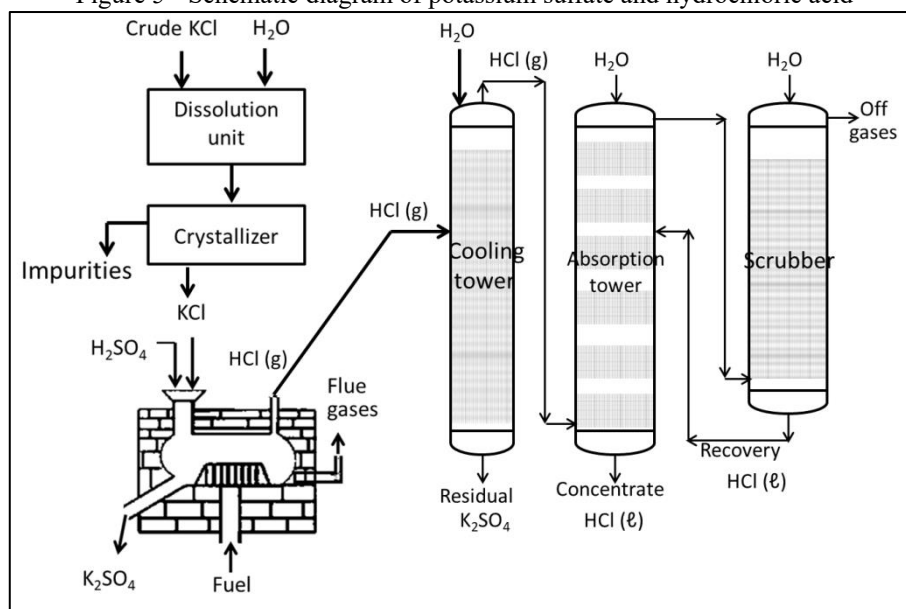
This process prioritizes the production of potassium sulfate as a fertilizer and hydrochloric acid as a byproduct. First, the crude potassium chloride is dissolved in water to remove the solid impurities and then directed to the crystallizer to remove the soluble impurities. Immediately afterwards, purified potassium chloride and sulfuric acid are injected into the Mannheim-type furnace in the temperature range between 300-400°C. Figure 5 shows the production process based on the following reactions [14, 15]:





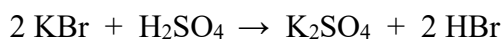
Or potassium sulfate is removed in solid form and hydrogen chloride flows into the Cooling Towers and absorption for the production of hydrochloric acid.

Figure 5 - Schematic diagram of potassium sulfate and hydrochloric acid



Potassium mineral deposits healthy sedimentary rocks, formed by the evaporation of saline water and found in various parts of the world. Generally, they are in the form of silvita (KCl), silvinita (KCl.NaCl) e carnalita (KCl.MgCl₂.6H₂O) [16, 17]. The main contaminants in the form of cations and anions present in these ores are: Ca²⁺, Mg²⁺, Fe²⁺, SO₄²⁻, Br⁻, SiO₃²⁻. and chloride ions can react with sulfuric acid and form CaSO₄, MgSO₄, FeSO₄, contaminating the sodium sulfate formed.

The reaction between KBr and H₂SO₄ can generate HBr (g) that flows along with HCl (g) and contaminates hydrochloric acid, depending on the reaction:



SYNTHETIC PROCESS FOR THE PRODUCTION OF HYDROCHLORIC ACID

This process developed in the 1940s has the great advantage of being extremely pure, since it comes from the direct burning of chlorine and hydrogen molecules from the electrolytic production of sodium chloride, in obtaining sodium hydroxide. Its technology was only possible from the development of materials resistant to high temperatures and the oxidizing conditions of this burning.

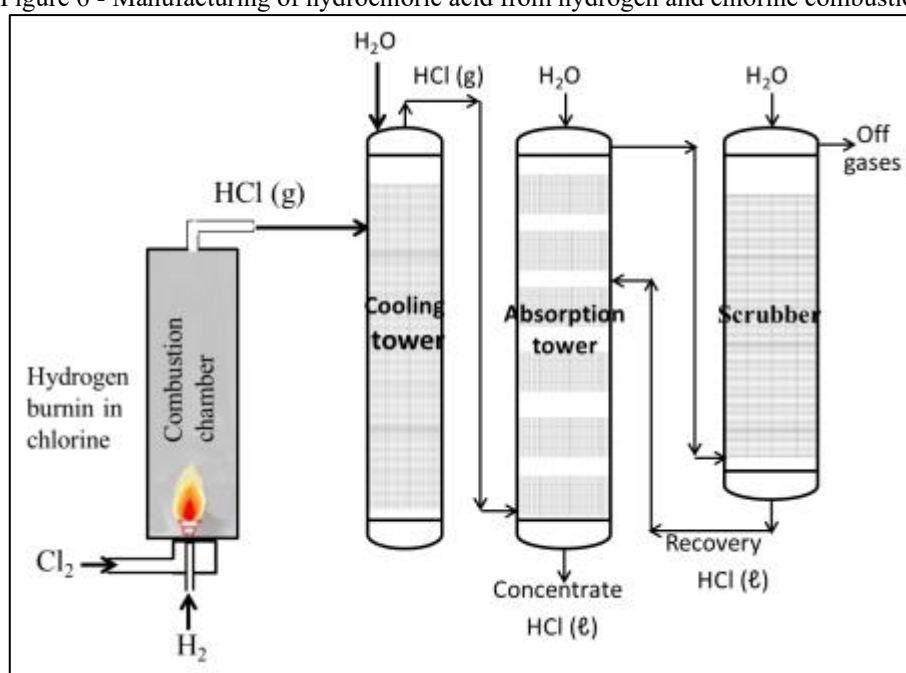
The reaction takes place in a vertical combustion chamber, with a structural carbon, lined with silica refractory bricks and provided with a continuous cold water cooling system [15, 18-20].

Generally, these combustion chambers have the shape of a cone trunk and a cap at the top, made of asbestos so that in the event of an explosion, this cap can break without compromising the structure of the reactor. The size of the chamber is dimensioned so that there is a complete reaction between the chlorine and hydrogen molecules as shown in the flowchart below in Figure 6.

To ensure a complete reaction with chlorine, an excess of 10% hydrogen is required. The reaction occurs at a temperature of 2,400°C with a greenish flame, and is represented by the following reaction:

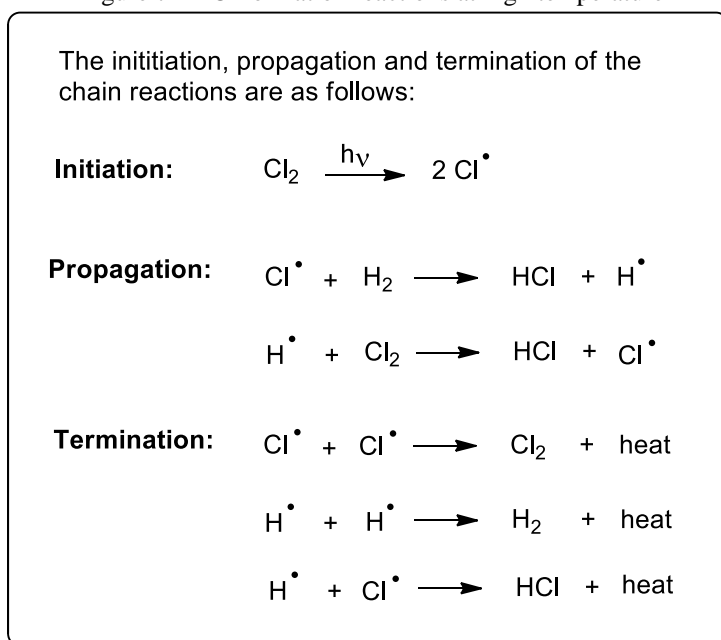


Figure 6 - Manufacturing of hydrochloric acid from hydrogen and chlorine combustion



The reaction is exothermic and propagates in the gas phase by alternating the following intermediate reactions, including the initiation, propagation and termination of chain reactions, as shown in Figure 7.

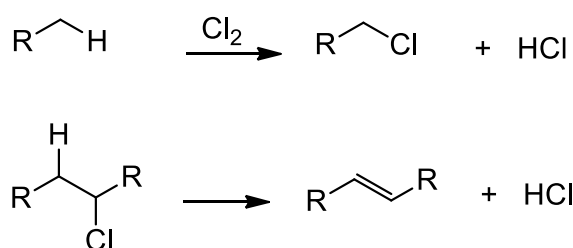
Figure 7 - HCl formation reactions at high temperature



Considering that the chlorine and hydrogen from the electrolytic cells are extremely pure, this production is characterized by obtaining a high purity hydrochloric acid. However, if H_2 and Cl_2 come from other processes, it is possible to contaminate the acid.

RECOVERY OF HYDROCHLORIC ACID FROM CHLORINATION OF ORGANIC COMPOUNDS

Since the 1960s, there has been an increasing use of hydrochloric acid from the chlorination of organic molecules or the decomposition of organochlorines, as shown in the following reactions:



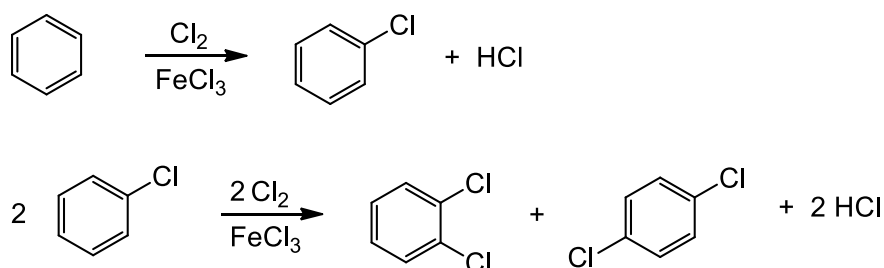
Mercado Libre Internacional offers hydrochloric acid for sale without identifying the origin of the process, and consequently does not report the presence of organochlorines. In order to evaluate the main contaminants in hydrochloric acid, some processes for obtaining organochlorine products and the recovery of hydrochloric acid are presented below.

Recovery of hydrochloric acid from monochlorobenzene and dichlorobenzene

The production of chlorobenzenes peaked in 1969, but its production has been falling precipitously due to its replacement by more environmentally friendly Chemicals. However, in the international scenario, such molecules have been used as additives, chemical intermediates in rubber, paints, anilines, insecticides, dyes, etc. [21].

The process of obtaining monochlorobenzene and dichlorobenzene consists of the reaction of chlorine with benzene in the presence of a ferric chloride catalyst (FeCl_3). Chlorine is bubbled at a temperature ranging from 40 to 60°C, so that the yield of monochlorobenzene synthesis varies between 60 and 75%, while that of dichlorobenzene is between 10 and 20%.

The reactions involved in this process are:



The simplified flowchart presented in Figure 8 shows that after the organochlorines are formed in the reactor, the hydrogen chloride passes through a condenser to retain the organochlorines, benzene, and chlorine to return to the chlorinator. Hydrogen chloride is absorbed in the absorption tower with water to form hydrochloric acid. The organochlorine products from the chlorinator pass through a neutralization tank to neutralize the traces of HCl and Cl_2 , and then the organochlorines go to a distillation and rectification column to separate the monochlorobenzene from the dichlorobenzene.

The neutralization reactions that occur in the neutralization tank are:

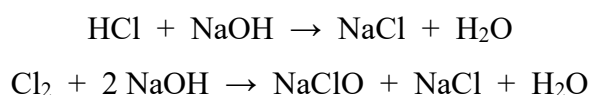
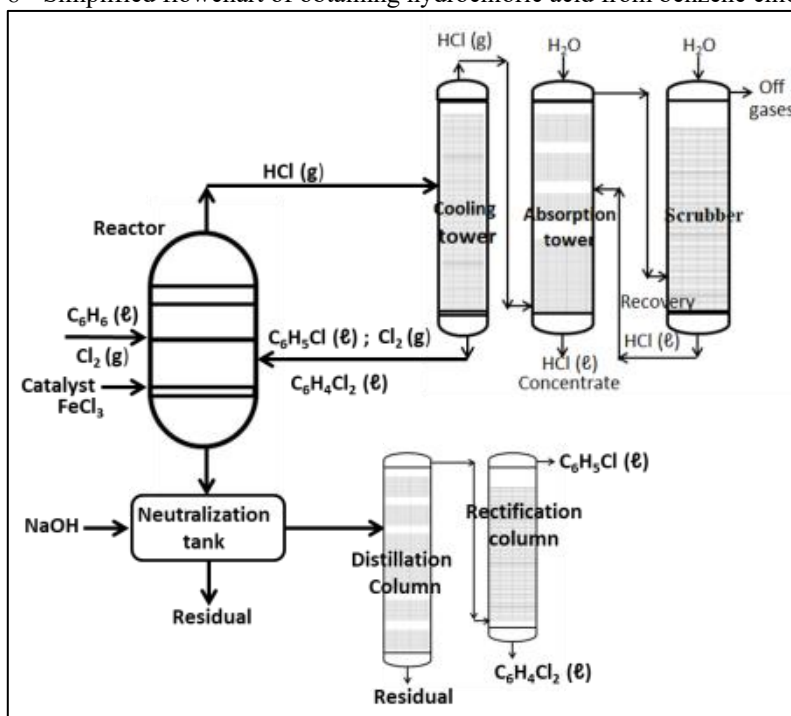


Figure 8 - Simplified flowchart of obtaining hydrochloric acid from benzene chlorination



As shown in the diagram shown in Figure 8, depending on the operating conditions or *bypass*, the following contaminations are possible: C_6H_5Cl , $C_6H_4Cl_2$, Cl_2 and C_6H_6

Recovery of hydrochloric acid from the production of benzyl chloride

This product is used as a chemical intermediate in the manufacture of pharmaceuticals, especially in the synthesis of phenobarbital, benzedrine, etc. It is also used to obtain plasticizers for paints and the like [15, 22].

The process consists of the direct reaction of chlorine with toluene in a reactor with no light, as shown in the reaction and flowchart in Figure 9:

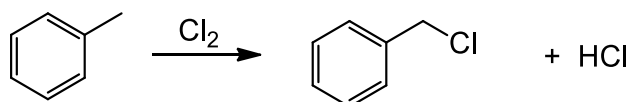
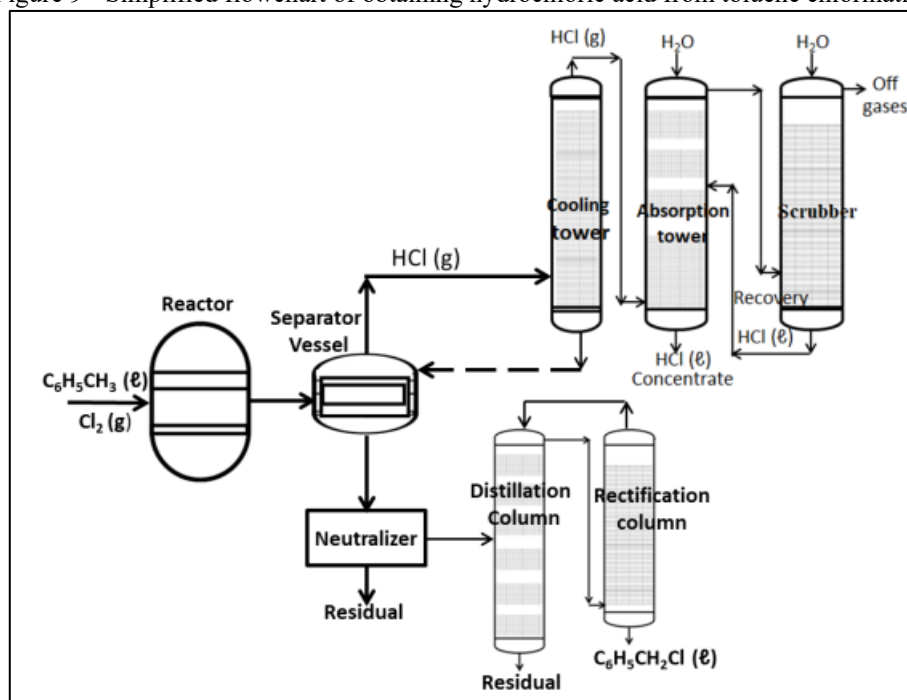


Figure 9 - Simplified flowchart of obtaining hydrochloric acid from toluene chlorination



The mixture consisting of benzyl chloride and hydrogen chloride, which comes out of the chlorination reactor, passes through a separator vessel where the hydrogen chloride gas stream is separated from the liquid phase consisting of benzyl chloride. Hydrogen chloride is absorbed into water, forming a hydrochloric acid solution.

Based on the production process, it is possible that the hydrochloric acid obtained in the absorption tower may be contaminated mainly with chlorine and toluene due to the recycle operation.

Recovery of hydrochloric acid from the process of obtaining carbon tetrachloride from organochlorine residues

Carbon tetrachloride (CCl_4) is used as a chemical intermediate in the rubber industry and as solvents in the chemical and pharmaceutical industries. However, its use has been questioned due to environmental contamination because it is considered as a volatile organic compound (VOC) [15, 22-24].

From the point of view of hydrochloric acid contamination, this is an interesting process, as it aims to transform various hydrocarbons and organochlorines into carbon tetrachloride.

The process consists of a direct reaction of mixing organochlorines with chlorine at a temperature of 600°C in a chlorination reactor, aiming at the production of carbon tetrachloride and hydrochloric acid, as shown in the reactions and the flowchart shown in Figure 10.

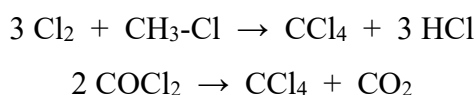
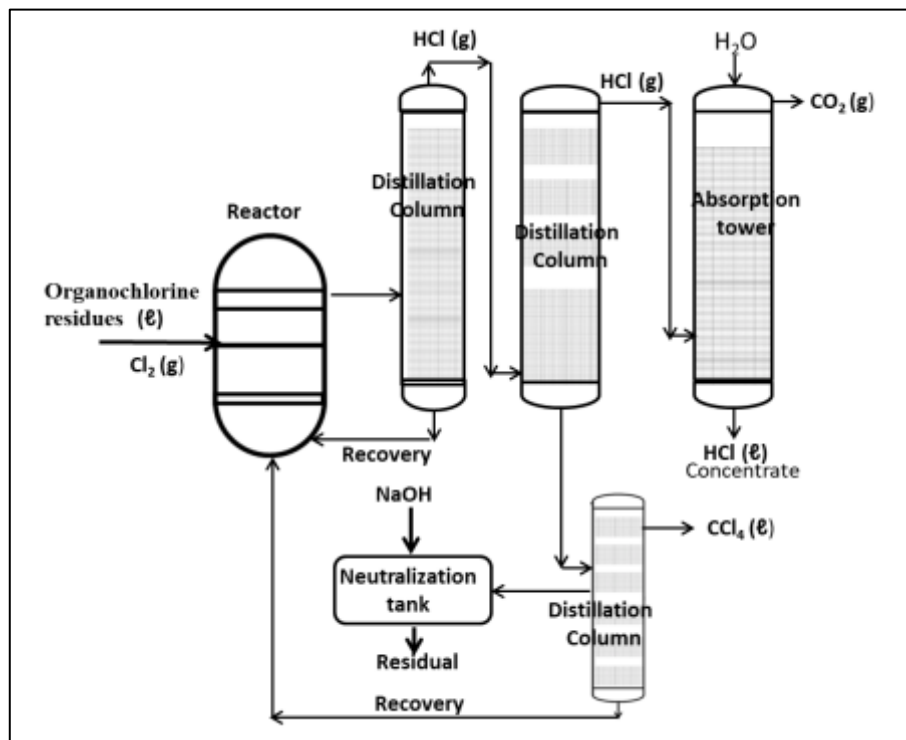


Figure 10 - Simplified flowchart of hydrochloric acid recovery from obtaining carbon tetrachloride from organochlorine residues

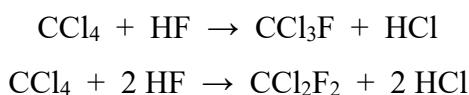


Considering the origin of this raw material (organochlorine compounds) it is possible to visualize organochlorines and chlorine as possible contaminants of hydrochloric acid obtained in the absorption tower.

Recovery of hydrochloric acid from the process of obtaining dichlorodifluoromethane (Freon-12)

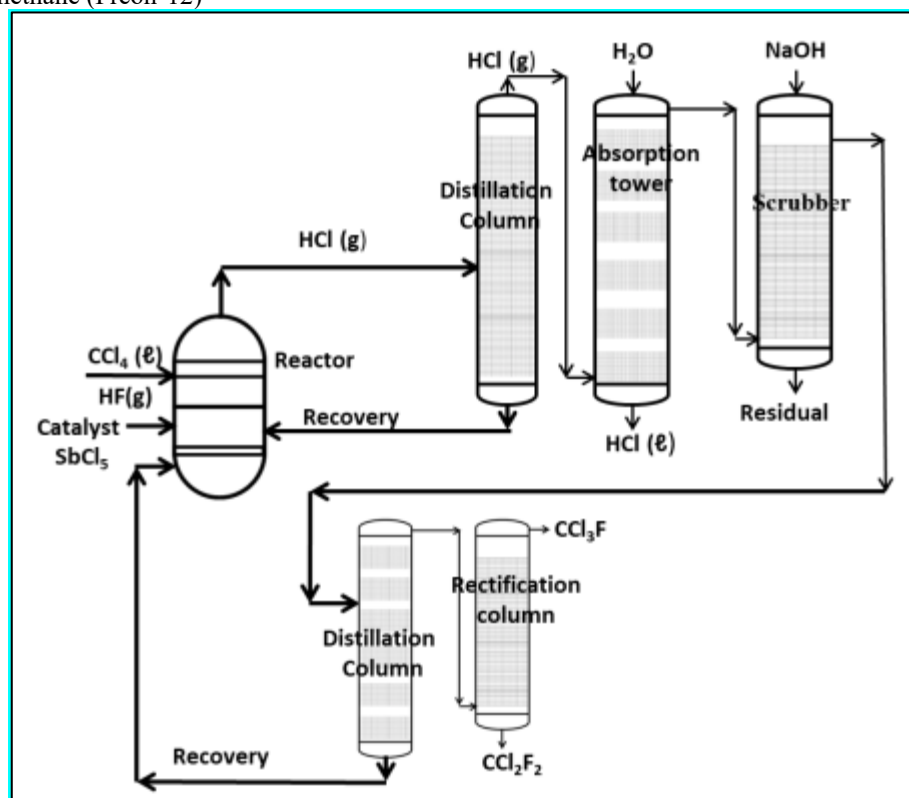
Currently, the industrial production of some organochlorofluorinated products has been discontinued due to environmental problems. However, some international units still exist, considering the demand for the product without the environmental concern, typical of international free markets.

The industrial production process consists essentially of the bubbling of hydrogen fluoride (HF), anhydrous, and carbon tetrachloride in used antimony pentachloride (SbCl_5), which acts as a catalyst for the reaction. Depending on the molar relationship, dichlorodifluoromethane and trichloromonofluoromethane may be formed. The reactions are endothermic and occur in the temperature range of 65 to 100°C and in the presence of the catalyst [25].



The hydrogen chloride produced in the reaction is removed through an absorption tower with water and the possibility of contamination with hydrogen fluoride with hydrofluoric acid formation. HF levels can vary between 100 and 1,000 ppm.

Figure 11 - Simplified flowchart of the recovery of hydrochloric acid from the process of obtaining dichlorodifluoromethane (Freon-12)



ANALYSIS OF CONTAMINANTS FROM HYDROCHLORIC ACID PRODUCTION PROCESSES

As previously mentioned, hydrochloric acid is a basic input used in the various industrial segments. It is offered in the international free market as concentrated solutions at 37 wt.% (by mass), of high purity for analytical, pharmaceutical and food industry purposes; as well as in commercial concentrations ranging from 10 to 30% wt.%.

The Material Safety Data Sheet (MSDS) [26] shall accompany the sale of hydrochloric acid for various purposes and shall have 16 sections identified as: (a) Identification of Chemicals and Companies; (b) Composition and information on ingredients; (c) identification of hazards; (d) first aid measures; (e) data on fires and explosions; (f) Accident clearance measures; (g) Handling and storage; (h) Exposure/personal protection controls; (i) physical and chemical properties; (j) stability and reactivity data; (k) toxicological information; (l) ecological information; (m) disposal considerations; (n) transport information; (o) other regulatory information; (p) other information.

Data sheets do not always report the contaminants, the production process, and the raw material used. Therefore, the objective of this study is to identify and quantify the main industrial processes, the possible contaminants that may be present in hydrochloric acid solutions. Thus, criteria are proposed in which the possibilities of occurrence of contaminants with their levels are established, aiming at their use in various industrial segments (Table 1).

The possibility of contaminants existing in the processes of obtaining hydrochloric acid will depend on several direct or indirect factors, although the raw material is the most important, as it can aggregate the contaminants and pass them on to the acid.

Table 1 - Possibility of contaminants and hydrochloric acid

<i>Possibility of contaminants</i>	<i>Legend</i>
Very likely	VL
Possible	PO
Very unlikely	VU
Unlikely	UN

Table 2 shows the probable levels of contaminants that may be added to the hydrochloric acid solution.

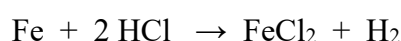
Table 2 - Level of probable contaminants in hydrochloric acid solution

<i>Level of contaminant (ppm)</i>	<i>Legend</i>
0 – 1	A
1 – 10	B
10 - 100	C
100 - 1000	D
> 1000	F

The main contaminants that may be present in hydrochloric acid will be analyzed, below:

TOTAL IRON

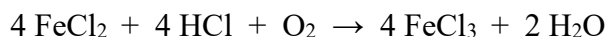
Generally, the total iron found in chemical analyses of hydrochloric acid is referred to as total iron, considering it in the form of Fe²⁺ (ferrous) and Fe³⁺ (ferric). The Fe²⁺ ion may come from the contamination of sodium chloride obtained from solar evaporation from seawater or from the mining of rock salt [10-13]. Another possibility is the acid attack on carbon steel pipes, generating ferrous chloride according to the reaction:



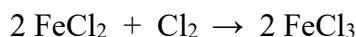
The occurrence of the ferric ion can be explained by the oxidation of the Fe²⁺ ion, by means of oxygen solubilized in hydrochloric acid. The high concentration of H⁺ ions does not favor the oxidation of Fe²⁺ to Fe³⁺, but as the concentration of H⁺ ions decreases, there is a tendency for



hydrolysis of ferric ions and, consequently, an increase in the oxidation rate. The transformation of ferrous chloride to ferric chloride can be evidenced by the reaction:



If chlorine (Cl_2) is present in the acidic solution, ferrous chloride can be oxidized to ferric chloride based on the reaction:



The total iron contents vary from 0.2 to 10 ppm, however, in some commercial hydrochloric acids offered in the International Free Market these values can be higher than 100 ppm.

CHLORINE AND ORGANOCHLORIDE

Free chlorine (Cl_2), present in hydrochloric acid solutions, can come from a synthetic process or from hydrochloric acid recovery processes from the chlorination of organic substances. However, it is impossible for chlorine to come from processes that have sodium chloride or potassium chloride as raw material.

In the synthetic process, the occurrence of chlorine is due to the incomplete reaction of hydrogen with chlorine, in such a way that there is an excess of chlorine that is solubilized in the acid solution, while the hydrogen, due to its low solubility, is given off, and thus does not solubilize in the acid solution.

In the hydrochloric acid recovery process, the presence of free chlorine in the acid solution is due to the deficiencies that occurred during the separation and purification process, that is, it depends on the efficiency of the gas separation processes.

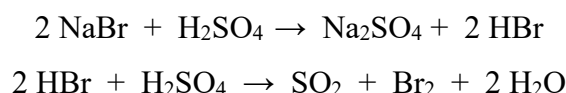
The chlorine content, present in commercial acids, is in the range of 2 to 10 ppm, although values of up to 50 ppm have been observed, mainly in commercial hydrochloric acid recovered from chlorination processes.

The presence of organochlorines in hydrochloric acid recovered from chlorination processes of organic substances is usually due to operational deficiencies in the extraction and purification system of the recovered acid. The contaminant content is a function of the reactions involved and the solubility of these chlorinated compounds in the hydrochloric acid produced. Organochlorine concentrations can range from 5 to 1,000 ppm.

BROMINE AND HYDROBROMIC ACID

The occurrence of bromine (Br₂) and hydrobromic acid (HBr) in hydrochloric acid solution can be explained by supposing that this acid comes from the salt-acid process. The sodium chloride used as a raw material can be extracted from rock salt mining, which depending on the rock formation may contain sodium bromide (NaBr).

Sodium bromide, when reacting with H₂SO₄ at high temperatures, can generate Br₂ and HBr, as shown by the following reactions:

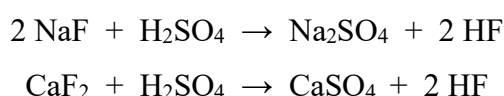


Br₂ and HBr can be entrained into the hydrochloric acid absorption tower and absorbed as a contaminant in this acid. The concentration of bromide (HBr) can be in the range of 0.01 to 10 ppm.

FLUORIDE AND ORGANOFLUORINES

The occurrence of fluoride (F⁻) or in the form of hydrofluoric acid (HF) occurs in salt-acid processes, in the recovery of hydrochloric acid from the fluoridation of organic compounds (Figure 11). The occurrence of HF only does not occur in the synthetic process.

Considering that the saline raw material may contain sodium fluoride (NaF) and/or calcium fluoride (CaF₂) and the reactions that occur with H₂SO₄ in the salt-acid process are as presented, as follows:



Hydrogen fluoride (HF) gas can escape from the furnace and be drawn into the hydrochloric acid absorption tower, being absorbed and incorporated as a contaminant into this acid. In the organofluorines production process, HF (g) can be entrained into the hydrochloric acid absorption tower and be incorporated as a contaminant.

Chemical analyses carried out on commercial acids offered in the International Free Market have shown values even higher than 1,000 ppm in HF.

SULPHATE

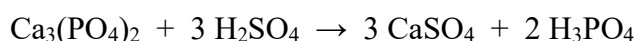
Generally, the occurrence of sulfate in hydrochloric acid solutions is due to the absence of H₂SO₄ droplets and solid Na₂SO₄ particles that accompany the detachment of hydrogen chloride in



salt-acid processes. Chemical analyses reveal values from 10 to 1,000 ppm that depend on the operating conditions of the process.

PHOSPHATE

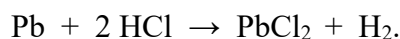
The occurrence of phosphate (PO_4^{3-}) or phosphoric acid (H_3PO_4) in hydrochloric acid solutions is unlikely. However, contaminations can be admitted if the H_2SO_4 used in the salt-acid process is contaminated by phosphoric acid. Such a possibility could occur in the recovery of sulfuric acid from the fertilizer industry, where the reaction would occur:



LEAD

The occurrence of Pb^{2+} ions in hydrochloric acid solutions is practically unlikely, as such contaminant is not related to industrial manufacturing routes. In the case of salt-acid processes that use sulfuric acid, the only possibility would be the use of a sulfuric acid contaminated with this ion. For example, the recovery of lead batteries and the H_2SO_4 associated with the process could result in probable contamination.

Another possibility of finding Pb^{2+} ions would be the attack on the lead gaskets used in bombs by hydrochloric acid, resulting in lead chloride, as shown in the reaction:



SODIUM

Na^+ ions are not usually present in hydrochloric acid solutions, however, it has been observed in commercial hydrochloric acid offered in the International Free Market. This is due to fraudulent additions of sodium chloride in order to increase the density of the acid and in a way to evade the increase in acid concentration. Some samples analyzed showed sodium values higher than 1,000 ppm.

ORGANIC COMPOUNDS

In recycle operations, during the recovery of hydrochloric acid from chlorination and/or fluorination of organic compounds, it is possible that these molecules detach and are incorporated into the acid stream at the hydrochloric acid absorption tower. Some organic compounds can also solubilize in small amounts in acidic solutions, such as: benzene, toluene, methyl alcohol and etc.

The levels of hydrocarbons present in hydrochloric acid solutions can vary from 1 to 100 ppm, which will depend on the efficiency of the removal process as shown in Figures 9 to 11.

Based on Tables 1 and 2, which present the possibility of contamination and contamination levels, Table 3 was constructed, interrelating these indices with the main hydrochloric acid production processes.

Table 3 - Matrix of the possibility and levels of contaminants with the main hydrochloric acid production processes

<i>Contaminants</i>	<i>Possibility and level of contaminants</i>			
	Salt-Acid Process	Synthetic process	Recovery of HCl from chlorination of organic compounds	Recovery of HCl from fluorination of organic compounds
Fe ²⁺ (ferrous)	VL,C	PO,B	PO,B	PO,B
Fe ³⁺ (ferric)	VL,C	PO,B	PO,B	PO,B
Chlorine (Cl ₂)	UN	PO,B	PO,C	PO,B
Organochlorine	UN	UN	PO,D	PO,B
Bromine (Br ₂)	VU,A	UN	VU,A	VU,A
Hydrobromic acid (HBr)	VU,A	UN	VU,A	VU,A
Hydrofluoric acid (HF)	VL,E	UN	VU,A	VL,C
Organofluorines	UN	UN	VU,A	VL,C
Sulfate (SO ₄ ²⁻)	VL,E	UN	VU,A	VU,A
Phosphate (PO ₄ ³⁻)	PO,A	UN	UN	UN
Lead (Pb ²⁺)	VU,A	UN	UN	UN
Sodium (Na ⁺)	UN	UN	UN	UN
Organic Compounds	UN	UN	PO,C	PO,C

LEGEND 1: (VL) Very likely ; (PO) Possible; (VU) Very unlikely; (UN)Unlikely.

LEGEND 2: A (0–1 ppm); B (1–10 ppm); C (10-100 ppm); D (100-1.000 ppm); B (> 1.000ppm)

USE AND INFLUENCE OF HYDROCHLORIC ACID IN INDUSTRIAL PROCESSES

As shown in Figure 2, hydrochloric acid is used in various industrial segments including the manufacture of food, pharmaceuticals, dyes, metal chlorides, pickling of metal products, among others, and is also injected into oil wells to remove calcareous scale in order to increase their oil and natural gas.

Table 4 shows the results of hydrochloric acid analysis in four samples used as examples for industrial purposes offered in the International Free Market and called: Food Grade, Commercial 01, Commercial 02 and Commercial 03.

Table 4 - Hydrochloric acid analysis of samples offered on the International Free Market

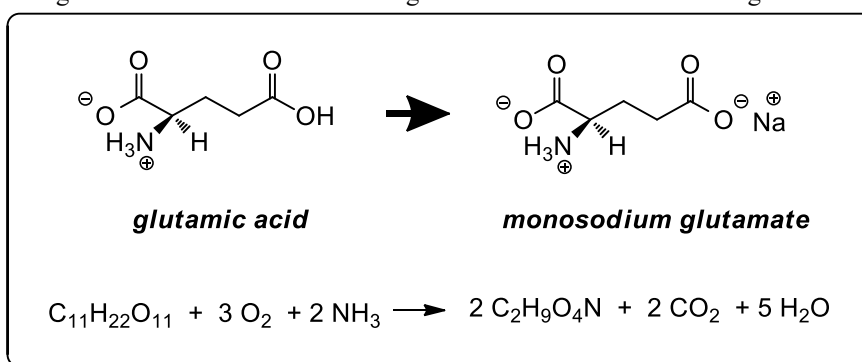
<i>Contaminants</i>	<i>Food Grade</i>	<i>Commercial 01</i>	<i>Commercial 02</i>	<i>Commercial 03</i>
Assay, wt. %	37.0	32.4	27.4	15.2
Density, 20°C, g/cm ³	1.19	1.16	1.14	1.11
Iron as Total Fe, ppm	0.1	0.1	25	35
Chlorine (Cl ₂), ppm	0	13.1	10.3	15.2
Organochlorine	0	13.1	10.3	15.2
Bromine (Br ₂)	0	0	2.0	1.5
Hydrobromic acid (HBr)	0	0	0	0
Hydrofluoric acid (HF)	0	0	25	23
Organofluorines	0.1	10	50	34
Sulfate (SO ₄ ²⁻)	0	< 1.0	< 2.0	< 2.0
Phosphate (PO ₄ ³⁻)	0	0	0	0

To evaluate the use of hydrochloric acid as a function of possible contamination, the industrial production of the food additive (monosodium glutamate) and acid injection in oil wells were chosen. The use of contaminated acids in the process can result in final products with contamination, which in most cases, are not listed in the technical specifications and that can cause problems to public health, the environment or the process itself with great losses.

INDUSTRIAL ASSESSMENT OF MONOSODIUM PRODUCTION

Monosodium glutamate (Figure 12) is a sodium carboxylate, i.e., an organic salt derived from glutamic acid, obtained by fermentation of carbohydrates. It is an important condiment used in food. Although it does not have a taste of its own, it has the function of accentuating the flavors of food by enhancing sensory perception, particularly the aromas of meat and derivatives in canned goods, ready-to-eat soups, sausages, etc. [27-31].

Figure 12 - Schematic structure of glutamic acid and monosodium glutamate



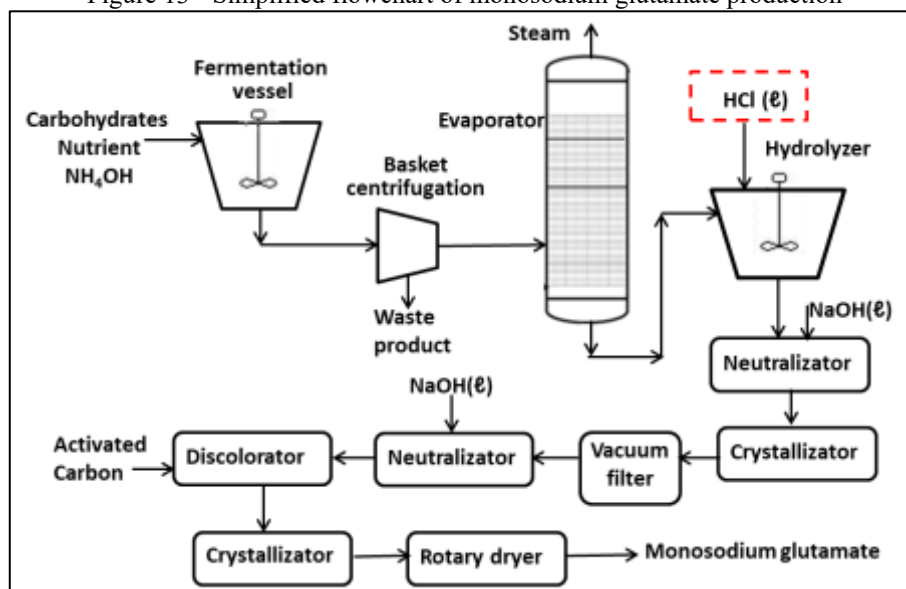
The fermentation process for the production of monosodium glutamate is represented by the simplified flowchart in Figure 13, consisting of the following steps:

- Concentration and preparation of fermentative matter.
- Hydrolysis with the addition of sodium hydroxide.
- Acidification with hydrochloric acid.

- d) Removal of inorganic acids formed by the action of hydroxide with acid.
- e) Crystallization, separation and purification of the formed glutamic acid.
- f) Neutralization with sodium hydroxide.
- g) Deodorization.
- h) Crystallization, centrifugation, and drying of the final product (27, 28).

In the process of obtaining monosodium glutamate (Figure 13), it is verified that hydrochloric acid is added to the hydrolyzer in order to form glutamic acid. This means the need to use hydrochloric acid with high purity. If an acid with impurities is used, it is clear that the monosodium glutamate will incorporate these contaminants into the final product. As a result, the final product will become a public health problem.

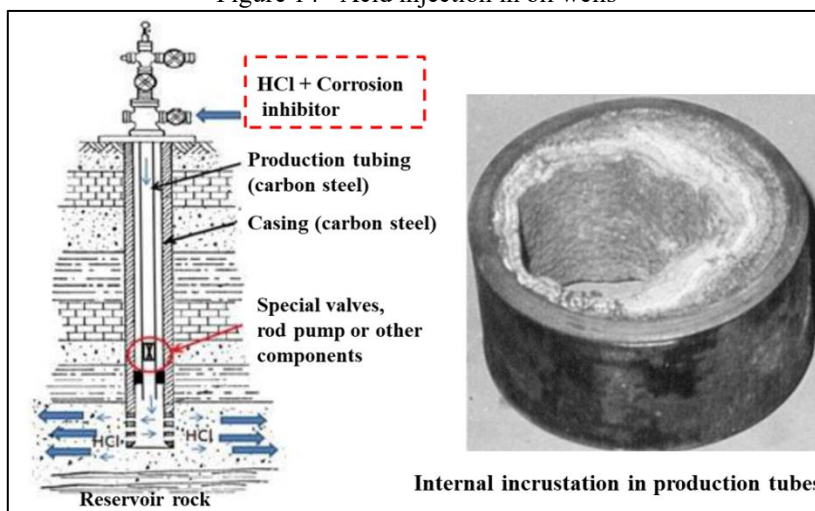
Figure 13 - Simplified flowchart of monosodium glutamate production



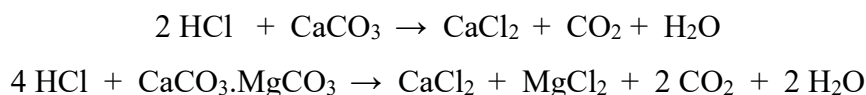
ASSESSMENT OF ACIDIFICATION OF OIL WELLS

The acidification of oil wells, also called acid stimulation, comprises the injection of hydrochloric acid (10 to 28%) into the reservoir rock, aiming to increase the productivity of the well. In addition, this injection also dissolves the internal fouling in the oil and natural gas production pipes. The injection of the acid into the well and the internal fouling in the tubes are shown in Figure 14.

Figure 14 - Acid injection in oil wells



The main determination of this process is to remove wellbore formation damage, promoting the dissolution the reservoir rock and consequently increasing the permeability of rock to the passage of oil & natural gas. [32, 33]. HCl is the most widely used in acidifications due to its ease of dissolving carbonate rocks, such as limestone (CaCO_3) and dolomite ($\text{CaCO}_3 \cdot \text{MgCO}_3$). The formation of soluble salts (CaCl_2 and MgCl_2) occurs when HCl penetrates the reservoir rock, as shown by the following reactions:



The injection of hydrochloric acid is done by the production pipe and fittings which are made of carbon steel (Figure 14), while other equipment involved in the operation (valves, rings, special pump, etc.), are usually stainless steel. To prevent the corrosion of these materials, it is essential to add a corrosion inhibitor, whose function is to avoid or minimize the accentuated attack of hydrochloric acid on metallic materials.

An oil well is worth thousands of dollars and damage to the permeability of the reservoir rock can mean the total loss of the well, i.e. the loss of production. On the other hand, if there is corrosion of the pipes and equipment involved, the cost is also very high. The equipment can be exchanged or recovered, but in most cases, the damage to the reservoir rock, the recovery of the well is irrecoverable.

In view of this catastrophic scenario, it is essential to use a hydrochloric acid that meets a specification and that does not cause damage to oil production or equipment corrosion. Thus, it is essential that the maximum levels of iron, sulfate (SO_4^{2-}), phosphate (PO_4^{3-}), chlorine (Cl_2) and organochlorines do not exceed the values presented in Table 5.

The SO_4^{2-} and PO_4^{3-} ions present in hydrochloric acid can react with the Ca^{2+} , Sr^{2+} and Ba^{2+} ions in oil production waters and precipitate the respective sulfates (CaSO_4 , SrSO_4 , BaSO_4) and phosphates [$\text{Ca}_3(\text{PO}_4)_2$, $\text{Sr}_3(\text{PO}_4)_2$, $\text{Ba}_3(\text{PO}_4)_2$], as they are insoluble and can occlude and buffer the flow of fluids.

According to the literature, laboratory tests performed with carbon steel specimens and with additions of ferric ions (Fe^{3+}) and free chlorine (Cl_2) in high purity hydrochloric acid, conclude that such substances can affect the performance of the protection exerted by corrosion inhibitors [34-36].

Table 5 - Maximum concentrations of contaminants that may be present in hydrochloric acid solution for acidification operations in oil wells

<i>Maximum concentrations of contaminants (%)</i>	<i>Value</i>
Iron as Total Fe	0.002
Chlorine (Cl_2)	0.0005
Organochlorine	0.0005
Sulfate (SO_4^{2-})	0.005
Phosphate (PO_4^{3-})	0.002

EXAMPLES OF EXPERIMENTS SHOWING THE INFLUENCE OF THE EXISTING CONTAMINANT ON HYDROCHLORIC ACID

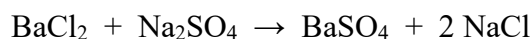
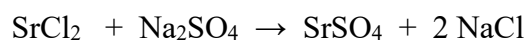
In order to demonstrate that some contaminations present in hydrochloric acid can, directly or indirectly, contaminate the process or the final product, laboratory experiments were developed for this purpose.

PRECIPITATION OF BARIUM SULPHATE AND STRONTIUM SULPHATE IN PETROLEUM PRODUCED WATER CONTAINING Ba^{2+} AND Sr^{2+} IONS

This simple experiment seeks to demonstrate that the acidification of an oil well with hydrochloric acid can become a problem related to scale or insoluble deposition when hydrochloric acid contaminated with sulfate encounters a oilfield produced water containing Ba^{2+} and Sr^{2+} ions.

The simulated oilfield produced water for laboratory tests is considered as a saline solution containing 20 wt.% of NaCl, 200 mg/L of SrCl_2 and 100 mg/L of BaCl_2 representing respectively, 110 mg/L of Sr^{2+} and 66 mg/L of Ba^{2+} .

Three 15 wt.% solutions of high-purity hydrochloric acid were prepared. The first is sulfate-free, the second is 400 mg/L of Na_2SO_4 is added, and the third is 800 mg/L of Na_2SO_4 . Then, 10 mL of each acid solution were poured into three test tubes containing 10 mL of produced oilfield produced water containing Ba^{2+} and Sr^{2+} ions. It was found that in the first tube there was no precipitate formation, while in the other two there was an intense white precipitation, due to the formation of strontium sulfate and barium sulfate, represented by the reactions:

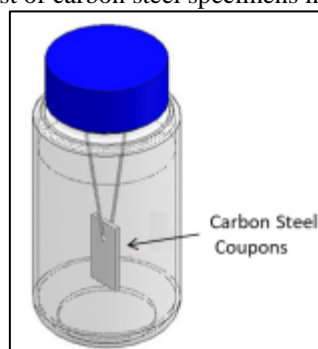


It is concluded that the formation of insoluble sulfates can compromise the acidification operation.

EVALUATION OF THE ACTION OF FERRIC IONS PRESENT IN HYDROCHLORIC ACID USED IN THE ACIDIFICATION OF AN OIL WELL OR IN THE PICKLING OF CARBON STEEL

The test consists of the total immersion of carbon steel coupons (dimensions: 45 x 15 x 1.2mm) in a glass container (Figure 15), at a temperature of 65°C, for 1 h in 15% wt.% of hydrochloric acid containing 100, 500, 1,000 and 5,000 mg/L of Fe^{3+} and additions of 300, 500 and 1,000 mg/L of corrosion inhibitor. The corrosion inhibitor used in these tests is a mixture of 70 wt.% of propargyl alcohol, 20% wt.% of high molecular and 10% wt.% of solvent. The corrosion rate is calculated by the mass loss of the coupons before and after the test.

Figure 15 - Immersion mass loss test of carbon steel specimens in 15 wt.% hydrochloric acid solution



Three coupons were used to verify the reproducibility of the results. The corrosion rate (CR) was defined by the following expressions:

$$\text{Corrosion rate} = \text{CR} = (\text{W}_o - \text{W}_i) / \text{S} \cdot \text{h} \text{ (mg/cm}^2 \cdot \text{h)}.$$

Where: W_o and W_i are the mass losses in the absence and presence of the corrosion inhibitor.

The laboratory results shown in Table 6 demonstrate that the ferric ion interferes with the protective action exerted by the mixture of corrosion inhibitors, increasing the mass loss of carbon steel, i.e., decreasing the efficiency of the inhibitor. The corrosion inhibitor reduces acid attack, but does not prevent the attack of oxidizing agents such as ferric ions present in the acid solution. The experiment also demonstrates that the presence of ferric ions in hydrochloric acid can act as an

oxidant, reducing the efficiency of the corrosion inhibitor and can, in theory, compromise the acidification of the oil well.

Table 6 - Results of tests of weight loss of carbon steel coupons in 15 wt.% of HCl at 65 °C, with addition corrosion inhibitor (70 wt.% propargyl alcohol, 20 wt.% high molecular weight amines and 10 wt.% solvent)

Corrosion inhibitor concentration (mg/L)	Mass loss, mg/cm ² .h				
	Concentration of ferric ions, Fe ³⁺ , mg/L				
	0	100	500	1000	5000
300	0.50	0.55	0.80	3.10	7.50
500	0.30	0.40	0.70	2.55	6.85
1000	0.25	0.35	0.55	1.50	5.45

EVALUATION OF THE CHLORINE ACTION OF HYDROCHLORIC ACID USED IN THE ACIDIFICATION OF AN OIL WELL OR IN THE PICKLING OF CARBON STEEL

The test consists of total immersion of carbon steel coupons (dimensions: 45 x 15 x 1.2mm) in a glass container (Figure 15), at a temperature of 60°C, for 1 h in a solution at 10 to 15% wt.% of hydrochloric acid containing 100, 500, 1,000 and 1,500 mg/L of chlorine (Cl₂) and the addition of 1,000 mg/L of corrosion inhibitor. The corrosion inhibitor used in these tests is propargyl alcohol. Chlorine was added to hydrochloric acid in the form of calcium hypochlorite.

The corrosion rate was calculated by the mass loss of the coupons before and after the test.

The laboratory results presented in Table 7 attest that chlorine (Cl₂) interferes with the protective action exerted by the corrosion inhibitor, increasing the mass loss of carbon steel, i.e., decreasing the efficiency of the inhibitor. These facts are based on studies carried out by several researchers.

Table 7- Results of tests of weight loss of carbon steel coupons in 10 at 15 wt.% of HCl at 60 °C, with addition corrosion inhibitor (propargyl alcohol)

Chlorine (Cl ₂) concentration, mg/L	Mass loss, mg/cm ² .h	
	10 wt.% HCl	15 wt.% HCl
0	0.478	0.595
100	0.585	0.778
500	0.703	0.790
1000	0.748	1.033
1500	0.854	1.683

The referenced literature show that propargyl alcohol based corrosion inhibitors show excellent performance in protecting carbon steel in hydrochloric acid solutions at all concentration and temperature combinations [37 - 39].

The corrosion protection capacity is based on good adsorption capacity of propargyl alcohol molecules by carbon steel is linked to their π -electrons, which interact with metal surfaces and, consequently, form triple bonds, HC≡C-CH-OH [40]. It can be concluded that certain levels of



chlorine in hydrochloric acid cause problems in the corrosion protection of equipment related to acidification operations in oil wells.

CONCLUSIONS

Based on the study, it is concluded that:

- It is necessary to develop a critical technical awareness that must be built in society, especially in the University, aiming at the understanding of industrial routes and the possible aggregations of contaminants during industrial processing.
- It is essential that the formation of critical technical awareness can determine, based on quality assurance, the correct use of hydrochloric acid solutions in the various industrial segments.
- It is important that general and specific quality criteria are set, culminating in a responsibility that unites the acid manufacturer, the intermediate product manufacturer and finally the end customer.
- Laboratory tests have shown that some contaminants present in hydrochloric acid used in acidification operations can cause fouling or corrosion problems, preventing or restricting the protective action exerted by corrosion inhibitors in acidic media.
- Finally, it is important to reinforce the use of hydrochloric acid from the synthetic process, i.e. of high purity, in the production of food and pharmaceutical products.


REFERENCES

- [1] SALAGER, J. L., MARQUEZ, R., BULLON, J. & FORGIARINI, A. (2022). Formulation in surfactant systems: from-Winsor-to-HLDN. Encyclopedia, 2 (2), 778-839. <https://doi.org/10.3390/encyclopedia2020054>.
- [2] MAKRA, L. (2019). Anthropogenic air pollution in ancient times. In Toxicology in Antiquity, 267-287. Academic Press. <https://doi.org/10.1016/B978-0-12-815339-0.00018-4>.
- [3] AFRIN, S. & GUPTA, V. (2020). Pharmaceutical formulation. <https://europepmc.org/article/NBK/nbk562239>.
- [4] PAREZANOVIĆ, G. Š., LALIC-POPOVIC, M., GOLOCORBIN-KON, S., VASOVIC, V., MILIJAŠEVIĆ, B., AL-SALAMI, H. & MIKOV, M. (2019). Environmental transformation of pharmaceutical formulations: a scientific review. Archives of Environmental Contamination and Toxicology, 77, 155-161. <https://doi.org/10.1007/s00244-019-00630-z>.
- [5] HONIKEL, K. O. (2008). The use and control of nitrate and nitrite for the processing of meat products. Meat Science, 78, 1-2, 68-76. <https://doi.org/10.1016/j.meatsci.2007.05.030>.
- [6] SINDELAR, J. J. & MILKOWSKI, A. L. (2011). Sodium nitrite in processed meat and poultry meats: a review of curing and examining the risk/benefit of its use. American Meat Science Association White Paper Series, 3, 1-14. <http://www.meatscience.org/SodiumNitriteReview.aspx>.
- [7] MAINIER, F. B., BARROS, E. F., MAINIER, R. J. and TORRES, L. (2022). Sodium nitrite as corrosion inhibitor for carbon steel in simulated oilfield produced water system, Current Topics in Electrochemistry, Vol. 24, 51–56. http://www.researchtrends.net/tia/title_issue.asp?id=19&in=0&vn=24&type=3.
- [8] LANDES, D. S. (2003). The unbound Prometheus: technological change and industrial development in Western Europe from 1750 to the present. Cambridge: Cambridge University Press, 590.
- [9] REED, P. (2008). Acid towers and the control of chemical pollution 1823–1876. Transactions of the Newcomen Society, 78 (1), 99-126. <https://doi.org/10.1179/175035208X258310>.
- [10] LEFOND, S. J. (2012). Handbook of world salt resources. Springer Science & Business Media.
- [11] HUSSAIN, S. A., FENG-QING, H., YUNQI, M., KHAN, H., JIAN, Y., HUSSAIN, G. & WIDORY, D. (2021). An overview of Pakistan rock salt resources and their chemical characterization. Pakistan Journal of Scientific & Industrial Research Series A: Physical Sciences, 64 (2), 137-148.
- [12] LOGANATHAN, P., NAIDU, G. & VIGNESWARAN, S. (2017). Mining valuable minerals from seawater: a critical review. Environmental Science: Water Research & Technology, 3 (1), 37-53. <https://doi.org/10.1039/c6ew00268d>.
- [13] SUMADA, K. & DEWATI, R. (2018). Improvement of seawater salt quality by hydro-extraction and re-crystallization methods. In Journal of Physics: Conference Series (Vol. 953, No. 1, p. 012214). IOP Publishing. <https://doi.org/10.1088/1742-6596/953/1/012214>.
- [14] HIGNETT, T. P. (Ed.). (2013). Fertilizer manual (Vol. 15). Springer Science & Business Media.

- [15] PATEL, H. J. (2023). Handbook for Chemical Process Industries. CRC Press.
- [16] GARRETT, D. E. (2012). Potash: deposits, processing, properties and uses. Springer Science & Business Media.
- [17] MCEACHERN, R., WIST, W. & LEHR, J. H. (2009). Water softening with potassium chloride: process, health, and environmental benefits. John Wiley & Sons.
- [18] STRINGER, R. & JOHNSTON, P. (2001). Chlorine and the environment: an overview of the chlorine industry. Kluwer Academic Publishers, Dordrecht, Netherlands.
- [19] ACID HYDROCHLORIC (2001). Chemicals Economics Handbook. SRI international, 733-4000.
- [20] YUE, Z., XIAOQU, Q., YUNJU, G. & YUHUI, W. (2014). Synthetic hydrochloric acid production and energy consumption process monitoring system. In: 2014 IEEE Workshop on Advanced Research and Technology in Industry Applications (WARTIA), 472-475). IEEE.
- [21] SYALOM, M. N., DANUWIJAYA, F. A., RUSULLY, L. M. I. & ARADHEA, M. A. T. (2024). Maximizing chlorobenzene product yield by modifying the benzene chlorination process. Journal of Chemical Engineering Research Progress, 1 (1), 1-10. <https://doi.org/10.9767/jcerp.20097>.
- [22] MORRISON, R. D. & MURPHY, B. L. (2015). Chlorinated Solvents: A Forensic Evaluation. Royal Society of Chemistry, Cambridge, United Kingdom.
- [23] RAMAMOORTHY, S. & RAMAMOORTHY, S. (1997). Chlorinated organic compounds in the environment: regulatory and monitoring assessment. CRC press.
- [24] DAI, C., ZHOU, Y., PENG, H., HUANG, S., QIN, P., Zhang, J., ... & ZHANG, X. (2018). Current progress in remediation of chlorinated volatile organic compounds: A review. Journal of Industrial and Engineering Chemistry, 62, 106-119. <https://doi.org/10.1016/j.jiec.2017.12.049>.
- [25] MEISSNER, E. & MILCHERT, E. (2003). Kinetics of tetrachloromethane fluorination by hydrogen fluoride in the presence of antimony pentachloride. Journal of Fluorine Chemistry, 119(1), 89-95. [https://doi.org/10.1016/S0022-1139\(02\)00241-5](https://doi.org/10.1016/S0022-1139(02)00241-5).
- [26] WATER, H. C (2019). MATERIAL SAFETY DATA SHEET (MSDS) Hydrochloric acid. Itthad Chemicals Limited.
- [27] MUSTAFA, A., MISAILIDIS, N. & PETRIDES, D. (2020). Production of monosodium glutamate (MSG) modeling and evaluation with SuperPro Designer®. Intelligen, Inc.
- [28] SÁNCHEZ, A. P. (2021). Evaluación técnico-económica del proceso de producción de glutamato monosódico por la ruta fermentativa utilizando bagazo de caña de azúcar. Revista EIA, 18(36), 36014. <https://doi.org/10.24050/reia.v18i36.1489>.
- [29] WONG, D. W. (2018). Mechanism and theory in food chemistry, Second Edition, Springer International, <https://doi.org/10.1007/978-3-319-50766-8>.
- [30] WALKER, R. & LUPIEN, J. R. (2000). The safety evaluation of monosodium glutamate. The Journal of Nutrition, 130 (4), 1049S-1052S. <https://doi.org/10.1093/jn/130.4.1049S>.

- [31] ROGERS, M. D. (2016). Monosodium glutamate is not likely to be genotoxic. Food and chemical toxicology, 94, 260-261. <https://doi.org/10.1016/j.fct.2016.05.001>.
- [32] ECONOMIDES, M. J. & NOLTE, K. G. (1989). Reservoir stimulation. Third Edition, Prentice Hall. Englewood Cliffs, NJ, USA:
- [33] FINK, J. K. (2003). Oil field chemicals. Massachusetts, USA: Gulf Professional Publishing.
- [34] MAINIER, F. B., DE FREITAS, A. E. R. & GONÇALVES, M. V. S. (2020). Corrosion inhibition effect of thiourea on mild steel in hydrochloric acid contaminated with chlorine. International Journal of Advances in Engineering & Technology, 13 (3), 72-79.
- [35] MAINIER, F. B., FREITAS, A. E. R., FIGUEIREDO, A. A. M., & TEOBALDO SILVA, T. (2016). Reduction of the protective action of corrosion inhibitors for carbon steel in acidification by using hydrochloric acid contaminated with chlorine. Journal of Materials Science and Engineering A, 6 (9-10), 260-269. <https://doi.org/10.17265/2161-6213/2016.9-10.004>.
- [36] NANI, B. F. (2016). Comportamento do inibidor de corrosão álcool propargílico em solução de ácido clorídrico contendo íon férrico. Mestrado em Engenharia Química, Universidade Federal Fluminense. (In Portuguese).
- [37] YU, Q., JIANG, X., ZHOU, L., LIAO, Y., DUAN, M., WANG, H. & PU, Q. (2014). Synthesis and anticorrosion for X70 steel of propynol derivatives in acid medium. Journal of Materials and Environmental Science, 5, 13-32.
- [38] PATI, B. B., CHATTERJEE, P., SINGH, T. B. & SINGH, D. D. N. (1990). Effect of propargyl alcohol on corrosion and hydrogenation of steel in hydrochloric acid solution. Corrosion, 46 (5), 354-359. <https://doi.org/10.5006/1.3585116>.
- [39] JAYAPERUMAL, D. J. M. C. (2010). Effects of alcohol-based inhibitors on corrosion of mild steel in hydrochloric acid. Materials Chemistry and Physics, 119 (3), 478-484. <https://doi.org/10.1016/j.matchemphys.2009.09.028>.
- [40] FENG, Y., SIOW, K. S., TEO, W. K. & HSIEH, A. K. (1999). The synergistic effects of propargyl alcohol and potassium iodide on the inhibition of mild steel in 0.5 M sulfuric acid solution. Corrosion Science, 41 (5), 829-852. [https://doi.org/10.1016/S0010-938X\(98\)00144-9](https://doi.org/10.1016/S0010-938X(98)00144-9).
- [41] AVDEEV, Y. G., ANFILOV, K. L. & KUZNETSOV, Y. I. (2022). Some aspects of the mechanism of steel protection in hydrochloric acid solutions by propargyl alcohol. International Journal of Corrosion and Scale Inhibition, 11 (2), 577-593.

Endophytic bacteria in the biological control of *Spodoptera frugiperda*

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ABSTRACT

The objective of this study was to evaluate the pathogenicity of bacteria isolated from neem, *Azadirachta indica*, on adults of *Spodoptera frugiperda*. All bacterial suspensions evaluated were calibrated to a concentration of 5.0×10^8 cells/mL. The adults evaluated were the survivors of caterpillars that ingested corn leaves treated with bacterial suspensions. With these surviving adults, couples were formed, which were kept in cages. The longevity of males and females, the pre-oviposition and fertile period, the total number of eggs, fecundity and fertility of females were evaluated. Of the total isolates evaluated, 64.0% of them caused some adverse effect to adults, to the point of affecting one or more of the variables evaluated. The ingestion of the bacteria by the caterpillars reduced the longevity of adults, both male and female. Females had a reduction in the fertile period, in the number of layings, in fecundity and in fertility. Only the pre-oviposition period was not affected. The isolates *Bacillus* sp. Epi 9, *Bacillus subtilis* and Neem 10 stand out because they affect the largest number of variables evaluated. The results obtained in this study are promising and important, as this is the first report of bacteria isolated from neem with pathogenic action to *S. frugiperda*.

Keywords: *Azadirachta indica*, Biological control, Fall armyworm.

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INTRODUCTION

Plant species are symbiotically associated with an extensive and diverse community of microorganisms, including bacteria and fungi (HARDOIM et al., 2015; VERMA et al., 2009). These endophytic microorganisms do not cause disease symptoms in their hosts, but live symbiotically with the plant (WILSON, 1995).

One of the most studied plant species in terms of its microbiota is *Azadirachta indica*, neem, due to its importance as a medicinal plant, since it is used by about 80.0% of developing nations (EID et al., 2017; CHUTULO & CHALANNAVAR, 2018), in addition to its importance as an insecticidal plant (VERMA et al., 2011). All parts of this plant have already been evaluated for use in insect control and all of them have been shown to be harmful to pests. It has already been verified that neem has an anti-feeding effect on insects, repelling oviposition and inhibiting other biological and physiological activities of these organisms. In addition to these interferences, neem can reduce the growth of insects, inhibit ecdysis and reproduction, and cause their death (ROEL, 2010; COSTA et al., 2004). Azadirachtin, the main compound present in neem, affects exoskeleton shedding and insect growth, as it resembles the ecdysis hormone for this reason (ANURADHA et al., 2007; MARTINEZ, 2011).

In *A. indica*, in addition to the secondary metabolites, fungi and bacteria symbiotically associated with this plant have been isolated, characterized and identified (VERMA et al., 2007; VERMA et al., 2009; VERMA et al., 2011; CARDOSO, 2012; KUSARI et al., 2012; SINGH et al., 2017; D'LUIS et al., 2017). These endophytic microorganisms are responsible for the partial or complete biosynthesis of the secondary metabolites of their host plants (RAJAGOPAL et al., 2012; LUDWIG-MÜLLER, 2015). An example of this fact was found with the endophytic fungus, *Eupenicillium parvum*, which was isolated from the neem plant. According to the authors, the substances azadirachtin A and B were identified in the filtrate of its artificial growth medium (KUSARI et al., 2012). The fungus *Nigrospora* sp., also endophytic of neem, produced in its growth medium solanapyrones N, O and C, substances analogous to those produced in the plant (WU et al., 2009).

Among the groups of microorganisms most cited in the literature and that have already been isolated from the neem plant are fungi (VERMA et al., 2007; VERMA et al., 2011), actinomycetes (VERMA et al., 2009; VERMA et al., 2011) and bacteria (D'LUIS et al., 2017).

Cardoso (2012) isolated 33 bacteria associated with the neem plant, among them 16 have already been identified, *Bacillus pumilus* (7), *Bacillus methylotrophicus* (1), *Bacillus licheniformis* (2), *Bacillus subtilis* (2) and *Bacillus amyloliquefaciens* (1), in addition to two others belonging to the genus *Bacillus* sp. and one to the genus *Methylobacterium* sp. This author found that some of these isolates have potential for the production of indole-3-acetic acid (IAA). Soares (2013)

evaluated the 33 isolates of Cardoso (2012) for pathogenicity and virulence of *S. frugiperda* larvae. The author found that when 10-day-old caterpillars ingested corn leaves treated with bacterial suspensions, it caused an increase in the duration and mortality of the larval and pupal stages, a reduction in the weight of male and female pupae, and an increase in adult deformation, which reduced the number of viable adults in the population.

The results obtained by Soares (2013) demonstrate the great potential of these bacteria isolated from *A. indica* for the control of *S. frugiperda*. This author proved the pathogenic action of these microorganisms on the survival and development of fall armyworm, which enabled the selection of those bacteria that are more virulent to *S. frugiperda*. These more virulent bacteria reduced the number of viable *S. frugiperda* adults that would be incorporated into the population. Despite the recognized importance of the results obtained by this author, he did not evaluate the performance of the surviving adults. In the present study, these adults were evaluated, since it is postulated that the ingestion of bacterial isolates by caterpillars negatively affects the fecundity and fertility of adults. Thus, based on the results obtained by Soares (2013), this study aimed to evaluate the fecundity and fertility of adults of *S. frugiperda* after the caterpillars ingested corn leaves treated with bacteria isolated from *A. indica*.

MATERIAL AND METHODS

The experiment was carried out in laboratories, under controlled conditions (temp.: $25\pm 2^{\circ}\text{C}$, U.R.: $60\pm 10\%$ and photophase: 12 h), using newly hatched caterpillars of *Spodoptera frugiperda* taken from the stock rear, where they were fed an artificial diet (GREENE *et al.*, 1976). Adults were fed 10.0% honey solution.

The bacterial isolates evaluated were: Epi 1, Epi 7 (*Bacillus pumilus* - E value of 0.0, identity of 99.0% and number of access to Genbank - KR010188.1), Epi 9 (*Bacillus* sp. - E value of $3.e-50$, identity of 95.0%, Genbank access number - KM678261.1), Epi 12, Epi 13 (*Bacillus* sp. - E value of $3.e-55$, identity of 97.0%, Genbank access number - JN700129.1), Nim 5 (*Bacillus methylotrophicus* - E value of 0.0, identity of 99.0%, Genbank access number - KM659219.1), Neem 8 (*Bacillus subtilis* - E value of 0.0, identity of 98.0%, Genbank access number - KF818630.1), Neem 10, Neem 12, Neem 14 and Neem 15 (*Bacillus pumilus* - And value of 0.0, identity of 99.0%, Genbank access number - KR010188.1). These isolates were obtained from the Bacteriotecca of the Phytopathology Laboratory of UNIMONTES, Janaúba Campus, MG, where they are stored in sterile mineral water and kept under controlled conditions (temp.: $25\pm 2^{\circ}\text{C}$, U.R.: $60\pm 10\%$ and photophase: 14 h). These bacteria were isolated from the surface (epiphytic - Epi) and from the fermented extract (Neem) of *Azadirachta indica* leaves (CARDOSO, 2012).

CULTIVATION OF MAIZE PLANTS

Creole maize seeds, susceptible to *S. frugiperda*, were sown in plastic pots (3.0 dm³). The plants were kept under screened conditions. During the cultivation period, the plants did not receive any phytosanitary treatment for pest control. Leaves from the plant cartridge region, 15 days after germination, were used to feed newly hatched caterpillars of *S. frugiperda*, in order to carry out the assay with the adult insects of the pest.

MULTIPLICATION OF BACTERIAL ISOLATES

For the multiplication of bacterial isolates, TSA (Tryptic Soy Agar) solid culture medium (40 g in 1,000 mL distilled water) was used. The medium was sterilized in an autoclave, set to 120°C/1.0 atm, for 20 minutes. The bacterial isolates were multiplied in Petri dishes (90 mm x 15 mm) from the transfer of an aliquot (1.0 mL) obtained from the storage suspension. The isolates were incubated at room temperature for 24 hours.

To obtain the bacterial suspension, 5.0 mL of sterile saline solution (0.85% NaCl) was added to the incubated bacterial colonies. The bacterial cells were disaggregated using a sterile microscope glass slide and then transferred to test tubes (2.5 cm x 15 cm) for homogenization in a vortex apparatus. In a spectrophotometer set to 540 nm optical density, the absorbance of the bacterial suspensions of each of the isolates was adjusted so that the concentration reached 5.0×10^8 cells/mL. The absorbance adjustments were based on the growth curves of these bacterial isolates established by Silva (2014). Sterile NaCl (0.85%) was added to adjust the concentration of bacterial suspensions.

OBTAINING PUPAE OF *SPODOPTERA FRUGIPERDA*

Leaves removed from the central region of the corn plant cartridge were cut into fragments (5.0 cm x 5.0 cm) that were immersed for 20 seconds in the bacterial suspensions. This procedure was performed in a laminar flow chamber. As a control of the experiment, the fragments were immersed in sterile distilled water. The treated and untreated fragments were placed on filter paper to cause excess moisture loss.

In transparent plastic containers (250 mL), containing a thin layer of sterilized agar-agar medium, five fragments of treated or untreated corn leaves were distributed, depending on the treatment or control to be evaluated. Agar-agar was used to prevent the corn leaves from curling and also to maintain their turgidity. For each treatment (isolates and control), three of these containers were prepared. In each of the containers, approximately 200 newly hatched caterpillars of *S. frugiperda* were transferred over the corn leaves, which were closed with the lids. The caterpillars were left feeding on these leaves for three days, when the food was replaced by untreated ones. The

larvae remained feeding on the untreated leaves for another five days, when they were individualized in glass tubes with flat bottoms (2.5 cm x), also containing a thin 8,5 cm agar-water layer at the bottom and a fragment of inserted corn leaf, as previously described. In the tubes, the caterpillars were fed until pupation. Food exchange at this stage of the experiment was performed whenever necessary. The control caterpillars were reared on untreated corn during the entire larval period.

The pupae obtained were removed from the tubes, cleaned and sexed, as described by Butt and Cantu (1962). After sexing the pupae, the males and females were individualized in new glass tubes, where they remained until emergence.

EVALUATION OF *SURVIVING SPODOPTERA FRUGIPERDA* ADULTS

The emerged adults, males and females, up to two days of age and without deformations were used in the formation of *S. frugiperda* pairs. The couples were transferred, individualized, to a cage consisting of a PVC tube (7.0 cm in diameter x 10 cm in height), with the inner wall covered with sulfite paper, which served as a substrate for laying. The lower end of the cage was closed with a Petri dish (80 mm x 80 mm) and the upper end with a thin Voil-type fabric. The adults were fed in the cages with a 10.0% honey solution, which was changed every two days. The insects were kept in these conditions until death.

On a daily basis, during the oviposition period of the females, the eggs of *S. frugiperda* were removed from the cages, accounted for and placed on transparent acrylic plates (50 mm x 50 mm) lined with filter paper moistened with distilled water, aiming at hatching. The plates were kept in the laboratory under controlled conditions (temp.: $25\pm 2^{\circ}\text{C}$, RH: $60\pm 10\%$ and photophase: 12 h).

The longevity of males and females, the pre-oviposition and fertile period of females, the total number of lays, the total number of eggs per female (fecundity) and the viability of the eggs (fertility) were evaluated. The longevity of males and females corresponded to the time elapsed between emergence and death of the insect. The fertile period of the females corresponded to the time elapsed between the first and the last day of oviposition. The pre-oviposition period corresponded to the time elapsed between the emergence of the female until the day she started oviposition.

The experimental design was completely randomized and consisted of eleven treatments (corn leaves treated with bacterial isolates) and one control (untreated corn leaves). Each treatment consisted of 15 replicates (cages), each containing a pair of *S. frugiperda*.

Tests of homogeneity of variances and normality of errors were performed and, as the variables evaluated did not fit these requirements, the results were submitted to the Kruskal-Wallis analysis and the means were compared by the Bonferroni test, at 5% probability. The statistical program used in all analyses was Statisticx, version 9.0.

RESULTS

The ingestion of *corn leaves immersed in the suspensions of bacteria isolated from the neem plant, A. indica*, by the caterpillars of *S. frugiperda*, affected all the variables evaluated, except for the pre-oviposition period of the females of this insect (Table 1).

For longevity, a reduction in the life span of females was observed after the caterpillars of *S. frugiperda* ingested leaves containing the isolates Epi 9 and Neem 8, which caused them to live 5.0 days less than those of the control ($X^2 = 88.1989$; $P < 0.00001$) (Table 1). The caterpillars that ingested the other isolates resulted in females that were as long-lived as those of the control. Males also had their longevity reduced ($X^2 = 68.2614$; $P < 0.00001$). This reduction occurred after the caterpillars ingested the isolates Epi 7, Epi 9, Epi 13, Neem 8 and Neem 12, which made them live around 3.0 days less than those of the control. For the other treatments, the males were as long-lived as the control ones.

The pre-oviposition period of *S. frugiperda females* was not altered by the ingestion of bacterial isolates by the caterpillars, which were similar to the control ($X^2 = 13.9380$; $P = 0.2364$) (Table 1). However, the fertile period of females was reduced by the ingestion of bacteria by the caterpillars ($X^2 = 38.3200$; $P < 0.0001$). This occurred when the caterpillars ingested the isolates Epi 9, Epi 12, Neem 8 and Neem 10. There was a reduction of up to 4.0 days when they ingested the Epi 9 treatment. In the other treatments, the fertile period of the females was similar to that observed for the control.

The number of eggs laid by females was reduced after ingestion by the caterpillars of isolates Epi 9 and Neem 10 ($X^2 = 27.0767$; $P < 0.0045$) (Table 1). The females of these treatments performed a maximum of up to 3.1 postures. In the other treatments, the number of eggs per female was similar to the control group.

The fecundity of females was reduced after the larvae ingested the isolates Epi 9, Neem 8, Neem 10 and Neem 12 ($X^2 = 40.6837$; $P < 0.00001$) (Table 1). The number of eggs laid by these females ranged from 230 to 370. In the other treatments, the females laid an average number of eggs similar to the control. Fertility was also reduced by the ingestion of Epi 9 and Neem 12 isolates ($X^2 = 87.8114$; $P < 0.00001$). The viability of the eggs of these females ranged from 32.6% to 46.6%. For the other females evaluated, egg viability was similar to the control control.

Table 1. Longevity of male and female (days), pre-oviposition and fertile periods of females (days), number of eggs, fecundity (number) and fertility (%) of *Spodoptera frugiperda*, from caterpillars fed corn leaves treated with suspension of bacteria isolated from *Azadirachta indica*.

Isolated	Longevity*		Period*		No. of postures*	Fertility*	Fertility*
	Female	Male	Pre-oviposition	Fertile			
Control	13,8 ± 0,5** bc	12,3 ± 0,4 bc	4,0 ± 0,3 a	6,3 ± 0,3 c	7,1 ± 0,4 b	884,8 ± 76,3 c	96,9 ± 2,2 bc
Epi 1	16,3 ± 0,6 c	12,3 ± 0,8 bc	3,5 ± 0,3 a	5,5 ± 0,7 bc	6,3 ± 1,0 ab	750,6 ± 118,3 bc	100,0 ± 0,0 c
Epi 7	11,9 ± 1,3 ab	9,3 ± 0,7 a	3,8 ± 0,4 a	4,5 ± 0,8 abc	4,7 ± 0,5 ab	434,0 ± 52,6 abc	62,4 ± 9,4 ab
Epi 9	8,5 ± 0,5 a	9,5 ± 0,7 a	4,7 ± 0,9 a	1,8 ± 0,5 a	2,7 ± 0,8 a	230,7 ± 78,2 a	46,6 ± 15,7 a
Epi 12	15,3 ± 0,8 bc	12,9 ± 0,7 c	5,4 ± 0,6 a	3,1 ± 0,6 ab	4,0 ± 0,8 ab	413,9 ± 77,7 abc	84,6 ± 10,4 bc
Epi 13	11,7 ± 0,5 ab	9,3 ± 0,5 a	3,6 ± 0,2 a	4,0 ± 0,6 abc	4,3 ± 0,7 ab	536,1 ± 98,3 abc	100,0 ± 0,0 c
Nim 5	13,6 ± 0,5 bc	10,3 ± 0,4 abc	3,5 ± 0,2 a	4,8 ± 0,6 abc	5,3 ± 0,7 ab	659,9 ± 114,6 abc	96,6 ± 1,7 bc
Nim 8	8,5 ± 0,5 a	9,3 ± 0,5 a	3,6 ± 0,2 a	3,2 ± 0,5 ab	5,1 ± 0,8 ab	370,7 ± 60,3 ab	60,7 ± 11,2 ab
Nim 10	12,5 ± 0,8 abc	12,5 ± 0,5 c	4,4 ± 0,6 a	2,9 ± 0,8 ab	3,1 ± 0,9 a	307,6 ± 91,4 ab	100,0 ± 0,0 c
Nim 12	11,3 ± 0,8 ab	9,5 ± 0,6 a	5,9 ± 0,9 a	3,9 ± 0,9 abc	4,3 ± 0,8 ab	308,2 ± 58,2 ab	32,6 ± 11,3 a
Nim 14	13,7 ± 0,8 bc	10,5 ± 0,5 abc	4,0 ± 0,2 a	4,8 ± 0,7 abc	5,3 ± 0,9 ab	746,9 ± 133,6 abc	97,7 ± 1,2 bc
Nim 15	16,9 ± 0,7 c	13,1 ± 0,5 c	4,1 ± 0,3 a	3,7 ± 0,8 abc	4,0 ± 0,8 ab	472,6 ± 113,0 abc	100,0 ± 0,0 c
X ²	88,20	68,26	13,94	38,32	27,08	40,68	87,81

* Means followed by the same letter in the columns do not differ significantly from each other, according to the Kruskal-Wallis test, at 5% probability.

DISCUSSION

In this study, 64.0% of the bacteria isolated from the neem plant caused some harmful effect to the adults of *Spodoptera frugiperda*, to the point of affecting one or more of the variables evaluated (Table 1). The bacteria Epi 7 (*Bacillus pumilus*), Epi 9 (*Bacillus* sp.), Epi 12 (unidentified), Epi 13 (*Bacillus* sp.), Neem 8 (*Bacillus subtilis*), Neem 10 (unidentified) and Neem 12 (unidentified) were entomopathogenic to adults. These isolates differed in terms of their virulence to adults of *S. frugiperda*. The isolates Epi 1, Neem 5, Neem 14 and Neem 15 were not pathogenic to adults, since they did not cause any change in the variables evaluated.

Gram-positive bacteria of the genus *Bacillus* have several mechanisms to infect and kill insects. Several species of this genus are entomopathogenic to several orders of insects and, for this reason, used for pest control (RAJASHEKHAR et al., 2017).

The longevity of males and females of *S. frugiperda* was reduced by the ingestion of entomopathogenic bacteria to adults (Table 1). Two of the isolates evaluated, Epi 9 and Neem 8, were effective in causing this reduction in both females and males. On the other hand, the isolates Epi 7, Epi 13 and Neem 12 only reduced the longevity of the males. Of these three isolates, Epi 7 and Epi

13, affected only males. The same was not found for the Neem 12 isolate, which also affected females, as it reduced their fecundity and fertility. None of the isolates affected the pre-oviposition period of the females.

Among the 11 isolates evaluated on adults of *S. frugiperda*, Epi 9 stood out from the others, because in addition to reducing longevity (females and males), it also affected the fertile period, the number of eggs, fertility and fecundity of females. This bacterium reduced the life span of females by 38.0%, the fertile period by 71.0%, the number of eggs by 62.5%, and its females were 74.0% less fertile and 51.0% less fertile.

Several hypotheses may explain this type of action observed for the Epi 9 isolate. The pathogenicity of this bacterium may be linked to the intracellular presence of a protein crystal such as that found in the bacterium *Bacillus thuringiensis*, but the genus *Bacillus* can produce a wide range of active substances (BRAVO et al., 2007; CRICKMORE et al., 2008; GUTIÉRREZ-MANERO et al., 2001).

At first, it can be suggested that the Epi 9 bacterium was able to produce active crystals containing both the Cry and Cyt proteins. It has been proven in several studies that the Cry and Cyt proteins synergistically occur, which causes greater toxicity of the bacterium to the hosts (BRAVO et al., 2007; CRIALESILEGOR et al., 2014; ÖSKAN et al., 2003; VILAS-BÔAS et al., 2012; RIBEIRO et al., 2017).

The proteins Cry and Cyt are synthesized in the form of protoxins. Thus, its action depends on activation processes, which occur inside the digestive tract of the insect (ANGELO et al., 2010). It has been shown that the Cyt protein can increase the toxicity of the Cry protein that functions as a receptor molecule (CRICKMORE et al., 1995; PÉREZ et al., 2005; PONCET et al., 1995). Thus, the higher efficiency of the Epi 9 isolate is probably linked to the production of these two proteins acting synergistically, i.e., Cry as a toxin and Cyt as its receptor. Thus, the synergism between Cry and Cyt may have caused damage to the digestive system of *S. frugiperda caterpillars* and, concomitantly, a reduction in the variables evaluated, due to an anti-feeding effect, for example, as a consequence, malnutrition in the insects. The lack of nutrients or even the low amount assimilated by the caterpillars may have affected the maturation of the ovaries of the females and the number of ovarioles present, which caused a reduction in the fecundity and fertility of the females (CHAPMAN, 2013).

Bacillus sp. (Epi 9) showed promise for use in integrated management programs of *S. frugiperda*. This is an important fact, because in Brazil most of the products sold are based on the bacterium *B. thuringiensis* (Bt) and for the domestic market this technology is imported, which results in an increase in the final price of this product to the consumer and, consequently, a decrease in the competitiveness of these biological products in relation to synthetic insecticides (ANGELO et



al., 2010). Another important fact to be highlighted is that, in the world, *B. thuringiensis* is the only microbial insecticide with widespread use, and there are already several cases of insect species that have developed resistance to the toxin produced by this bacterium. This is one of the reasons why research has been carried out to evaluate other species of bacteria (BERGAMASCO et al., 2013; RAJASHEKHAR et al., 2017). The information obtained for the Epi 9 isolate sets precedents for the realization of new experiments, now carried out in the field, aiming to study and prove the efficiency of this entomopathogen under Brazilian crop conditions.

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REFERENCES


1. Angelo, E. A., Vilas-Bôas, G. T., Castro-Gómez, R. J. H. (2010). *Bacillus thuringiensis*: características gerais e fermentação. *Semina: Ciências Agrárias*, 31(4), 945-958.
2. Anuradha, A., Annadurai, R. S., Shashidhara, L. S. (2007). Actincytoskeleton as a putative target of the neem limonoid azadirachtin A. *Insect biochemistry and molecular biology*, 37(6), 627-634.
3. Bergamasco, V. B., Mendes, D. R. P., Fernandes, O. A., Desidério, J. A., Lemos, M. V. F. (2013). *Bacillus thuringiensis* Cry1Ia10 and Vip3Aa protein interactions and their toxicity in *Spodoptera* spp. (Lepidoptera). *Journal of invertebrate pathology*, 112(2), 152-158.
4. Bravo, A., Gill, S. S., Soberon, M. (2007). Mode of action of *Bacillus thuringiensis* Cry and Cyt toxins and their potential for insect control. *Toxicon*, 49(4), 423-435.
5. Butt, B. (1962). Sex determination of lepidopterous pupae. USDA, Agricultural Research Service Report, 33(75), 1-7.
6. Cardoso, A. M. S. (2012). Caracterização fisiológica de isolados bacterianos obtidos de *Azadirachta indica* e de bananeira 'Prata-anã'. Monografia (Graduação em Agronomia) – Universidade Estadual de Montes Claros, Janaúba.
7. Chutulo, E.C., Chalannavar, R.K. (2018). Endophytic mycoflora and their bioactive compounds from *Azadirachta Indica*: A comprehensive review. *Journal of Fungi*, 4(42), 1-12.
8. Costa, E. L. N., Silva, R. F. P. da, Fiuza, L. M. (2004). Efeitos, aplicações e limitações de extratos de plantas inseticidas. *Acta Biologica Leopoldensia*, 26(2), 173-185.
9. Crickmore, N., Bone, E. J., Williams, J. A., Ellar, D. J. (1995). Contribution of the individual components of the δ -endotoxin crystal to the mosquitocidal activity of *Bacillus thuringiensis* subsp. *israelensis*. *FEMS Microbiology Letters*, 131(3), 249-254.
10. D'Luis, R. L., Chamorro, A. L., Pérez, C. A. (2017). Diversidad de bacterias endófitas aisladas de árbol de neem y su actividad inhibitoria contra el *Colletotrichum gloeosporioides* causante de la antracnosis del ñame en el departamento de Sucre. *Revista Colombiana de Ciência Animal-RECIA*, 9, 48-54.
11. Eid, A., Jaradat, N., Elmarzugi, N. (2017). A Review of chemical constituents and traditional usage of Neem plant (*Azadirachta Indica*). *Palestinian Medical and Pharmaceutical Journal (PMPJ)*, 2(2), 75-81.
12. Greene, G.L., Lepla, N.C., Dickerson, W.A. (1976). Velvetbean caterpillar: a rearing procedure and artificial medium. *Journal of Economic Entomology*, 69(4), 488-497.
13. Hardoim, P. R., Overbeek, L. S. V., Berg, G., Pirttilä, A. M., Compant, S., Campisano, A., Döring, M., Sessitsch, A. (2015). The hidden world within plants: Ecological and evolutionary considerations for defining functioning of microbial endophytes. *Microbiology and Molecular Biology Reviews*, 79, 293-320.
14. Kusari, S., Hertweck, C., Spiteller, M. (2012). An endophytic fungus from *Azadirachta indica* A. Juss. that produces azadirachtin. *World journal of microbiology and biotechnology*, 28(3), 1287-1294.

15. Ludwig-Müller, J. (2015). Plants and endophytes: Equal partners in secondary metabolite production?. *Biotechnology letters*, 37, 1325-1334.
16. Martinez, S. S. (2011). *O nim - Azadirachta indica - um inseticida natural*. Londrina: IAPAR. 2^o Ed., 205 p.
17. Öskan, M., et al. (2003). Nutritional and cultural parameters influencing antidipteran delta-endotoxin production. *Research in Microbiology*, 154(1), 49-53.
18. Pérez, C., Fernandez, L. E., Sun, J., Folch, J. L., Gill, S. S., Soberón, M., & Bravo, A. (2005). *Bacillus thuringiensis* subsp. *israelensis* Cyt1Aa synergizes Cry11Aa toxin by functioning as a membrane-bound receptor. *Proceedings of the National Academy of Sciences*, 102(51), 18303-18308.
19. Poncet, S., Delécluse, A., Klier, A., Rapoport, G. (1995). Evaluation of synergistic interactions among the CryIVA, CryIVB, and CryIVD toxic components of *B. thuringiensis* subsp. *israelensis* crystals. *Journal of Invertebrate Pathology*, 66(2), 131-135.
20. Rajagopal, K., Maheswari, S., Kathiravan, G. (2012). Diversity of endophytic fungi in some tropical medicinal plants - A report. *African Journal of Microbiology Research*, 6, 2822-2827.
21. Rajashekhar, M., Shahanaz, E., Vinay, K. (2017). Biochemical and molecular characterization of *Bacillus* spp. isolated from insects. *Journal of Entomology and Zoology Studies*, 5(5), 581-588.
22. Ribeiro, B. M., Martins, É. S., De Souza Aguiar, R. W., Corrêa, R. F. T. (2017). Expression of *Bacillus thuringiensis* toxins in insect cells. In: *Bacillus thuringiensis and Lysinibacillus sphaericus*. Springer, Cham, 99-110.
23. Roel, A. R., Dourado, D. M., Matias, R., Porto, K. R., Bednaski, A. V., Costa, R. B. D. (2010). The effect of sub-lethal doses of *Azadirachta indica* (Meliaceae) oil on the midgut of *Spodoptera frugiperda* (Lepidoptera, Noctuidae). *Revista Brasileira de Entomologia*, 54(3), 505-510.
24. Silva, H. D. (2014). Virulência de bactérias associadas a *Azadirachta indica* sobre *Spodoptera frugiperda*. Dissertação (Mestrado em Produção Vegetal no Semiárido) - Universidade Estadual de Montes Claros, Janaúba, MG, 73 p.
25. Singh, A. K., Sharma, R. K., Sharma, V., Singh, T., Kumar, R., Kumari, D. (2017). Isolation, morphological identification and in vitro antibacterial activity of endophytic bacteria isolated from *Azadirachta indica* (neem) leaves. *Veterinary world*, 10(5), 510-516.
26. Soares, E. P. S. (2013). Patogenicidade de bactérias isoladas de nim à *Spodoptera frugiperda* (J. E. Smith). Dissertação (Mestrado em Produção Vegetal no Semiárido) - Universidade Estadual de Montes Claros, Janaúba, MG, 82 p.
27. Verma, V. C., Gond, S. K., Kumar, A., Kharwar, R. N., Strobel, G. (2007). The endophytic mycoflora of bark, leaf, and stem tissues of *Azadirachta indica* A. Juss. (Neem) from Varanasi (India). *Microbial Ecology*, 54(1), 119-125.
28. Verma, V. C., Gond, S. K., Kumar, A., Mishra, A., Kharwar, R. N., Gange, A. C. (2009). Endophytic actinomycetes from *Azadirachta indica* A. Juss.: isolation, diversity, and anti-microbial activity. *Microbial Ecology*, 57(4), 749-756.



29. Verma, V. C., Gond, S. K., Kumar, A., Kharwar, R. N., Boulanger, L. A., Strobel, G. A. (2011). Endophytic fungal flora from roots and fruits of an Indian neem plant *Azadirachta indica* A. Juss., and impact of culture media on their isolation. *Indian Journal of Microbiology*, 51(4), 469-476.
30. Vilas-Bôas, G. T., Alvarez, R. C., dos Santos, C. A., Vilas-Boas, L. A., et al. (2012). Fatores de virulência de *Bacillus thuringiensis*: o que existe além das proteínas Cry. *EntomoBrasilis*, 5(1), 1-10.
31. Wilson, D. (1995). Endophyte: The evolution of a term, and clarification of its use and definition. *Oikos*, 73, 274-276.
32. Wu, S. H., Chen Y. W., Shao, S. C., Wang, L. D., Yu, Y., Li, Z. Y., Yang, L. Y., Li, S. L., Huang, R. (2009). Two new solanapyrone analogues from the endophytic fungus *Nigrospora* sp. YB-141 of *Azadirachta indica*. *Chemistry & Biodiversity*, 6(1), 79-85.

Hydrogen production: The future pillar of energy sector

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ABSTRACT

This chapter comprehensively explores Hydrogen Production Technologies, recognizing them as a set of key techniques that play a crucial role in the generation of the fundamental energy vector for the future of the energy sector. The growing importance of these technologies is evident, especially in the face of the imperative need to meet the climate goals set out in the Paris Agreement. In this context, the study presents a detailed classification of Hydrogen Production Methods, taking into account three fundamental parameters: the Primary Energy Source used, the Physical/Chemical Process employed and the Substrate consumed in the process. This approach revealed the existence of eleven distinct production methods, all of which were grouped and identified through a "Hydrogen Rainbow". In each of the colors of this rainbow, we explore the main aspects of relevance, deepening knowledge in this area.

Keywords: Hydrogen Production, Hydrogen Rainbow, Green Hydrogen.

INTRODUCTION

Since the Second Industrial Revolution, dating from the second half of the nineteenth century and characterized by the technological advents of Steam Engines and Internal Combustion Engines (ICMs), both consumers of fossil fuels for the execution of tasks that enabled the evolution of society, the significant increase in Greenhouse Gas (GHG) emissions into the atmosphere has been notorious.

In this context, GHGs are gases such as carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O), which absorb infrared radiation emitted by the Earth's surface and radiate it, keeping the atmosphere warm. It is worth mentioning that the Greenhouse Effect is a natural phenomenon and essential for the development and maintenance of life on planet Earth.

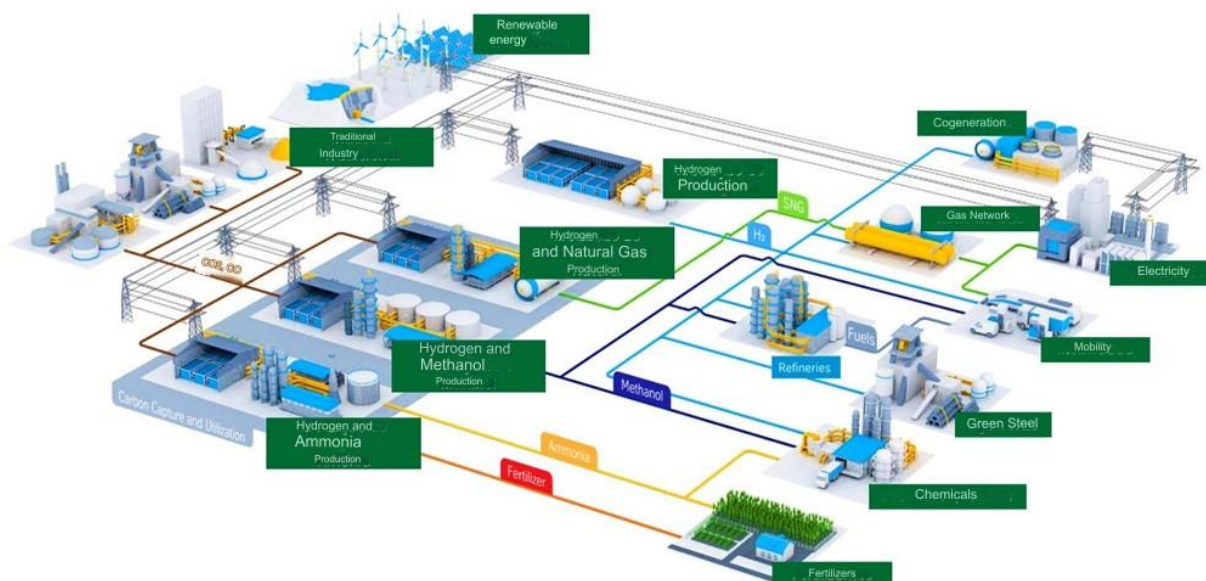
However, the use of fossil fuels, as well as other anthropological factors, such as deforestation and cattle ranching, have increased the atmospheric concentration of GHGs. In the pre-industrial era, CO₂ had an average concentration of 280 parts per million (ppm) (ARTAXO, 2014), rising to 410 ppm according to the Sixth Report of the Intergovernmental *Panel on Climate Change (IPCC)* (GULEV et al., 2021), which also mentions average concentrations of 1866 parts per billion (ppb) of CH₄ and 332 ppb of N₂O. indicators that confirm, unequivocally, the influence of human activities on the planet's climatic conditions.

Since the 1970s, several climate conferences of global importance have been held periodically, with emphasis on the Paris Agreement in 2015, which established an approach to climate action, based on clear targets for reducing GHG emissions profiles for each country, with the aim of halting global warming at a maximum limit of 2 °C above pre-industrial levels. in addition to committing efforts to limit it to 1.5°C, considering that this would have a significant effect on reducing the risks and impacts of climate change.

Thus, Hydrogen emerges as an alternative to fossil fuels, since, in its molecular form (H₂), it is a colorless and odorless gas, with a density of 0.08987 kg.m⁻³ at 0 °C and 1 bar, and an upper (PCS) and lower calorific value (PCI) of 141,880.0 kJ.kg⁻¹ and 119,960 kJ.kg⁻¹.

The low density combined with the high energy content give Hydrogen a wide range of applications still little explored in the global economy, such as: Agriculture, with the production of fertilizers from Ammonia; Chemical Industry, with direct use, such as processes with hydrogenation and combined with the production of methanol for application in fuels and steel; Urban Mobility, with direct supply in Fuel Cell Electric Vehicles (FCEVs) and with the production of synthetic fuels, such as Aviation Kerosene (QAV); Reelectrification, with the use of gas turbines and fuel cells. The list of applications of Hydrogen is illustrated in Figure 1.

Figure 1 – Hydrogen Value Chain and its Applications in the Economy



Source: Adapted from Thyssenkrupp (2023).

In view of this, it can be said that Hydrogen has uses similar to oil and its derivatives, and can therefore act as an energy vector in the context of a decarbonized global economy, especially with the drop in the Levelized *Cost of Energy* (LCOE) of Renewable Energy sources, which can compete, in terms of cost, with fossil fuels. but they still need more efficient forms of storage and distribution, finding in Hydrogen a promising solution for consolidation as the main energy alternative.

However, despite being very abundant, since it makes up 75% by mass and 90% in number of moles of the universe, most of the Hydrogen is only found in other compounds, such as water (H₂O). Therefore, Hydrogen is not considered an energy source. Therefore, in order to enable the use of Hydrogen by society, it is necessary to understand the set of techniques, devices and knowledge that enable its use as a vector of the Global Energy Transition, comprising the entire technological chain, that is, Production, Storage, Distribution and End Use. Thus, in this chapter, the various methods of Hydrogen production will be addressed in the subsequent sections, highlighting the technology involved in each method, its levels of application and Greenhouse Gas emissions.

HYDROGEN PRODUCTION CHAIN



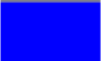







Currently, there is a great diversity of ways to produce hydrogen gas, due to the diversity of compounds that contain hydrogen atoms, as well as the various primary energy sources that can be used to extract these atoms and synthesize H₂. This wide variety of technological routes in the production chain will be explored in this section, in which the main Hydrogen Production Methods will be discussed. In an initial analysis, it is important to emphasize that a "Hydrogen Production Method" is made up of five main aspects, namely:

- a) **Primary energy source consumed:** It may or may not be renewable in nature, in addition to different profiles of CO₂ emissions and other GHGs;
- b) **Chemical/Physical Process employed:** It can range from traditional methods, such as Steam Reforming, to highly innovative approaches, such as Bioelectrohydrogenesis;
- c) **Substrate:** It can range from long-chain compounds, such as oils or hydrocarbons, to diatomic compounds such as water (H₂O), in which the main function is to provide protons for the formation of H₂;
- d) **Emissions:** It can vary in high, low, zero and even negative levels, that is, when a production method acts as a carbon sink;
- e) **Co-products:** It can include common substances, such as oxygen gas, as well as complex and even dangerous compounds, such as nuclear waste.

Thus, in order to facilitate the understanding of the different Hydrogen Production Methods, the scientific community has developed a nomenclature associating each method with a color, resulting in the popularly known "Hydrogen Rainbow". It is important to note that, due to the level of innovation of many of the techniques used in hydrogen production, there is still no universal consensus on the colors associated with each method, varying according to the author and/or locality.

In this context, Table 1 presents eleven distinct methods of the "Hydrogen Rainbow", each associated with a color and detailed as to the five main aspects involved. This information was compiled from data from the Energy Research Company (EPE) and recent scientific articles, in addition to the CO₂ emission profile associated with each method.

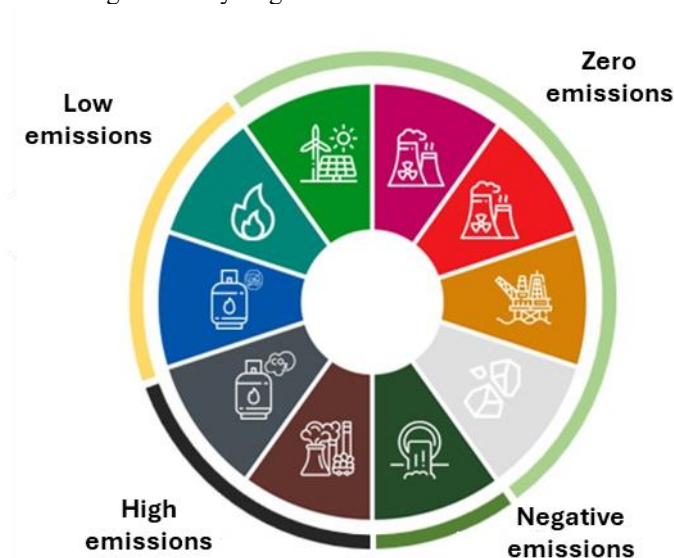
Table 1 – Hydrogen Production Methods: Main Aspects

Cor	Energia Primária	Processo	Substrato	Emissões	Coprodutos
	Térmica (Com emissões)	Gaseificação	Carvão Mineral	Alto	CO, Alcatrão, Amônia e etc
	Gás Natural sem CCUS	Reforma a Vapor	Gás Natural	Alto	CO, CO ₂
	Gás Natural com CCUS	Reforma a Vapor	Gás Natural	Baixo	CO, CO ₂
	Térmica (Sem emissões)	Pirólise	Gás Natural	Baixo	Negro de fumo
	Energias Renováveis	Eletrólise	Água Ultrapura	Nulo	Gás Oxigênio
	Energia Nuclear - Elétrica	Eletrólise	Água Ultrapura	Nulo	Gás Oxigênio
	Energia Nuclear - Térmica	Separação Catalítica	Água ou Metano	Nulo	Rejeitos nucleares
	Não há (Espontâneo)	Mecanismo Biológico	Hydrocarbonetos	Nulo	Não há
	Não há (Natural)	Craqueamento Hidráulico	Água Pressurizada	Nulo	Não há
	Energia da Biomassa	Mecanismo Biológico	Matéria Orgânica	Negativo	CO ₂ e Biofilme

Source: Prepared by the author.

There are several technical, economic, social and environmental criteria that must be evaluated in each Hydrogen Production Method, such as Acquisition Costs (CAPEX), Operation and Maintenance (O&M) costs, among others. This variety of points of analysis enhances Hydrogen Technologies beyond purely technical-scientific factors, elevating the discussion to the real application. In this context, Figure 2 divides the Hydrogen Rainbow in relation to the Emissions Profile, in which it is possible to observe the predominance of scientific development in production methods with a zero/negative net emissions profile, such as Green Hydrogen and Moss Hydrogen.

Figure 2 – Hydrogen Rainbow: Emission Profiles



Source: Prepared by the author.

GASIFICATION

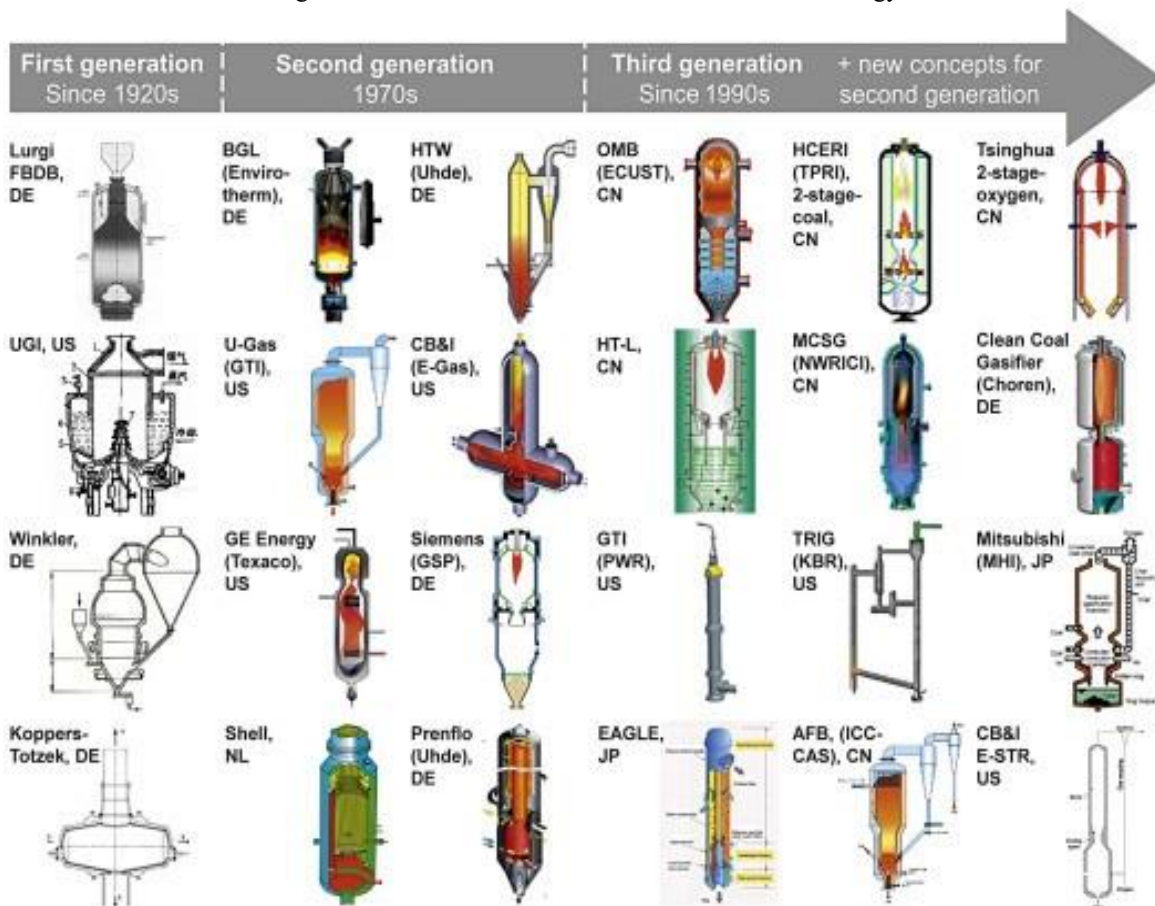
Analyzing Table 1, it is first observed the Brown Hydrogen, which is obtained from Gasification, that is, a thermochemical process created in the nineteenth century, which involves the thermal decomposition of coal in an environment with absent or controlled oxygen, using Thermal Energy from sources with a high level of CO₂ emissions for the formation of the syngas. In this context, gasification reactors are a consolidated technology, subdivided into several types, as illustrated in Figure 3.

The term syngas refers to the mixture between Carbon Monoxide (CO), Carbon Dioxide (CO₂) and Hydrogen (H₂), that is, Hydrogen was produced with high direct emissions from the substrate gasification process (mineral coal) and indirect emissions in the generation of energy used in the process. It is worth mentioning that, for some authors and organizations, there is a subdivision between Brown Hydrogen and Black Hydrogen, in which coal and anthracite are used as substrates, respectively.

In summary, Brown Hydrogen is an extremely polluting option, with an estimated emission profile between 18 and 20 kgCO₂eq (Kilogram of CO₂ equivalent) per kilogram of Hydrogen produced, but, due to the low associated costs and technological maturity, 20% of all Hydrogen produced on the planet in 2020 used this method.

(International Renewable Energy Agency, 2022)

Figure 3 – Gasification Reactors: Evolution of Technology



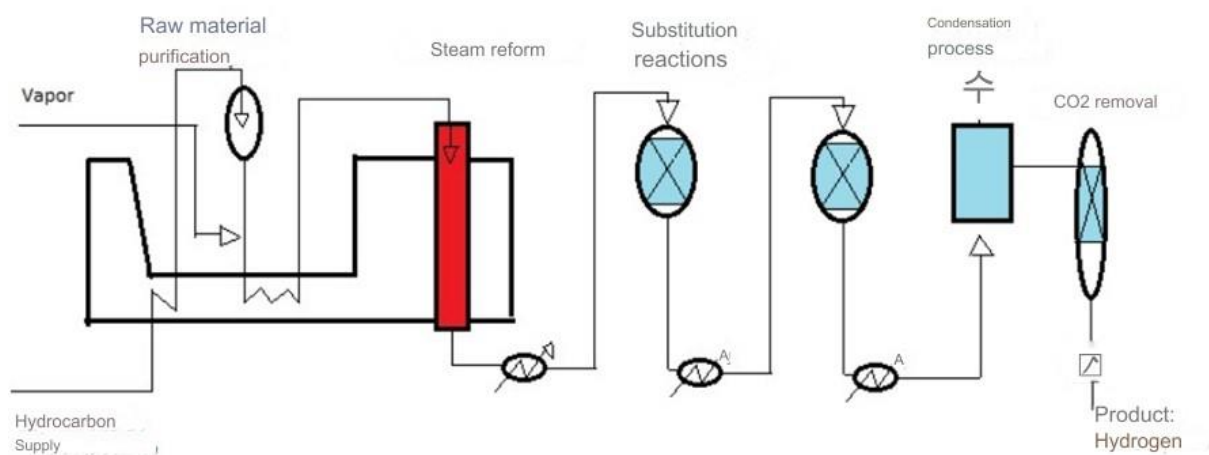
Source: Adapted from Wolfersdorf and Meyer (2017).

STEAM REFURBISHMENT

According to Table 1, both Grey Hydrogen and Blue Hydrogen are obtained through Natural Gas Steam Reforming, a technique used to convert hydrocarbons into syngas. This technique involves heating hydrocarbons, such as natural gas, in an environment with superheated water vapor, which causes the hydrocarbon bonds to break into smaller compounds, including hydrogen gas. It is important to highlight that Steam Reforming is a catalytic process that uses Natural Gas not only as a substrate, but also as a primary energy source for heating the water and the reactor. In other words, during the process, Natural Gas is used both as a raw material for the production of syngas and as a source of energy to promote the necessary chemical reactions.

Thus, both Steam Reforming and Gasification are thermochemical processes that involve chemical reactions for the production of syngas. However, the conversion techniques are distinct: Steam Reforming uses hydrocarbons as a feedstock, while Gasification uses biomass, coal or waste as feedstock. Figure 4 illustrates the Steam Reforming process for the production of Hydrogen. In view of this, the proximity of the Gray and Blue Hydrogen Production Methods is notorious, employing the same chemical/physical process (Steam Reforming) and the same substrate (Natural Gas), but the difference between the two methodologies consists in the Primary Energy Source.

Figure 4 – Steam Reforming: Flow Diagram of the process applied to Hydrogen production



Source: Ribeiro (2011).

In the case of Grey Hydrogen, Natural Gas without Carbon Capture, Utilization and Storage (CCUS) is used, that is, the GHGs resulting from the process are released into the atmosphere, resulting in a high emissions profile for Grey Hydrogen, estimated between 9 and 11 kgCO₂eq per kilogram of Hydrogen produced. (International Renewable Energy Agency, 2022)

In Blue Hydrogen, Natural Gas with CCUS is used, that is, the GHGs resulting from the process are captured, compressed and stored in underground geological locations, such as depleted oil or gas reservoirs, which makes it a cleaner option compared to Gray Hydrogen, however, a relevant emissions profile is still observed, estimated between 4 and 5 kgCO₂eq per kilogram of hydrogen produced. (International Renewable Energy Agency, 2022). It is worth mentioning that, according to data from the International Energy Agency (IEA), in 2019 the world production of Grey Hydrogen was about 71 million tons (Mt), which represents about 76% of the total world production of hydrogen that year. (International Energy Agency, 2021)

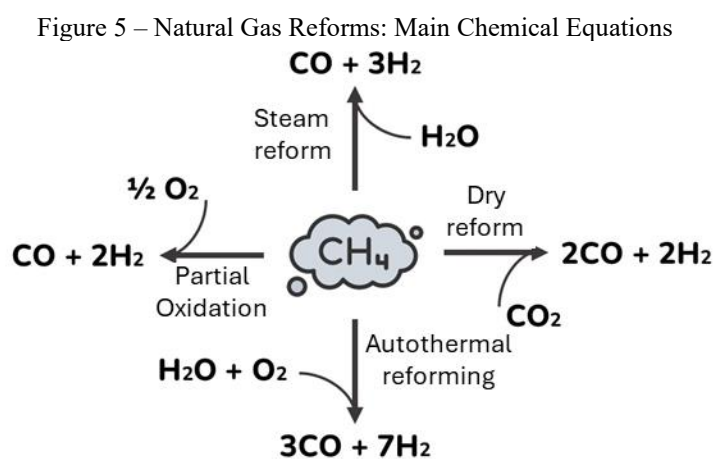
In addition, it is important to highlight the existence of other chemical processes for the production of Hydrogen from Hydrocarbons, as well as Steam Reforming, namely: Partial Oxidation, Autothermal Reforming, and Dry Reforming, both are reactions with specific industrial characteristics and applications.

PARTIAL OXIDATION, AUTOETHERMAL REFORMING AND DRY REFORMING

In Partial Oxidation, hydrocarbon (Natural Gas) is mixed with oxygen in a controlled combustion environment rather than superheated water vapor. The reaction produces the syngas, containing a mixture of hydrogen and carbon monoxide (CO). Again, hydrogen can be purified and CO can be converted into CO₂ through the *water-gas shift reaction*, which is most commonly used in petrochemical processes and ammonia production.

Autothermal Reforming, on the other hand, combines the Steam Reforming and Partial Oxidation reactions in a single reactor, using a mixture of water vapor and oxygen. This process is called "autothermal" because it does not require an external source of heat, since Partial Oxidation generates enough heat to promote steam reforming, combining the benefits of Steam Forming and Partial Oxidation, and ideal for applications that require high energy efficiency, such as in the synthesis of complex hydrocarbons.

There is also the Dry Reform, in which the hydrocarbon (Natural Gas) is mixed with CO₂ at high temperatures, without the presence of water, producing the syngas mainly in situations with limited water availability or in remote and isolated locations. In this aspect, it is important to highlight that each hydrocarbon-to-hydrogen conversion reaction has advantages and disadvantages and the choice of technique used depends on specific characteristics in each application. Figure 5 summarizes the chemical equation of each reaction.



Source: Prepared by the author.

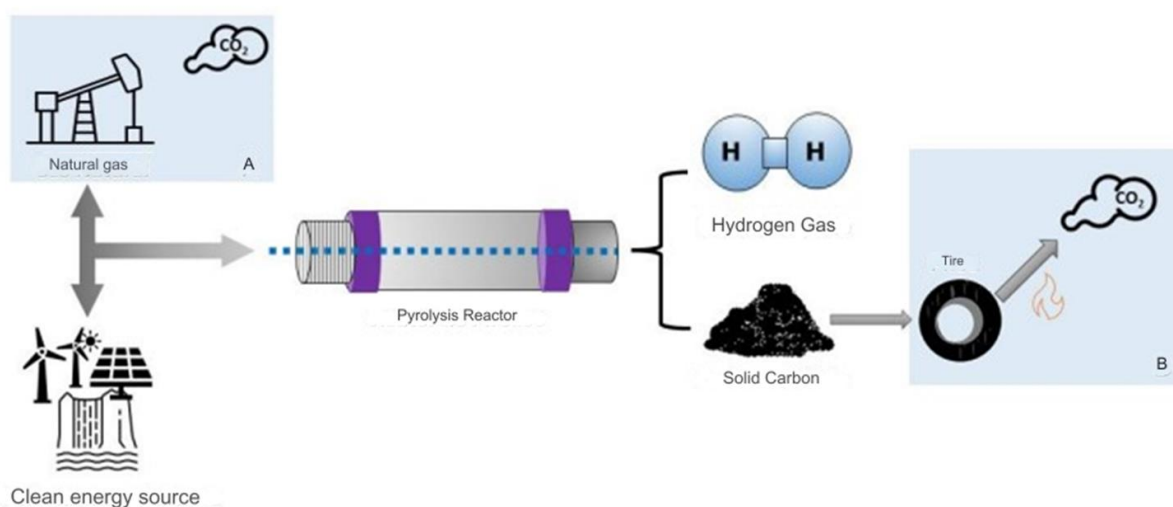
HYDROCARBON PYROLYSIS

In the above-mentioned chemical processes, i.e., Gasification and Hydrocarbon Reforming, the production of Hydrogen occurs together with the syngas. In view of this, in the context of the Energy Transition and, consequently, the search for alternative energy vectors to fossil fuels, Hydrogen can only be considered a viable option when it combines low production costs and low GHG emission profiles.

However, despite the low cost, the production of Hydrogen associated with syngas necessarily implies high emissions of CO₂ and CO, which can be mitigated with CCUS, as is the case with Blue Hydrogen. Despite this possibility, CCUS techniques represent additional energy consumption, can have environmental impacts, and only partially eliminate greenhouse gas emissions. Therefore, the Hydrocarbon Pyrolysis process is a good alternative for the production of CO₂-free Hydrogen, since the by-product of this technique is carbon (solid). In the rainbow illustrated in Table 1, Turquoise Hydrogen uses Pyrolysis applied to Natural Gas, which can also be obtained by biological processes (biomethane).

In this context, the thermal decomposition of methane, into carbon and hydrogen, occurs through pyrolysis at elevated temperatures (1,000 °C to 2,000 °C), resulting in a considerable energy deficit. To meet this consumption, in the case of Turquoise Hydrogen, it is essential to use an emission-free primary energy source. Analyzing the chemical equation of Turquoise Hydrogen, for each kilogram of methane, 250 grams of hydrogen and 750 grams of solid carbon, also known as carbon black, are produced, which has a high added value due to its industrial applications. Figure 6 illustrates the Turquoise Hydrogen Production Method.

Figure 6 – Turquoise Hydrogen: Process and Emissions in the Production Chain



Source: Energy Research Company (2022).

Finally, it should be noted that the Natural Gas Pyrolysis processes can be carried out in different ways, namely: Thermal Decomposition; Catalytic Decomposition and Plasma. The technological development of these techniques is of great relevance for the establishment of Turquoise Hydrogen as a technically, economically and environmentally viable route, since the development of Methane Pyrolysis reactors is recent and does not yet have extensive commercial application, with few tests on a pilot scale.

WATER ELECTROLYSIS

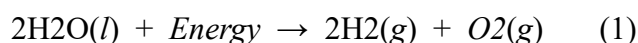
In the previous sections, the chemical/physical processes involved in the production of Brown, Gray, Blue and Turquoise Hydrogens were described, in which fossil fuels are used as substrates for the supply of hydrogen elements for the composition of the gas. In these processes, Natural Gas, consisting mainly of CH₄, is used as a substrate, that is, a chemical compound responsible for the donation of Hydrogen atoms to the composition of H₂. In view of this, the chemical reactions involved in these techniques generally result in GHG emissions, thus not obtaining a significant environmental advantage from the use of Hydrogen compared to the direct use of fossil fuels as an energy vector.

In this context, it is important to remember that Hydrogen makes up 90% of the atoms in the Universe, making up the vast majority of chemical substances, far beyond the Hydrocarbons used in the previous sections, water (H₂O) aggregates the largest share of Hydrogen on the planet. In addition, the breakdown of the water molecule for the generation of hydrogen gas does not release GHGs, thus having the main environmental contribution of Hydrogen as an energy vector. The process commonly related to the breakdown of the water molecule is Electrolysis.

Table 1 shows the Green and Pink Hydrogen effected by Electrolysis, both with a zero emission profile. The prominence of Green Hydrogen is notorious, especially after the Paris Agreement and the Russia-Ukraine conflict, which put European energy security at risk and boosted investments in Green Hydrogen in places with great potential for the production of Renewable Energy. However, there is little visibility for Pink Hydrogen, which also has a zero emissions profile, this is mainly due to the use of a primary source of nuclear energy, which, despite not emitting GHGs, has environmental problems related to the use of radioactive materials.

Electrolysis is a chemical process of oxidation reduction that occurs when an electric current is passed through a solution, where electrolytes are ionized. This physicochemical phenomenon is not spontaneous and requires energy to happen. During the electrolysis of water, the passage of electric current in the inert electrodes of the cathode and anode results in obtaining the gaseous compounds Hydrogen and Oxygen from the molecular compounds of the solution. The term "electrolysis" comes from the Greek "elektron," which means "electricity," and "lysis," which means "breakdown." (FELTRE, 2004)

Thus, the global reaction of the Water Electrolysis process can be described according to Equation 1.



The reduction and oxidation semi-reactions occurring at the cathode and anode, respectively, are determined by the electrolytes present in the aqueous solution and this can result in different types of Water Electrolysis, namely: Alkaline, Proton Exchange Membrane or Anions and Solid Oxide.

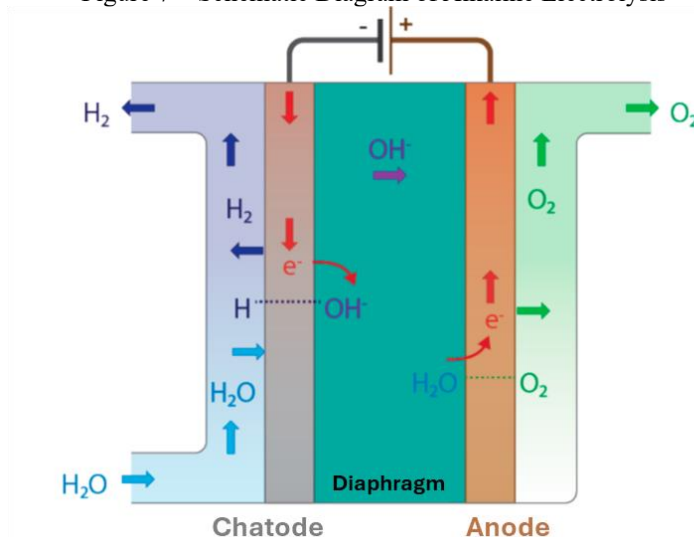
ALKALINE ELECTROLYSIS

Since the discovery of the phenomenon of electrolysis by Troostwijk and Diemann in 1789, Alkaline Electrolysis technology has evolved significantly into large-scale hydrogen production, reaching *megawatt ranges*, and has become the most widespread commercial electrolytic technology worldwide. Alkaline electrolysis uses two electrodes, commonly metallic, immersed in a basic liquid solution of potassium hydroxide (KOH) with a concentration between 20 and 30%. A diaphragm separates the two electrodes and keeps the product gases separate to ensure efficiency and safety.

Thus, the anodic and cathodic semireactions are represented by Equations 2 and 3, and the process, which occurs in the range of 40 °C to 60 °C, is represented in Figure 7, also highlighting the materials involved in Alkaline Electrolysis.



Figure 7 – Schematic Diagram of Alkaline Electrolysis



Source: Adapted from Gallandat, Romanowicz e Zuttel (2017).

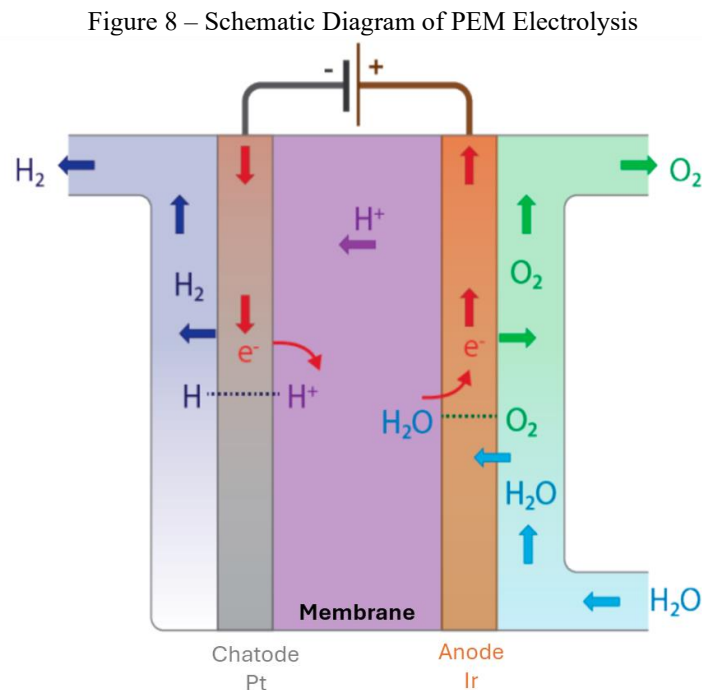
Alkaline Electrolysis Cell (AEC), despite having reached a high level of development and applicability, still face some problems that make their large-scale application in the market unfeasible. Among these problems, the low partial charge range stands out, resulting from the cross-diffusion of the gases produced through the diaphragm, which reduces the efficiency of the

electrolyzer by allowing the diffusion of oxygen at the cathode and hydrogen at the anode; the limitation of current density, due to high ohmic losses through the liquid electrolyte and diaphragm; and low operating pressure, which results from the inability to operate at high pressures with the liquid electrolyte.

PROTON EXCHANGE MEMBRANE ELECTROLYSIS

The scenario of overcoming the disadvantages of alkaline electrolyzers changed when General Electric, in the 1960s, developed the first water electrolyzer based on a solid polymer electrolyte concept. This concept introduced the proton exchange membrane or polymer electrolyte membrane (PEM), composed of a solid sulfonated polystyrene membrane that provides high proton conductivity, small gas cross-diffusion, compact system design, and high-pressure operation (CARMO et al., 2013).

Thus, the anodic and cathodic semireactions are represented by Equations 4 and 5, and the process, which occurs in the range of 20 °C to 100 °C, is represented in Figure 8, also highlighting the materials involved in PEM Electrolysis.

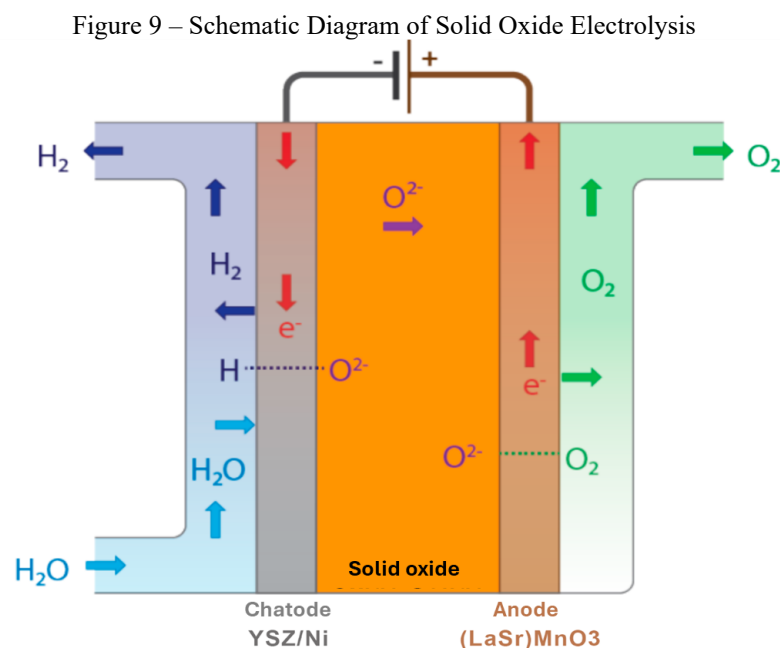


Source: Adapted from Gallandat, Romanowicz e Zuttel (2017).

The main obstacle of the PEM Electrolysis technology is the high cost of the components used, especially the platinum cathode and the material that composes the membrane, based on Perfluorosulfonic Acid Polymer. Despite this, the marketing context of PEMEC (*Proton-Exchange Membrane Electrolysis Cell*) electrolyzers has been gaining a lot of notoriety in international scientific development forums. With a large financial contribution, this technology is expected to predominate in the electrolyzer market in the coming years. Some companies are already planning to launch commercial solutions in the 100 MW range for hydrogen production in 2023.

SOLID OXIDE ELECTROLYSIS

Solid Oxide Electrolysis is still in the pre-commercial stage, since, despite having the highest energy efficiency among electrolysis technologies, in addition to high-pressure operations, it still faces challenges such as: corrosion, sealing, thermal cycling and chromium migration, demanding the use of higher cost materials, making it impossible, for the time being, to use Solid Oxide electrolyzers on a large scale (SOEC, *Solid Oxide Electrolysis Cell*). Thus, the anodic and cathodic semireactions are represented by Equations 6 and 7, and the process is represented in Figure 9, also highlighting the materials involved in Solid Oxide Electrolysis.



The chemical process occurs with the use of water vapor at elevated temperatures, ranging between 500°C and 800°C, which differentiates this technique from the other types of electrolysis discussed and indicates that the application should be focused on large-scale projects. The electrolyte used is Tritium Oxide Stabilized Zirconia (YSZ), which has high ionic conductivity and thermochemical stability at operating temperatures. The electrodes are composed of porous ceramics, with the cathode composed of YSZ and Metallic Nickel, and the anode composed of Lanthanum Manganite doped with Strontium.

Solid oxide electrolyzers are devices that can perform both the conversion of electricity into hydrogen, and the conversion of hydrogen into electricity. This reversibility characteristic is a major advantage over other electrolysis technologies, allowing the process to be adjusted according to the demand for electrical energy or hydrogen. In addition, SOECs have high energy efficiency and can operate at elevated temperatures, which makes it possible to use various types of fuels for electricity generation, such as biogas and natural gas.

BIOLOGICAL METHODS

As well as water and natural gas (hydrocarbons), there are several other compounds with hydrogen atoms in their chemical formula, which can act as donors in H₂ production processes. Among these compounds, there is a great emphasis on Organic Matter, since its basic composition by essential molecules, namely: Carbohydrates, Lipids and Proteins, has a high number of Hydrogen atoms.

Thus, Biomass, when subjected to certain biological processes, configures the method known as Hydrogen Moss or Bio-Hydrogen, which has the great advantage of a negative net emissions profile, that is, it removes GHGs from the atmosphere during the production of Hydrogen, especially when compared to the absence of the application of these methods. In addition, it is also common to associate Bio-Hydrogen with lower energy consumption compared to other processes. In summary, there are three main bioprocesses, namely: Biophotolysis, which can be direct or indirect; Fermentation, subdivided into Photofermentation and Dark Fermentation and Microbial Electrolysis.

In Direct Biophotolysis, microalgae such as green algae (*Chlamydomonas reinhardtii*) or cyanobacteria (*Synechocystis*) convert water into hydrogen and oxygen in the presence of light during photosynthesis. Microalgae have simple nutritional requirements and are easily cultivated, they are also good fixers of CO₂. All these factors indicate that direct biophotolysis has a great potential for the production of Bio-Hydrogen. However, direct biophotolysis has several limitations, including high sensitivity to O₂, the need for light, and the production of the explosive H₂-O₂ mixture as a result of the process. (CAGALITAN; ABUNDO, 2021)

Indirect Biophotolysis differs from Direct Biophotolysis in that oxygen evolution occurs at a separate step of hydrogen production, eliminating the formation of explosive mixtures. The first step involves the photosynthesis of cyanobacteria, where CO₂ and H₂O are converted into organic substances and oxygen. Then, a light-independent reaction occurs in which the organic materials from the first step are broken down by the cyanobacteria into H₂, CO₂, and other compounds. However, hydrogen production by Indirect Biophotolysis is still quite low and this multi-step process requires a complex system that often leads to high investment and operational costs. (CAGALITAN; ABUNDO, 2021)

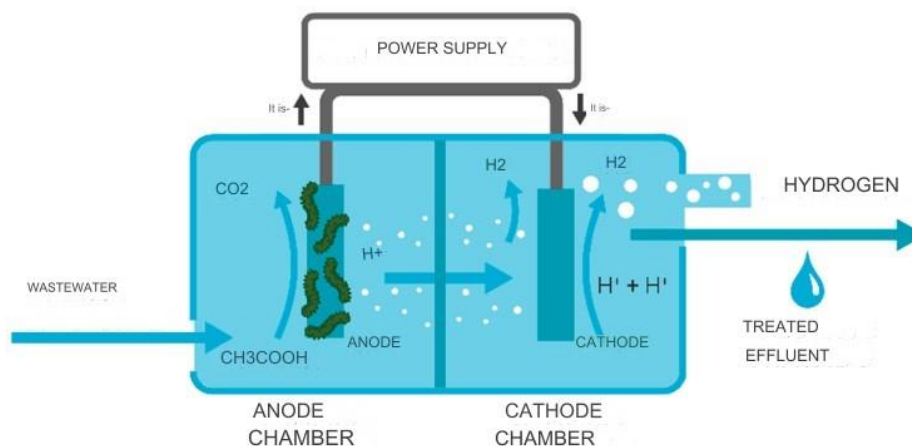
Fermentation is a biochemical process in which microorganisms produce alcohols, organic acids, hydrogen, carbon dioxide and other substances from the degradation of organic matter present in a substrate. In this sense, in Photofermentation, microorganisms use light energy to convert organic acids produced during anaerobic fermentation into H₂ and CO₂. Non-sulfur photosynthetic bacteria, such as those of the genera *Rhodobacter*, *Rhodobium* and *Rhodospseudomonas*, are examples of microorganisms capable of performing photofermentation. In Dark Fermentation, anaerobic fermenting bacteria, such as those of the genera *Clostridia*, *Escherichia*, *Citrobacter* and *Bacillus*, transform organic substrates into H₂ and CO₂ in the absence of oxygen and light. (CAGALITAN; ABUNDO, 2021)

Microbial Electrolysis is part of the field of Bioelectrochemical Technologies, that is, it uses oxidation reactions to generate high-value products, such as hydrogen. In this sense, a Microbial *Electrolysis Cell (MEC)* promotes both the production of hydrogen gas and the reduction of the organic charge of a substrate. ECMs are devices powered by the anaerobic digestion of exoelectrogenic bacteria, that is, capable of producing protons (H⁺) and electrons (e⁻) by oxidizing the organic matter present in a substrate, located in a chamber with an electrode (anode), also called an anodic chamber.

These electrons are collected by the anode and directed to another electrode (cathode), located in the cathode chamber, through an external electrical circuit. At the cathode, electrons are combined with protons in the absence of oxygen, producing hydrogen gas, this process consumes a small amount of electrical energy compared to the electrolysis of water. Figure 10 illustrates the process of Microbial Electrolysis. (LOGAN, 2008)

Although it is a promising alternative, the large-scale production of Moss Hydrogen still faces challenges, especially in relation to operating costs that are currently not competitive when compared to traditional hydrogen production routes.

Figure 10 – Schematic Diagram of Microbial Electrolysis



Source: Adapted from FUDGE et al. (2021).

However, biotechnology can be an ally to enable the processes associated with Bio-Hydrogen, regardless of the production route, some research aims to increase the yield and reduce the costs of the process, including the design of the reactors, the selection of microorganisms with greater productive capacity and the genetic and metabolic engineering to optimize the production routes of H_2 . In addition, the use of alternative substrates, such as urban, agricultural or industrial waste, can be an interesting option to reduce the operating costs of the process.

NUCLEAR CATALYTIC SEPARATION, THERMOLYSIS, PHOTOCATALYSIS, HYDRAULIC CRACKING AND OTHERS

Table 1 shows the presence of a method called Red Hydrogen, which uses the high heat from nuclear reactors for the thermal decomposition of water or methane molecules (from natural gas or biological mechanisms, such as methanogenesis). This process is called Nuclear Catalytic Separation. In this aspect, a similarity is observed with Turquoise Hydrogen, due to the thermal decomposition of molecules and the production of hydrogen without the release of GHGs, generating oxygen gas as a by-product (when using water as a substrate) or carbon black (when using methane as a substrate), as well as in the Pyrolysis of Hydrocarbons.

However, the highlight of this method is the use of Nuclear Energy, similar to Pink Hydrogen, but with greater overall efficiency of the production stations, due to the possibility of using the waste heat from the reactors. However, despite the technological maturity of all the equipment involved in this technological route, there are still no pilot, demonstrative or even laboratory-scale projects, mainly due to the prioritization of Renewable Energies for the production of Hydrogen, due to competitive costs and the possibility of accidents in nuclear fission reactors.

In addition, there are two forms of Hydrogen production with a certain degree of spontaneity, namely: Gold Hydrogen and White Hydrogen. In the case of Gold Hydrogen, there is no need to use a primary energy source, since it arises spontaneously in depleted and/or deactivated oil and natural




gas reservoirs, due to the action of anaerobic microorganisms, which produce hydrogen by digesting the remaining hydrocarbons in these places. White Hydrogen, on the other hand, is known as Natural Hydrogen, due to the fact that it does not need to employ a physical/chemical process, occurring naturally in caves submerged in deep rivers and in the soil. Recently, it has been the subject of potential surveys, verifying its existence on all continents. In Brazil, there are reserves in 6 states, namely: Ceará, Goiás, Tocantins, Roraima, Minas Gerais and Bahia, notably related to the São Francisco River Basin, due to the Hydraulic Cracking promoted by high geological pressures.

Finally, there are other chemical processes related, especially to Green Hydrogen, as alternatives to traditional Chemical Electrolysis, due to the high energy consumption, relatively low efficiency and the use of high-cost materials, thus, studies on thermal decomposition processes of the water molecule, that is, Thermolysis, and processes catalyzed by the presence of light, are highlighted. i.e. Photocatalysis. Thus, it can be said that Hydrogen Production Technologies are quite diverse, both in technological maturity and in aspects such as the emissions profile, the processes used, the substrates used, cost, scale and application possibilities.

REFERENCES

1. Artaxo, P. (2014). Uma nova era geológica em nosso planeta: o antropoceno? **Revista USP**, (103), 13–24. Disponível em: <<https://www.revistas.usp.br/revusp/article/view/99279>>.
2. Cagalitan, D. D. T. F.-D., & Abundo, M. L. S. (2021). A review of biohydrogen production technology for application towards hydrogen fuel cells. **Renewable and Sustainable Energy Reviews**, 151, 111413.
3. Carmo, M., et al. (2013). A comprehensive review on pem water electrolysis. **International Journal of Hydrogen Energy**, 38(12), 4901–4934.
4. Empresa de Pesquisa Energética. (2022). Nota Técnica - Hidrogênio Turquesa.
5. Feltre, R. (2004). **Química: Química Geral**. Moderna.
6. Fudge, T., et al. (2021). Microbial electrolysis cells for decentralised wastewater treatment: The next steps. **Water**.
7. Gallandat, N., Romanowicz, K., & Zuttel, A. (2017). An analytical model for the electrolyser performance derived from materials parameters. **Journal of Power and Energy Engineering**, 5, 34–49.
8. Gulev, S., et al. (2021). Changing state of the climate system. In **Climate Change 2021: The Physical Science Basis**.
9. International Energy Agency. (2021). **Tracking Clean Energy Progress 2021**. Disponível em: <<https://www.iea.org/reports/tracking-clean-energy-progress-2021>>.
10. International Renewable Energy Agency. (2022). **Geopolitics of the Energy Transformation: The Hydrogen Factor**. Abu Dhabi.
11. Logan, B. E. (2008). **Microbial fuel cells**. John Wiley Sons, Inc.
12. Ribeiro, C. G. (2011). Análise Técnica e Financeira da Produção de Hidrogênio com a Utilização do software HOMER. Trabalho de Conclusão de Curso, Universidade Federal do Pampa.
13. Thyssenkrupp. (2023). **thyssenkrupp expands production capacities for water electrolysis plants**. Acessado em 9 de abril de 2023, de <<https://www.thyssenkrupp-industrial-solutions.com/en/media/press-releases/thyssenkrupp-expands-production-capacities-for-water-electrolysis-plants>>.
14. Wolfersdorf, C., & Meyer, B. (2017). The current status and future prospects for igcc systems. In T. Wang & G. Stiegel (Eds.), **Integrated Gasification Combined Cycle (IGCC) Technologies**. Woodhead Publishing. Disponível em: <<https://www.sciencedirect.com/science/article/pii/B978008100167700024X>>.

Surface water quality assessment with a fuzzy inference system

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ABSTRACT

Freshwater is a water resource that has been deteriorating due to natural causes and anthropogenic activities, requiring the evaluation of water quality, comparing the values of physical, chemical and biological parameters with a Water Quality Index. In this study, the surface water quality of the Huaura River Basin (2019-2021) was evaluated, with a fuzzy inference system (FIS), based on the Environmental Quality Standards (ECA), and the categorization of water use according to the National Water Authority (ANA), category 3: Irrigation of vegetables and animal beverages. The theoretical underpinnings of the ICARHF fuzzy index were designed in four steps: define fuzzy sets and membership function; fuzzy set operations; fuzzy logic and inference rules. The Technical Reports of two surface water quality monitoring points in the Huaura River Basin (2019-2021) were analyzed. FIS logic (ICARHF) was implemented with Matlab R2022a. The fuzzy index is correlated with the Surface Water Resources Environmental Quality Index (ICARHS) ($r=0.92$), accepting that there is no statistically significant difference between the two indices. The results prove that it is possible to design a fuzzy inference system to determine surface water quality, depending on the use to which the water is intended, based on the information available from governmental and non-governmental entities, even when there is little accessible information.

Keywords: Water quality index, Fuzzy logic, Water resource.

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INTRODUCTION

Anthropogenic activities are negatively affecting water quality, considering that the term water quality is not directly related to an absolute or close to absolute degree of purity; it is closer to the concept of "natural" (Koch, Bianchi, Grutka, Martins, de Almeida, da Silva, da Rosa, & Alessi, 2023), these activities such as mining, cattle ranching, production and waste disposal, generate the presence of organic matter, through domestic wastewater discharges, agricultural runoff, industrial process effluents (Quiñones-Huatangari, Ochoa, Milla-Pino, Bazán, Gamarra, & Ráscon, 2020; Uddin, Nash, Rahman, & Olbert, 2023), and according to the report of the National Institute of Statistics and Informatics (INEI), the quality of water in Peru is being affected by the pollution of rivers, along their course, by the dumping of mining tailings, urban sewage and industrial drains (INEI, 2017), with harmful effects on health and the ecosystem, requiring water quality assessment, to maintain human health and protect the environment (Nayak, Patil & Patki, 2020), and this is determined by comparing physical, chemical and biological characteristics of a water sample with water quality guidelines or environmental quality standards (ECAs), to obtain water quality indices (AQIs) (ANA, 2018), to do this, mathematical equations are used, which qualify the body of water and provide a unique number that expresses the quality of the water (Yogendra & Puttaiah, 2008), allowing the assessment of water resource quality more easily in different locations, rather than comparing numerical values of several parameters (Nayak et al., 2020) of a water sample, the values of which will provide relevant information to promote efficient environmental management at local, regional and national levels.

The fuzzy logic approach has inherent advantages of "flexibility" and the ability to address "vagueness" and "uncertainty" more effectively. (Nayak et al., 2020), providing conditions for reasoning, inference, control, and decision-making in cases of uncertainty that allow real-world problems to be addressed (Zadeh, 1978; Sarkheil, Rahbari, & Azimi, 2021), through the inclusion of a linguistic term that is easy for the population to understand, due to its ability to reflect human thoughts and experience in ICAs, which processes non-linear, uncertain, ambiguous and subjective information (McKone and Deshpande, 2005; Oladipo, Akinwumiju, Aboyeji, & Adelodun, 2021) whose success is based on the possibility of solving complex problems, difficult to solve using traditional methods (Martínez & Andrade, 2016), and simulates the human reasoning pattern in the design of the ICA (Oladipo et al., 2021).

This article is based on the results of the doctoral thesis: Evaluation of the surface water quality of the Huaura River Basin, Huaura district, with a diffuse inference system, based on pollutants, whose objective of the study is to evaluate the surface water quality of the Huaura River Basin with a fuzzy inference system taking as a reference the water-related environmental quality

standards (ECAs-Water) and the use of to which the water of the Huaura River, in the District of Huaura, is destined.

MATERIALS AND METHODS

To meet the objective of the research, we proceeded to build an FIS, which allows to determine the quality of the water, from the observation of the facts and the generalization of rules of inference, such that it seeks to emulate the behavior of what is observed, in four steps: (1) Define the fuzzy sets and belonging function; (2) fuzzy set operations; (3) fuzzy logic; and (4) rules of inference (Uddin et al., 2021). The Technical Reports for Monitoring Surface Water Quality in the Huaura River Basin (2019-2021) were analyzed, from two monitoring points: Point 25 RHuau2: Huaura River, downstream of the CD Quipico Intake (571 meters above sea level) and Point 26 RHuau3: Huaura River, downstream of the Huaura Bridge (54 meters above sea level). The parameters were chosen according to the categorization of the National Water Authority (ANA), which establishes that the use of water from the Huaura River is classified in category 3: Irrigation of vegetables and animal beverages (MINAM., 2017), 12 parameters were considered, according to the ICARHS methodology (ANA, 2020): Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Thermotolerant Coliforms, Hydrogen Potential (pH), Arsenic (As), Cadmium (Cd), Manganese (Mn), Lead (Pb), Aluminum (Al), Iron (Fe) and Copper (Cu).

The process was carried out in two stages, in the first, it was sought to know the concentration of pollutants in the water, through the presence of parameters that exceed the values established in the RCT, the universe of discourse of each parameter was identified. The triangular membership function was selected for the normal or acceptable linguistic variable, when the RCT value of the selected parameter is unique, and trapezoidal if the RCT value is an interval; and for the linguistic variables Very Low, Low, High and Very High, measured from 0 (zero presence of contaminants), to 100 (Very high concentration), it is characterized with trapezoidal functions. The max operator that extracts the maximum degree of belonging of a parameter that exceeds the values of the ECA is used. The parameters were grouped into subsystems, respecting the characteristics and interaction in the water, the correlation of the parameters, following theoretical and statistical approaches (Uddin et al., 2021), in strict compliance with the regulations of the RCTs and the regulations in force in Peru (MINAM., 2017), with conditional inference rules IF – THEN, Mamdani type, for each subsystem.

In the second stage, the quality of the water was evaluated according to the presence of pollutant concentration, using fuzzy rules; To assess the quality of the water, the MIN operator is used, i.e. the lower the degree of contamination, the better the water quality, classified into five ranges, which are levels of sensitivity that express and qualify the state of the water quality, in:

Excellent (Very low, Low (min) or No contamination); Good (Very low (max), Low, Normal, or Acceptable (min)); Fair (Low (max), Normal or Acceptable (min)), High). Poor (Normal or Acceptable (max), High, Very high (min)) and Terrible (High (max) and Very high), with the discourse universe being from 0 to 100 (ANA, 2018, 2020). The FIS logic was built using the Fuzzy Logic Designer App, and the user interface was built using the App Designer, components of the Matlab R2022a software.

RESULTS AND DISCUSSION

For the theoretical support of the FIS, in stage 1, the fuzzy variable was identified:

values of the parameters obtained from the Water Monitoring; X :

Y : concentration of pollutants in water, generated by the presence of the substance (agent k), and the function of belonging to the substance.

$$y_k = \mu_{A_k}(x_k)$$

Where:

x_k = maximum value set in the RCT for the parameter k

A_k = fuzzy set of some parameter, as input set k

U_k = Parameter Speech Universe, $kU_k = [0, x_n]$;

When the RCT of a parameter has only one value, a triangular membership function is constructed for the linguistic variable: normal or acceptable, denoted by ; with; $kx_k \in U_k \mu_{A_k}(x_k) = 1$

When the RCT, for some parameter, has an interval, or more than one value, the trapezoidal membership function denoted by ; $k, I_k = [0, x_n] \subset U_k \mu_{A_k}(I_k) = 1$

Subsystems were generated that evaluate parameters with similar characteristics or consequences in water (), of the parameters: ; with Universe of discourse of the proportion of the pollutant generated by the presence of the parameters, of each subsystem ; $LnA_s = A_1 \cup A_2 \cup \dots \cup A_L$ $L < n$; $U_j = 1, \dots, L$ $m =$ acceptable ratio; ; , with the max operator, you get the output value for the rules for each subsystem . $U_j = [0,100]$; $m \in U_j \mu_{B_j}(m) = 1$ j

In stage 2:

Y : represents the proportion of the concentration of pollutants in the water (input), resulting from stage 1 of the subsystems. j

Z the Water Quality Index, which defines the fuzzy set (output) that represents the quality of the water, affected by the set of parameters that are part of the subsystem; with the min. C_j

Being Universe of discourse; with; Referential value where the membership function of linguistic variables is normal. $U_j = U_j = [0,100]$; $a \in U_j \mu_{C_j}(a) = 1a =$

Trapezoidal functions are considered for all linguistic variables: Excellent with an index of 95-100; Good with 80-94; Fair with 65-79; Bad at 45-64; and Abysmal 0-44 (Anna, 2020; Uddin et al., 2021).

The FIS mathematical model was then implemented through the Fuzzy Logic Designer App for the 12 selected parameters (ANA, 2018, 2020), in addition to two sub-indices: ICAMOF, Fuzzy Water Quality Index, based on parameters related to Organic Matter; ICAFQF, Fuzzy Water Quality Index and the ICARHF (Water Quality Index of the Huaura Fuzzy River).

For the ICAMOF, the subsystem 1:OD is considered with , which indicates the recovery capacity of the watercourse, and its absence causes anaerobic decomposition; COD measures the pollution of wastewater and effluents from domestic and industrial organic wastewater; BOD with , measures the amount of oxygen required by microorganisms (bacteria) to oxidize, degrade, or stabilize organic matter under aerobic conditions. Subsystem 2, with the parameter Thermotolerant coliforms, as a pollutant resulting from fecal contamination from untreated domestic discharges and animal waste that is incorporated into the receiving bodies. $U_1 = [0,130] \text{ mg } L^{-1} \text{ y } ECA = 15 \text{ mg } L^{-1}$ $U_2 = [0,250] \text{ mg } L^{-1} \text{ y } ECA = 40 \text{ mg } L^{-1}$, $U_3 = [0,10] \text{ mg } O_2 L^{-1} \text{ y } ECA > 4 \text{ ó } > 5$

For the ICAFQF, subsystem 3, which contains pH, is considered with ACE: or , which is the concentration of hydronium ions contained in a solution, if $\text{pH} < 7$ (acidic water) causes corrosivity; neutral water $\text{pH} = 7$ (ideal) and alkaline water $\text{pH} > 7$, unpleasant taste, and causes changes in the fauna and flora of water bodies $U_4 = [0,14] \text{ y } 6.5 - 8.5$ $6.4 - 8.4$ (Sierra Ramírez, 2011), sources of Mn ion contamination with ACE= and with , ACE= are produced from industrial wastewater (mining, pesticides, organic chemicals and others) and the reaction rate depends on the pH. $U_5 = [0,0.3] \text{ mg } L^{-1} \text{ y } 0.2 \text{ mg } L^{-1}$ $FeU_6 = [0,8] \text{ mg } L^{-1} 5 \text{ mg } L^{-1}$,

In subsystem4, As with 0.2 was included; with ACE= and Cd with ACE= As, a heavy, poisonous and highly toxic metal; Pb is a widely distributed element in low concentrations in sedimentary rocks and is toxic to aquatic organisms; Cd, a metal that is toxic to plants and animals, which are the product of industrial activities (mineral concentrator plants, poultry and others) and introduced into the environment through wastewater and the use of fertilizers. $U_7 = [0,0.30] \text{ mg } L^{-1} \text{ y } ECA = 0.1 \text{ ó } PbU_8 = [0,0.1] \text{ mg } L^{-1} \text{ y } 0.05$ $U_9 = [0,0.1] \text{ mg } L^{-1}$, $0.01 \text{ ó } 0.05$.

In subsystem5, Al con = and ECA= were considered to be of toxic relevance to plants (Pabón, Benítez, Sarria, & Gallo, 2020) $U_{10} [0,8] \text{ mg } L^{-1} 5 \text{ mg } L^{-1}$, and Cu, and ACE= , since at higher levels, it generates toxic effects on plant growth. $U_{11} = [0,1] \text{ mg } L^{-1} 0.2 \text{ ó } 0.05$

The Mamdani conditional inference rules IF – THEN for each subsystem have the following syntax:

R_1 If the values of (BOD) is low and the values of (COD) are low and high values of (DO), then the proportion of pollutants in the river water is low. $x_1x_2x_3$

In a similar way, the rules of inference are constructed for the 5 subsystems considered in this research.

In relation to the FIS output, 145 inference rules are constructed with the AND operator, as follows:

: If the proportion of the pollutant is very low and the proportion of is very low, and the proportion of is very low and the proportion of is very low, proportion of is very low then Water Quality Index is (excellent). $R_1y_1y_2y_3y_4y_5z_5$

To validate the FIS, the values obtained from the monitoring (Table 1) of the water quality of the Huaura River of two monitoring points were used, according to the regulations in force in Peru, are in charge of the Local Water Authorities (ALA-Huaura), these points were selected, because they are located in the jurisdiction of the district of Huaura, scope of study of the thesis, and at the same time have a greater number of selected parameter values; since it is not always possible to take all the samples, due to the fact that it is conditioned to the dry season and flood according to the characteristics of the Basin, as can be observed in the Huaura River, in the month of October 2019, samples of thermotolerant coliforms were not taken, because the flow of the river was very low, and did not comply with the water quality monitoring protocol.

Table 1. Surface water quality monitoring results of the Huaura River -CD Quipico and Puente de Huaura:2019 – 2021

Date		Physicochemical and biological parameters											
		DBO	DQO	OD	Coli	pH	Mn	Fe	Pb	As	Cd	Al	Cu
		mg O ₂	--mg L ⁻¹ --	ug L ⁻¹		-----mg L ⁻¹ -----							
03 2019	RHuau 2	2	3	7.7 2	5400	6.85	0.21	5.74	0.000	0.008	0.000 1	4.6 2	0.01
	RHuau 3	2	2	7.7 3	>40000	7.21	0.21	6.48	0	0.008	0.000 1	5.5 0	0.01
10 2019	RHuau 2	3	27	5.9 3	0*	7.85	0.06	0.47	0.002	0.005	0.000 1	0.3 0	0.02
	RHuau 3	3	32	4.9 1	0*	7.07	0.05	0.14	0.000	0.004	0.000 1	0.0 7	0.00
06 2020	RHuau 2	2	16	7.3 2	4600	8.36	0.02	0.11	0.000	0.004	0.000 1	0.1 8	0.00
	RHuau 3	9	42	8.3 9	>40000	7.76	0.02	0.19	0.002	0.003	0.000 1	0.1 2	0.00
11 2020	RHuau 2	3	2	7.6 4	490	8.31	0.02	0.35	0.001	0.004	0.000 1	0.2 9	0.00
	RHuau 3	10	37	2.2 6	40000	7.62	0.03	0.20	0.004	0.003	0.000 1	0.1 5	0.00
05 2021	RHuau 2	2	16	7.6 8	33	8.49	0.03	0.27	0.001	0.004	0.000 1	0.1 9	0.00

	RHuau 3	5	16	8.3 6	2800	7.77	0.02	0.12	0.000	0.003	0.000 1	0.0 8	0.00
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0* no sampling was performed for this parameter

The values obtained from the water quality monitoring were entered into the FIS interface, which was implemented in the Matlab software, using Mamdani-type conditional rules, and with a defuzzification method, the centroid, as a center of gravity, with triangular and trapezoidal membership functions coinciding with Quiñones-Huatangari et al. (2020) while Nayak et al. (2020) He believes that the defuzzification method of the bisector works best. In this study, the fuzzy indices were obtained: ICAMOF, ICAFQF and ICARHF, all independent in the calculation, since it does not require a historical record of data, and they are obtained in real time, and in the absence of the value of a parameter in the monitoring, the logic of the system assumes that the parameter is in the permissible range. which can be seen as an advantage, as it does not prevent the index from being obtained, however it could influence the final result.

For validation purposes of the fuzzy index, the result of the FIS is compared with the values obtained by the ICARHS index (ANA, 2020) whose methodology requires knowing the values of the total parameters to be evaluated (F1-Scope), amount of data that do not comply with the regulations requiring historical data, at least information from 4 monitorings (F2-Frequency), total surpluses that indicate the deviation of the data (monitoring results) from the standard (F3-Amplitude), to obtain Subindex 1 and Subscript 2, being the ICARHS, The lower value of both, i.e. the index depends on the values of the sub-indices and in the absence of either of the values, the calculation of the index is difficult.

In both methodologies, it is rated on a scale of 00-100, establishing five ranges: 95-100 Excellent (E); 80-94 Good (B); 65-79 Regular (R); 45-64 Bad (M); 0-44, lousy (P) (Table 2)

Table 2. ICARHS Vs ICARHF Index Values in CD Quipico and Puente de Huaura: 2019 – 2021.

Water Quality Monitoring	ICARHS [†]				ICARHF [‡]			
		S1	S2	Decision	ICAMOF	ICAFQF	Index	Decision
CD Quipico	2019	42.66 (P)	74 (R)	Lousy	32.74 (P)	81.25(B)	48.27	Lousy
	2020	99.2 (E)	81 (R)	Regular	83.28 (B)	88.76(B)	83.65	Well
	2021	89.4 (B)	99(E)	Well	96.37(E)	88.76(B)	88.76	Excellent
Huaura Bridge	2019	42.46 (P)	99 (E)	Lousy	32.74 (P)	70.24(R)	42.45	Lousy
	2020	42.44 (P)	99(E)	Lousy	31.31 (P)	88.76(B)	46.23	Lousy-Bad
	2021	42.68 (P)	99 (E)	Lousy	32.74 (P)	88.33(B)	43.76	Abysmal

Terrible (P); Bad(M); Regular (R); Good (B); Excellent (E); Sub-Index1 (S1) Water Quality Index - Organic Matter (ICARHS); Sub-Index2 (S2): Water Quality Index -Physical and Chemical Parameters: $ICARHS = \min(S_1, S_2)$

$$\dagger CCMEWQI = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right)$$

‡ Fuzzy Inference System (FIS), proposed in this research.

For the calculation of the ICARHS for the year 2019, monitoring information corresponding to the years 2017 and 2018 was used, since it is necessary for this methodology to have all the values of the parameters to be considered for the calculation of the index.

As can be seen in Table 1 and Table 2, there is contamination due to the presence of organic matter in the water of the Huaura River, especially downstream of the Huaura River bridge, since it is an area adjacent to the capital of the district, so the ICAMOF at both monitoring points is terrible; and in relation to the presence of metals, they do not exceed the ACE, which does not considerably influence the decrease in surface water quality.

When contrasting the results obtained by both methodologies, the substantial difference is that the ICARHS needs information on the frequencies (number of data, which the RCTs do not meet, on the total amount of data), while the FIS, evaluates the results for each monitoring without the need to know the frequency, uses the information of all the parameters and presents the result in real time. However, by not considering historical data as a reference, it could give erroneous information, for such a case, personalized analysis is used for each parameter, and this allows to know the percentage of affectation to the variation of an indicator, to identify the group of substances that are affecting the natural ecosystem, postulating itself as a computational tool, which allows identifying sampling points, with little information available, and depending on the use, to which the water is to be put.

Since fuzzy logic allows evaluation of subjective information, the results must be correlated to validate the results (Vergara & Gayso, 2008), and to determine if there is a statistical difference in the results of both methodologies, Pearson's correlation coefficient is obtained and with $r=0.92$, it represents a high and positive correlation, so it is accepted that there are no significant differences between the results of the ICARHS index and the diffuse ICARHF index, agreeing with what was obtained by Oliveira et al. (2014), who found a significant correlation between the results of the fuzzy index (IQABF) and the IQAB, while $R^2 = 91\%$ Quiñones-Huatangari et al. (2020) obtains, between the fuzzy index (DQWDI) and the values of the NSF WQI index. $R^2 = 0.81$

Therefore, FIS is an effective tool to address water quality issues (Quiñones-Huatangari et al., 2020) as it gathers expert knowledge and manages uncertainties by entering a range rather than a single value (Oladipo et al., 2021), on which water quality standards are generally based, in addition to the FIS, carries out the evaluation in real time, without the need for data, which, due to the economic cost of water analysis or the geographical complexity of the area, makes it difficult to obtain the information required to evaluate the quality of surface water.



CONCLUSIONS


If it is possible to design a fuzzy inference system of surface water quality, based on the information available from governmental and non-governmental entities regarding the monitoring of certain parameters of interest according to the objective of the institution, based on fuzzy inference rules, if... So..., so it is important to identify the universe of discourse of each parameter to be evaluated, based on the current regulations, the location of the area and the categorization of the use of the river water, which is going to be analyzed, and the opinion of the experts to adequately formulate the rules of inference and simulate their interaction, based on the user's requirements, in a friendly and simple way in real-time operation.

REFERENCES

1. ANA. (2018). Metodología para la determinación del índice de calidad de agua Ica-PE, aplicado a los cuerpos de agua continentales superficiales. Perú. Retrieved from <https://hdl.handle.net/20.500.12543/2440>
2. ANA. (2020). Índice de Calidad Ambiental de los Recursos Hídricos Superficiales (ICARHS). Perú. Retrieved from <https://hdl.handle.net/20.500.12543/4479>
3. INEI. (2017). Estadísticas Ambientales. (INFORME TÉCNICO N° 12 - Diciembre 2017). Retrieved from <https://m.inei.gob.pe/biblioteca-virtual/boletines/estadisticas-ambientales/2017/1/#lista>
4. Koch, S., Bianchi, V., Grutka, S. A., Martins, C. T. A., de Almeida Alves, A. A., da Silva, J. A. G., da Rosa, J. A., & Alessi, O. (2023). Diagnosis of Water Quality in an Urban Wetland. *Revista de Gestão Social e Ambiental*, 17(2), e03225-e03225. <https://doi.org/10.24857/rgsa.v17n2-022>
5. Martínez, R. N., & Andrade, S. H. H. (2016). Integración de la lógica difusa a la dinámica de sistemas para la selección de terrenos de cultivos agrícolas. *Elementos*, 6*(6), 149-166. <https://doi.org/10.15765/e.v6i6.842>
6. Nayak, J. G., Patil, L., & Patki, V. K. (2020). Development of water quality index for Godavari River (India) based on fuzzy inference system. *Groundwater for Sustainable Development*, 10*, 100350. <https://doi.org/10.1016/j.gsd.2020.100350>
7. Oladipo, J. O., Akinwumiju, A. S., Aboyeji, O. S., & Adelodun, A. A. (2021). Comparison between fuzzy logic and water quality index methods: A case of water quality assessment in Ikare community, Southwestern Nigeria. *Environmental Challenges*, 3*, 100038. <https://doi.org/10.1016/j.envc.2021.100038>
8. Oliveira, M. D. d., Rezende, O. L. T. d., Oliveira, S. M. A. C., & Libânio, M. (2014). Nova abordagem do índice de qualidade de água bruta utilizando a lógica fuzzy. *Engenharia Sanitária e Ambiental*, 19*, 361-372. <https://doi.org/10.1590/S1413-41522014019000000803>
9. Pabón, S., Benítez, R., Sarria, R., & Gallo, J. (2020). Contaminación del agua por metales pesados, métodos de análisis y tecnologías de remoción. Una revisión. *Entre Ciencia e Ingeniería*, 14*(27), 9-18. <https://doi.org/10.31908/19098367.1734>
10. Quiñones-Huatangari, L., Ochoa, L., Milla-Pino, M., Bazán C, J., Gamarra T, O., & Rascón, J. (2020). Water quality index using fuzzy logic Utcubamba River, Peru. *Revista de Ciencias Agrícolas*, 37*(1), 6-18. <https://doaj.org/article/dadddef3eba4410db1e63a476d8cc8ef>
11. Sarkheil, H., Rahbari, S., & Azimi, Y. (2021). Fuzzy-Mamdani environmental quality assessment of gas refinery chemical wastewater in the Pars special economic and energy zone. *Environmental Challenges*, 3*, 100065. <https://doi.org/10.1016/j.envc.2021.100065>
12. Sierra Ramirez, C. A. (2011). Calidad del agua: evaluación y diagnóstico. *Ediciones de la U*
13. Uddin, M. G., Nash, S., & Olbert, A. I. (2021). A review of water quality index models and their use for assessing surface water quality. *Ecological Indicators*, 122*, 107218. <https://doi.org/10.1016/j.ecolind.2020.107218>

14. Vergara, G., & Gayoso, J. (2008). Una aplicación de métodos de conocimiento base y clasificación difusa para predecir calidad de agua en tres comunas del sur de Chile. *Bosque (Valdivia), 29*(2), 127-135. <https://doi.org/10.4067/S0717-92002008000200005>
15. Yogendra, K., & Puttaiah, E. (2008). Determination of water quality index and suitability of an urban waterbody in Shimoga Town, Karnataka. *Proceedings of Taal2007: The 12th world lake conference*.
16. Zadeh, L. A. (1978). Fuzzy sets as a basis for a theory of possibility. *Fuzzy sets and systems, 1*(1), 3-28. [https://doi.org/10.1016/S0165-0114\(99\)80004-9](https://doi.org/10.1016/S0165-0114(99)80004-9)

Analysis of hemoglobin values in prostate cancer patients treated with external radiotherapy

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ABSTRACT

Introduction: The world estimate points to prostate cancer as the second most frequent cancer in men worldwide, and radiotherapy is an important modality of curative treatment to manage this neoplasm. The prevalence and impact of cancer-related anemia are not widely known and may be overlooked or considered clinically significant. It is believed that the results and toxicity of radiation therapy in the treatment of prostate cancer may be influenced by hemoglobin levels in the blood. **Objective:** To evaluate hemoglobin levels in patients with prostate cancer before and after radiotherapy treatment. **Methods:** This was a retrospective and longitudinal study of patients diagnosed with malignant prostate cancer who underwent external radiotherapy. Hemoglobin levels were measured before radiotherapy and after completion of treatment (20-40 days). Anemia was defined by the World Health Organization as values below 13 g/dl. The classification of the risk of prostate cancer recurrence was based on the National Comprehensive Cancer Network risk criteria. **Results:** Forty patients were evaluated with measurement of hemoglobin levels before and after radiotherapy treatment. The mean age was 67 years. According to the classification of the risk group, 4 patients were at low risk (10%), 27 patients were at intermediate risk (67.5%), and 9 patients were at high risk (22.5%). Mean pre-radiotherapy hemoglobin levels were 13.3 g/dL and mean post-radiotherapy hemoglobin levels were 10.4 g/dL, $p < 0.0001$. **Conclusion:** In this study, a reduction in serum hemoglobin levels was observed after radiotherapy, highlighting the need for better monitoring of these patients.

Keywords: Radiotherapy, Prostate neoplasms, Anemia.

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INTRODUCTION

The world estimate points to prostate cancer as the second most frequent cancer in men worldwide¹, and radiotherapy is an important curative treatment modality in the management of this neoplasm. The prevalence and impact of cancer-related anemia are not widely known and may be overlooked or considered clinically significant. However, the restoration of normal hemoglobin (Hb) concentrations in patients undergoing radiotherapy has the potential to improve local tumor control and survival, as well as significantly improve patient quality of life². While there is emerging data on the importance of Hb levels in some cancers, there is limited published data on its role in prostate cancer. It is believed that the results and toxicity of radiotherapy in the treatment of prostate cancer may be influenced by blood levels of Hb³.

OBJECTIVE

To assess hemoglobin (Hb) levels in prostate cancer patients before and after radiation therapy treatment.

METHODS

This was a retrospective, longitudinal study of patients diagnosed with malignant prostate neoplasms who underwent external radiotherapy. Hb levels were measured before radiotherapy and after completion of treatment (20-40 days). Anemia was defined by the World Health Organization (WHO) as men with values lower than 13 g/dl⁴. The classification of the risk of prostate cancer recurrence was based on the National Comprehensive Cancer Network (NCCN) risk criteria⁵, with patients classified as low risk, favorable intermediate and unfavorable intermediate, and high-risk groups. PSA levels were also assessed. Patients indicated for hormonal blockade (central and/or peripheral) started hormonal treatment after Hb collection and measurement in this study. Inclusion criteria: prostate neoplasm with confirmatory histopathological diagnosis, referred for radiotherapy with or without antiandrogen therapy. Exclusion criteria: metastatic disease, initiation of chemotherapy, or hematologic diseases. For the descriptive statistical analysis of the collected data, the Statistical Package for the Social Sciences (SPSS), version 23.0, was used. Only results with a significance level of 5% probability ($P \leq 0.05$) and a 95% confidence interval were considered. The study was approved by the Research Ethics Committee of the Faculty of Medicine of the Universidade Federal Fluminense - CAAE: 58121422.1.0000.5243.

RESULTS

Forty patients were evaluated with measurement of Hb levels before and after radiotherapy treatment. The mean age was 67 years (range 55-79 / 95% CI 65-69 / SD \pm 5.4). The mean PSA was

13.5 ng/ml (3.2-70/95%CI 11.0-16.0/SD \pm 12.2). According to the classification of the risk group, 4 patients were at low risk (10%), 27 patients were at intermediate risk (67.5%), and 9 patients were at high risk (22.5%). Patients received an external radiotherapy dose of 70 Gy in 28 fractions (moderate hypofractionation). Table 1 shows the general characteristics of the patients evaluated.

Table 1 – General characteristics of patients		
	n	%
Race		
White	14	35%
Brown / Black	26	65%
Smoking		
Yes	07	17,5%
No	33	82,5%
Alcohol use		
Yes	13	32,5%
No	27	67,5%
Staging		
T1	07	17,5%
T2	33	82,5%
ISUP (International Society of Urological Pathology)		
1	20	50,0%
2	07	17,5%
3	06	15%
4	07	17,5%

Mean pre-radiotherapy Hb levels were 13.3 g/dL (range 12-16.5/95% CI 13.0-13.6/SD \pm 0.9), and mean post-radiotherapy Hb levels were 10.4 g/dL (range 9-13/95% CI 10.0-10.7/SD \pm 1.1), with a statistically significant difference, $p < 0.0001$. **DISCUSSION** It has been suggested that prostate cancer survival outcomes and radiotherapy toxicity may be influenced by Hb levels. The *Trans-Tasman Radiation Therapy Oncology Group* (RTOG 96.01) study reported late radiation toxicity at its median 5-year follow-up of 818 prostate cancer patients treated with androgen deprivation therapy and radiotherapy. They found that patients with higher pre-treatment Hb had a reduction in late rectal toxicity⁶. In our study, a lower Hb level was observed after radiotherapy. NCCN guidelines recommend transfusion or erythropoietin for symptomatic patients with Hb of 10-11 g/dL and state that erythropoietin should be strongly considered if Hb falls below 10 g/dL. These recommendations were based on studies that showed an improvement in the quality of life of cancer patients, but not in their survival with the correction of anemia⁵.


CONCLUSION

In this study, a reduction in serum Hb levels was observed after radiotherapy, highlighting the need for better monitoring of these patients.

REFERENCES

1. Instituto Nacional de Câncer (Brasil). (2022). Estimativa 2023: incidência de câncer no Brasil. Rio de Janeiro: INCA.
2. Hofmann, A., Aapro, M., Fedorova, T. A., Zhiburt, Y. B., Snegovoy, A. V., Kaganov, O. I., & Poddubnaya, I. V. (2022). Patient blood management in oncology in the Russian Federation: Resolution to improve oncology care. *Journal of Cancer Policy, 31*, 100315.
3. Yu, S., Tao, X., Suyan, Z., & Hongbin, X. (2023). Characteristics of adverse drug reactions induced by flutamide and bicalutamide: a real-world pharmacovigilance study using FAERS. *Expert Opinion on Drug Safety*. <https://doi.org/10.1080/14740338.2023.2267978>.
4. Jordão, R. E., Bernardi, J. L. D., & Filho, A. A. B. (2009). Prevalência de anemia ferropriva no Brasil: uma revisão sistemática. *Rev. Paul. Pediatr., 27*(1), 90-98.
5. National Comprehensive Cancer Network (NCCN). (n.d.). Guidelines. Prostate Cancer. Disponível em: https://www.nccn.org/login?ReturnURL=https://www.nccn.org/professionals/physician_gls/pdf/prostate.pdf.
6. Denham, J. W., Steigler, A., Lamb, D. S., Joseph, D., Turner, S., Matthews, J., ... D'Este, C. (2011). Short-term neoadjuvant androgen deprivation and radiotherapy for locally advanced prostate cancer: 10-year data from the TROG 96.01 randomised trial. *The Lancet Oncology, 12*(5), 451-459.

Environmental impact of pollutants and the potential contribution to phytoremediation

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ABSTRACT

This chapter revisited an experiment that evaluated elicitors for the germination of *Vigna unguiculata* (Cowpe Beans): the plant extract of *E. tirucalli*, the ultra-diluted and dynamized solution of Sulfur 5CH and the two in combination. At that time (2017), due to the significant results observed for the engorgement of seeds exuding an ammoniacal odor, the participation of the sodium/potassium pump, detoxifying enzymes from the thiol group and the suggestive participation of the nitrogenous route of oxidative stress was discussed, by monitoring the factors abiotic and detection of cyanuric acid in similar hydroponic solutions where Cowpea was cultivated, thus questioning the potential phytoremediation effect of test solutions as herbicides. Later, with the literature showing the association of the thiol group with mercury as another mechanism for phytoremediation, removing it from contaminated soil and water, it was also shown that very few plant species have this ability (two). So, based on the figure and scheme drawn up by environmental engineer Alexandre Pereira (2022), this potential was thought to be possible for the succulent species studied, *E. tirucalli*. From then on, the experiment was re-discussed thinking about the association with another likely mechanism for the results previously verified. Now also thinking about the potential participation of dairy ducts as structures capable of extracting and even bioaccumulating pollutants, in this case, mercury, since biotransformation was empirically observed in this species through phytovolatilization, which caused

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intoxication through inhalation of researchers, using an odorless substance released (NAGAMATSU et al., 2019). To conclude, therefore, based on practical experience with this plant species, this appears to be a viable mechanism that will be investigated in future water cultivation trials of *Vigna unguiculata*, this time with micropropagated *Euphorbia tirucalli* to be carried out in partnership with agricultural engineering, agronomic (phytosanitary) and environmental. The aim is through research in plant biotechnology to study the effects on phytoremediation, the consequent interdisciplinary promotion of environmental health.

Keywords: *Vigna unguiculata*, SUD 5CH Sulphur, *Euphorbia tirucalli*, Phytoremediation, Heavy metals.

INTRODUCTION

According to the World Health Organization (1993 In RIBEIRO, 2004):

"Environmental health is all those aspects of human health, including quality of life, that are determined by physical, chemical, biological, social and psychological factors in the environment. It also refers to the theory and practice of valuing, correcting, controlling and avoiding those environmental factors that could potentially harm the health of current and future generations" (WHO, 1993).

The large number of environmental factors that can affect human health is an indication of the complexity of existing interactions and the range of actions necessary to improve environmental factors that determine health. However, environmental improvement programs have actions that are quite different from those of medical care, even though they cannot be separated from them (RIBEIRO, 2004).

As already reflected by professor Helena Ribeiro (2004), concerns about environmental aspects, both in relation to Public Health and in relation to other characteristics of different social groups (social, cultural and economic organization), have existed since the beginning of human history and constituted an important analytical basis for social thought in the past. Today, these questions are once again attracting the attention of different sciences. Clarence Glacken (1967) summarizes these concerns in three major questions, which have been highlighted at different moments in human history:

1. What is the meaning of human creation and what is the conception of the earth? In other words, the earth was created for human beings?
2. What is the influence of the physical environment - the environment - on the characteristics of human beings and societies?
3. How have human beings been transforming the earth?

Despite this large-scale and serious problem about pollutants in nature and non renewable resources, novel models of investigations may be able to answer complexity present in nature, aiming reduction of impacts of pollutants upon nature but also to living beings. So, some types of studies were developed in this theme all over the years focusing in water – removal of pharmacological waste and hipersalinity (KATHAR et al., 2023; GASPAR et al., 2023) - and in soil – by attended local cultivates aiming to decrease toxicity of plants species (VARRICCHIO et al., 2006), besides persistence of endocrine disruptors (HANSEL-MARTINS et al., 2023; 2024; GASPAR et al., 2024), once it is known that some plant species can clean soil and water from heavy metal pollution from industries in a process of Phytoremediation, when is able to degrade, remove or stabilize toxic substances from contaminated soil or water, as previously discussed by KATHAR et al. (2023).

There are several hyperaccumulator plant species, that is, plants that can store metals that they do not need for their development (or that metabolize them for less harmful species) favoring

the removal of these elements in nature. Because, if these polluting heavy metals are not removed or prevented from migrating, they will accumulate in edible vegetables or contaminate the water table, causing problems on contact such as allergic dermatitis, inhalation of volatile substances, resulting in perforations of the nasal septum, intoxication, headache, nausea and fainting and chronic poisoning can trigger cancer in animals, humans and non-humans. Using this technique, soil and water contaminated by petroleum derivatives can also be recovered (DE SOUZA, 2021), by herbicides (GASPAR et al., 2023; 2024, a), besides removal of waste of medicines (KATHAR et al., 2023).

The rate of reduction of pollutants will depend on factors such as climate, nature of pollutants and characteristics of plants (AGUIAR et al., 2012). Regarding pollution from heavy metals, their high concentration in the environment does not always indicate a high accumulation by plant species, as the interpretation of results can be complicated, the removal system through the roots used by plant species has not yet been developed. is fully clarified (MULGREW & WILLIAMS, 2000; AGUIAR et al., 2012). Mulgrew & Williams (2000) in their study demonstrated that plant species have been used as biological indicators and bioaccumulators of various pollutants, many of which are removed from the air, soil and water, thus reducing pollutant levels in the environment.

Some plants are suitable for phytoremediation (DUSHENKOV et al., 1995; AGUIAR et al., 2012). Plants that are grown hydroponically tend to develop more robust root systems, providing a greater surface area for the absorption of pollutants (MANT, 2001; AGUIAR et al., 2012). Brazil has a vast number of plant species with great potential for phytoremediation and hydroponics; however, these species are still little explored and their studies are almost scarce regarding their potential as phytoremediators (AGUIAR et al., 2012).

Among environmental pollutants, there is mercury. The expression “mercury cycle” refers to the transformations that the metal mercury can undergo in the environment, such as the formation of methyl mercury, harmful to living organisms and the bioaccumulative form of the metal in them. It is a metal that is liquid at room temperature, used both in industry, through various products, and also in mining, for example.

The chemical element mercury is symbolized by Hg, a reduction of the Greek word Hydrargyros, in Latin, it represents liquid silver, given that mercury was known in this way in ancient times. However, the name “mercury” is a legacy of the Egyptians who, knowing seven stars (Sun, Moon, Venus, Mars, Saturn, Jupiter and Mercury), promoted the association with the seven metals known until then: gold, silver, copper, iron, lead, tin and mercury, respectively. The associations were not by chance: Mercury, as it apparently moves faster than the other planets, would adequately represent the volatile metal, in addition to appearing in liquid form at room temperature (DAMAS, 2014).

In the formation of mercury metal, the distribution of the various species that enter the aquatic system is guided by physical, chemical and biological processes, which occur in the air/water and water/sediment relationships. The conversion between these different forms is the basis of the complex distribution pattern of mercury in local and global cycles and its biological enrichment. Regardless of the processes that regulate these cycles, the mercury that enters different environmental compartments can be inorganic and/or organic (BISINOTI & JARDIM, 2004).

Thus, the methylation of mercury in the aquatic environment is possible due, among others, to sulfate-reducing bacteria. Methylation can be separated into two pathways, biotic and abiotic. As for the first, it is mediated by microorganisms or fungi and is related to methylcobalamin, known as vitamin B12, which is a coenzyme capable of transferring the methyl group to the Hg^{2+} ion. Several bacteria commonly present in the aerobic environment are sensitive to mercury methylation, such as *Aerobacter aerogenes*, *Bacillus megaterium* and *Candida albicans*, for example (MICARONI; BUENO & JARDIM, 2000).

In inorganic form it can be found under three different oxidation states: elementary Hg (Hg^0), which is found mainly in gas form, the mercurous ion (Hg^{2+}), a form that is not very stable in natural systems, and the mercuric ion (Hg^{2+}). In organic form, the mercuric ion is covalently linked to an organic radical, with methyl mercury (CH_3Hg^+) and dimethylmercury ($(\text{CH}_3)_2\text{Hg}$) being the most common, or with natural organic ligands. In addition, there is a generic biogeochemical cycle in which methyl mercury and Hg^{2+} , dimethylmercury and Hg compounds are interconverted in atmospheric, aquatic and terrestrial systems (MICARONI; BUENO & JARDIM, 2000).

A small portion of the Hg^0 that reaches the atmosphere is converted into water-soluble species (probably Hg^{2+}), which can be re-emitted into the atmosphere as Hg^0 , through deposition on soil or exchange at the air/water interface. The atmospheric cycle involves retention of Hg^0 in the atmosphere for long periods; consequently, this compound can be transported over great distances. The sediment at the bottom of the oceans is considered to be the place where mercury is found abundantly deposited in insoluble form (HgS) (MICARONI; BUENO & JARDIM, 2000).

For this reason, it is believed that fires release a significant portion of mercury through volatilization or sulfate, capable of stimulating methylation processes. Thus, mercury methylation can occur in both soils and sediments, aerobically and anaerobically (DAMAS, 2014). However, it can also be associated with sulfur, which forms a cinnabar ore (HgS), which can then be heated and condensed to obtain metallic mercury. It is also found in volcanic eruptions, natural evaporation and mercury mines, used in various things, as previously mentioned (MICARONI; BUENO & JARDIM, 2000; BISINOTI & JARDIM, 2004).

However, due to the bioaccumulation of methylmercury, methylation prevails over demethylation in aquatic environments, as the reaction can be reversible. Once formed,

methylmercury enters the food chain through rapid diffusion and strong binding with the proteins of living beings in the aquatic environment, promoting its maximum concentration in fish tissues at the top of the aquatic food chain due to biomagnification (BISINOTI & JARDIM, 2004).

The process of biomagnification is understood as the increase in the concentration of a substance or element in living organisms, as it travels through the food chain and begins to accumulate at the highest trophic level; bioaccumulation, biomagnification, bioconcentration, trophic magnification. Trophic magnification is a phenomenon that occurs when there is progressively greater accumulation of a toxic substance from one trophic level to another along the food chain due to a reduction in biomass. Therefore, consumers have a higher concentration of toxic products than producers (BISINOTI & JARDIM, 2004; KEHRIG et al., 2011).

Furthermore, eutrophication produces changes in water quality, including the reduction of dissolved oxygen and aquatic biodiversity and, consequently, the loss of biodiversity quality, as it can lead to the death of fish. In this way, it was possible to notice the large amount of mercury in predatory fish, as they are at the top of the food chain in the waters, mainly in tributary areas of the Amazon River. However, it is possible to analyze its bioaccumulative aspects from the planktonic community to predatory fish (KEHRIG et al., 2011).

However, poisoning can occur in several ways, which include inhalation, digestive and cutaneous. In the lungs, its retention varies from 74% to 76% at an environmental concentration of 100 MG/m³. When the metal reaches the lungs, due to hematosi, via the serum it is distributed to the rest of the body, and can accumulate in the kidneys, central nervous system, liver, bone marrow, placenta, among other organs. The contamination reference point is based on exposure through methyl mercury, an organic form of this metal. Absorption through food is around 15%, while in the form of methyl mercury it is around 90%. Both forms of mercury, inorganic and organic, quickly bind to glutathione, present in most cells in the body. Mercury in its inorganic form is not captured by the body, being eliminated through feces, while organic mercury is eliminated through saliva, kidneys and skin (through sweating). Methyl mercury is eliminated through feces and can also be eliminated by epithelial cells through exfoliation (ROCHA, 2009).

In ecology, it is known that pioneer plants are those plants that originate from inhospitable, uninhabitable places, such as grasses in a desert. They are characterized by the fact that they can cope with the harsh conditions of bare land and, in addition, they have a very large annual seed production. They are described as species that survive due to their high reproductive capacity. They die and decompose, replacing the soil to increase the humus content. This leads to an increase in the soil's ability to hold water and mineral nutrients. As a result, pioneer plants create a gentle microclimate. This creates the basis for a migration of plants that are efficient in competing for light, nutrients and water. Although in the literature, *Euphorbia tirucalli* is not considered a pioneer species,

the millennial existence and survival of the genus since Pangea, in addition to its cosmopolitan distribution, encourages us to persist in studying this intriguing species. *E. tirucalli* Avelós, is classified as follows: “Aveloz – euphorbiaceae. ORN – CV – MED (Ornamental, Cerca Viva, Medicinal by EMBRAPA (RIBEIRO, 2010, p. 19).

Even though it is considered a toxic species, it is regularly used by traditional, ethnic communities and indigenous peoples around the world (VARRICCHIO et al., 2008; CAMPOS et al., 2016) and even in popular use (MOLIN et al., 2015). Laboratory investigations have already investigated its angiogenic (BESSA et al., 2015), genotoxic and cytotoxic action on human leukocytes (MACHADO et al., 2016) in addition to its effect on gene expression in laryngeal carcinoma (FRANCO-SALA et al., 2016), in vitro investigation of mechanisms in malignant neoplasia (SILVA et al., 2019).

An interesting review on phytochemistry and pharmacological activities was carried out by MALI & PANCHAL (2017) and new substances with antimicrobial activity produced by the roots of *E. tirucalli* from the Brazilian northeastern Caatinga biome were verified by LIMA (2019), described below. The chemical and biological investigation of three plant species collected in the caatinga: *Euphorbia tirucalli* Linn., *Bredemeyera floribunda* Willd and *Bredemeyera brevifolia* Benth. The LC-MS analysis, in negative mode, applied to the extracts of the three species made it possible to evaluate the phytochemical profile of the species and thus verify flavonoids as the predominant class of metabolites (LIMA, 2019).

The chemical study of hexane extracts from the aerial part and ethanolic extracts from the roots of *E. tirucalli*, applying chromatographic techniques, allowed the isolation of five constituents: two already isolated in the species, β -amyrin and 4-O-methyl-gallic acid, in addition to three new compounds for the species, ampelopsin, myricetin and 3,3'-dimethoxyelagic acid-4-O- α raminopyranoside. The evaluation of the antioxidant activity of *E. tirucalli* extracts against DPPH and ABTS tests made it possible to verify that the ethanolic extract of the roots showed better efficiency against the two radicals, while among the isolated compounds, myricetin showed better inhibition of the radicals with IC₅₀ of 22.62 μ g/mL for DPPH and 53.22 μ g/mL for ABTS (LIMA, 2019).

The evaluation of antimicrobial activities revealed that only the ethanolic extracts presented antibacterial and antifungal potential, while all isolated compounds showed an inhibitory effect against strains of *Staphylococcus aureus*, *Escherichia coli*, *S. brasiliensis* and *Candida Albicans*, with a greater effect on myricetin and ampelopsin (LIMA, 2019).

In parallel, the description of chronic, unexpected nasal intoxication of a volatile, odorless substance during daily contact with *E. tirucalli* for experiments provided clues to think about possible pathogenic effects and, consequently, potential biological applications (NAGAMATSU et al.

, 2019). Furthermore, it made us question its potential for phytotransformation through phytovolatilization, thus beginning our study in this area of phytoremediation research (KATHAR et al., 2023). Could there be an association of mechanisms if it were to play a phytoremediation role? Could this mechanism determine not only the type of phytoremediation, but which waste it can filter?

AIM

Revisit an experiment already carried out (GASPAR et al., 2024) to deepen the discussion regarding yet a new and possible mechanism of action in phytoremediation.

METHODOLOGY

The assay aimed to evaluate the biological effect of the total ethanolic extract 30% *E. tirucalli* and HUD 5DH Sulfur on the germination of cowpea (*V. unguiculata*). As methodology, assisted cultivates of *V. unguiculata* in 200 ml of mineral water were carried out. Three seeds per pot, in three pots, in triplicate per row, with one more pot (N = 30). It was administered separately: 1 drop of total extract of *E. tirucalli*, HUD5DH, and respective controls prepared by the Hahnemannian method of multiple flasks. The action/time curve was verified on the first, third and seventh day of cultivate: pH, free chlorine, total alkalinity, color, turbidity and presence of cyanuric acid were measured by the colorimetric method. Temperature measured by an Infrared thermometer B-Max. Morphology and germination were observed by ANOVA statistical programme (In GASPAR et al., 2017).

RESULTS

Results showed that it had an inhibition on the germination of *V. unguiculata* ($p < 0,05$), curiously associated with engorgement of the seeds, an evidence of metabolic route deviation. Hormetic ponderal phytoextracts with also HUD 5DH Sulfur test solutions, induced cyanuric acid at water where seeds were suggestive of protein breakdown, possibly due to erosion of the bean skin. Cyanuric acid is commonly used as pesticide, mosquito insecticide and mainly as a repellent of invasors plant species and their microbiological pathogens, through allelopathy mediated by radicle secretions emissions by roots (BEZERRA, 2015; HANSEL – MARTINS et al., 2023).

Cyanuric acid is also able to compete with some chemicals. It is a precursor to polyesters, polyurethanes, bleaches, disinfectants and herbicides. This last function, in turn, can be used in plant biotechnology in the bioremediation of soils contaminated with herbicides, used to combat invasive weeds. So, this experiment will be repeated separately to further study the mechanisms. Under this vision, the use of herbal extracts and diluted solutions (infinitesimals) seeks to become an alternative for the cultivation of small farmers, reducing their exposure to insecticides and pesticides currently

used in industry, such as organochlorines, which are considered endocrine disruptors (HANSEL – MARTINS et al., 2023) that can cause serious health problems, including mental disorders (HANSEL – MARTINS et al., 2024).

Attended cultivate of *Vigna unguiculata* elicited with *E.tirucalli* extract and HUD 5CH Sulphur as elicitors: Biotechnological potential on phytoremediation?

DISCUSSION

ATTENDED CULTIVE OF *VIGNA UNGUICULATA* ELICITED WITH *E.TIRUCALLI* EXTRACT AND HUD 5CH SULPHUR AS ELICITORS

Was it found one more biotechnological potential on phytoremediation? A biotechnological potential for bioremediation of soils contaminated with herbicides, a response through nitrogen oxidative stress, was evidenced. Assays on this route will be carried out in phytopathology laboratory and cyanuric acid will be the pathogenetic marker of biological activity for HUD solution tested (GASPAR et al., 2024), as already evidenced at this present assay. Furthermore, herbal extracts obtained from roots (VARRICCHIO, 2008; LIMA, 2019) and high ultradiluted succussioned solutions may be an alternative to the cultivate of small farmers, reducing exposure to pesticides and soil contamination. So, there are phytoremediation potential but, perhaps, also a bioremediation potential (GASPAR et al., 2017; 2024a).

Furthermore, it might be another possible explanation and application of these prepares from now on this preliminar observation. This assay was evaluated through abiotic factors whose, naturally, suggested mechanism of action through sulfur enzymatic pathway, object of several of our studies along years (APOLINARIO et al., 2000). There is a relationship of mercury with the covalent bonds to thiol groups, cellular enzymes in lysosomes and mitochondria is one of the factors that contribute to knowing the level of toxicity, due to the fact that the metal interrupts metabolism and cellular functions (ROCHA, 2009).

However, there is no exact target for interaction preference, because thiol groups exist in proteins that have extracellular and intracellular membranes, and can be related in both function and structure. As a consequence of toxicity, several mechanisms can be enumerated, such as: inactivation of enzymes, structural proteins, transport processes and even changes in the permeability of the cell membrane. Furthermore, it is worth mentioning that, despite its low affinity, it can bind to the carboxyl, amide, amine and phosphoryl groups of enzymes. There are some studies that relate toxicity to increased permeability of the blood-brain barrier, inhibition of proliferation and formation of microtubules, interruption of protein synthesis, among others (ROCHA, 2009).

One of the effects of mercury on the body is related to oxidative stress, due to the loss of levels of glutathione, superoxide dismutase, catalase and glutathione peroxidase, thus providing less

protection to cells. Furthermore, mercury can induce lipid peroxidation, mitochondrial disorders and changes in the heme group. Furthermore, mercuric chloride can cause depolarization of the inner mitochondrial membrane, increasing the formation of peroxidase. Another factor related to increased oxidative stress is related to changes in mitochondrial calcium homeostasis, influenced by mercury chloride in kidney cells. Consequently, biochemical changes occur, such as excretion of porphyrins in the urine (ROCHA, 2009).

One of the main causes of the affinity of methyl mercury in myelin is its lipid solubility, which inhibits the excitability of neurons. Furthermore, HgCl₂ has an inhibitory activity when it binds to the sulfhydryl groups of calcium transport proteins, consequently, muscle contraction does not occur, in addition to the inhibition of neurons. One of the main targets of methyl mercury in the body are microtubules, which are essential in cell division and migration. Therefore, when they are affected, they block the development of the nervous system. Additionally, methylmercury inhibits GABA receptors (Gamma-AminoButyric Acid receptors), which are located on Purkinje cells and neurons (ROCHA, 2009).

So, returning to the point of the article, the dramatic engorgement of the seeds under the effect of SUD 5CH suggested that it was able to act on the sodium/potassium pump, but it also may have been able to act as a phytoextractor. Indeed, there is the possibility that phytoextractive action was increased and even noticed due to the effect of ultradilution and succussion by Samuel Hahnemann's multiple flask method, HUD mineral, as already discussed by GASPAR et al. (2024a).

Novel assays with raw extracts obtained from Cowpea bean of different assisted culture and micropropagation will go on being evaluated through abiotic factors as this present assay described and about their mechanisms of action through sulfur enzymatic pathway, when under effect of HUD of *Mercurius solubilis* and its controls, not more as a homeopathic effect, but an isopathic effect. The relationship of mercury with the covalent bonds to thiol groups, cellular enzymes in lysosomes and mitochondria is one of the factors that contribute to knowing the level of toxicity, due to the fact that the metal interrupts metabolism and cellular functions (ROCHA, 2009) and it will be used as a pathogenetic biological marker to understand the mechanism of action (HANSEL-MARTINS et al., 2024; GASPAR et al., 2024, a).

In turn, *Vigna unguiculata* (Caupi Bean) is the bean with the highest concentration of iron and proteins still used by quilombolas and northeastern people in Brazil (GASPAR et al., 2017; MUSMANNO et al., 2019), some of them exposed to environmental pollutants as herbicides and agrotoxics (HANSEL-MARTINS et al., 2023; 2024).

Although its ethnobotanic use (MOTA et al., 2022; MOTOO et al., 2022; BINCKLEY & ZAHRA, 2023) there is a point of use of *E. tirucalli* to Malaria (VARRICCHIO et al., 2008; VEIGA & SCUDELLER, 2015), studies regarding its antitumor activity for solid tumors remain in the

spotlight (MUNRO et al., 2015; PALHARINI et al., 2017), with increasing emphasis on research into its antioxidant and antimicrobial activity (LE et al., 2021).

As Alexandre Pereira ponders, Phytoremediation (phyto = plant; remedium = cure, restoration) is the process in which plants are used for environmental decontamination, through removal, reduction, degradation and containment of the contaminant. In this process, various plants can be used, including aquatic plants and algae. Phytoremediation strategies have the potential to treat a broad spectrum of contaminants. Brazil has great potential to use phytoremediation in the treatment of contaminated areas due to its high biodiversity and climate, which are favorable to biological processes to remove contaminants (PEREIRA, 2022).

The technique is often used in the remediation of heavy metals, radionuclides, as well as recalcitrant organic pollutants. For satisfactory performance in metal remediation, it is desirable that plants have tolerance to the contaminant, good metal absorption or adsorption capacity, high growth rate, deep root system, easy harvest. Knowledge of potentially phytoremediating plant species is an initial and fundamental step for decontamination studies and projects (PEREIRA, 2022).

Therefore, considering the great plant diversity in Brazil, this review aimed to survey Brazilian flora species that potentially phytoremediate heavy metals. To this end, the capacity and tolerance, as well as the predominant phytoremediation process in the decontamination of heavy metals by different species and botanical families native to Brazil, were investigated in the literature. 108 species of native plants were found used in metal phytoremediation studies. The identified species belong to 42 different botanical families. With 19 species, the Fabaceae family is the most represented in studies, showing potential to phytoremediate 8 heavy metals. Asteraceae also stood out with 9 species remediating 4 types of metals, and Poaceae with 5 species studied remediating 6 metals. (PEREIRA, 2022).

In relation to metals, it is clear that most phytoremediation studies used copper and zinc as decontamination targets. Although there is much to be explored regarding the use of species from Brazilian flora, the results are satisfactory, contribute to the advancement of knowledge, and already offer a significant number of possible plant species for metal remediation. The plant species used for the phytoremediation of heavy metals are called metallophytes, which have good tolerance to high levels of metals. Another definition is that they are plants that have evolved, adapted and even thrived in soils rich in heavy metals (BOTHE et al., 2011, SHEORAN et al., 2011 In PEREIRA, 2022).

Metallophytes are divided into three categories: metal excluders, metal indicators and metal hyperaccumulators. Excluders accumulate heavy metals from the substrate in their roots, but restrict their transport and entry into their parts. Indicators accumulate heavy metals in other aerial parts.

Hyperaccumulators are plants, which can concentrate metals in their above-ground tissues to levels much higher than those present in the soil (MALIK and BISWAS, 2012 In PEREIRA, 2022).

In Brazil, several research teams are already focusing on this process, on a laboratory scale. For example, a type of fern is studied for arsenic phytoextraction and cowpea is used for the recovery of soils containing herbicides. The whiner for the recovery of waters containing petroleum derivatives; castor, sunflower, Amazon pepper and tobacco for the treatment of soils containing cadmium, lead, copper, zinc and nickel. One of them is *Thalaspia caerulescens*, from the Brassicaceae family, and it is one of the main focuses of research on phytoremediation (AGROAMBIENTE, 2023).

In the US, GM Indian mustard has been used to treat arsenic-containing soils in California. In Canada, lead, copper and zinc were removed from the soil thanks to 3 species: willow, Indian mustard and fescue (pasture grass). The University of Georgia is developing 60 transgenic cotton plants to clean soil contaminated with mercury on land in the city of Danbury, in the US state of Connecticut, where they will remove mercury deposited by an old hat factory (AGROAMBIENTE, 2023).

Most plant species have the capacity to absorb, translocate, immobilize and/or degrade contaminants (CUNNINGHAM & OW, 1996), thus being able to repair contaminated environments. Plants act in such a way that they are able to modify the physical and chemical properties of contaminants in the soil by releasing exudates through their roots. These strategies that allow phytoremediation can occur through a single or a combination of the following basic mechanisms: removal, accumulation and withdrawal of the contaminant with the removal of the plant; contaminant removal and degradation; removal and volatilization to the atmosphere; or facilitating soil treatment (accumulation, immobilization and stimulation of rhizosphere microbiota). Therefore, the types of phytoremediation carried out by plants adapted to the presence of heavy metals can be classified as phytoextraction, rhizofiltration, phytostabilization and phytovolatilization (In PEREIRA, 2022).

Regarding the advantages, phytoremediation stands out for: having good public acceptance, low cost, and can be used in large areas; because it is a natural process that requires little mechanical work and because it makes the place more pleasant. Taking into account these characteristics and the expected low cost, phytoremediation can be used on a larger scale than would be possible in the case of other methods (PIRES et al. 2003).

The time required is generally long due to the plant's growth and development cycle. There is the possibility of contamination of the food chain, the phytodegraded toxic compound can become an even more toxic compound (LAMEGO & VIDAL 2007, PROCÓPIO et al., 2009 In PEREIRA, 2022). Whether the treatment process takes longer or longer will depend on some factors or

conditions such as the species and number of plants; the factors (physical, chemical and biological) of the soil; the weather; the rhizosphere; the type and concentration of the contaminant. The size and depth of the contaminated area also influence. So, types of phytoremediation were shown by the environmental engineer Alexandre Pereira (2022), named as Table 1 and Figure 5 in his work.

Table 1: Summary of phytoremediation techniques.

Tabela 1 - Resumo das técnicas de fitorremediação.	
Resumo das diferentes técnicas de fitorremediação.	
Técnica	descrição
Fitoextração	Acúmulo de poluentes na biomassa colhível, ou seja, pode retirada.
Fitoestabilização	Limita a mobilidade e biodisponibilidade dos contaminantes no solo através das raízes.
Fitoestimulação	Estimula a planta para a biodegradação microbiana dos contaminantes, mediante exsudatos radiculares e/ou fornecimento de tecidos vegetais.
Fitovolatilização	Conversão de poluentes para a forma volátil e posterior liberação para a atmosfera.
Rizofiltração	Absorção e adsorção de contaminantes na rizosfera por microorganismos rizosféricos.

Figura 5: Phytoremediation techniques.

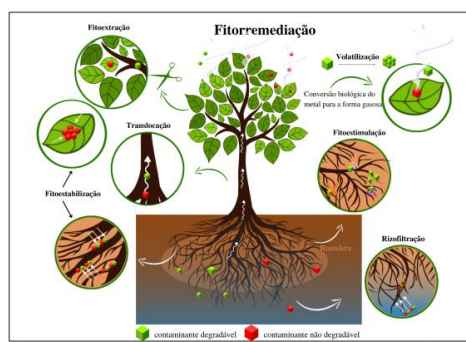


Figura 5- Resumo das técnicas da Fitorremediação. Fonte: Elaborado e adaptado pelo autor, 2022.

Source: Prepared and adapted by PEREIRA (2022).

As Alexandre Pereira (2022) reflects, when selecting plants that have phytoremediation capacity, it is desirable that they present some indicator characteristics (PIRES et al. 2003). It is unlikely that a species or variety brings together all these characteristics, however, one should look for those that bring together the greatest number of desirable attributes (MILLER, 1996). The main desirable characteristics are: suitability for the climate (temperature and humidity), tolerance to contaminants; resistance to pests and diseases; the ability to absorb, concentrate and/or metabolize the contaminant; retention of the contaminant in the roots (phytostabilization); rapid growth and biomass production; practicality in harvesting, removal if necessary; ease of acquisition or propagation; ease of control or eradication; stimulation of soil biota; depth of the root system; natural occurrence in contaminated areas (CUNNINGHAM et al., 1996; NEWMAN et al., 1998; ACCIOLY & SIQUEIRA, 2004. All in PEREIRA, 2022).

The importance of studies of native plants, whether at a local or regional level, is due to the fact that they are already adapted to the climate and the chemical properties of the soil. Native and exotic plant species are classified according to their origin. According to the IBF – Brazilian Forestry Institute, a native species is defined as a plant that is natural, originating in the region in which it lives, that is, that grows within its natural limits including its potential area of dispersal (PEREIRA, 2022).

With the exception of water hyacinth (aguapé) and cattail (taboa), no other plants were found that naturally hyperaccumulate Hg, but plants that can develop mechanisms to deal with the presence of this contaminant in the environment, as previously proposed by WAGNER-DÖBLER (2013).

Indeed the fourth circulation through laticiferous ducts of *E. tirucalli* and its “roots in hair” may be the way to study this strongly suggestive potential of action. So, also HUD might be a viable alternative, being discussed through other reasoning (VARRICCHIO, 2008).

What toxicology at primary effect and secondary effect obtained thorough HUD administration can show to us?

PRIMARY AND SECONDARY TOXICOLOGICAL EFFECTS (PATHOGENESIS) SYMPTOMS OF MERCURY POISONING

In humans, contact with mercury can cause everything from mild symptoms, such as itching and redness of the skin and eyes, to serious interference with cellular metabolism, in case of prolonged exposure. Know the main symptoms of mercury poisoning: Fever, tremors, allergic reactions to the skin and eyes, drowsiness, delirium, muscle weakness, nausea, headache, slow reflexes, poor memory, malfunction of the kidneys, liver, lungs and nervous system.

- Pathogenesis HUD of mercurium black oxide (ILLAH, 2019; VARRICCHIO, 2024):
MERCURIUS OXYDULATUS NIGER (*Mercurius solubilis Hahnemanni*)

“Dizziness more when sitting than when standing, lack of clarity and darkness before the eyes, especially towards dusk. Dizziness as if he were drunk; he gets up and walks from one side of the room to the other staggering, then anxious heat breaks over him, with nausea; Dizziness, cold hands with feverish trembling, then confusion of the head, forcing him to lie down. A type of dizziness; when lying down he feels as if he were swaying longitudinally. It takes away the sharpness of his intellect, makes him bewildered, he does not hear what is said to him, he cannot retain well what he reads, and he is apt to make mistakes when speaking. Unconsciousness and mutism; In the evening, a dull painful sensation in the head until he falls asleep; loud talk distressed him. Pressive headache as if it were tightly tied. As if the head was going to explode, at the same time the eyes were watering. Dilated pupils (after 1 h). Black insects or flies always seem to be flying before the view. Heat in the eyes and tearing. Painful in both eyes as from sand. Sore in eye, when it is moved;



It also hurts when touched. Itchy eyeballs. He can barely hear anything and yet everything resonates loudly in his ear. Bleeding from the nose (epistaxis) during sleep. Gums are painful when touched and when chewing, particularly hard food. In her sleep at night she grinds her teeth, and bites them so hard that it causes pain, which awakens her. Loss of speech and voice; she can't sleep and feels very exhausted; but she has an appetite for all kinds of food, and a thirst for beer; Swallowing is difficult and painful, as if it has burned the back of your throat. Pain and swelling of the salivary glands. Swelling of the ganglia of the neck and parotids, so that the jaws are closed, and cannot be moved at the cost of pain. Metallic taste in his mouth that almost makes him vomit. Salty expectoration. Sweet taste on the tip of the tongue. Putrid, very unpleasant taste in the throat. He has an aversion to sweet things. Extreme aversion to fresh meat. Aversion to coffee. Aversion to butter. No appetite for any hot food, only for cold things, bread and butter, etc. More thirsty than hungry, and constant slight shivering from the cold. After eating, violent sobbing. If he eats just a little too much, he becomes so bad-tempered that he can hardly bear it. Pain in the abdomen and a lot of noisy flatulence. A terrifying stab perpendicularly from the middle of the lower abdomen down to the anus. Inguinal bubo. Bloody stools, with painful acrid sensation in the anus. Brownish-red urine, very frequent with burning, burning pain. Pulling pain in the testicles and groin. Painful erections. Seminal emission without voluptuous dreams. Nocturnal seminal emission, mixed with blood. Suppressed menstruation. Harsh cough. Blood expectoration when walking outdoors. Periodic pain in the breasts, as if something in them was about to suppurate. Sharp needles in the spinal column, between the shoulder blades, in bed after midnight. Painful stiffness of neck, so that she cannot turn her head around, with heavy feeling in it. Visible fasciculation. Fatigue and restlessness in the legs, in the evening. At the same time heaviness, indolence and drowsiness. Jaundice with burning itching over the abdomen. Exhausted, not inclined to do anything and irritated. Fainting with an indescribable discomfort in the body and mind, which forces you to lie down. He doesn't like to talk, he can't read, his head is confused; he can't work, and falls asleep when he sits down. Exhaustion with sadness. Great exhaustion at dusk. First drowsiness, then insomnia. Sleep interrupted by frightened jerks, palpitations of the heart, and terrible images (e.g., as if he feared an epileptic fit). Very willing to sleep; sleeps very long and very soundly. Lots of delirious sleep talk. Sleeping is more unpleasant than pleasant for him. Anxious dreams with palpitation of the heart and yet he cannot wake up. Scary dreams at night, as if he fell from a height. Restless nights, dreams of highway robbers. Vivid dreams of the day's occupations; Dreams about water danger. Scary dreams of shooting. Violent thirst for cold drinks, particularly for fresh water. In the morning, immediately after rising, cold and shivering. Febrile attacks, particularly at night. Anxiety as if he had committed a crime. He doesn't rest, and needs to go from here to here, and can't stay in one place for long. He thinks he is losing his reason, that he is going to die; with fancies of the imagination, e.g. (e.g.), he

sees water flowing where there is none (in the morning). With absence of thought he feels as if he has done something bad. No desire for serious work. He doesn't have the courage to live. He was indifferent to everything, even what he loved most. Throughout the day great seriousness with great indifference; he got irritated when others laughed at trifles, and at the same time he was extremely indifferent to everyone around him. Everything is unpleasant to him, even music. For no reason he is very dissatisfied with himself and his condition. Throughout the day, depression of spirit combined with anxiety; he always thought he was going to hear something unpleasant. All day long, grumpy; he was extremely laconic and serious. Throughout the day, nervous and moody; he believed that all his efforts would ultimately fail. Irritable, irascible, cheeky spirit. Very nervous and intolerant, easily irritated, very suspicious. Fights with anyone, stubborn, quarrelsome. Contentions. All day long, grumpy and suspicious; he almost insulted those around him, and considered them all as his greatest enemies. All day nervous, as if in contradiction and dissatisfied with himself, and he had no desire to talk and play. He is overwhelmed, acts like a clown, and does stupid, meaningless things; During his senseless acts he felt very much like crying, and when this paroxysm passed, he felt very exhausted. I almost involuntarily cry with relief.”

The wealth of symptoms observed and methodologically collected from the secondary response was increased and opened a range of possibilities for the study of action mechanisms in search of effective contributions. Having noted the breadth of scope and similarity for its use for the current period, in accordance with the law of similarity to contemporary society. Will it be intoxicated?

MERCURY EXPOSURE ROUTES

Mercury is a liquid, heavy metal that, under normal conditions, is found in low concentrations in the environment. It is naturally released due to erosion processes and volcanic eruptions. Environmental contamination by mercury is, therefore, the result of human actions involving this element. The main anthropogenic sources of mercury are (AGROAMBIENTE, 2023):

- Burning coal, oil and wood: the process releases the mercury contained in these materials;
- Manufacture of products that use the substance as raw material, such as thermometers and fluorescent lamps;
- Inadequate disposal of mercury after its use in industrial processes, such as chlor-alkali production;
- Incorrect disposal of electronic products containing mercury;
- Gold mining, in which the substance is used to facilitate the particle separation process.

Brazil does not produce mercury, as it does not have reserves of cinnabar (a commercially exploited form of it). Therefore, the country imports it mainly from the USA and Spain. According to a study, the main sources of environmental contamination by the substance in Brazil are: Industrial effluents from the manufacture of caustic soda and gold mining in the Amazon region (AGROAMBIENTE, 2023).

The burning of large forest areas in the Amazon region is highlighted in the Ministry of the Environment's report as a significant source of mercury emissions in the country. Furthermore, there is the problem of soil contamination due to incorrect disposal of products containing the substance, covered by the National Solid Waste Policy (AGROAMBIENTE, 2023).

Most of the substance's atmospheric emissions occur in the form of metallic or elemental mercury (Hg^0). This form of the metal is quite stable, which allows it to be transported over long distances, in addition to remaining in the environment for a long period. As a consequence of contamination, inhaling high concentrations of metallic mercury vapor can cause lung damage. Chronic inhalation causes neurological disorders, memory problems, skin rashes and kidney failure. It is possible to identify poisoning by the elementary substance through a urine test. Elemental mercury binds to other elements, creating two other forms, organic and inorganic mercury compounds (AGROAMBIENTE, 2023):

Methylmercury [CH_3Hg]⁺ (organic compound)

Methylmercury is just one of the representatives of organic mercury compounds. However, it is considered the most important due to its high toxicity to the human body. It is produced from the elementary substance and synthesized by bacteria present in aquatic environments as a result of the detoxification process. In this process, mercury (Hg) binds to a methyl group (a carbon linked to three hydrogens - CH_3).

Methylmercury is incorporated into the aquatic ecosystem and accumulates in the tissues of organisms. The higher the organism's position in the food chain, the higher the concentration of methylmercury in its body, naturally. Therefore, when consuming fish that occupy the top of the food chain, the individual is possibly eating food contaminated by methylmercury. They are salmon, trout, tuna and others. The routes of exposure are through ingestion of water and consumption of fish contaminated by methylmercury. Ingestion of methyl-Hg causes damage to the central nervous system. But also neural dysfunctions, and in severe cases, leads to paralysis and death.

Inorganic mercury

Inorganic mercury is represented by a set of mineral salts and compounds. These are formed by the bonding of the substance with elements such as sulfur and oxygen. Its main uses occur in the

manufacture of batteries, paints and seeds; biocides in the paper industry, antiseptics, chemical reagents, protective paints for ship hulls, pigments and dyes. There is no industrial or commercial use for methylmercury (AGROAMBIENTE, 2023).

MERCURY CONTAMINATION - CONSEQUENCES TO HEALTH AND ECOSYSTEMS:

The main route of exposure is occupational. When workers come into contact with inorganic mercury through inhalation and dermal contact. Another route of exposure to consider is the ingestion of pharmaceutical products and the consumption of contaminated food. Contact with the dermis can cause rashes. Ingestion of a high concentration of the inorganic substance causes irritation and corrosion of the digestive system. Just like elementary mercury, inorganic mercury poisoning can be identified through urine testing (AGROAMBIENTE, 2023).

Water provides a habitat for countless species, and many of these species absorb this mercury. Some of these species are consumed by humans, thus, there is exposure of humans through this route, as mercury is easily absorbed by our body. The biotransformation of inorganic mercury to methyl mercury by bacteria is the process responsible for the high levels of the metal in the environment, as already explained (LACERDA & MALM, 2008).

In general, the pollutants that cause the most damage to ecosystems can be divided into two large groups. The first includes substances present in effluents from large urban areas, especially associated with the improper disposal of solid waste (garbage) and inadequate or non-existent treatment of sanitary sewage (LACERDA & MALM, 2008).

The second group, made up of pollutants of industrial and mining origin, includes toxic substances such as metals, greenhouse gases and organic pollutants, especially those generated by the burning of oil. Unlike contaminants in the first group, whose effect is generally local or, at most, regional, these have the power to affect the environment on a global scale. For example, the emission of greenhouse gases (especially carbon dioxide and methane) and metals (such as mercury and lead) into the atmosphere largely originates from the generation of energy by burning fossil fuels (LACERDA & MALM, 2008).

Although the effects of these contaminants are much less visible, their impacts are much more difficult to remediate. Little is known about the response of natural ecosystems to chronic exposure to this group of contaminants. Several of them, especially metals, are non-degradable, progressively accumulating in natural ecosystems and affecting their functioning over decades or even centuries (LACERDA & MALM, 2008). For example, old mining areas, although deactivated since the penultimate century, such as the tailings of the gold rush of the American West, still affect the local biota today (In PEREIRA, 2022).

In everyday life, mercury is present in various forms and objects, made by industry or caused by it, such as burning fossil fuels, electrolytic production of chlorine-soda, production of acetaldehyde, garbage incinerators, paper pulp, paints, pesticides, fungicides, mercury vapor lamps, batteries, dental products, amalgamation of mercury in gold extraction, among others (MICARONI; BUENO & JARDIM, 2000; LACERDA & MALM, 2008).

Pollution caused by Mercury is a worldwide problem related to inadequate mining practices, causing intense environmental impacts and the health of workers exposed to this metal. Miners use mercury to collect concentrates in the form of an amalgam and recover the metallic gold by burning it, volatilizing the mercury, which is carried by the wind and then precipitates. The lack of technical-operational knowledge of this process and the lack of culture for recycling mercury, combined with the relatively low cost of the liquid metal, causes large quantities of mercury to be released into the soil, water and air (TUTUNJI; DE-PAULA & LAMAS-CORRÊA, 2008).

Mining can also morphologically damage the original form of the soil, eliminate vegetation and siltation of water courses, generating waste containing metallic mercury. Poor land use can also increase mercury methylation levels. Erosion can transport the metal to the water table, contaminating it. So, abiotic factors, such as pH, electrical conductivity, oxygen availability, temperature, as well as biotic factors such as biological activities and nutrient concentrations, among others, are important in the processes of organization of mercury and other heavy metals in soil and water (TUTUNJI; DE-PAULA & LAMAS-CORRÊA, 2008).

One of the widely used and dangerous methods in gold extraction is dredging. This process takes place using pumps measuring 5 to 12 inches in diameter, sucking gravel from a depth of up to 30m. This procedure can be carried out using lances, which are pipes with a system of cutting heads that allow penetration into the hard crusts at the bottom of rivers, or by divers (TUTUNJI; DE-PAULA & LAMAS-CORRÊA, 2008).

Submarine workers, as they are popularly called, spend more than 4 hours submerged holding gravel pulp suckers. Due to low visibility, fatal accidents caused by underwater slopes collapsing are frequent. Also frequent are the cuts of air supply to divers by opponents, who seek the points with the highest concentration of gold in the rivers (TUTUNJI; DE-PAULA & LAMAS-CORRÊA, 2008).

Another very relevant factor in this gold extraction process are the environmental consequences that the methods used, such as dredging, and their high levels of mercury contamination, environmentally affect the course of rivers, and consequently the bodies of people who work directly with This method indirectly affects people who live around rivers, and end up becoming contaminated with: water, soil, crops and fish contaminated and consumed by the population (AGROAMBIENTE, 2023).

Faced with the need to select plant species capable of carrying out phytoremediation of contaminated soils, several groups of plants are being researched and have been obtaining promising responses as phytoremediation agents for petroleum-derived contaminants. The groups include: grasses, legumes, vegetables, arboreal species and several other monocotyledons and eudicots (CUNNINGHAM et al., 1996; MERKL et al., 2004; HYNES et al., 2004; HUANG et al., 2005; ZULFAHMI et al., 2021. All In DE SOUZA, 2021).

Although this phytoremediation technique has limitations such as a long decontamination time, it is economically viable and is an excellent use of natural resources. It requires efforts to go beyond the laboratory scale and reach the fields (AGROAMBIENTE, 2023).

CONCLUSION

This chapter revisited an old experiment that tried to evaluate elicitors for the germination of *Vigna unguiculata* (Cowpea): the plant extract of *E. tirucalli*, the ultra-diluted and dynamized solution of *Sulfur 5CH* and the two in combination. At that time, due to the results, the participation of the sodium/potassium pump, detoxifying enzymes from the thiol group and the suggestive participation of the nitrogenous route of oxidative stress were discussed, with an increase in abiotic factors and cyanuric acid in similar hydroponic solutions where the Cowpea was cultivated, and the potential phytoremediation effect for herbicides in the soil was questioned.

With the literature showing the association of the thiol group with mercury, as a perspective of a mechanism for phytoremediation, allowing the removal of mercury from contaminated soil and water sources, in addition to showing that very few plant species have this ability. Based on the figure and diagram drawn up by environmental engineer Alexandre Pereira, this potential was considered for the succulent species studied, *E. tirucalli*, with the likely mechanism being re-discussed, considering the participation of the dairy ducts as capable of extracting and even bioaccumulating pollutants, in this case, mercury, since biotransformation was observed in this species from phytovolatilization that caused inhalation poisoning of researchers from an odorless substance.

To conclude, this seems to be a viable mechanism to be investigated in future trials for the cultivation of *Vigna unguiculata* with micropropagated *Euphorbia tirucalli* extratus in water, this time, to be carried out in partnership with agricultural, agronomic (phytosanitary) and environmental engineering, aiming through from research into phytoremediation, the interdisciplinary promotion of environmental health.

REFERENCES

1. AGROAMBIENTE. Phytoremediation. Recuperado de <https://agroambiente.com.br/fitoremediacao-as-plantas-que-limpam-o-planeta/>
2. BESSA, G., MELO-REIS, P. R., ARAÚJO, L. A., MRUÉ, F., FREITAS, G. B., BRANDÃO, M. L., & SILVA JÚNIOR, N. J. (2015). Angiogenic activity of latex from *Euphorbia tirucalli* Linnaeus 1753 (Plantae, Euphorbiaceae). *Brazilian Journal of Biology*, 75(3), 752-758. <https://doi.org/10.1590/1519-6984.01214>
3. BINCKLEY, S., & ZAHRA, F. (2023, janeiro). *Euphorbia tirucalli*. StatPearls. PMID: 34662040. ID estante: NBK574526.
4. BISINOTI, M. C., & JARDIM, W. F. (2004, Aug). The behavior of methylmercury (methylHg) in the environment. *Química Nova*, 27(4), 593-600.
5. CAMPOS, S. C., SILVA, C. G., CAMPANA, P. R. V., & ALMEIDA, V. L. Toxicity of plant species. *Rev. bras. med plants*. 18(1 suppl 1), 2016. https://doi.org/10.1590/1983-084X/15_057
6. DAMAS, G. B., BERTOLDO, B., & COSTA, L. T. (2014). Mercury: from Antiquity to Nowadays. *Virtual Journal of Chemistry*, 6(4), 1010-1020.
7. DE SOUZA, B. G. (2021). PHYTORREMIATION OF DIFFERENT SOIL CONTAMINANTS. Tese de curso, Instituto Federal Goiano – Câmpus Rio Verde. Recuperado de <https://repositorio.ifgoiano.edu.br/bitstream/prefix/1882/3/TCC%20FINALof.pdf>
8. ECYCLE. (n.d.). What is mercury and what are its impacts? Recuperado de <https://www.ecycle.com.br/mercurio/>
9. FRANCO-SALLA, G. B., PRATES, J., CARDIN, L. T., DOS SANTOS, A. R. D., SILVA, W. A. da JR., da CUNHA, B. R., ... RODRIGUES-LISONI, F. C. (2016). *Euphorbia tirucalli* modulates gene expression in larynx squamous cell carcinoma. *BMC Complementary and Alternative Medicine*, 16(1). <https://doi.org/10.1186/s12906-016-1115-z>
10. GASPAR, S. A., GUALBERTO, M. J. V., & VARRICCHIO, M. C. B. N. (2017, maio). Germination of *Vigna unguiculata* with ultra-diluted and energized solutions. *INFO-SAPB Magazine*, 1(1). Recuperado de https://sites.google.com/view/lipat/sapb-revista_info-sapb#h.p_Ao3lwclpMYL6
11. GASPAR, S. A., MUSMANNO, P. G., BELLIZZI, G. M., KATHAR, K. R., VARRICCHIO, M. T., VARRICCHIO, M. C. B. N., ... BRIOSO, P. S. T. (2023, jun). Environmental and Economic Values of salt tolerance. *Euphorbia tirucalli*: Phytoremediation potential. *International Journal of Advanced Engineering Research and Science (IJAERS)*, 10(6). <https://doi.org/10.22161/ijaers.106.5>
12. GASPAR, S. A., WENDLING da SILVA, A. V., GORINI, C. C., ... BOLOGNANI, F. de A. (2024). Sustainability and Environmental Ethics (from the environmental primer to the intercultural garden). *Contemporary Journal of Ethics and Politic Phylosophy*, 4(2), 01-48. DOI: 10.56083/RCV4N2-103. Recuperado de <https://ojs.revistacontemporanea.com/ojs/index.php/home/article/view/3407>
13. GASPAR, S. A., RAMOS SILVA, I. DE S., BELLIZZI, G. M., GOMES, N. B. N., BOLOGNANI, F. DE A., CASTELO BRANCO, M. T. L., ... VARRICCHIO, M. C. B. N. (n.d.). Environmental ethics at na intercultural Garden (Scientific initiation in sustainability). *Em Exploring the Field*


14. HANSEL - MARTINS, C., BOLOGNANI, F. de A., BENTES LOPES, J., PYRRHO, A. dos S., & VARRICCHIO, M. C. B. N. (2023). Endocrine Disruptors, Mental Disorders: Strategies in Environmental Health. *Foco Magazine*. Recuperado de <https://ojs.focopublicacoes.com.br/foco/article/view/2861>
15. HANSEL-MARTINS, C., MUSMANNO, P. G., BELLIZZI, G. M., GASPAR, S. A., BOLOGNANI, F. de A., KUSTER, R. M., ... VARRICCHIO, M. C. B. N. (2024). Medicinal intercultural plant garden: Homeopathy and Phyto-nutritional care. *Revista Contribuciones a Las Ciencias Sociales*, 17(1), 6173-6188. <https://doi.org/10.55905/revconv.17n.1-371>
16. ILLAH – INSTITUTE OF HEALTH AND EDUCATION. (n.d.). Pure Materia Medica - Hahnemann. Recuperado de <https://illah.com.br/wp-content/uploads/2019/02/Materia-Medica-Pura-Hahnemann.pdf>
17. KATHAR, K. R., WASIM, N., DA SILVA, S., PYRRHO, A. DOS S., & VARRICCHIO, M. C. B. N. (2023, Apr). CONSTRUCTED WETLANDS: TECHNOLOGY FOR REMOVING DRUG CONCENTRATION FROM WATER. *International Journal of Advanced Engineering Research and Science (IJAERS)*, Issue-4. <https://doi.org/10.22161/ijaers.104.13>
18. KEHRIG, H. A. et al. (2011). Bioconcentration and biomagnification of methylmercury in Guanabara Bay, Rio de Janeiro. *Química Nova*, 34(3), 377-384.
19. LACERDA, L. D., & MALM, O. (2008). Mercury contamination in aquatic ecosystems: an analysis of critical areas. *Study. av.*, 22(63), 173-190.
20. LE, N. T. M., CUONG, D. X., VAN THINH, P., MINH, T. N., MANH, T. D., DUONG, T.-H., ... OANH, V. T. T. (2021). Phytochemical Screening and Evaluation of Antioxidant Properties and Antimicrobial Activity against *Xanthomonas axonopodis* of *Euphorbia tirucalli* Extracts in Binh Thuan Province, Vietnam. *Molecules* (Basel, Switzerland), 26(4). <https://doi.org/10.3390/molecules26040941>
21. LIMA, M. F. R. (2019). Chemical and biological prospecting of species collected in the Caatinga: *Euphorbia tirucalli*, *Bredemeyera floribunda* and *Bredemeyera brevifolia*. Tese de Doutorado, Universidade Federal do Rio Grande do Norte.
22. MACHADO, M. M., OLIVEIRA, L. F. S. de, ZURAVSKI, L., SOUZA, R. O. de, FISCHER, P., DUARTE, J. A., ROCHA, M. O., GÜEZ, C. M., BOLIGON, A. A., & ATHAYDE, M. L. (2016). Evaluation of genotoxic and cytotoxic effects of hydroalcoholic extract of *Euphorbia tirucalli* (Euphorbiaceae) in cell cultures of human leukocytes. *Anais Da Academia Brasileira de Ciencias*, 88(1). <https://doi.org/10.1590/0001-3765201520140076>
23. MALI, P. Y., & PANCHAL, S. S. (2017). *Euphorbia tirucalli* L.: Review on morphology, medicinal uses, phytochemistry and pharmacological activities. *Asian Pacific Journal of Tropical Biomedicine*, 7(7). <https://doi.org/10.1016/j.apjtb.2017.06.002>
24. MICARONI, R.C.C.M., BUENO, M.I.M.S., & JARDIM, W. F. (2000). Mercury compounds. Review of determination, treatment and disposal methods. *Química Nova*, 23(4), 487-495.

25. MOLIN, G. T. D., CAVINATTO, A. W., & COLET, C. (2015). Use of medicinal plants and herbal medicines by patients undergoing chemotherapy at an oncology center in Ijuí/RS. *Mundo Da Saude* (1995), 39(3), 287–298. <https://doi.org/10.15343/0104-7809.20153903287298>
26. MOTOO, Y., YUKAWA, K., HISAMURA, K., & ARAI, I. (2022). Pharmacists' perspectives on traditional, complementary, and integrative medicine in Japan with special reference to Kampo medicines: an internet survey with preliminary interviews. *Journal of Pharmaceutical Health Care and Sciences*, 8(1). <https://doi.org/10.1186/s40780-022-00238-x>
27. MOTA, L. A. da, PEREIRA, D. T. M., ASSIS, M. E. S., MARQUES, S. B., & SILVA, B. B. da. (2022). Ethnopharmacology of medicinal plants used by the rural and riverside population of the municipality of Itacoatiara-AM. *Research, Society and Development*, 11(5). <https://doi.org/10.33448/rsd-v11i5.27735>
28. MUNRO, B., VUONG, Q., CHALMERS, A., GOLDSMITH, C., BOWYER, M., & SCARLETT, C. (2015). Phytochemical, antioxidant, and anti-cancer properties of *Euphorbia tirucalli* methanolic and aqueous extracts. *Antioxidants* (Basel, Switzerland), 4(4). <https://doi.org/10.3390/antiox4040647>
29. NAGAMATSU, D., HOBAICA, P. E. M., VARRICCHIO, M. T., PYRRHO, A. dos S., CASTELO BRANCO, M. T. L., & VARRICCHIO, M.C.B.N. (2019). *Geopharmacobotany Iii: Semiological Aspects, Toxicology, Bioproducts Of EUPHORBIA tirucalli*. RJ: Edition Marcia C.B.N. Varricchio. Available at <https://sites.google.com/view/lipat/sapb-livros>
30. PALHARINI, J. G., RICHTER, A. C., SILVA, M. F., FERREIRA, F. B., PIROVANI, C. P., NAVES, K. S. C., ... & SANTIAGO, F. M. (2017). Eutirucallin: A Lectin with Antitumor and Antimicrobial Properties. *Frontiers in Cellular and Infection Microbiology*, 7. <https://doi.org/10.3389/fcimb.2017.00136>
31. PEREIRA, A. R. (2022). Native Brazilian plant species with metal phytoremediation potential [electronic resource]: A literature review. Course Completion Work - Graduation in Environmental Engineering from the Institute of Agricultural Sciences at the Federal University of Uberlândia.
32. GREEN THOUGHT EDITORIAL. (2018). Understand what pioneer species are and their importance in the recovery of degraded areas. Available at: <https://www.pensamentoverde.com.br/meio-ambiente/entenda-o-que-sao-especies-pioneiras-e-sua-importancia-na-recuperacao-de-areas-degradadas/>
33. RIBEIRO, H. (2004). Public Health and environment: evolution of the knowledge and the practice, some ethical aspects. *Saude Soc.* 13(1). <https://doi.org/10.1590/S0104-12902004000100008>
34. RIBEIRO, G. D. (2010). Some plant species grouped by families and their properties. Porto Velho, RO: Embrapa Rondônia. Available at: <https://ainfo.cnptia.embrapa.br/digital/bitstream/item/54453/1/livro-plantastropicais-2.pdf>
35. ROCHA, A. F. (2008). Cadmium, Lead, Mercury – The problem of these heavy metals in Public Health. Monograph (Specialization) - Nutrition and Food Course, University of Porto, Porto, 2009.
36. SILVA, V. A. O., ROSA, M. N., TANSINI, A., MARTINHO, O., TANURI, A., EVANGELISTA, A. F., CARLONI, A. C., LIMA, J. P., PIANOWSKI, L. F., & REIS, R. M. (2019). Semi-synthetic ingenol derivative from *Euphorbia tirucalli* inhibits protein kinase C isoforms and promotes

autophagy and S-phase arrest on glioma cell lines. *Molecules* (Basel, Switzerland), 24(23), 4265. <https://doi.org/10.3390/molecules24234265>

37. TUTUNJI, V. L., DE-PAULA, V. G., & LAMAS-CORRÊA, R. (2008). Mining and mercury: environmental impacts and human health. *Universitas: Health Sciences*, 4(1), 101-110.
38. VARRICCHIO, M.C.B.N., DIREITO, I.C.N., MOREIRA, C.B., EMMERICH, V., MORENO, G., PEREIRA, C., ARAÚJO, B.E., SALES, M.D.C., CASTELO BRANCO, M.T.L., HOLANDINO, C., & KUSTER, R.M. Qualitative evaluation of the production of *Euphorbia tirucalli* diterpenoids (aveloz) under controlled conditions for medicinal purposes. *Revista Anais da FERTBIO/EMBRAPA CENTRO-OESTE*, 20-24. September 2006.
39. VARRICCHIO, M.C.B.N. (2008). *Euphorbia tirucalli* L.: Special Metabolites, Biotechnology, Toxicology, Antitumor and Adaptogenic Activities. Doctoral thesis, Postgraduate Program in Plant Biotechnology, Federal University of Rio de Janeiro.
40. VARRICCHIO, M.C.B.N. et al. (2008). *Euphorbia tirucalli*: qualitative analysis of plant development during in vitro cultivation. *Revista de Biologia e Farmácia*, 3(1), 53-65.
41. VARRICCHIO, M.C.B.N. (n.d.). REVIEW STUDY: PURE PATHOGENETIC EXPERIMENTATION SUD 30CH BLACK MERCURY OXIDE. *VITAE* (9)- Homeopathy Service Support Magazine Santa Casa Da Misericórdia General Hospital – RJ 7th Ward.
42. VEIGA, J. B., & SCUDELLER, V. V. (2015). Ethnobotany and folk medicine in the treatment of malaria and associated illnesses in the Julião riverside community – lower Rio Negro (Central Amazon). *Brazilian Journal of Medicinal Plants*, 17(4 suppl 1), 737–747. https://doi.org/10.1590/1983-084x/14_039

Impact of the Charitas-Cafubá tunnel on vehicle travel time

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ABSTRACT

One of the objectives of the Charitas-Cafubá Tunnel is to reduce travel time on the way to the city center of Niterói or the city of Rio de Janeiro. To measure the impact of the tunnel, a comparison of the travel time and vehicle flow of the current two existing routes after the construction of the tunnel with the single previous route was conducted. The results indicated that the travel time between the two alternatives after the construction of the tunnel approaches an equilibrium, both with a shorter travel time than the previous one. However, there was an increase in the total number of vehicles at the point of convergence between the routes. By analyzing the section after the convergence point, it is concluded that the reduction in the initial travel time provided by the Tunnel is counterbalanced by the increase in travel time in the segment after the convergence of the current routes.

Keywords: Urban mobility, Traffic engineering, Transport planning.

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INTRODUCTION

One of the main challenges of large cities is to provide conditions for the safe and efficient movement of people and vehicles. It is the job of public agencies to implement measures to mitigate congestion. Among the solutions indicated by the experts are the investment in public transport so that there is an increase in supply and operates with a level of service that meets the demand of the population. In this way, investing in quality public transport implies improving urban mobility.

However, there is a thought that one of the solutions adopted to solve the problems of congestion is the creation of new roads or the expansion of existing ones. However, studies highlight (Hansen and Huang, 1997; *Surface Transportation Policy Project*, 1998) that these actions do not reduce traffic, on the contrary, in the long run they tend to increase it. Stanley and Spivak (1993) indicate that there is an existing demand (on average 30% of the current traffic on the road) restricted by the fact that drivers do not use the vehicles due to congestion, such that adding a new lane will induce these drivers to use the automobile.

Therefore, before choosing the creation of a new road as a solution, extensive studies are needed to evaluate the characteristics of the current road system, because with the reduction of travel time, the motivation to use private transport is greater and travel time can increase again. If the studies are superficial, the scenario may still arise where the expected demand is not reached, leaving the road underutilized and not generating the expected benefits of the investment.

The objective of this work is to evaluate the impacts of the construction of the Charitas – Cafubá Tunnel on traffic in the region of the city of Niterói. Travel times and flows of vehicles found to travel two different routes from the same place of departure and arriving at the same point at the destination will be analysed. The first route, already in existence before the construction of the tunnel, starts at the place called "Trevo do Cafubá" to the Raul Veigas Tunnel, where drivers can choose between going to the center of Niterói or to Rio de Janeiro. The second, between the same "Clover", but now following the new Charitas – Cafubá Tunnel, bound for the same end point as the previous route, the Raul Veigas Tunnel.

The data prior to the construction of the tunnel were obtained from a technical feasibility study carried out by the city of Niterói, where, among other information, there are vehicle counts at certain points and the travel time required to travel specific stretches on some roads. Traffic volume data after the construction of the tunnel were collected through field research, at the same points used in the feasibility study, while travel time data were obtained through the tool available on Google *Maps*.

WARDROP EQUILIBRIUM THEORY

Techniques for distributing the flow of vehicles in a transport network emerged in the 1950s. In general, these techniques basically seek to follow two principles defined by Wardrop (1952). In the first of them, the author points out that in road networks in which the user can choose between two or more different routes to make a trip of common origin and destination, the travel time for all routes converges to the same value, lower than that of any other route not commonly used. In his publication, he argues that this principle is close to what has been tried in practice by assuming that traffic tends to settle into a situation of equilibrium in which the user always tries to reduce the cost and travel time by choosing a new route. This theory became known as the 1st Principle of Wardrop.

The Second Principle, also known as the Optimal System or altruistic Wardrop equilibrium, is based on the idea that car drivers would choose the route to their destination that would be best for all drivers in order to optimize the flow of the available road system in such a way that the overall average travel time of all drivers is minimal.

When dealing with the relationship between the Wardrop Principles and user behavior, Holden (1989) highlighted the possibility that in the future, electronic devices would provide information in real time, and this would affect route choices and consequently the entire behavior of the road system. The author indicates that one of the possible changes suffered in the transport network would be the occurrence of the *rat-runs phenomenon*, used to describe when drivers start to use roads with less capacity to avoid the congestion of the main roads.

Another impact of travel time and real-time traffic conditions tools, such as *Global Positioning System* (GPS) devices, mobile applications such as *Waze* or *Google Maps*, the time for Wardrop balancing to happen tends to be shorter. By instantly showing the fastest route between the source and the destination desired by the user, such tools shorten the time that would be spent by the user for system recognition with the availability of a new route. According to Holden (1989), this process could take up to months to define which route is faster and more convenient to your destination.

CHARACTERIZATION OF THE REGION

The city of Niterói is located to the east of Guanabara Bay, which along with 21 other municipalities, makes up the Metropolitan Region of Rio de Janeiro. Data from the Brazilian Institute of Geography and Statistics (IBGE, 2018) show that the population increased from 487,562 in 2010 to 499,028 inhabitants in 2017.

Until December 2017, Niterói's fleet was estimated at 290,824 vehicles (Detran-RJ, 2018), of which 207,668 are automobiles, 33,920 motorcycles and 2,799 buses. Relating these values to the population of the municipality, the Motorization Rate is 482 cars per 1000 inhabitants, higher than

the rate of the southeast region, which has 363 vehicles per 1000 inhabitants (Observatório das Metrópolis, 2015). The average salary income of the municipality estimated by the census carried out in 2010 by the IBGE (2018) is R\$2,303.46, which places the city at the top of the list of per capita income among Brazilian cities in that year's study.

The city has 51 neighborhoods, subdivided into 5 regions: Beaches of the Bay, North, East, Oceanic and Pendotiba, as shown in the map in Figure 1, and has municipal and intercity bus systems, ferries that connect Niterói to the city of Rio de Janeiro, through the stations of Araribóia, located in the center of Niterói and the catamaran station in Charitas, located in the Beaches of the Bay Region.

With facilities that facilitate access to Rio de Janeiro through ferries and the Presidente Costa e Silva bridge, a significant portion of the population of Niterói works in the State Capital (PDTU, 2015). However, residents of neighboring municipalities who work in Rio de Janeiro also use these alternatives to reach the capital, through the access roads to the bridge, and to the Barcas station at Praça Araribóia in downtown Niterói. Figure 2 marks the territory of Niterói, highlighting the main routes between the Oceanic Region and the city of Rio de Janeiro available to users before the construction of the Charitas-Cafubá Tunnel.

Figure 1: Regional division of the City of Niterói



Source: Department of Urbanism and Mobility of Niterói (2018)

Figure 2: Access roads between Região Oceânica and Rio de Janeiro



Source: Sinergia (2013)

THE CHARITAS – CAFUBÁ TUNNEL

The Charitas – Cafubá tunnel is part of the Transoceanic Road Corridor project, which is 11.2 km long, of which 1.35 km correspond to the tunnel. According to the Environmental Impact Report of the Transoceanic Road Corridor (2013), the main objective of the Transoceanic Highway project in Niterói is to improve the mobility of citizens and the connection with the center of Rio de Janeiro. To enable the integration of the Transoceanic Road Corridor with the Charitas Waterway Terminal, the Charitas-Cafubá Tunnel was built, allowing the reduction of travel time between the Oceanic Region and the center of Rio de Janeiro.

Due to the mountainous relief that separates the Oceanic Region from the Beaches of the Bay Region, the construction of the tunnel was the solution found to connect the neighborhoods of Charitas (Beaches of the Bay Region) to Cafubá (Oceanic Region), as shown in Figure 3.

Figure 3: Location of the Charitas – Cafubá Tunnel



Source: Google Maps (2018)

The tunnel has two galleries with a length of 1350 meters. Each with two asphalt pavement lanes, a concrete lane for the bus systems and a bike lane that will use an auxiliary lane. One of the factors for choosing the location of the tunnel is the proximity of the Charitas landslide to the Charitas Waterway Station (Transoceânica Niterói, 2018), as shown in Figure 4.

The operation of the tunnel is carried out through 40 cameras, 6 variable message panels, 6 control panels, 80 emergency telephones and an exhaust system with 16 high-capacity fans according to Transoceânica Niterói (2018).

Figure 4: Entrance to the Tunnel through the Charitas neighborhood

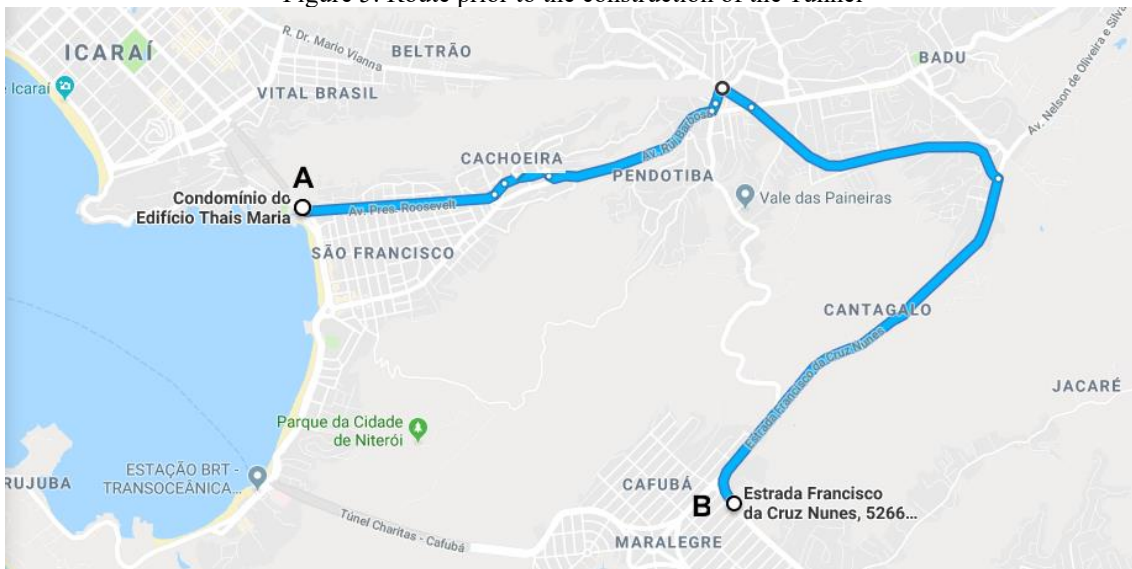


Source: Google Maps (2018)

TRAFFIC CONDITIONS PRIOR TO TUNNEL CONSTRUCTION

Before the completion of the Charitas-Cafubá Tunnel, the path commonly used by users moving from the Oceanic Region towards the Bay Beaches Region was using the Francisco da Cruz Nunes Road (Point "B" of Figure 5), following until reaching Presidente Roosevelt Avenue (Point "A" of Figure 5). In this place, the user can go to the neighborhood of Charitas to have access to the center of Rio de Janeiro through the Catamaran station, or head towards the center of Niterói, through the Raul Veigas Tunnel, having access to the neighborhoods of the Bay Beaches Region, the commercial area in the center, the Presidente Costa e Silva Bridge, and the ferry station located in Araribóia square, in the city center.

Figure 5: Route prior to the construction of the Tunnel



Source: Google Maps (2018)

The route described in Figure 5 has sections with a number of lanes ranging from 1 to 3 per direction. The route has a height variation of 158 meters, making it difficult for heavy vehicles to make the route on a ramp due to the slope. The length of the highlighted section is 8,900 meters.

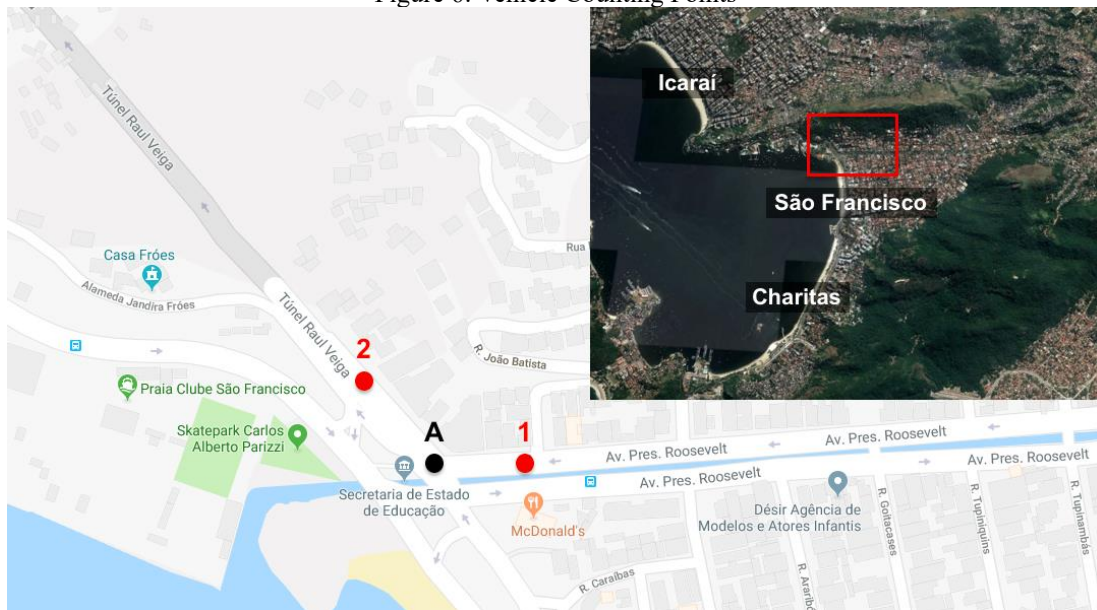
In the demand study carried out to evaluate the feasibility of the construction of the Transoceanic Way (Sinergia 2013), the results of traffic volumes and travel time on the main roads from Monday to Friday, during the morning (7:00 am to 9:00 am) and afternoon (5:00 pm to 7:00 pm) peak hours, were presented. Table 1 shows the volumetric count in the direction of the highest flow (towards the Praias da Baía region) and the points where the counts were made are marked in Figure 6, where point number 1 marks the point of volumetric counting made on Av. President Roosevelt, and point 2 marks the counting point before the entrance to the Raul Veiga Tunnel.

2782

Point	Local	Direction	Private Vehicles	Bus	Motorcycles	Total
1	Av. Presidente Roosevelt	B to A	1548	73	138	1758
2	Túnel Raul Veiga	B to A	2390	149	243	2782

Source: Sinergia (2013)

Figure 6: Vehicle Counting Points



Source: Google Maps (2018)

The average travel time over a period of one week, in the morning (direction from B to A) and afternoon (direction from B to B) peak hours, for the stretch used to connect the Oceanic region to the Bay Beaches Region before the completion of the Charitas-Cafubá Tunnel is shown in Table 2.

Direction	Travel Time (min)
B to A	18,43
A to B	10,8

Source: Sinergia (2013)

SCENARIO WITH THE TUNNEL

After 1 year and 6 months from the beginning of the work, on May 6, 2017 the tunnel was opened to users, even with the bus system of the Transoceanic Road Corridor still inoperative. With the inauguration, a second option is provided for access to the Oceanic Region, with the aim of alleviating the flow of vehicles on the existing road. According to Transoceânica Niterói (2018), in the first 6 months of operation, more than 5.3 million vehicles crossed the Charitas - Cafubá Tunnel, with an average of 40 thousand vehicles per day and 1600 vehicles per hour.

Figure 7: Available routes for the route



Source: Google Maps (2018)

Figure 7 shows the new route section made possible by the Charitas – Cafubá Tunnel (Section 2) and the existing route before the construction of the tunnel (Section 1). Points "A" and "B" mark the places where vehicles to and from the Oceanic Region are divided between the path prior to the construction of the Tunnel and the new route. The connection between the two points through "Section 1" is 8,900m long and the path through "Section 2" is 6,000m.

IMPACT ON TRAVEL TIME

In order to compare the travel time to travel the same route after the construction of the tunnel, data regarding the travel time to complete the route were collected through Google Maps. The method adopted was the same as Sinergia (2013), an average of the 5 days of the week, considering the direction from A to B in the morning peak and from B to A in the afternoon peak. The results are shown in Table 3.

Direction	12.8 Average Travel Time (min)		
	Before Tunnel Construction		After Tunnel Construction
	Excerpt 1	Excerpt 1	Excerpt
A to B	10.8	10.6	11.4
B to A	18.4	16.0	12.8

The average travel time for private vehicle users from point "B" to point "A" through the tunnel (Section 2) during the morning peak is 12.8 minutes. The average time for "Section 1" is 16 minutes, close to the time indicated by the Synergy report (2013), of 18.4 minutes. These values indicate that in the morning rush hour the flow of vehicles has a greater impact on section 1 than on section 2, in such a way that through the tunnel there is a time gain of 20%.

In the direction from A to B by the new path generated by the tunnel, despite presenting a shorter distance and inclination of the track to be overcome by the automobiles, the travel time was close to that executed before by the old route (Section 1). Even with a difference in the length of the route of 32.5%, the travel time of both is closer. One of the factors for this time to be close is that the flow during the morning peak (from 7 to 9 am) is greater compared to the flow in the afternoon peak hours, as the latter is diluted throughout the end of the day, without forming large retentions in the accesses between the regions studied. In this sense, for the analysis of the increase in flow, the direction of greater flow of vehicles that travel between the regions during the morning peak was considered.

IMPACT ON VEHICLE FLOW

The data regarding the flow of vehicles after the construction of the tunnel were obtained through volumetric counts carried out between April 23 and 27, 2018, during the morning peak (B to A), at the access points of the Oceanic Region to the Beaches of the Bay region. The counting points were chosen because they are the same as the counting made by the company Sinergia in the feasibility study of the Transoceanic Road Corridor. For this, a manual volumetric count of traffic was carried out on Av. President Roosevelt (Point 1 of Figure 6) and the Raúl Veiga Tunnel (Point 2 of Figure 6).

Local	3144 Vehicle Flow (vehicles/hour)	
	Before Tunnel Construction	After Tunnel Construction
Túnel Charitas-Cafubá	-	1348
Av. Presidente Roosevelt	1758	1228
Túnel Raul Veiga	2782	3144

When comparing the total number of vehicles per hour that passed through the Raul Veiga tunnel before and after the construction of the tunnel, it was recorded that the number of vehicles per hour increased by 13%, from 2782 to 3144 vehicles per hour. The data in Table 4 show that the number of vehicles per hour that use the Charitas - Cafubá Tunnel in the direction of downtown Niterói or Rio de Janeiro during the morning rush hour, exceeded the flow of vehicles that arrived at point A through Av. President Roosevelt.

Thus, the travel time from B to A and the division of flows between the two routes after the tunnel is opened to traffic, indicate that the travel times of Sections 1 and 2 are in the process of equilibrium. Therefore, as indicated by Wardrop (1952), the flow of vehicles using the fastest route will continue to grow until the time spent by users in congestion and traffic when using "Stretch 2" will result in a travel time close to that experienced by users on "Stretch 1".

It is possible to see that the travel times of the routes fluctuate according to the different divisions of the flow. According to Wardrop (1952), the variable with the greatest impact on the decision of road users in route choices is the travel time of each one, that is, the driver tends to choose the fastest one, even if it has a longer length. Therefore, users' route choices will oscillate between the two alternative paths until an equilibrium point where the travel time tends towards the same value.

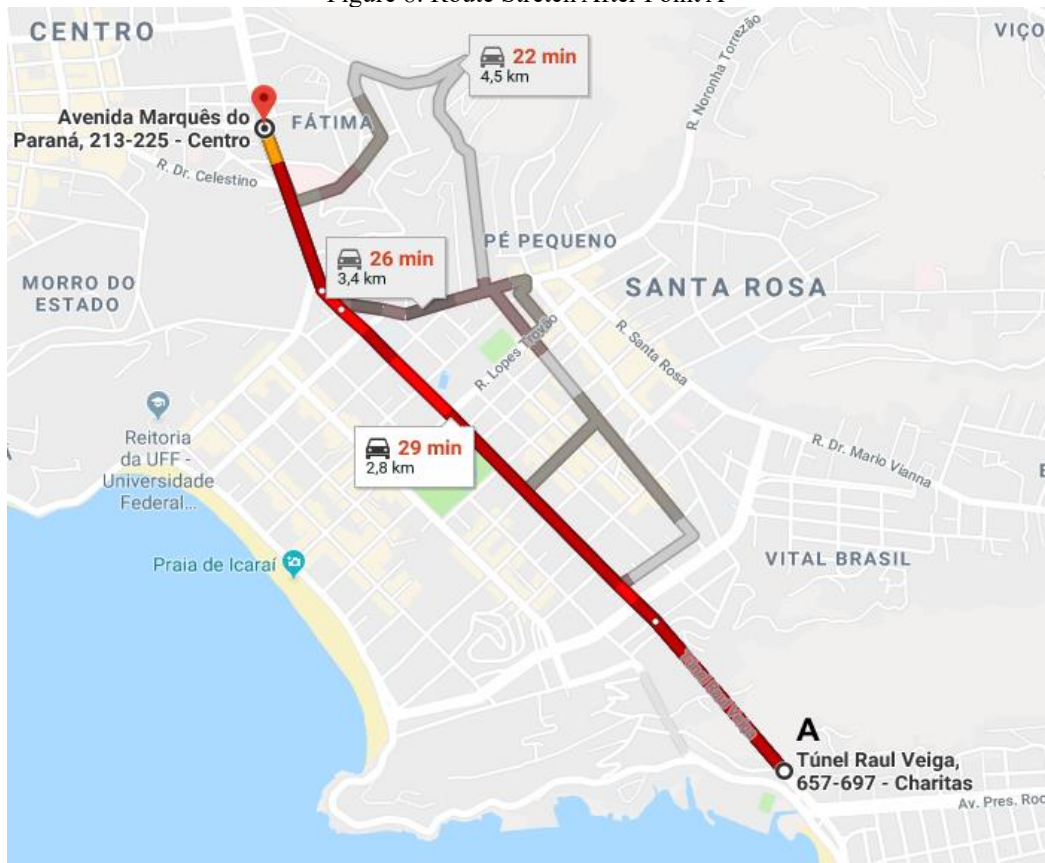
Although the travel time of the two sections is reduced compared to Section 1 in the scenario prior to the construction of the Charitas – Cafubá Tunnel, this gain in travel time may be lost in the section after the convergence of the two paths that occurs at "Point A" (Figure 6), as the flow of vehicles that passed through the two routes join again and this total flow follows the Raul Veiga Tunnel.

IMPACT ON TRACKS AFTER CONVERGENCE

This increase in the number of vehicles accessing the Raul Veiga Tunnel during the morning peak reflects on the flow of adjacent roads, as they have not undergone any intervention such as increasing the number of lanes, changing traffic lights or implementing reversible lanes to increase capacity to accommodate the increase in demand. Therefore, this additional flow of vehicles tends to aggravate traffic on the roads after the convergence of routes and, consequently, increases travel time on this stretch.

Therefore, the reduction in travel time provided by the division of the flow of vehicles from the Oceanic Region between two alternative stretches for the route to the Bay Beaches Region is compensated by the increase in travel time on the stretch following "Point A", on the route to the center of Niterói or Rio – Niterói Bridge. as shown in Figure 8, where to cover a 2.9 km stretch, 29 minutes are needed in the morning peak, while data from Sinergia (2013) for this same stretch indicated 20 minutes. In the same Figure it is possible to observe the *rat-run* phenomenon, where adjacent streets, with characteristics of local roads, are also used by drivers, considering that it takes approximately the same time as the main road to make the journey.

Figure 8: Route Stretch After Point A



Source: Google Maps (2018)

CONCLUSIONS

Through the new route generated by the construction of the Charitas Cafubá Tunnel, a new alternative has emerged for drivers to make the trip. The travel time of the available routes converges to the same value, according to the First Principle of Wardrop. The total number of vehicles that started to travel after the implementation of the tunnel increased by 13%, indicating that the increase in capacity implies an increase in traffic.

This increase caused a reflection on the travel time on the roads after the meeting between the flows of Sections 1 and 2 in the direction of the Oceanic Region to the Beaches of the Bay Region. This counterbalanced the reduction in travel time initially provided, at first, by dividing the flow of vehicles from the Oceanic Region between two alternative stretches for the route to the Bay Beaches Region.

The study detected values indicating that just offering a new route does not necessarily imply a gain in travel time as a whole, as there is an increase in the number of vehicles attracted by the initial reduction in the time to complete the route. In this sense, without the migration of users from private transport to public transport, the opening of a new path connecting the Oceanic Region with the Bay Beaches Region, does not reduce the travel time between the main points of attraction (downtown Niterói and the City of Rio de Janeiro), and the reflection caused by the opening of the




tunnel can be perceived in a negative way by users of the road system of Niterói. in view of the worsening of traffic on the stretch after the Raul Veiga Tunnel.

The success of the Charitas - Cafubá Tunnel in improving mobility in the transportation system by reducing the flow of vehicles circulating in the region during peak hours will depend on the success of the Transoceanic Road Corridor in promoting integration with the Charitas Waterway Terminal, connecting the region served by the road corridor with downtown Rio de Janeiro and through the implementation of a bus system that uses an exclusive lane within the tunnel.

REFERENCES

1. DETRAN. (2018). Estatísticas – Frotas por tipo de veículo – Niterói. Departamento de Trânsito do Estado do Rio de Janeiro (DETRAN-RJ). Disponível em: <http://www.detran.rj.gov.br/_estatisticas.veiculos/02.asp>. Acessado em 10 de março de 2018.
2. Hansen, M. & Huang, Y. (1997). Road supply and traffic in California urban areas. *Transportation Research Part A: Policy and Practice, 31*(3), 205-218.
3. Holden, David J. (1989). Wardrop's Third Principle – Urban Traffic Congestion and Traffic Policy. *Journal of Transport Economics and Policy*, Londres, p.239-262.
4. IBGE. (2018). Panorama da cidade de Niterói – Rio de Janeiro. Instituto Brasileiro de Geografia e Estatística. Disponível em: <<https://cidades.ibge.gov.br/brasil/rj/niteroi/panorama>>. Acesso em: 15 de janeiro de 2018.
5. Observatório das Metrôpoles. (2015). Estado da Motorização Individual no Brasil: Relatório 2015. Disponível em: <http://www.observatoriodasmetrolopes.net/download/automoveis_e_motos2015.pdf>. Acesso em: 15 de fevereiro de 2018.
6. PDTU. (2015). Plano Diretor de Transporte da Região Metropolitana do Rio de Janeiro. Secretaria Estadual de Transportes.
7. RIMA. (2013). Relatório de Impacto Ambiental do Corredor Viário Transoceânica - Niterói. Secretaria do Meio Ambiente da cidade de Niterói.
8. Sinergia. (2013). Relatório Final Volumes 1, 2 e 3 - BHLS Transoceânica. Niterói. Sinergia Estudos e Projetos LTDA.
9. Surface Transportation Policy Project. (1998). An analysis of the relationships between highway expansion and congestion in metropolitan areas. Washington, DC.
10. Transoceânica Niterói. (2018). Disponível em: <<https://transoceanicaniteroi.com>>. Acessado em: 20 de Abril de 2018.
11. Wardrop, J. G. (1952). Some Theoretical Aspects of Road Traffic Research. Road Paper No. 36. *Proceedings of the Institution of Civil Engineers*, p. 325 – 378.

Spectral behavior of tree species of individuals of the families Fabaceae and Myrtaceae, present in the Botanical Garden of the Federal University of Santa Maria (UFSM)

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ABSTRACT

The objective of this study was to analyze the spectral behavior of individuals of six species present in the Botanical Garden of the Federal University of Santa Maria. The individuals were randomly chosen, taking into account three species belonging to the Myrtaceae families and three species belonging to the Fabaceae family. The leaves selected by means of visual diagnosis were green and healthy, with no presence of symptoms of pest or disease on the adaxial or abaxial surface of the leaf. The spectral behavior of the leaves was recorded with the FieldSpec® HandHeld spectroradiometer sensor, which acts in the range between the wavelengths of 325nm to 1075nm of the electromagnetic spectrum. In the SAMS application, the reflectance factor (ρ) graphs were generated as a function of the wavelength (nm) for each species. The differences between the spectral behaviors of the species were tested by analysis of variance (ANOVA) and Tukey's test, using the R software. It was observed that *Psidium guajava* and *Eugenia involucrata* differ from each other regarding the means of reflectance in all visible spectral bands. The species *Acca sellowiana* and *Psidium guajava* differ from each other in the blue, red and near-infrared bands. For the other comparisons, no significant differences were found. For individuals of the Fabaceae family, the species *Libidibia ferrea* differed from the species *Senna multijuga* and *Cassia leptophylla* in the three bands of the visible spectrum. *Libidibia ferrea* differed from *Cassia leptophylla* in the near-infrared spectrum. The spectroradiometer proved to be efficient in the analysis and identification of differences between the species of the Myrtaceae and Fabaceae families.

Keywords: Remote Sensing, Reflectance Factor, Spectroradiometer.

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INTRODUCTION

With the development of Remote Sensing, the possibility of quantifying individual photosynthetic pigments contained in vegetation has been expanded, providing in other studies the aid in determining the physiological state of vegetation (identification of stress), discrimination of different species (monitoring of phenological characteristics), estimation of productivity (absorption of photosynthetically active radiation) (FERRI et al., 2001).

More in-depth studies on the spectral behavior of vegetation in the most diverse landscapes require the acquisition of punctual data, and in this context, spectroradiometry is fully used, since it enables the detection of the spectral response through direct contact with the target, without the interference of external and environmental factors (SCHRODER et al., 2015). Also according to Santos et al. (2017), spectroradiometry aims to analyze the radiometric properties of a given material through reflectance spectroscopy, an advanced technique within Remote Sensing that records the flux of electromagnetic radiation reflected by materials.

According to Ponzoni and Shimabukuru (2010), photosynthetically active vegetation behaves differently in different regions of the electromagnetic spectrum in relation to its spectral response: in the visible region it has a low reflectance, due to the absorption of incident radiation carried out by the chlorophyll and carotenoids of the plant, while in the near infrared region it is characterized by a high reflectance due to the cellular structure of the leaf. It should also be noted that such conditions can be altered when subjected to stressful situations, influencing leaf reflectance in the regions of the electromagnetic spectrum mentioned above (LIPPERT et al., 2015).

Therefore, it is considered the hypothesis that the reflectance differs along the electromagnetic spectrum, varying according to the morphological and physiological characteristics of the vegetative material, and in this purpose, the present work aims to analyze the spectral behavior, in different bands of the electromagnetic spectrum, of individuals of six species that are part of the families Myrtaceae and Fabaceae present in the Botanical Garden of the Federal University of Santa Maria.

MATERIAL AND METHODS

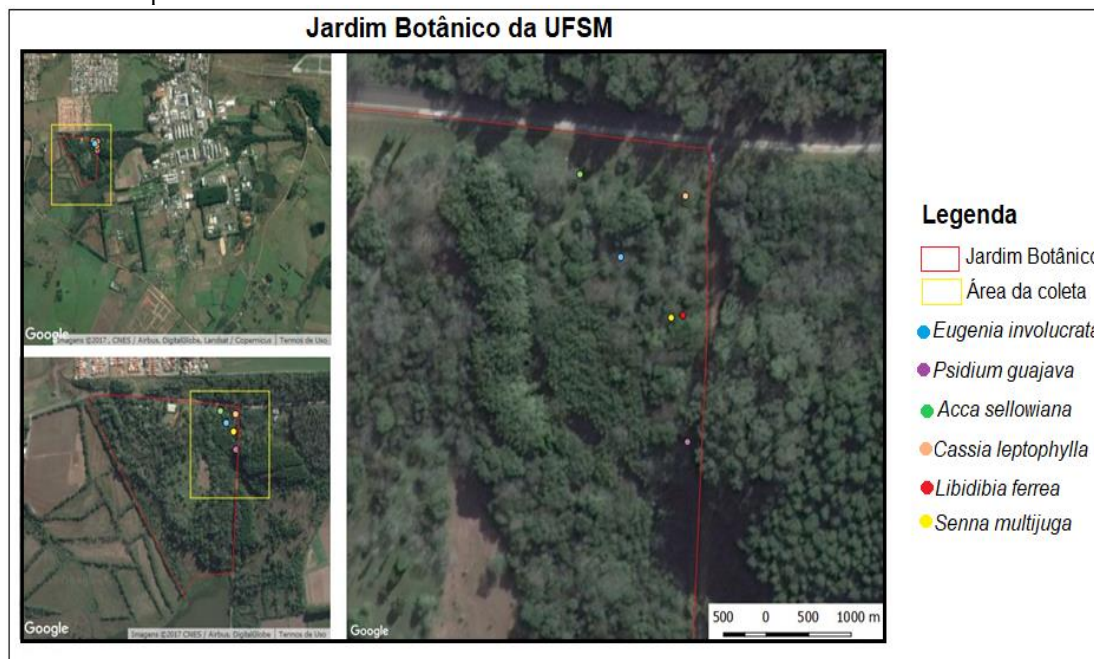
AREA OF STUDY

The material was collected on October 17, 2017, between 2 pm and 3 pm; during this period, the temperature was approximately 28°C and the relative humidity was 50%, according to INMET (2017). Five leaves were collected and chosen through visual diagnosis, being green and healthy, without the presence of symptoms of pest or disease on the adaxial or abaxial surface.

The choice of individuals occurred randomly at the Botanical Garden of UFSM, taking into account only the representativeness of three species of the two different families, thus selecting six

forest species, among them: *Acca sellowiana* (O.Berg), Burret (guava-da-serra), *Eugenia involucrata* (D. C.) (cherry), *Psidium guajava* (L.) (common guava), belonging to the Myrtaceae family and the species *Cassia leptophylla* (Vogel) (false-barbatimão), *Senna multijuga* (Rich.) H.S. Irwin & Barneby (cicada wood) and *Libidibia ferrea* (Mart. ex Tul.) L. P. Queiroz (ironwood) of the Fabaceae family. Figure 1 shows the location of the Botanical Garden within the UFSM campus, as well as the random distribution of the individuals chosen for the removal of vegetative material.

Figure 1 - Location of the Botanical Garden on the campus of the Federal University of Santa Maria – RS and distribution of the sampled individuals.



The spectral behavior of the leaves was recorded with the FieldSpec® HandHeld 2™ spectroradiometer sensor, which reads the reflectance factor (ρ) between wavelengths between 325nm and 1075nm, i.e., it operates from the visible to the near-infrared region of the electromagnetic spectrum, with a spectral resolution of 10nm.

To perform the readings in the spectroradiometer, the sheets were positioned with the adaxial face to the interior of the integrating sphere of the equipment. Three sample readings were taken for each of the five sheets taken from the individual, totaling 15 readings per species. Therefore, 45 sample readings were counted for each of the families.

The reflectance factor (ρ) values were processed using ASD ViewSpec Pro version 4.05, Microsoft Office Excel 2010, *Spectral Analysis and Management System* (SAMS) version 3.2 and R x 64 version 3.4.2. To generate the reflectance factor curves and subsequent analysis of the spectral behavior of the individuals, the values referring to the wavelengths between 400nm and 1075nm (visible spectra up to the near infrared) were considered, and the values recorded in the region of the ultraviolet spectrum (between 325nm and 400nm) were eliminated.

The tabulation of the data was organized in order to represent the different spectral bands, having adapted from Jensen (2009), the wavelength intervals: blue (400 to 500nm), green (500 to 600nm), red (600 to 700nm) and near infrared (IVP), with interval (700 to 1075nm).

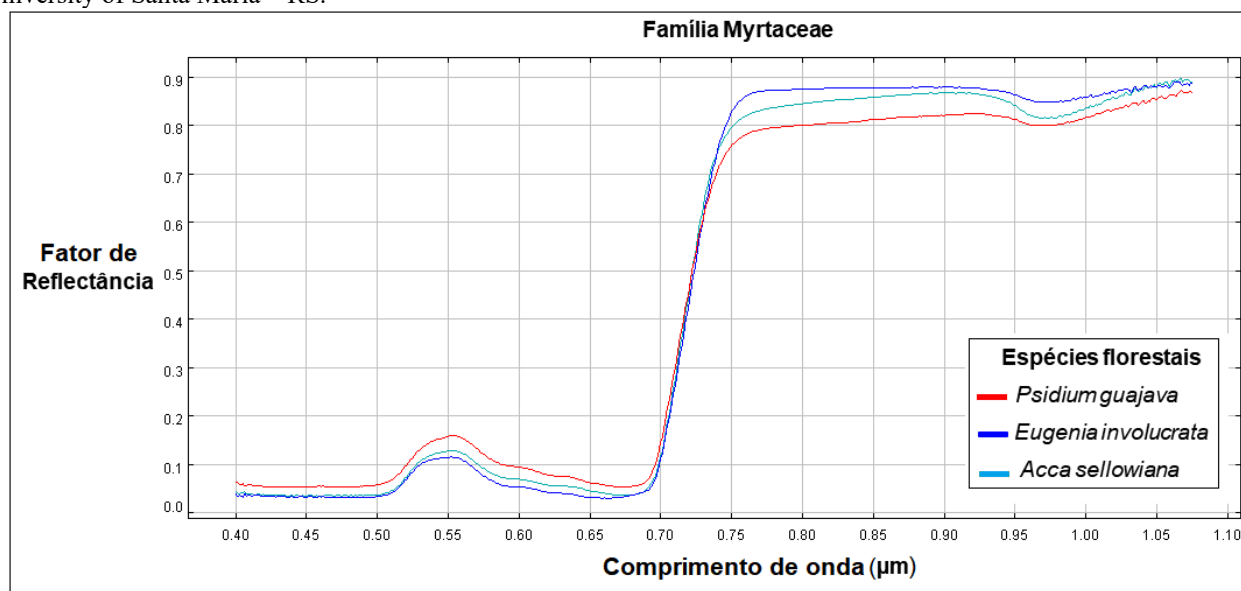
In the *Spectral Analysis and Management System* (SAMS) application, graphs of the reflectance factor (ρ) as a function of wavelength (nm) for each species were generated in order to visualize spectral differences between species of the same family. Subsequently, in the R software, the hypothesis of the existence of differences in the reflectance factor of the species of the same family, in the different spectral bands (blue, green, red and IVP) was tested. To this end, we used analysis of variance (ANOVA) and the Tukey HSD (*Honestly Significant Difference*) test at 5% probability for multiple comparisons of the reflectance means in each band.

RESULTS AND DISCUSSION

SPECTRAL BEHAVIOR OF INDIVIDUALS OF THE MYRTACEAE FAMILY

The spectral behavior shown in Figure 2 is characterized by the typical response of healthy green vegetation, but reveals some particularities, probably attributed to the species and its own morphological and physiological characteristics.

Figure 2 - Spectral response of three individuals of the Myrtaceae family, present at the Botanical Garden of the Federal University of Santa Maria – RS.



In the visible spectrum (blue, green and red bands) the low reflected energy (around 5% of the incident radiation) between 400 and 500 nm and between 600 and 700 nm are observed for the three species; as a result of the higher energy absorption in this region. Typically, between 500 and 600nm, it is found that more than 10% of the energy is being reflected. Photosynthetic leaf pigments such as chlorophyll and carotenoids are responsible for the amount of energy absorbed or reflected

by the leaf in this region of the electromagnetic spectrum. According to Sims and Gamon (2002), these photosynthesizing leaf pigments exert a great influence on the leaf spectral behavior in these regions, thus occurring a high correlation between the concentration of chlorophyll pigments and the absorption of energy by the leaves.

Psidium guajava showed a higher reflectance factor in the visible spectrum, especially in the green region (between 500 and 600nm), compared to the other species analyzed in the same family. Studies carried out by Käfer et al. (2016), found high reflectance in the green region for the species of *Psidium cattleianum*, *Eugenia uniflora* and *Eugenia involucrata*, also belonging to the Myrtaceae family. In the visible spectrum, probably due to the lower presence of photosynthetic pigments in relation to the others.

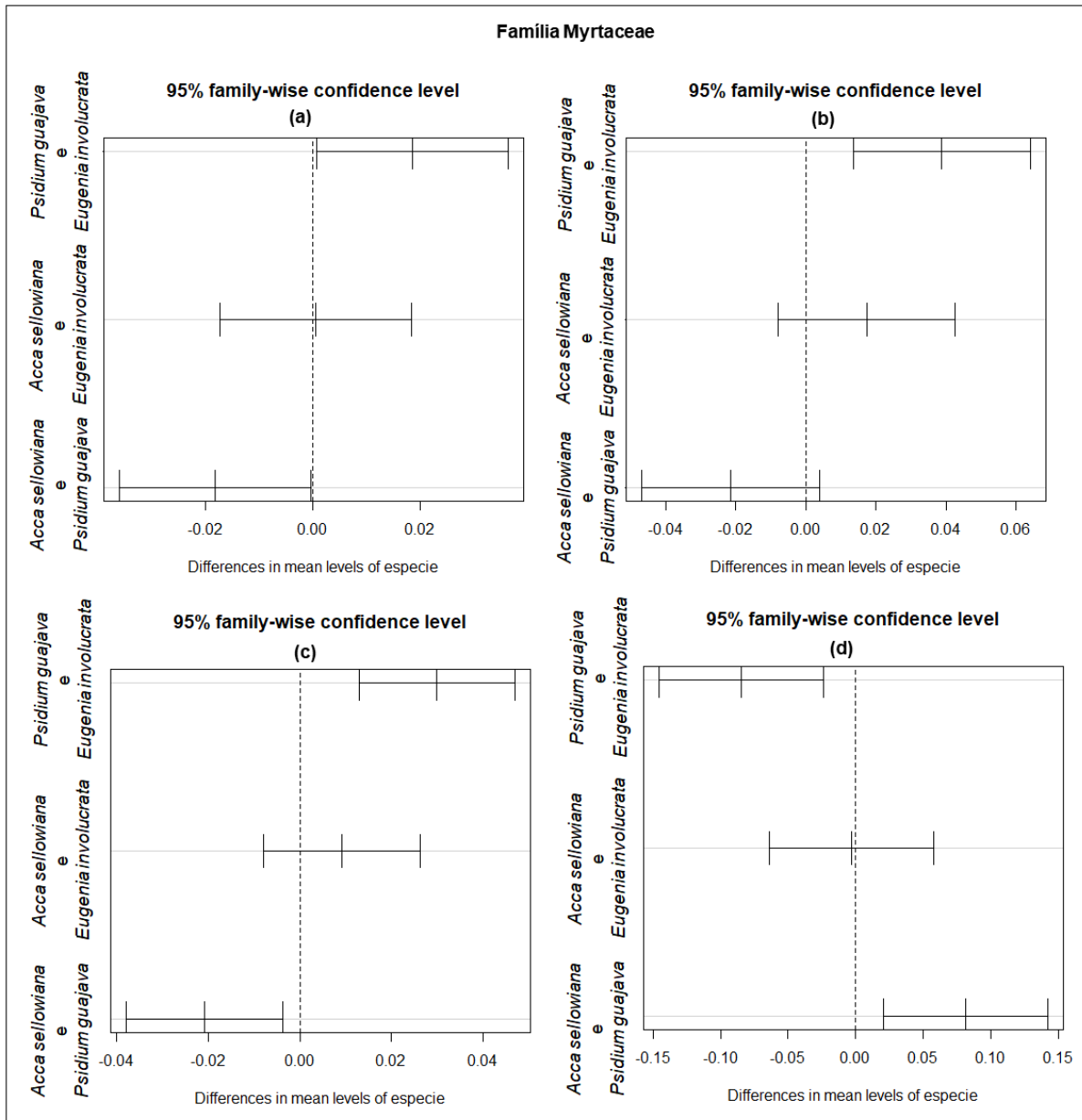
Eugenia involucrata (cherry) was the species of this family that showed the highest reflectance in the IPV. This fact can probably be explained by the structures of the cells that make up the leaf tissues and the environmental conditions in which the species is inserted. Between 750 and 800nm, the species is reflecting almost 90% of the incident radiation, denoting the intensity of its photosynthetic activity.

By applying the analysis of variance (ANOVA) using the mean reflectance values in each band (visible and PVI) it was found that there were significant differences at the 5% probability level. In the blue band, ANOVA resulted in a calculated F (calc.) of $0.00876 > F$ tabulated (tab.) to (0.05). In the green band, F calc was obtained. = $0.00364 > F$ tab. (0.05). For red, the F calc. = $0.00427 > F$ tab. (0.05) and in IVP F calc. = $0.0263 > F$ tab. (0.05).

In order to verify which species differ in terms of spectral behavior in each band, the Tukey HSD test was performed. Figure 3 shows between which forest species the significant differences detected in ANOVA occurred.

Among the individuals of the Myrtaceae family, it was observed that the species *Psidium guajava* and *Eugenia involucrata* differ from each other regarding the means of reflectance in all visible bands. The species *Acca sellowiana* and *Psidium guajava* differ from each other in the blue, red and near-infrared bands. For the other comparisons, no significant differences were found. These differences between the species may be linked to their different leaf shapes, mesophyll size, which has different behavior in the absorption, transmission and reflection of the waves of the electromagnetic spectrum, in addition, the leaves are made up of a fibrous structure of organic matter, within which there are pigments, cells containing water and air (COURA et al., 2005). Thus, each of these elements: pigments, physiological structure and water content have an effect on the reflectance, absorptance and transmittance properties of the green leaf (CURRAN, 1986).

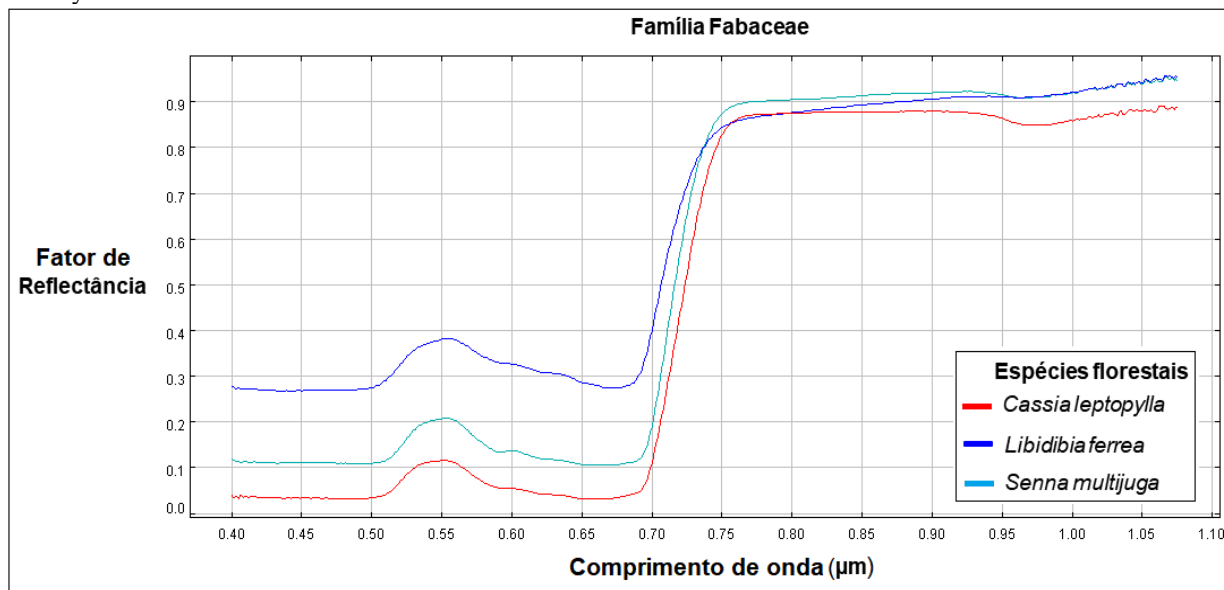
Figure 3 - Plot of the Tukey HSD test for the comparison of the reflectance means in the blue (a), green (b), red (c) and IVP (d) bands between the species of the Myrtaceae family.



SPECTRAL BEHAVIOR OF INDIVIDUALS OF THE FABACEAE FAMILY

The visual analysis of the spectral behavior of the individuals of the Fabaceae family, shown in Figure 4, also reveals some specificities of the species *Cassia leptophylla* (false barbatimão), *Senna multijuga* (cicada wood) and *Libidibia ferrea* (ironwood).

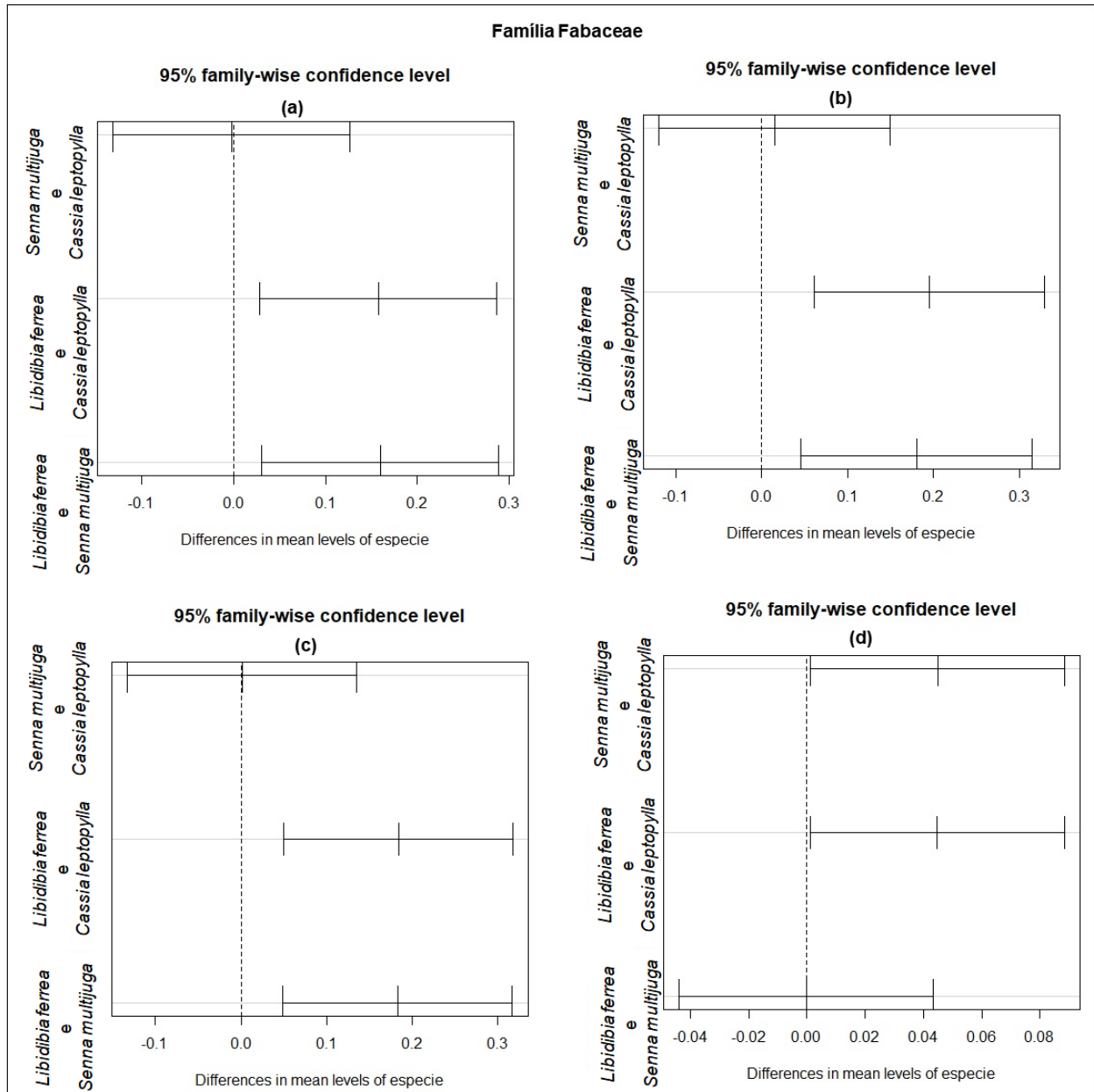
Figure 4 - Spectral response of individuals of the Fabaceae family, present at the Botanical Garden of the Federal University of Santa Maria – RS.



Libidibia ferrea stands out from the other species due to the reflectance of approximately 40% of the energy in the green band (between 500 and 600nm). This response may be associated with differences in chlorophyll content in relation to other species, which tends to produce large differences in leaf reflectance and transmittance (GITELSON et al., 2005). In addition, what may have contributed to this differentiation of the ironwood species from the others is the morphology of its leaves (pinnate or bipinnate), since the spectral behavior of a leaf is a function of the composition, morphology and internal structure (Ponzoni et al., 2012). As can be seen, in the IVP range (between 700 and 1100nm), there is a decrease in the reflectance of *Cassia leptophylla*. The variation of the reflectance value in the spectral region of the IVP for Guyot et al. (1989) is proportional to the number of layers and size of the cells, as well as the orientation of the leaf walls.

ANOVA showed that the reflectance averages in each spectral band were different between species. In the blue band, an F calc was obtained. = 0.0254 > F tab. (0.05), in the green band F calc. = 0.00526 > F tab. (0.05). In the red F calc. = 0.00161 > F tab. (0.05) and in IVP F calc. = 0.00433 > F tab. (0.05). Subsequently, the Tukey test compared the species two by two to indicate which ones differed from each other in terms of the mean reflectance value in each band (Figure 5).

Figure 5 - Plot of the Tukey HSD test for the comparison of the reflectance averages in the blue (a), green (b), red (c) and IVP (d) bands between the species of the Fabaceae family.



Among the individuals of the Fabaceae family, the species *Libidibia ferrea* differed from the species *Senna multijuga* and *Cassia leptophylla* in the three bands of the visible spectrum. *Libidibia ferrea* also differed from *Cassia leptophylla* in the near-infrared spectrum. Similarly, *Senna multijuga* and *Cassia leptophylla* showed significant differences in this range, as shown in the zero-free intervals in Figure 6. The fact that *Libidibia ferrea* differs from other species may be related to the level of illumination, number of leaves (composite, with 4-6 pairs of leaflets) and the roughness of the canopy, factors that influence the spectral response (CARVALHO, 2010; FARIAS, 2015).

CONCLUSION

The analyzed species of the Myrtaceae and Fabaceae families, present in the UFSM Botanical Garden, showed relevant differences in spectral responses. *Psidium guajava* showed a higher reflectance factor in the visible spectrum, while *Eugenia involucrata* showed a higher reflectance in the IPV. The species *Acca sellowiana* and *Psidium guajava* showed differences between them in the visible and near-infrared (PVI) bands. As for the species belonging to the Fabaceae family, *Libidibia ferrea* stood out from the others due to the energy reflectance in the green band, while in the IVP range there was a decrease of the species *Cassia leptophylla* when compared to *Libidibia ferrea* and *Senna multijuga*.

REFERENCES


1. Carvalho, P. E. R. (2010). Espécies arbóreas brasileiras. Coleção espécies Arbóreas, v. 4 Brasília, DF: Embrapa informações Tecnológica; Colombo, PR: Embrapa Florestas.
2. Coura, S. M. D. C., Piromal, R. A. S., Canavesi, V., Gomes, M. N., Quirino, V. F., Ponzoni, F. J. (2005). Comparação das características espectrais das espécies *Ligustrum japonicum* Thunb. e *Cassia macranthera* DC. *Anais... XII Simpósio Brasileiro de Sensoriamento Remoto*, Goiânia, INPE, p. 1477-1484.
3. Curran, P. (1986). Principles of remote sensing. New York, USA.
4. Faria, R. M. (2015). Classificação temporal de imagens Landsat 8 para o monitoramento das mudanças do uso da terra. Monografia Graduação em Geografia da Universidade Federal de Viçosa, Minas Gerais – MG.
5. Ferri, C. P., Formaggio, A. R., & Schiavinato, M. (2001). Avaliação de índices de pigmentos fotossintéticos na estimativa da concentração de clorofila a, clorofila b, clorofila total e carotenóides nas diferentes fases de desenvolvimento da cultura da soja (*Glycine max* [L], Merrill). *Anais... X Simpósio Brasileiro de Sensoriamento Remoto*, Foz do Iguaçu, INPE, p. 71-78.
6. Gitelson, A., Viña, A., Ciganda, V., Rundquist, D., & Arkebauer, T. (2005). Remote estimation of canopy chlorophyll content in crops. *Geophysical Research Letters*, 32*(8).
7. Guyot, G., Guyon, D., & Riom, J. (1989). Factors affecting the spectral response of forest canopies: a review. *Geocarto International*, 4*(3), 3-18.
8. INMET. Instituto Nacional de Meteorologia. [Link](http://www.inmet.gov.br/sonabra/pg_dspDadosCodigo_sim.php?QTgwMw). Acessado em: 17 de abr. de 2018.
9. Jensen, J. (2009). Sensoriamento Remoto do Ambiente: uma perspectiva em Recursos Terrestres. São José dos Campos, SP: Parênteses.
10. Käfer, P. S., Rex, F. E., Santos, M., & Sebem, E. (2016). Caracterização espectral e NDVI de espécies florestais das famílias Fabaceae, Myrtaceae, Rutaceae e Salicaceae. *Enciclopédia Biosfera*, 13*(23).
11. Lippert, D. B., Benedetti, A. C. P., Muniz, M. F. B., Pereira, R. S., Biernaski, C. A. J., Finkenauer, E., & Berra, E. F. (2016). Comportamento espectral de folhas de *Eucalyptus globulus* (Labill.) atacadas por *Mycosphaerella* spp. nas regiões do visível e do infravermelho próximo do espectro eletromagnético. *Ciência Florestal*, 13*(23), 262-275.
12. Ponzoni, F. J., & Shimabukuro, Y. E. (2010). Sensoriamento remoto no estudo da vegetação. São José dos Campos: Parêntese.
13. Ponzoni, F. J., Shimabukuro, Y. E., & Kuplich, T. M. (2012). Sensoriamento Remoto da vegetação. São José dos Campos, SP: Oficina de Textos.
14. Santos, J. J. D., Chaves, J. M., Souza, D. T. M., Rocha, W. D. J. S. D. F., & Santos, S. M. B. D. (2017). Análise do comportamento espectral das espécies vegetais Algaroba e Catingueira em



ambiente semiárido: um estudo em Curaçá-BA. *In: Anais... XVIII Simpósio Brasileiro de Sensoriamento Remoto*, Santos, INPE, 5492-5498 p.

15. Sims, D., & Gamon, J. (2002). Relationships between leaf pigment content and spectral reflectance across a wide range of species, leaf structures and developmental stages. *Remote Sensing of Environment, 81*(2-3), 337-354.
16. Schröder, T., Pereira, R. S., Zimmermann, A. P. L., Redin, C., Machado, L. M., Fleck, M. D., & Rocha, N. S. D. (2015). Influência de métodos de coleta de dados espectrorradiométricos sob índices de vegetação em eucalipto. *Revista Eletrônica de Gestão, Educação e Tecnologia Ambiental, 19*(3), 690-701.

Investigation of the quality of refined soybean oil after the short-term domestic frying process of breading nuggets

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ABSTRACT

Frying is one of the most attractive food preparation techniques and has been in use for centuries. It refers to a gastronomic practice that is widely accepted around the world and used both in the industrial area and domestically. It is worth noting that this preference of consumers for fried foods is due to their unique sensory properties, such as taste, aroma and texture. However, with the high temperature that is used in the cooking method, the chemical composition of the frying oil can be modified. The reactions that occur in vegetable oils during frying (hydrolytic processes) are associated with several mechanisms, such as reactive species, chemical formation of the lipid, medium and method, inducing the speed and nature of frying. The purpose of this work is to investigate the characteristics of the vegetable oil most used by the population (refined soybean oils) used in the domestic method of short-term frying, using the electric fryer for domestic use and conventional method. Nugget-type breaded products were used because they are a convenient product, widely consumed in industrialized countries. Short-term domestic frying was done over the course of three days, with a period of one week. After each frying, the refined oil was researched. The methodology is based on bromatological evaluations of quality research using acidity analyses, where the content of free acidity, compounds formed by hydrolytic rancidity, was verified. According to the results, the samples of fresh soybean oil were within the regulatory limits. However, soon after the short-term frying process, there was an increase in the free fatty acid content of both short-term domestic frying using soybean oil. In addition, there was no considerable difference in the increase in the value of fatty acids in relation to both domestic frying techniques. However, as a rule, the oil showed an excellent thermal quality, bromatological analyses showed that it is necessary to be cautious when reusing short-term frying oils. It is analyzed that the electric fryer is efficient in the quality of the oil in terms of preservation in contrast to the conventional method, possibly for the reason of temperature control and better sealing effectiveness.

Keywords: Soybean oil quality, Home frying, Bromatology, Acid value.

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INTRODUCTION

The frying process is one of the most attractive ways of preparing food. This is one of the ways used in cooking, where it is well known and used in industry and domestically. Fried foods are foods accepted by consumers, as they have different sensory characteristics, such as texture, appearance and flavor. The frying process is the public's preference in the home environment, as this cooking method has a more economical value, as well as being more practical, thus bringing the reason for its favoritism (Nhatave, 2015; Wang, 2016; Ruixue, 2016; Jesus, 2019).

However, the high temperatures used in soybean oil in the frying process are capable of impairing the chemical stability of this oil. The oil used in the frying process when heated repeatedly, is called discontinuous frying, this process of heating and reheating is usually used because of the way to reduce costs. The process occurs when high temperatures cause chemical decomposition, causing losses of sensory as well as nutritional qualities (Farhoosh, 2012; Millin, 2016; Multari, 2019; Jesus, 2019). During the frying process, the temperature favors the loss of water from the food, where this water is absorbed by the oil, in this way the oil undergoes a chemical decomposition through the pathways that occur in the oil, such as the hydrolysis that the oil undergoes because of this absorption of this water (Nhatave, 2015; Ruixue, 2016; Multari, 2019). Thus, the soybean oil used in this frying process undergoes changes, such as hydrolytic rancidity, that is, with the increase in fatty acids due to the hydrolysis of the triacylglycerols of the oils, the oils become more vulnerable to the loss of soluble fatty acids, vitamins and essential fatty acids, causing food insecurity (Lee, 2012; Calixto, 2013; Coradi, 2017; Dodo, 2022).

Brazil, one of the important producers of soybeans, and as a result the population uses the oil in the frying process (Nhatave, 2015; Jesus, 2019). In 2022, exports in the Brazilian country reached more than 2.16 million soybean oils (CONAB, 2022). Chicken nuggets breaded foods are also widely consumed by the population, as they also present practicality and sensory pleasure after the frying process (Nazário, J., Fontana, M., 2014). Thus, the food industry has invested in technologies and advanced in the creation of products that respond to consumer needs, such as chicken-based breaded products (Lima, et al., 2022). Nugget-type breaded products can be made by different parts of the chicken, such as a portion of meat with bone and skin, without bone and skin, as well as a whole piece, or processed, but usually nuggets are produced with ground muscle (Araújo, 2021).

Short-term frying is used recurrently in homes because of its functionality and through the acceptance of the palate, especially chicken breading like nuggets. Often, in homes, this cooking process is usually done in a short period of time, where this oil is saved to be reused in another frying later. On the other hand, this practice of reuse can lead to an acceleration of oil deterioration (Farhoosh, 2012; Lee, 2012; Choe, 2007).

To date, there are relevant gaps in knowledge about the chemical changes of fried foods for short periods, in addition to the storage of oil in a domestic situation, using the traditional form of frying (with pan and stove) and domestic electric fryer, in contrast to commercial circumstances, about which a lot of knowledge is obtained. Thus, with this study, the purpose of this study is to analyze the changes in the chemical quality of soybean oil after being used in short-term domestic frying with chicken nuggets, as well as to analyze the quality of this oil after the storage process at the domestic level and be reused. It is worth mentioning that it also plans to ascertain and compare the chemical quality of two frying techniques used in the home kitchen - traditional method and domestic electric fryer.

MATERIALS AND METHODS

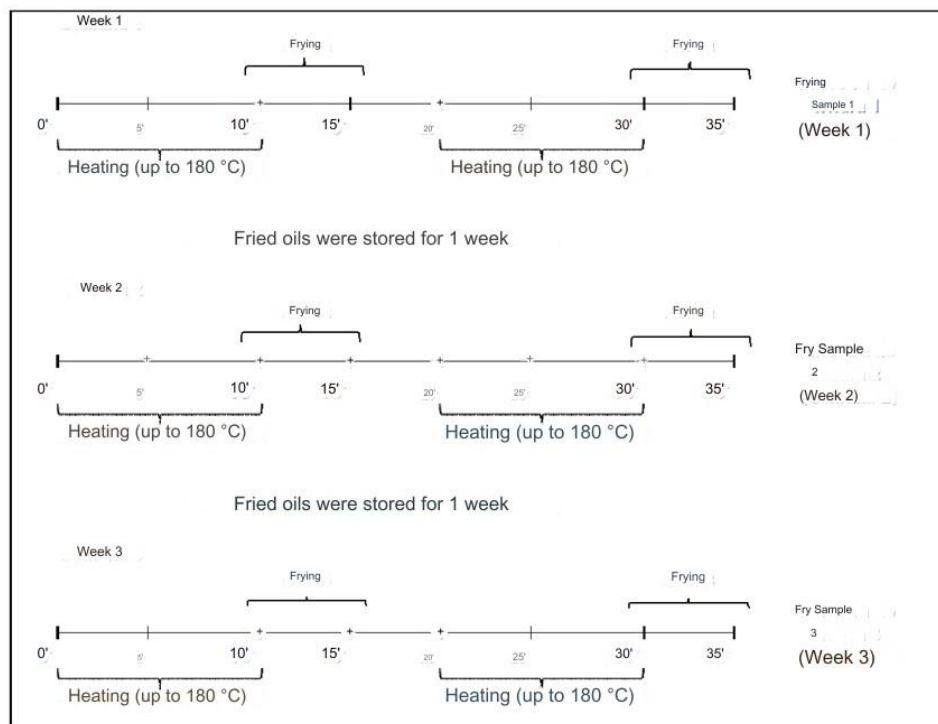
SAMPLES

The samples of refined soybean oils were purchased in the local market in the city of Rio de Janeiro, the soybean oils belonged to the same brands and were obtained in the same trade. Thus, six units of the same soybean oil manufacturing batch were purchased, where sampling methods were used to obtain reliable aliquots of these samples in each batch for the execution of the frying test. After the frying tests, the soybean oil samples were preserved in amber glass bottles, where they were protected from light, in a nitrogen atmosphere and at a temperature of -18°C until the analysis was performed. Nuggets (Sadia®, Brazil) were purchased at local markets in Rio de Janeiro, Brazil. Before beginning the analyses and experiments, the purchased nuggets were fully thawed and the rest of the water was dried with a clean cloth.

FRYING EXPERIMENTS AT 180°C

Soybean oils were used in short-term frying experiments at $180 \pm 1^{\circ}\text{C}$ with chicken nuggets. In this way, two frying methods were used: a domestic electric fryer with a capacity of 1000 mL of oils (Philco®, Brazil) and frying in a stainless steel frying pan with a capacity of 1500 mL and 16 cm (Tramontina®, Brazil). Right after leveling 1000 mL of soybean oil for 10 minutes at 180°C in cabin frying methods, the nuggets went to the frying process for a time of 5 minutes in portions of 200 g. It is noteworthy that each serving of nuggets showed plausible appearance and texture after the established time of 5 minutes. After one serving of nuggets, the volume of oil was replenished to 1000 mL with 50 ± 1 mL and another 10 minutes to reheat the oil back to 180°C , then another portion of nuggets was placed to fry for 5 minutes and after that aliquots of oils (50 mL) were removed (Fig. 1). Then, all the oils were stored in glass jars at room temperature for a time of one week, replicating a home storage. It is noteworthy that this sequence was repeated three times. Therefore, the frying process with a domestic electric fryer had temperature control.

Figure 1. Experimental design of immersion frying tests using conventional technique with stainless steel pan and electric fryer.



DEFINITION OF HYDROLYTIC STABILITY DURING FRYING AT 180 °C

The quality acidity index of the oils was defined in a fresh sample and during frying at 180 °C in the frying methods – domestic electric fryer and conventional method with stainless steel frying pan. Quality standards were determined by the acid index. The knowledge was made following the AOCS (2004) methods, represented below. For a better presentation of the effects, three analyses were performed in the blank test and the results were presented with mean and standard deviation.

Acid value

The definition of the acidity value ensures the neutralization of free fatty acids until the time of equivalence by an alkaline solution, with the use of an indicator. This knowledge defines the amount of free fatty acids in the samples of refined soybean oils. The studies were performed by titration with 0.1M factored alkaline sodium hydroxide (NaOH) solution with 1% phenolphthalein indicator and with samples previously dissolved in alcohol-ether solution (1:2 v/v). It should be noted that acidity corresponds to the number of milliliters of alkaline solution essential to neutralize the free fatty acids in 100g of oil, expressed by a percentage of oleic acid, calculated according to the equation below (Method Ca 5-40, AOCS, 2004):

$$AV (\%) = (V_a - V_b) \times CF \times MW \text{ NaOH} / m$$

Where:

V_a = value of the 0.01 M NaOH white test used in titration;

V_b = test value of the 0.01 M NaOH samples used in titration;

CF = NaOH correction factor 0.01 M;

PM = peso molecular do NaOH;

m = weight of the sample quantity in g.

STATISTICAL ANALYSIS

Descriptive statistics were performed for the variables, with the purpose of calculating means, medians, standard deviation and estimating the regularity of the data. The conclusions were presented as mean \pm standard deviation considering three independent replications. Multifactorial analysis of variance (MANOVA) was used to make a comparison between means; Considerable diversity between pairs of means was defined by Fisher's test. P results lower than 0.05 were seen to be statistically significant. Statistical analyses were performed using the Statistica 8.0 software (StatSoft®, Oklahoma, USA).

RESULTS AND DISCUSSION

The cooking method, frying, is used in modern cooking, but it has archaic origins dating back to the time of 1600 BC. As much as the orientation is to keep the temperature around 180°C in the food frying process, it is common for the temperature to exceed this limit in home frying, especially when the medium used is conventional, in which there is no temperature control (Omer, 2015).

During the frying process, the oil is modified and deteriorated, which can lead to changes in the sensory and nutritional characteristics of the foods used in cooking, various reactions occur through the frying process, such as hydrolysis and other processes, which can create chemical compounds that generate chronic diseases, such as cardiovascular diseases and various tumors (Farhoosh, 2012; Jesus, 2019). In this way, it is necessary to keep track of the changes in the quality of the oil used in this cooking process. The reactions are influenced by various situations, including exposure to oxygen, the ease of water that is released from the food to the soybean oil, the temperature (time, instrument used for frying, etc.), as well as the structure of the food that was used in the process (Farhoosh, 2012; Zula, 2022).

However, having an understanding of the oil in order to select the appropriate procedures is essential to relate the products resulting from this deterioration of the oil and the appearance of various diseases, such as atherosclerosis, Alzheimer's disease and inflammation in general

(Broncano, 2009; Farhoosh, 2012; Zula, 2022). Throughout the frying process, it provides the entry of water into the oil on account of the food, causing the hydrolysis of the fatty acids in the oil and these are represented by the acidity value. According to Brazilian legislation (ANVISA, 2005), but also the international guideline Codex Alimentarius for Vegetable Oils (WHO, 2015), the acceptable acidity limits in refined seed oils are 0.6%. However, when the oil is exposed to the frying process, the limits of the acidity value are raised to 0.9% (ANVISA, 2004). When it exceeds 0.9% of free fatty acids, it indicates that the oil needs to be discarded for safety reasons, since the production of chemical compounds that are harmful to health can cause harm to people who are consuming the food exposed to this oil (Broncano, 2009; Frankel, 2010; Jesus, 2019). It should be noted that, according to ANVISA (2004), heated oil is recommended to be discarded when the creation of foam and smoke is observed, as well as color changes (Coradi, 2017; Millin, 2016).

In addition, chicken nuggets breaded has brought interest to consumers and slaughterhouses, because breaded products have longer shelf life, reduced water loss and their way of preventing damage caused by freezing the food through breading and the way the food brings attractiveness after it has been cooked. Nuggets are a source of lipids and have many calories, and the way they are cooked can modify the nutritional characteristics and their energy value (Nazario, J., Fontana, M., 2014). It is necessary to say that the chemical composition of the nuggets is: water, citric acid, chicken broth, modified corn starch, salt, glucose, sodium phosphate, dimethylpolysiloxam, and oil (Fernandes, et al., 2020). Nazario and Fontana (2014) suggest that the consumption of nuggets should be moderate, as this food can help in weight gain and the evolution of cardiovascular diseases.

ACIDITY LEVEL

The acidity index corresponds to the free fatty acids in the samples that were taken from the oxidation of triglycerides. Refined seed oils are more subject to degradation, this is because they are more prone to rancidity, since unsaturated fatty acids will prevail in their composition. Thus, soybean oils with high acidity values reveal high levels of free fatty acids. Decomposition alters the concentration of hydrogen ions, both by hydrolysis and fermentation. Although processing and storage take place chemical and enzymatic reactions (hydrolytic rancidity), because of the water that comes into contact with the oil and will interact with the triacylglycerol, hydrolysis occurs and causes acidification of the environment. Therefore, this acidification modifies the sensory qualities of the oils, such as taste and odor, in addition to the nutritional change that occurs a loss (Lee, 2012; Akil, 2015; Ramalho, 2006; Clemente, 2019).

It is worth mentioning that soybean oil is indicated to have its acidity presented in oleic acid less than or equal to 0.6% (ANVISA, 2015; WHO, 2015), if they are not exposed to warming.

However, when soybean oil is exposed to heat, values up to 0.9% are accepted (ANVISA, 2004). The fresh samples of soybean oil and they were consistent with the upper limit of the acidity value, which showed less than 0.01% (TABLE 1). According to Gunstone (2008), he indicated that the free fatty acid content of refined seed oils would need to be less than 0.1% because most of the free fatty acids from crude oils are removed during the refining process. In fresh soybean oil, its fatty acid content is 0.028%, which are similar to the value of free fatty acids for fresh oil mentioned by Gunstone (2008). The acidity result increased considerably from the fresh sample to the end of the experiments of the short-term frying process (week 3) in the total of the soybean oil samples. Thus, this shows that the components of triacylglycerol were undergoing hydrolytic degradation (Gupta, 2005; Liu, 2018).

0,042bB ± 0,02

Refined Soybean Oil				
Frying techniques	Fresh sample	Frying Sample 1 (Week 1)	Frying Sample 2 (Week 2)	Frying Sample 3 (Week 3)
Conventional	0,028 ^{aA} ± 0,00	0,043 ^{bA} ± 0,02	0,057 ^{cA} ± 0,00	0,057 ^{cA} ± 0,00
Home electric fryer	0,028 ^{aA} ± 0,00	0,028 ^{aB} ± 0,00	0,042 ^{bB} ± 0,02	0,042 ^{bB} ± 0,02

The results are expressed as mean ± standard triplicate derivation.

Superscript letters indicate a significant difference between the week of frying and between the frying techniques (MANOVA repeated measures): ^{ab} Differences in the same line (week effect); ^{AB}: Differences in the same column (between techniques).

The result of the acidity of the soybean oil used in the frying procedure in the conventional fryer were the same until the first week of frying, from the second week of frying there was an increase, remaining constant until the end of the heating experience. On the other hand, the acidity values in the conventional frying methods were 0.057 in the third week of the experiment, i.e., much lower than the maximum limit recommended by the legislation for fresh refined oil, as well as for heated refined oil (ANVISA, 2004). In the conventional process, it was found that the triacylglycerols broke more quickly, due to the lack of temperature control, which is existing in the electric fryer. Akil (2015) ascertains the acidity values of oils after short-term frying using the domestic electric fryer. The results certify that the soybean oil used in both techniques is more resistant to short-term frying. Sebastian (2014) investigated the samples of soybean oil used in frying in twenty commercial restaurants, collected 500 mL of the oil from each of the restaurants to analyze. It should be noted that fifteen samples collected showed unsatisfactory results, as their values were the highest for disposal (4.3% is the highest value). The study followed the short-term fried foods at the domestic level, showing values with satisfactory results of the greed index, being able to show

consumers that for their health safety the ideal was to produce their fried foods in the domestic environment.

In general terms, frying using the electric fryer had its heating contained, because in addition to the instrument being more sealed, its temperature remains more stable and did not oscillate, unlike the conventional technique, which is not well sealed and the temperature fluctuates, causing an increase in fatty acids in the triacylglycerol oil. Overall, this is able to clarify the behavior of the oils in the electric fryer. The study done by Nazarbakhsh (2014), observed that the acidity value is lower for the samples of the electric fryer than compared to the conventional technique, using canola oil. These studies collaborate and show the success of the electric fryer, as there is less stability of soybean oil during frying, highlighting its efficiency in preserving the characteristic of soybean oil compared to the conventional method.

CONCLUSION

Soybean oil is for consumers more attractive for short-term frying. Thus, with the results obtained, it was analyzed that the soybean oil in the domestic environment there was an increase until the end of the experiment (week 3) but it did not exceed the allowed limit, but the electric fryer had a greater control in the temperature. Thus, it can be said that soybean oil showed the creation of few free fatty acids and conserving unsaturated fatty acids. Consequently, the study indicates the use of the electric fryer for the frying process, as long as the consumer pays attention to signs of discarding this oil, such as smoke and foam.

REFERENCES


1. Akil, E., Castelo-Branco, V. N., Costa, A. M. M., Vendramini, A. L. A., Calado, V., & Torres, A. G. (2015). Oxidative stability and changes in chemical composition of extra virgin olive oils after short-term deep-frying of French fries. *Journal of American Oils Chemistry Society*, 92*, 409-421.
2. Gunstone, F. D. (2008). *Oils and fats in the food industry** (1st ed.). Wiley-Blackwell (Chapter 8).
3. FAO/WHO Alimentarius Codex. (1999). Codex standard for named vegetable oils. Codex stan 210-1999. Available in: www.fao.org/download/standas.
4. Brasil. (2005). Technical regulations for vegetable oils, fats and fats [Regulamento técnico para óleos vegetais, gorduras e creme vegetal]. ANVISA (Brazil), RDC n° 270.
5. Brasil. (2004). Oils and fats used in frying [Óleos e gorduras utilizados em frituras]. ANVISA, Informativo técnico, n. 11.
6. Izar, M. C. D. O., Lottenberg, A. M., Giraldez, V. Z. R., Santos Filho, R. D. D., Machado, R. M., Bertolami, A., & Machado, V. A. (2021). Posicionamento sobre o Consumo de Gorduras e Saúde Cardiovascular. *Arquivos brasileiros de cardiologia*, 116*, 160-212.
7. Omer, N. M. A., Ali, E. A., Mariod, A. A., & Mokhtar, M. (2015). Chemical reactions taken place during deep-fat frying and their products: a review. *Journal of Natural and Medical Sciences*, 16*(1), 1-16.
8. Zula, A., & Fikre, T. (2022). Effect of frying oil stability over repeated reuse cycles on the quality and safety of deep-fried Nile tilapia fish (*Oreochromis niloticus**): a response surface modeling approach. *International Journal of Food Properties*, 25*(1), 315-325.
9. Broncano, J. M., Petró, M. J., Parra, V., & Timón, M. L. (2009). Effect of different cooking methods on lipid oxidation and formation of free cholesterol oxidation products (COPs) in *Latissimus dorsi** muscle of Iberian pigs. *Meat Science*, 83*(3), 431-437.
10. Nazarbakhsh, V., Ezzatpanah, H., Tarzi, B. G., & Givianrad, M. H. (2014). Chemical changes of canola oil during frying under atmospheric condition and combination of nitrogen and carbon dioxide gases in the presence of air. *Journal of the American Oil Chemists' Society*, 91*, 1903-1909.
11. Liu, Y., Wang, Y., Cao, P., & Liu, Y. (2018). Combination of gas chromatography-mass spectrometry and electron spin resonance spectroscopy for analysis of oxidative stability in soybean oil during deep-frying process. *Food analytical methods*, 11*, 1485-1492.
12. Wang, S. N., Sui, X. N., Wang, Z. J., Qi, B. K., Jiang, L. Z., Li, Y., Wang, & R. Wei, X. (2016). Improvement in thermal stability of soybean oil by blending with camellia oil during deep fat frying. *European Journal of Lipid Science and Technology*, 118*, 524-531.
13. Multari, S., Marsol-Vall, A., Heponiemi, P., Suomela, J. P., & Yang, B. (2019). Changes in the volatile profile, fatty acid composition and other markers of lipid oxidation of six different vegetable oils during short-term deep-frying. *Food Research International*, 122*, 318-329.

14. Dodoo, D., Adjei, F., Tulashie, S. K., Adukpoh, K. E., Agbolegbe, R. K., Gawou, K., & Manu, G. P. (2022). Quality evaluation of different repeatedly heated vegetable oils for deep-frying of yam fries. **Measurement: Food, 7**, 100-135.
15. Choe, E., & Min, D.B. (2007). Chemistry of Deep-Fat Frying Oils. **Journal of Food Science, 72*(5)*, 77-86.
16. Millin, T. M., Medina-Meza, I. G., Walters, B. C., Huber, K. C., Rasco, B. A., & Ganjyal, G. M. (2016). Frying Oil Temperature: Impact on Physical and Structural Properties of French Fries During the Par and Finish Frying Processes. **Food and Bioprocess Technology, 9**, 2080-2091.
17. Lee, S., Kang, S. H., Kim, M. K., Song, S. R., Yoon, H. J., Lee, M. W., & Hwang, I. K. (2012). Degree of Rancidity and Sensory Characteristics of Frying Oils with Reuse and Storage at Home. **Korean Journal of Food and Cookery Science, 28*(3)*, 265-273.
18. Ramalho, V. C., & Jorge, N. (2006). Antioxidants used in oils, fats and fatty foods. **Química Nova, 29*(4)*, 755–760.
19. Ruixue, M. A., Tian G. A. O., Song, L., Zhang, L., Jiang, Y., Jiaolong, L., Zhang, X., Gao, F., & Zhou, G., (2016). Effects of oil-water mixed frying and pure-oil frying on the quality characteristics of soybean oil and chicken chop. **Food Science and Technology, 36*(2)*, 329–336.
20. Sebastian, A., Ghazani, S.M. & Marangoni, A (2014). Quality and safety of frying oil used in restaurants. **Food Research International, 64**, 420-423.
21. Gupta, M. K. (2005). Frying oils. In F. Shahidi (Ed.), **Bailey's industrial oil and fat products** (pp. 1–31). John Wiley & Sons.
22. Clements, D. J, Decker, E.A. (2019). Lipídeos. In Damodaran, S., & Parkin, K.L (Eds.), **Química de Alimentos de Fennema** (pp. 209-210).
23. Frankel, E. (2010) Chemistry of extra virgin olive oil: adulteration, oxidative stability, and antioxidants. **Journal of Agricultural and Food Chemistry, 58**, 5991–6006.
24. Sulieman, A. E. R. M., Makhzangy, A. E., & Ramadan, M. F. (2006). Antiradical performance and physicochemical characteristics of vegetable oils upon frying of french fries: A preliminary comparative. **Journal of Food Lipids, 13**, 259–276.
25. Coradi, P. C., Souza, A. E. M., & Borges, M. C. R. Z. (2017). Yield and acidity indices of sunflower and soybean oils in function of grain drying and storage. **Acta Scientiarum. Agronomy, 39*(2)*, 255-266.
26. Jesus, D. J. F., & Gomes, D. C. (2019). Comparative analysis of rancidity development in vegetable oils during frying process. **Journal of Applied Pharmaceutical Science, 6**, 65-74.
27. Calixto, C.F.S., Azevedo, J.F.M., Monteiro, M.A.M., & Schaefer, M.A. (2013). Assessing the amount of soybean oil in meals offered in a university restaurant. **Demetra: Food, Nutrition & Health, 8*(1)*, 53-72.
28. Nhatave, A. M. (2015). Estudo da estabilidade oxidativa e hidrolítica de vários tipos de óleos vegetais produzidos na fasorel sarl. Retrieved from

https://bdm.ufpa.br:8443/jspui/bitstream/prefix/4835/6/TCC_EstudoAplicacaoOleos.pdf.
Accessed January 16, 2024.

29. CONAB. (2022). Exportações de óleo e farelo de soja registram recorde entre janeiro e outubro. Retrieve from <https://www.conab.gov.br/ultimas-noticias/4838-exportacoes-de-oleo-e-farelo-de-soja-registram-recorde-entre-janeiro-e-outubro>. Accessed January 16, 2024.
30. Standard USA. (2004). AOCS - American Oil Chemists Society. Official methods and recommended practices (Ca 5-40 - 2004), 4th ed. Retrieved from <https://www.aocs.org>
31. Standard USA. (2004). AOCS - American Oil Chemists Society. Official methods and recommended practices (Cd 8-53 - 2004), 4th ed. Retrieved from <https://www.aocs.org>
32. Farhoosh, R., Khodaparast, M. H. H, Sharif, A., & Rafiee, S. A (2012). Olive oil oxidation: rejection points in terms of polar, conjugated diene, and carbonyl values. *Food Chemistry, 131*, 1385–1390.
33. Nazario, J. A., Fontana, M. O. (2014). Interferência do tratamento térmico sobre as características físico-químicas de nuggets de frango. Retrieve from FB_COALM_2013_2_06.pdf (utfpr.edu.br). Accessed January 16, 2024.
34. Fernandes, A. L., et al. (2020). Composição química dos alimentos tipo fast food. Retrieve from Composição química dos alimentos tipo fast food (unifeob.edu.br). Accessed January 16, 2024.
35. Lima, et al. (2022). Desenvolvimento de Nuggets de Frango em Formato de Coxinhas das Asas com Três Sistemas de Cobertura para Empanamento. *Revista Pleiade, 16*(35), 30-42.
36. ARAÚJO (2021). Desenvolvimento e avaliação físico-química de nuggets de frango adicionado do extrato da folha da aroeira (*Schinus terebinthifolius* Raddi). Retrieve from Desenvolvimento e avaliação físico-química de nuggets de frango adicionado do extrato da folha da aroeira (*Schinus terebinthifolius* Raddi). (ufcg.edu.br). Accessed January 16, 2024.

Sleep-related movement disorders

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ABSTRACT

Sleep is a fundamental aspect in the daily life of human beings, because it has essential functions, such as immunological, restorative, conservation and restoration of energy, in addition to interfering with thermoregulation and memory consolidation.

Keywords: Disorders, Sleep, Human being.

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INTRODUCTION

Sleep is a fundamental aspect in the daily life of human beings, because it has essential functions, such as immunological, restorative, conservation and restoration of energy, in addition to interfering with thermoregulation and memory consolidation.

It is considered a biological process conceptually defined in science as a coordinated set of behavioral and physiological changes that occur simultaneously and are associated with specific patterns of brain electrical activity. This state is characterized by a relaxed posture, decreased or absent motor activity, and a high tolerance to external stimuli, which can be reversed by stimulus. On the other hand, wakefulness is marked by increased motor activity, increased responsiveness, and a neurochemical environment that facilitates information processing and interaction with the environment. The alternation between sleep and wakefulness follows a circadian rhythm, varying according to age, sex, and other individual characteristics.

In this sense, its deprivation can determine important short- or long-term impairment in the patient's daily activities, fostering social, somatic, psychological, or cognitive impairments. In addition, poor sleep quality or insufficiency are factors associated with pathologies such as obesity, mental disorders, hypertension and diabetes. Sleep is actively initiated through two mechanisms that coordinate the sleep-wake cycle:

- (1) The homeostatic sleep impulse, which involves substances that promote sleep;
- (2) Or circadian cycle

Controlled by the suprachiasmatic nucleus of the hypothalamus, which is responsible for facilitating awakening. The homeostatic factor refers to the increase in sleepiness after prolonged periods of wakefulness, due to the accumulation of adenosine, while the circadian factor addresses the cyclical variations in the state of wakefulness and physiological sleep throughout the day. After awakening, during the morning part, the homeostatic impulse to sleep is almost negligible and the circadian factor takes on excitatory influences that lead to awakening. Throughout the day, both homeostatic drive and circadian excitatory activity increase; However, during the night, this excitatory activity is reduced, promoting the onset of sleep. (MULLER et al, 2007) (NEVES et al, 2017) (SIMÕES et al, 2022).

It is important to note that sleep is composed of two discrete states that alternate in cycles over the course of a typical night.

- Rapid eye movement (REM)-> Occupying approximately 20 to 25% of total sleep time in young adults, it ranges in duration from 5 to 30 minutes. This phase is characterized by the occurrence of dreams and bodily movements.

- Non-rapid eye movement (NREM) -> NREM sleep, comprising about 75% of the sleep cycle, is subdivided into three stages (N1, N2, and N3), with the deepest stage being the last.

Changes in sleep patterns are common in all age groups, but it should be noted that international studies indicate a high prevalence of sleep disorders in adults. However, variations in the amount of sleep are more significant during childhood, decreasing from about 16 hours a day in the first days of life to approximately 14 hours at the end of the first month and to 12 hours at the end of the sixth month of life. Subsequently, the duration of infant sleep decreases by an average of 30 minutes per year until the age of five. In adulthood, the amount of sleep decreases and the sleep cycle varies depending on age and external factors.

As one advances in age, losses in duration, maintenance, and quality in the sleep pattern are observed. Several factors, such as pain, medication use, and different clinical conditions, can affect both the quantity and quality of sleep, and this influence is particularly relevant among the elderly, who are more susceptible to such conditions. In addition, irregularities in sleep characteristics, together with associated factors, such as being a woman, being >55 years old, consuming alcoholic beverages, using illicit substances, angina, obesity and depression, increase the vulnerability of chronic damage to the health of individuals.

Recent studies have identified the association between sleep disorders and increased morbidity and mortality. This is due to the systemic effects exerted, with changes in endocrine, metabolic, and immunological pathways, related to unfavorable health outcomes, such as depression, diabetes mellitus, systemic arterial hypertension, obesity, which also contribute to the development of cardiovascular diseases. (BARBOSA et al, 2021)

As a result, symptoms related to sleep disorders (ST) are frequent in children and adults, such as insomnia, excessive daytime sleepiness (EDS), inability to sleep at the desired time, and abnormal events during sleep. The Third International Classification of Sleep Disorders (ICSD-3), published by the American Academy of Sleep Medicine in 2014, identifies seven main categories: insomnia, breathing-related sleep disorders, centrally caused hypersomnolence, parasomnias, circadian rhythm disorders, movement-related sleep disorders, and other sleep disorders (Chart 1). (NEVES et al, 2017)

Chart 1: Sleep disorders according to the 3rd edition of the International Classification of ST (ICSD-3).

<p>A-TRANSTORNO DE INSÔNIA</p> <ol style="list-style-type: none"> 1. Transtorno de insônia crônica. 2. Transtorno de insônia de curto prazo 3. Outro transtorno de insônia. 4. Sintomas isolados e variantes da normalidade. 5. Tempo excessivo na cama. 6. Dormidor curto. 	<ol style="list-style-type: none"> 5. Transtorno dos trabalhadores em turnos. 6. Jet Leg. 7. Transtorno do ritmo circadiano de sono-vigília não especificado.
<p>B-TRANSTORNOS RESPIRATÓRIOS RELACIONADOS AO SONO</p> <ol style="list-style-type: none"> 1. Apneia obstrutiva do sono. <ol style="list-style-type: none"> (a) Adulto (b) Pediátrico. 2. Apneia central do sono. <ol style="list-style-type: none"> (a) Com respiração de Cheyne-Stokes. (b) Devido à condição médica sem respiração de Cheyne-Stokes. (c) Devido à respiração periódica da alta altitude. (d) Devido a drogas ou substâncias. (e) Apneia central do sono primária. (f) Apneia central do sono primária da infância. (g) Apneia central do sono primária da prematuridade. (h) Apneia central do sono decorrente do tratamento. 3. Transtorno de hipoventilação relacionados ao sono. <ol style="list-style-type: none"> (a) Síndrome da hipoventilação da obesidade. (b) Síndrome de hipoventilação alveolar central congênita. (c) Hipoventilação central de início tardio com disfunção hipotalâmica. (d) Hipoventilação alveolar central idiopática. (e) Hipoventilação relacionada ao sono devido ao uso de drogas ou substâncias. (f) Hipoventilação relacionada ao sono devido à condição médica. 4. Hipoxemia relacionada ao sono. <ol style="list-style-type: none"> (a) Transtorno de hipoxemia relacionada ao sono. 5. Sintomas isolados e variantes da normalidade. <ol style="list-style-type: none"> (a) Roncos. (b) Catatrenia. 	<p>E-PARASSONIAS</p> <ol style="list-style-type: none"> 1. Parassonias do sono NREM. <ol style="list-style-type: none"> (a) Transtornos do despertar (a partir do sono NREM). (b) Despertar confusional. (c) Sonambulismo. (d) Terror noturno. (e) Transtornos alimentares relacionados ao sono. 2. Parassonias do sono REM. <ol style="list-style-type: none"> (a) Transtorno Comportamental do sono REM. (b) Paralisia do sono isolada recorrente. (c) Pesadelos. 3. Outras parassonias. <ol style="list-style-type: none"> (a) Síndrome da cabeça explosiva. (b) Alucinações relacionadas ao sono. (c) Enurese noturna. (d) Parassonia secundária a condição médica. (e) Parassonia devido a uso de droga ou substância. (f) Parassonia, não especificada 4. Sintomas isolados e variantes da normalidade. <ol style="list-style-type: none"> (a) Sonilóquio.
<p>C-TRANSTORNOS DE HIPERSONOLÊNCIA CENTRAL.</p> <ol style="list-style-type: none"> 1. Narcolepsia tipo 1. 2. Narcolepsia tipo 2. 3. Hipersonia idiopática. 4. Síndrome de Kleine-Levin. 5. Hipersonia devido a uso de droga ou substância. 6. Hipersonia associada a transtorno mental. 7. Síndrome de sono insuficiente. 8. Sintomas isolados e variantes da normalidade. <ol style="list-style-type: none"> (a) Dormidor longo. 	<p>F-TRANSTORNOS DO MOVIMENTO RELACIONADO AO SONO</p> <ol style="list-style-type: none"> 1. Síndrome das pernas inquietas. 2. Síndrome dos movimentos periódicos dos membros. 3. Câimbras nas pernas relacionadas ao sono. 4. Bruxismo relacionado ao sono. 5. Transtorno do movimento rítmico relacionados ao sono. 6. Mioclonia benigna do sono da infância. 7. Mioclonia espinhal do início do sono. 8. Transtorno do movimento relacionado ao sono secundário à condição médica. 9. Transtorno do movimento relacionado ao sono devido a uso de droga ou substância. 10. Transtorno do movimento relacionado ao sono, não especificado. 11. Sintomas isolados e variantes da normalidade. <ol style="list-style-type: none"> (a) Mioclonia fragmentária excessiva. (b) Tremor hipnagógico do pé e ativação muscular alternante das pernas. (c) Espasmos hipónicos.
<p>D-TRANSTORNO DO RITMO CIRCADIANO DE SONO-VIGÍLIA.</p> <ol style="list-style-type: none"> 1. Tipo atraso de fase do sono. 2. Tipo avanço de fase do sono. 3. Tipo sono-vigília irregular. 4. Tipo sono-vigília não de 24 horas. 	<p>G-OUTROS TRANSTORNOS DO SONO</p> <p>APÊNDICE A- CONDIÇÕES MÉDICAS E NEUROLÓGICAS RELACIONADAS AO SONO</p> <ol style="list-style-type: none"> 1. Insônia Familiar fatal. 2. Epilepsia relacionada ao sono. 3. Cefaléia relacionada ao sono 4. Laringoespasma relacionado ao sono 5. Refluxo gastroesofágico relacionado ao sono. 6. Isquemia miocárdica relacionada ao sono.

Source: Neves *et al*, 2017.

DISORDERS RELATED TO MOVEMENT AND SLEEP BEHAVIOR

Sleep-associated movement disorders are characterized by simple, stereotyped movements that occur during the sleep period, potentially disrupting its regular course. Generally, they are self-limiting and benign clinical conditions, however, difficult to diagnose and treat, and therefore the theme will be addressed and deepened in the present work. Patients complain or are observed with abnormal movements and behaviors during sleep. When the patient is a pediatrician, parents should be instructed to film the movements at home.

Analysis and recognition of these disorders typically involves identifying subjective complaints such as sleep disturbances during the night, excessive daytime sleepiness, or fatigue. This category encompasses a range of conditions, including restless legs syndrome, periodic limb movement disorder (PLMD), sleep-related leg cramps, sleep-related bruxism, sleep-related rhythmic movement disorder, benign childhood sleep myoclonus, sleep-onset propriospinal myoclonus,

systemic disease-related myoclonus, secondary sleep-related movement disorder, and more. In addition, some of these disorders may not have significant clinical consequences and may be considered normal variants, while others may be associated with underlying medical conditions or the use of certain medications. Therefore, a meticulous evaluation and multidisciplinary approach to diagnosis and treatment are key, involving sleep specialists, neurologists, and other healthcare professionals as needed. (MAINIERI et al, 2023).

STs are frequent and debilitating in the current situation, and therefore, based on the above information, the main objective of the present study is to review the specialized literature on the characteristics of the most frequent sleep movement disorders in the general population and their implications on the behaviors and quality of life of people with this condition. Since sleep alterations can compromise the individual's quality of life and safety, since estimates on the rate of accidents and deaths caused by sleepiness or fatigue range from 2% to 41%, with a high cost in financial and social terms. In addition, it emphasizes the importance of preventing/treating situations and diseases that favor this problem. (NEVES et al, 2017) (MULLER et al, 2007)

Epidemiology will be treated according to each disorder to be presented in this work.

PATHOPHYSIOLOGY

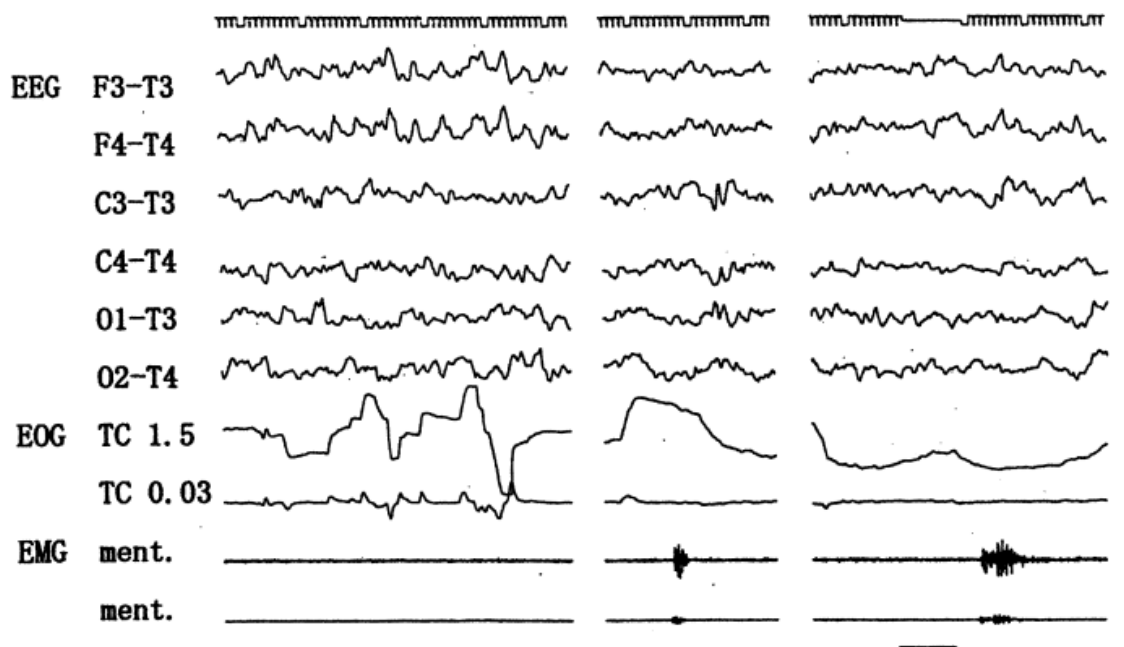
The REM and NREM phases of sleep are associated with important neurophysiological and neurochemical changes in the brain, which lead to changes in the control of motor functions. This explains why motor control disorders sometimes appear specifically during sleep. Multiple factors may be involved in the genesis of sleep-related disorders, from genetic factors to electrolyte disturbances and neurodegenerative conditions (e.g., Parkinson's disease). Focal brain damage, for example, is mostly related to nocturnal epilepsy.

Motor control requires mechanisms of integration of the afferent and efferent systems, involving the spinal cord, brainstem, cerebellum, basal ganglia, and cerebral cortex. (BARGIOTAS; BASSETTI, 2017). Sleep-related motor manifestations arise from a disruption of such mechanisms, often in the form of abnormal activation and/or lack of inhibition of motor circuits. In most situations, dysfunction occurs in both systems, but the exact contribution of these (and corresponding neurotransmitters) to these disorders is not fully understood. Sleepwalking, sleep-related motor epilepsy, and nocturnal panic attacks are thought to be due to a primary ascending dysfunction where activation systems prevail. REM sleep behavior disorder is primarily attributed to a primary dysfunction of the descending inhibitory system. In sleep paralysis, the participation of the mirror neuron system and interaction between several regions of the brain, especially the prefrontal cortex and sensory feedback, is supposed. Restless legs syndrome is mainly related to reduced brain iron content and dysfunction of nigrostriatal dopaminergic pathways and mesolimbic networks

(association with Parkinson's disease and other neurodegenerative diseases), diabetes mellitus, rheumatoid arthritis, peripheral neuropathy, pregnancy (over 20 weeks), use of antihistamines and antidepressants. Oromandibular dystonia and Huntington's disease may evolve with bruxism. Nocturnal cramps are associated with diabetes mellitus, amyotrophic lateral sclerosis, hypokalemia, hypocalcemia, hypomagnesemia, and some medications (statins and diuretics) Nocturnal/sleep-related complex motor manifestations are thought to arise from abnormal (non-epileptic/epileptic) activation of innate (genetically-determined) or learned (central pattern-generating) motor patterns that are essential for survival.

Finally, these disorders could be explained by a "state dissociation", i.e., the coexistence of abnormally activated brain areas with others that exhibit characteristics of normal sleep, the phenomenon of which has already been documented by means of neuroimaging and neurophysiological methods (Fig. 1) (NEVES; M; GOMES, 2018; BARGIOTES; BASSETTI, 2017).

Figure 1. Parts of a real polygram showing rhythmic disturbance of movement. A *burst* REM (left), a short (middle) and long (right) chin phasic muscle activity (AMFQ), respectively. No chin phasic muscle activity occurred in association with a rapid eye movement (REM) sequence. Chin phasic muscle activity was identified in the tracing with calibration at 50 mV/5 mm and a time constant of 0.003. A high-gain (upper) trace was recorded simultaneously to verify the continuity of the AMFQ. Calibration: 1 s, 50 mV; EEG, electroencephalography; EOG, electrooculography; EMG, electromyography; CT, time constant.



Source: KOHYAMA et al., 2002.

SLEEP-RELATED MOVEMENT DISORDERS

SLEEP-ONSET PROPRIOSPINAL MYOCLONUS

Sleep-onset propriospinal myoclonus (PSM) is a condition characterized by involuntary spasms that affect several muscle groups, mainly in the abdomen, trunk, and neck typically during

the early sleep phase. It was first described in 1991 and has since been increasingly identified as a functional movement disorder in most cases. These movements are abrupt and can occur both during contraction and during muscle relaxation, and can vary in their intensity and frequency. Although sleep myoclonus is a common occurrence, affecting up to 70% of the population, it is generally considered benign, being more frequent in the male population in adulthood. However, in certain cases, it can be associated with more serious conditions such as Parkinson's disease, spinal injuries, neuroinfections, medications, paraneoplastic diseases, and head trauma. (EBERHARDT et al, 2017)

There are different classifications of myoclonus, the first of which is physiological myoclonus, characterized by spasms that occur during sleep in healthy individuals, in a benign way, most of the time, lacking a therapeutic regimen. (EBERHARDT et al, 2017)

Myoclonic epilepsy usually occurs by activation of the cerebral cortex and is characterized by epilepsy that receives electrical discharges from the brain, generating a myoclonus that is abruptly interrupted, as in juvenile myoclonic epilepsy. (EBERHARDT et al, 2017)

In idiopathic myoclonus, myoclonic movements arise spontaneously, without being related to other specific conditions or symptoms. The precise etiology of this phenomenon is unknown, although it is often attributed to hereditary influences, which can interfere with daily activities. (EBERHARDT et al, 2017)

When caused by other diseases, myoclonus is called secondary or symptomatic, indicating that it is a symptom of another underlying condition or may emerge as a result of circumstances other than a disease, such as injury or poisoning. Several pathologies can be responsible for this type of myoclonus, including neurodegenerative movement disorders, infectious diseases such as Acquired Immunodeficiency Syndrome (AIDS), Whipple's disease and viral encephalitis, metabolic causes and exposure to toxic substances, such as mercury, in addition to drug use, among other factors. (EBERHARDT et al, 2017). The propagation time of the movement helps us to differentiate myoclonus, so that its duration is slower when compared to the others. Spinal cord injuries caused by trauma or degenerative diseases are characterized by movements that occur outside the night, helping in the differential diagnosis.

Treatment is directed towards the management of underlying medical conditions, depending on the etiology and severity of symptoms, and may include the use of medications, for example, valproic acid may be prescribed as an integral part of the therapeutic protocol, in addition to levetiracetam and clonazepam. (EBERHARDT et al, 2017)

It is imperative to identify and treat any underlying medical conditions that may be triggering muscle spasms during sleep, such as neurological disorders, metabolic dysfunctions, adverse drug reactions, and more. In addition, it is recommended to consult a medical professional specialized in sleep disorders, such as a neurologist, for an accurate evaluation and appropriate advice regarding the

most appropriate treatment for this pathology, which should be individualized. (EBERHARDT et al, 2017)

BENIGN SLEEP MYOCLONUS OF INFANTS

Benign myoclonus of the baby's sleep can begin in the neonatal period and extend into the second half of life. Family history may be positive in 10% to 25% of cases. In this disorder, the patient presents myoclonic movements in *clusters* during sleep, which may affect all four limbs, with the arms being more reported, usually during non-REM sleep, in any phase of sleep (although less frequent in REM sleep). Movements are restricted to periods of sleep and resolve themselves upon awakening, and a slight restriction or even a simple touch is enough to reduce them. Myoclonus is focal, multifocal, or generalized, but in almost all cases focal myoclonic activity migrates to other sites. The convulsions last for seconds and happen in about 3-15 minutes, but they can last up to 60 minutes. The movements can be so dramatic that even experienced neuropsychiatrists may mistake them for neonatal myoclonic epileptic seizures, and electroencephalography will be normal. The diagnosis is obtained through a clinical history (very detailed anamnesis with the child's routine, sleep schedules and movement characteristics) associated with nocturnal polysomnography. Polygraphic studies of benign neonatal myoclonus suggest that this movement pattern is mainly observed during non-REM sleep, however, up to 22% of events may occur during REM sleep or, less frequently, 3% of cases, during transitional sleep.

Electroencephalography is normal and may show motion artifacts. This test may be ordered to rule out epileptic myoclonus. The main differential diagnosis of this disorder is myoclonus of epileptic origin. The anamnesis should look for the presence of events also during wakefulness or possible alterations in neuropsychomotor development. Exclusion is performed by means of electroencephalography, which in benign sleep myoclonus will be normal, and may present only movement artifacts. Because it is a pathology with a good prognosis, it does not require specific treatment, as it tends to cease with growth and development (until the second half of life). The conduct consists of reassuring parents, and may associate behavioral strategies and sleep hygiene routines, such as avoiding exposure to the screen, reducing light and ambient music (EBERHARDT; TOPKA, 2017).

SLEEP BRUXISM

Bruxism is a condition characterized by grinding or clenching of the teeth, and can occur during the day (daytime bruxism) or during sleep (nocturnal bruxism). This condition can lead to a variety of problems, such as tooth wear, headaches, jaw pain, chewing difficulties, and even sleep disturbances. There are several causes associated with bruxism, including genetic, emotional,

psychological, postural, and even lifestyle-related factors. In addition, stress and anxiety are often pointed out as triggers of this disorder.

The diagnosis is usually made based on the patient's clinical history, self-report or complaints from those who may have witnessed the event, and on physical and dental examinations. In some cases, polysomnography may be necessary to diagnose sleep bruxism. (FURLANETTO, 2018). It is important to investigate other temporomandibular joint pathologies and malocclusions, anxiety, stress and attention deficit hyperactivity disorder (ADHD) that may be part of differential diagnoses.

Treatment may involve multidisciplinary approaches and conservative treatment is prioritized, including behavioral measures, use of bite plates, physical therapy, cognitive-behavioral therapy, and in some cases, the use of muscle relaxant medications, in some cases, Clonazepam is indicated in low doses of 0.6 to 4mg/day. Importantly, treatment should be individualized, taking into account the underlying causes in each patient. In short, this is a common condition that can bring several complications to the patient's oral health and well-being. Therefore, it is essential to seek professional help for an accurate diagnosis and an appropriate treatment plan (LAVIGNE et al, 2000).

MYOCLONUS RELATED TO SYSTEMIC DISEASES

Also known as secondary or symptomatic myoclonus, they are characterized by involuntary movements that interfere with the patient's sleep and that result from various diseases, including degenerative diseases such as some dementias and those affecting the basal ganglia. Therefore, its treatment consists of treating the underlying disease and the diagnosis is made by the patient's clinical history (EBERHARDT; TOPKA, 2017). They result from some pathologies in particular, as shown in Table 2:

Table 2. Causes of symptomatic myoclonus. In: CAMARGOS et al., 2012.

Neurodegenerative movement disorders
Wilson's disease, multiple system atrophy, Huntington's disease, cortico-basal degeneration, progressive supranuclear palsy, Parkinson's disease
Dementias
Alzheimer's disease, Creutzfeldt-Jakob disease, and dementia with Lewy bodies
Infectious diseases
AIDS, Whipple's disease, viral encephalitis, subacute sclerosing panencephalitis and herpetic encephalitis
Metabolic causes
Hepatic and renal failure, hypoglycemia, non-ketotic hyperglycemia, hyponatremia, biotin deficiency and multiple carboxylase deficiency
Toxic causes
Aluminum, mercury, bismuth, tetanus toxin, insecticides and drugs of abuse
Medicines
Psychotropic drugs, anticonvulsants, antineoplastic drugs, narcotics, cardiovascular drugs, antibiotics and antivirals
Nervous system injuries
Trauma, tumor, hemorrhage, ischemia, abscess, electric shock, spinal cord compression, peripheral nerve injury and others
Other diseases
Malabsorption diseases (Whipple's disease, Celiac disease and vitamin E deficiency), storage diseases (Lafora's disease, lipidoses and others), spinocerebellar degeneration, paraneoplastic syndromes, mitochondrial encephalitis, inborn errors of metabolism and others

Adapted from Blindauer, 2004 and Chaudhuri and Ondo, 2010.

SLEEP-RELATED RHYTHMIC MOVEMENTS

Rhythmic movement disorder is also known as *nocturnal jactatio capitis*, it is considered a sleep disorder with significant prevalence in early childhood, common in children aged 9 months, with self-limited remission up to 4 years. It is characterized by repetitive movements, especially in the cephalic and cervical segments, in the early stages of non-REM sleep.

There are three main types of movements:

-*Head banging*: consists of rhythmic movements of the head in an anteroposterior direction.

-*Head rolling* : consists of the lateral turning of the child's head while lying down in the supine position.

-*Body rocking*: with the hands on the knee, the child moves the body continuously in an anteroposterior direction.

In addition to these, there is even less frequent the swaying of the body and leg rhythmically, and the association of movements with vocalization. The episodes occur 1 to 2 times a night, and may persist in more frequent cases, starting as soon as the child falls asleep and lasting from seconds to 15 minutes. It is important to note that, in this age group, this disorder, even if "benign" and self-

limiting, can significantly impact quality of life, since sleep at this stage has important biological and cognitive functions, therefore, it is not uncommon for this disorder to be frequently related to irritability, tiredness, sleepiness, intellectual and socio-behavioral impairment (GOGO et al., 2019).

Diagnosis is obtained through clinical history and nocturnal polysomnography.

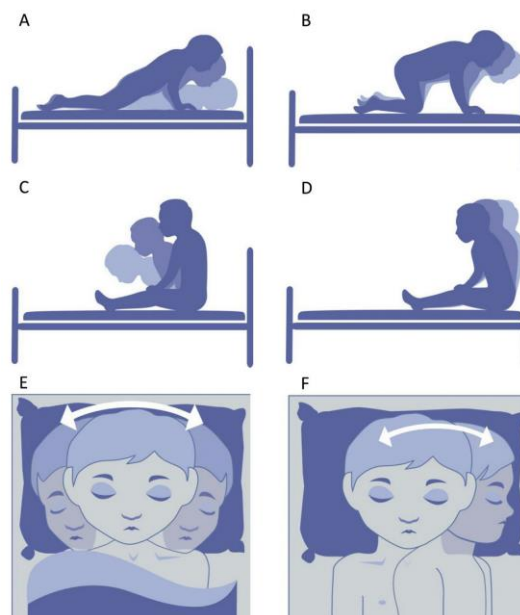
To differentiate from other possible causes, the child's sleep routine should be observed, as well as the characteristic of movements, durability, and the onset of episodes.

Polysomnography demonstrates the presence of rhythmic movement in the sleep-wake transition and in stage 2 of non-REM sleep, with the presence of slow-wave or REM sleep being rarer.

The differential diagnosis is made with other hyperkinetic disorders, mainly because it does not affect the neurological and cerebellar part, it is also differentiated by the period in which the episodes occur (soon after the onset of sleep). Also differentiate from movements related to children with autism spectrum or neuropsychomotor delay.

As it is a self-limiting resolution disorder, treatment guidance is given in relation to care so that physical damage does not occur during the episodes to avoid trauma. In general, remission occurs before 5 years of age, but in some cases episodes remain until this age. In these cases, the need to seek neuropsychological treatment to help with daily and school activities should be taken into account.

Fig.3 Different forms of rhythmic movements. A. Movement of the upper body that occurs with and without hitting the head on the pillow or mattress. B. Full-body movement that occurs with and without hitting the head on the headboard or wall. C and D. Swaying and slapping the body E. Rolling the head F. Rolling the body. All movements may be accompanied by rhythmic vocalizations. E/F may include slamming part of the body (e.g., head/limb) against a hard surface.



Source: GOGO et al., 2019.



MOVEMENTS RELATED TO MEDICATION OR SUBSTANCES

These are movements that impair sleep and are related to the use of medications or abstinence from a substance that promotes wakefulness. The diagnosis is made through careful anamnesis, and the treatment is based on the withdrawal of the drug and treatment of abstinence.

PERIODIC LEG MOVEMENT AND RESTLESS LEGS SYNDROME

Restless leg syndrome

Still with unknown cause, but some studies show it to be related to an imbalance of Dopamine in the body (a substance that improves the transport of electricity).

The origin of RLS is questioned as a dysfunction of the diencephalon-spinal dopaminergic system, or even serotonergic and opioid. That is, its pathophysiology is not yet fully defined/known. Patients report an irresistible movement of the lower limbs accompanied by a dragging sensation of the legs. This can lead to or can be a cause of depression, since lack of sleep can dysregulate dopamine, just like depression. This is the beginning of a cycle that is difficult to control. It is 2x more common in women than in men and its worldwide incidence is large, at 5%. There is underreporting and this is due to the fact that most patients do not direct their symptoms correctly to the doctor.

One of the causes is heredity, 3rd trimester of pregnancy, iron deficiency, peripheral neuropathy. There are several conditions that resemble RLS, but with a careful anamnesis, where circadian symptoms are associated with insomnia, they substantially help the differential diagnosis. Some of the DCS are: Hypotensive akathisia, neuroleptics-induced akathisia, peripheral neuropathy, lumbar radiculopathies, neurogenic claudication, vascular claudication, chronic pain syndrome, fibromyalgia, arthritis of the lower limbs, positional discomfort, nocturnal cramps, sleep myoclonus, depression with somatic symptoms, voluntary movements, peripheral vascular insufficiency, pruritus, painful legs syndrome and toe movements, Vesper's curse, Vesper's delirium infestation.

How to perform the Diagnosis? Polysomnography can be performed, where it is possible to check sleep time, sleep movements, apnea, etc., but it is not the first choice test, since polysomnography only checks the movements, but not the cause of the movements. Serum ferritin and transferrin dosage (in order to check for iron deficiency anemia).

Blood glucose, creatinine, TSH, pregnancy test, calcium and magnesium dosage, vitamin B12 and folic acid. Electroneuromyography should be ordered when peripheral neuropathy is suspected. A recent validated test is with the use of 100mg of Levodopa + 25mg of Benserazide at the onset of symptoms, with recording of the intensity of these symptoms every 15 minutes for a total period of 2 hours.

Computed tomography and magnetic resonance imaging have no diagnostic evidence in this syndrome.

Treatment

There is no single specific medication, but there are some that are prescribed in medical practice, according to their indication, such as: Pramipexole - Used for treatment of signs and symptoms of Idiopathic Parkinson's Disease. It is a dopamine agonist of the non-ergoline class. 0.125 to 0.75mg/day Gabapentin/Pregabalin - Anticonvulsants (used when the patient also has peripheral neuropathy) 188mg/day - Administered 2 hours before bedtime Tramadol - Centrally acting analgesic Muscle relaxants - CNS action Levodopa: Pregnant women. Maximum use of 200mg/day - Single dose 30 to 60min before bedtime Benzodiazepines - 0.2 to 1mg/day Iron Replacement (when needed) 4-6mg/kg/day Other recommendations: Warm bath before bed, relaxation, stretching, in addition to avoiding caffeine. Daily physical exercise is recommended, but never at night.

The following appendix refers to the article on the treatment of restless legs, which talks about the use of the medication Levodopa, where its effect of use in monotherapy and in combination is discussed.

"As monotherapy, RLS symptoms last only through the first half of the night. However, when used in combination, the benefits extend into the second half of the night."

Table 1 – Evidence for treatment of RLS with pharmacological therapy

Author/year	Sample size	Medication/dosage	Duration	Study design	Results	Side effects	Augmentation phenomena or rebound effect	Comments
Benes et al. ²¹ (1999)	35 (32 completed)	100-200 mg levodopa + 25-50 mg benserazide	2 cross-over periods of 4 weeks each	Double-blind randomized controlled multicenter cross-over trial	Improvement in number of PLMs/hour, time in bed without limb movements and subjective sleep quality	Diarrhea, reduced general drive, nausea and muscle weakness	No augmentation phenomena or rebound effect	—
Saletu et al. ²² (2003)	3 nights: 21 4 weeks: 18	100-200 mg rr-L-dopa/ benserazide + 100-200 mg sr-L-dopa/ benserazide	3 nights and a follow-up of 4 weeks	3 nights: double-blind, controlled, randomized crossover trial. 4 weeks: open non-controlled trial	Acute L-dopa/ benserazide improved PLM/h of sleep, total number of PLM, PLM/h of time in bed, PLM/h of REM and non-REM, PLM/h of wake time and PLM-arousals/h of sleep, but the subjective sleep quality only improved after chronic treatment	Nausea, stomachache, tachycardia, dry mouth, headache and nycturia.	One patient reported augmentation phenomena	—

Rev Bras Psiquiatr. 2006;28(4):308-15

Wayne H, Walters AS, Allen RP, et al. Impact, diagnosis and treatment of restless legs syndrome (RLS) in a primary care population: the REST (RLS epidemiology, symptoms, and treatment) primary care study. *Sleep Medicine* 2004;5:237-246.

Periodic Leg Movement

Many patients with RLS (Restless Legs Syndrome - 80%) also report having periodic leg movement, which are repeated movements of the lower limbs during sleep. This condition is more common in patients with advanced age and psychic conditions such as stress, irritability, depression, may also be accompanied. May be associated with: Nocturnal epilepsy, myoclonic epilepsy, sleep-onset convulsions, normal physical activity of REM sleep, and fragmentary sleep myoclonus.

SLEEP CRAMPS

It consists of sudden contractions of the leg and calf muscles, accompanied by pain during sleep. The duration of the movements is between 0.5 and 5.0 seconds, and may occur in up to hours with intervals of 20-90 minutes, the patient may have sleep interruption.

Most patients present with idiopathic background sleep cramps. Because it is a symptom of hyperactivity and neural fatigue, it is common to report it in high-performance athletes. Neuropathic patients such as peripheral neuropathies and Parkinson's and amyotrophic lateral sclerosis (ALS), so there is a high prevalence in the elderly. There is an association with the use of statins (promote muscle damage), diuretics (cause hydroelectrolyte changes), antidepressants, fibrates, nicotinic acid, morphine, nifedipine, terbutaline, penicillamine, phenothiazine, and anticholinesterase drugs; Potassium-sparing β -agonists and diuretics (these are more closely related to nocturnal cramps than non-potassium-sparing diuretics). Individuals undergoing treatment for chronic diseases like cancer, cirrhosis can cause neural damage causing cramps. Uremic individuals also have this symptom. (MCGRAW-HILL; 2001)

Some complementary tests can help in the diagnosis. Electromyography may be ordered in case of muscle weakness; Magnetic resonance imaging of the brain if muscle weakness or neurological signs suggest central nervous system involvement, but the diagnosis is well defined in the clinical history. Physical examination, reflex tests, palpation, and pulse checks can help identify pathologies that are associated with cramps.

Treatment is based on stretching the muscles, mobility exercises, metabolic compensation (controlling diabetes, making lifestyle changes), wearing shoes when sleeping to keep the muscle stretched, and removing or adjusting the precursor drugs of the cramp. Therapy and psychotropics to assist with depression-related sleep deprivation. In pregnant women, sodium supplementation and the use of multivitamins have benefits. For ALS, physiotherapy, antipathic and anti-inflammatory drugs are indicated. Most of the medications commonly prescribed to prevent cramps, such as calcium and magnesium supplementation are not as effective, there are quinines (since 2010 they are no longer used frequently due to many drug interactions). Diphenhydramine, benzodiazepines, mexiletine, carbamazepine, phenytoin, and gabapentin, as well as B vitamins and calcium channel blockers such

as verapamil and diltiazem, offer no efficacy and the adverse effects do not outweigh it. Avoiding caffeine and other sympathetic stimulants is essential. 2018 Brazilian Journal of Surgery and Clinical Research – BJSCR

Differential diagnosis

Sleep-related movement disorder is composed of several pathologies, which cause involuntary movements and disrupt the patient's sleep, they are: Bruxism, Restless Legs Syndrome, Periodic Leg Movement, Sleep Cramps, Sleep-Related Rhythmic Movements, Sleep-Onset Propriospinal Myoclonus, Medication-Related Movements, Myoclonus Related to Systemic Diseases and Benign Sleep Myoclonus in Babies. Thus, the differential diagnosis is given according to the pathology, as presented in each sleep movement disorder above.

Treatment - General Aspects

Each movement disorder has specific treatment demands (medication or not), but the need for behavioral strategies and sleep hygiene routines is common to all, such as avoiding exposure to the screen, reducing light and ambient music. Sleep hygiene is a method that aims to educate habits related to health and behavior that are beneficial or harmful to sleep. Sleep hygiene recommendations are as follows:

- Establish regular bedtimes
- Wake up regularly at the same time
- Regulate the amount of sleep you get each night
- Exercise daily and regularly, especially aerobics, but not at the end of the day.
- Sleep in a comfortable, quiet and cool environment
- Avoid caffeinated beverages and other stimulants (including smoking), especially around bedtime
- Avoid alcohol 3 hours before bedtime to sleep
- Avoiding Hypnotic Drugs
- Do something to relax before going to bed

Clinical case

Clinical history: Female, white, 78 years old, widowed.

2 months ago, she began to present a feeling of discomfort and paresthesias in her feet, legs and thighs, similar to "tingling", "burning", always at night, when lying down.

The patient reported partial improvement of symptoms when she got out of bed and walked.



Several diagnoses were made and several treatments were performed, including clonazepam, which did not improve the condition. The patient also reported insomnia and complained of depression.

Positive family history.

Physical examination: On physical examination, the patient was in good general condition, lucid, oriented, with normal vital data and no alterations in the general physical examination.

On neurological examination, the patient had depressive facies.

Complementary tests: No changes in the laboratory test.

Conduct: During treatment, the condition worsened with Mirgtazipine 30mg for 30 days, the patient was replaced by amineptin 200mg/day, which did not improve or worsen the symptoms and, finally, the use of pramipexole 0.125mg 2x/day caused the improvement of the symptoms.

Discussion: The origin of RLS is questioned as a dysfunction of the diencephalon-spinal dopaminergic system, or even serotonergic and opioid. The increase in brain serotonergic activity induced by the use of selective serotonin uptake inhibitor drugs can inhibit the release of dopamine by dopaminergic neurons, so patients with neuronal diseases that present reduced dopaminergic activity, such as RLS and Parkinson's disease, are at great risk of worsening the clinical picture.


REFERENCES

1. Eberhardt, O., & Topka, H. (2017). Myoclonic Disorders. **Brain Sciences**, 7(8), 103.
2. Bargiotas, P., & Bassetti, C. L. (2017). Sleep-related movement disorders and disturbances of motor control. **Current Opinion in Neurology**, 30(4), 405.
3. Barbosa, I. S., Souza, J. C., Muller, P. T. G., et al. (2021). Avaliação dos distúrbios do sono de pacientes submetidos à polissonografia. **Revista Brasileira de Neurologia e Psiquiatria**, 25(2), 34-41.
4. Mainieri, G., & Provini, F. (2023). Description of sleep-related movement disorders. In **Encyclopedia of Sleep and Circadian Rhythms (Second Edition)**, Academic Press, 601-611.
5. Müller, M. R., & Guimarães, S. S. (2007). Impacto dos transtornos do sono sobre o funcionamento diário e a qualidade de vida. **Estudos de Psicologia (Campinas)**, 24(4), 519–528.
6. Neves, G. S. M. L., Macedo, P., & Gomes, M. M. (2017). Transtorno do sono. **Revista Brasileira de Neurologia**, 53(3), 19-30.
7. Neves, G. S. M. L., Macedo, P., & Gomes, M. M. (2018). Transtorno do sono: Atualização (parte 2/2). **Revista Brasileira de Neurologia**, 54(1), 32-38.
8. Simões, A. D., et al. (2022). Principais distúrbios do sono e seus impactos na qualidade de vida humana: uma revisão sistemática de literatura. **Research, Society and Development**, 11(5), e38411528457–e38411528457.
9. Antoniuk, S. A., & Schwind, M. R. (2018). Distúrbios paroxísticos não epiléticos na infância e adolescência. **Revista de Residência Pediátrica da Sociedade Brasileira de Pediatria**, 8(1).
10. Jalal, B., & Ramachandran, V. S. (2017). Sleep Paralysis, “The Ghostly Bedroom Intruder” and Out-of-Body Experiences: The Role of Mirror Neurons. **Frontiers in Human Neuroscience**, 11.
11. Fahn, S. (2002). Overview, history, and classification of myoclonus. **Advances in Neurology**, 89, 13–17.
12. Blindauer, K. A. (2004). MYOCLONUS. **CONTINUUM: Lifelong Learning in Neurology**, 10(3), 174.
13. Camargos, S., et al. Manual para o diagnóstico dos distúrbios de movimento. Em: Manual para o diagnóstico dos distúrbios de movimento. [s.l: s.n.], 158–158.
14. Gogo, E., et al. (2019). Objectively confirmed prevalence of sleep-related rhythmic movement disorder in pre-school children. **Sleep Medicine**, 53, 16–21.
15. Kohyama, J., et al. (2002). Rhythmic movement disorder: polysomnographic study and summary of reported cases. **Brain and Development**, 24(1), 33–38.
16. Wayne H., Walters, A. S., Allen, R. P., et al. (2004). Impact, diagnosis and treatment of restless legs syndrome (RLS) in a primary care population: the REST (RLS epidemiology, symptoms, and treatment) primary care study. **Sleep Medicine**, 5, 237-246.



17. Furlanetto, R. M. (2018). Bruxismo: uma revisão de definição, classificação e etiologia. *Faculdade Sete Lagoas*.
18. Lavigne, G. J., & Manzine, C. (2000). Bruxism. In: Kryger, M. H.; Roth, T.; Dement, W. C. (Ed.). *Principles and practice of sleep medicine* Philadelphia: W. B. Saunders, 773-785.

Potential plastic digester of *Euphorbia Tirucalli*

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ABSTRACT

Natural products that cause oxidative stress and even local corrosion are of interest as degrading products of materials persistent in nature, such as plastic. This chapter evaluated the corrosive and shrinkage physicochemical action of total aqueous extracts of *Euphorbia tirucalli*, a species described as corrosive and shrinkage, from specimens with geographic variations (mangrove and mountains of Rio de Janeiro and the north coast of São Paulo) also subjected to temperature variations, on polypropylene (PP-5). This plastic is used on a daily basis and can be subjected to reuse processes. In the present experiment, aqueous extracts were prepared from temperature variations and their plant chemical productions were marked using high-performance liquid chromatography associated with the UV detection spectrum. Unlike previous tests, none of the extracts were capable of immediate extraction or digestion over 30 days. Only for the stems from Petrópolis (50%) and the north coast of São Paulo (33%) subjected to boiling was the activation of their gummy action observed, acting as glue on the PP-5. suggestive of natural polymerization for cellulose. Despite the observations regarding the potential practical, useful and cheap application of this test, it was evident that the raw latexes from the geographical regions tested at different temperatures were not capable of chemically digesting isopropylene, thus suggesting that the enzyme capable of digesting this plastic effectively participates when the endophytic fungus present in this species finds favorable conditions to develop as previously discussed. Phytopathology tests confirmed the biological effects verified through the roots of *E. tirucalli* and subsequently, new cultivars developed followed the variation in the release of cyanuric acid into the test environment, marking interest since cyanuric acid can play a role in recovery soil, in addition to being a herbicide, insecticide and being able to reduce contamination by gram-negative fecal coliforms in water, especially *Escherichia coli*. Based on this contribution, new tests will be carried out in order to investigate mechanisms of action in phytoremediation, comparing them with those already preliminarily evidenced and communicated. A specific protocol has been developed in Plant Biotechnology, as these jobs have the possibility of useful and profitable application in reuse, to be carried out by small solid waste recyclers. It will also aim at autonomy for ethnic groups in urban situations, as well as promoting environmental sustainability.

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INTRODUCTION

Euphorbia tirucalli L. (Aveloz, fire stick) is a succulent species of African origin, with a cosmopolitan distribution. In high salinity soils, it produces diterpene esters, some with aromatic chains, which induce oxidative stress in cell membranes and plant walls (FURSTENBERGER & HECKER, 1986; BETANCUR-GALVIS et al., 2002; 2003).

However, plant chemical marking by HPLC/UV of the species from the IPPN/UFRJ garden detected the conditions where it is more active on the membrane and cell wall due to the presence of polyhydroxylated diterpenes, hydrophilic, cytotoxic and erosive, at a local level that vary in concentration according to seasonality. They were detected in root exudation, but they can be removed from the soil by leaching (VARRICCHIO, 2007; VARRICCHIO et al., 2008, a).

Natural products that cause oxidative stress and even local corrosion are of interest as degrading products of materials persistent in nature, such as plastic (SINGER et al., 2003). Thermoplastic polymers bond by weak forces. When heated, they become flexible. They return to their solid state when cooled. Heating and cooling cycles in the manufacture of PET bottles make them remoldable, an interesting advantage for environmental issues (PEREIRA & MACHADO & SILVA, 2002), since the polluting accumulation of plastic has been causing damage to public health (being found even in breast milk and placenta) and irreversible impacts on the environment (FREIRE SOUZA SILVA et al., 2019).

Among plastic materials, polypropylene (PP - 5) is a crystalline resin with high chemical resistance, with resistance to traction, acid and basic attacks, and deformation due to heat (ABREU, 2006). It can burn without the presence of a flame. It is transparent and unbreakable. Its drying time is 2 hours at 80°C and achieves shrinkage that varies between 1.5 and 3.0%. It is found in films, syringes, biscuit and bread packaging, and it is known that even other materials with PP-5 can persist in nature.

In the literature, it is described that diterpene esters are corrosive at room temperature. DELAUNAY DE SOUZA et al. (2023, a) have already demonstrated the retractable digesting effect of raw *E. tirucalli* latex on isopropylene. Could *E. tirucalli* extracts cause corrosion or shrinkage in PP-5?

AIMS

To evaluate the corrosive and shrinkage physicochemical action of total aqueous extracts of *E. tirucalli* subjected to temperature variations on polypropylene.

SPECIFICS AIMS

- Evaluate the physicochemical action of geographically distinct total extracts of *E. tirucalli*.
- Evaluate the physical action of total extracts of *E. tirucalli* obtained by temperature variations on polypropylene.

METHODOLOGY

BOTANICAL CERTIFICATION:

Record in the Herbarium of the National Museum/UFRJ.

SOLUTIONS PREPARED FOR THE TESTS:

- 1 Petrópolis mineral water.
- 2 Total aqueous stem extract from Petrópolis/RJ, Room temperature (22 °C).
- 3 Total aqueous extract of stem from Petrópolis/RJ, boiled (100°C).
- 4 Total aqueous stem extract from Petrópolis/RJ cooled to -15 °C.
- 5 Total aqueous extract of stem from the north coast of SP Room temperature (22 °C).
- 6 Total aqueous extract of stem from the north coast of SP, boiled (100°C).
- 7 Total aqueous extract of stem from the north coast of SP cooled to -15 °C.
- 8 Total aqueous stem extract from IPPN/UFRJ, Room temperature (25 °C).
- 9 Total aqueous extract of IPPN/UFRJ stem, boiled (100°C).
- 10 Total aqueous extract of IPPN/UFRJ stem cooled to -15 °C.

QUALITATIVE MARKER DESCRIPTION OF HPLC/UV (CHANNEL FOCUSED AT 210 AND 230 NM – VARRICCHIO, 2005)

Qualitative assessment of the corrosive and shrinkable physical effect on PP-5 using scales adjusted for this material (CÂMARA, 2003; ABREU et al., 2006; MIGUEL, 2010):

- Regarding speed: immediate, short-term (< 2 hours), medium (2 to 3 hours) and long-term (> 3 hours).
- Regarding the intensity of contraction in relation to the surface: Low (< 2.5%), Medium (2.5%), High (> 3.0%).

Polypropylene (PP - 5) was cut into 1.5 x 1.5 cm segments organized in groups of 3, arranged in quadruplicates (N = 12) per solution, making a total of 120 segments arranged in three aluminum trays. Then, 0.1mL of control solution (nº 1) and test solutions (2 to 10) were applied to each cut PP surface. Next, a time and activity curve was established.

RESULTS/DISCUSSION

PLANT CHEMICAL ANALYSIS

A qualitative analysis of the plant chemical production of *E. tirucalli* from IPPN/UFRJ, Petrópolis/RJ and the north coast of SP was proposed. All lattices collected between 8 am and 10 am. The HPLC/UV analysis of *E. tirucalli* from the municipality of Petrópolis/RJ remains similar to that from the IPPN/UFRJ garden for the channels focused on 210 and 230 nm. The production of polyhydroxylated and less esterified diterpenoids did not vary, as previously reported (VARRICCHIO et al., 2008). The solution obtained from the species from Caraguatatuba, north coast of SP evaluated by CLAE/UV demonstrated detection of a similar pattern to other samples from Rio de Janeiro.

Based on classical literature, a probable difference in plant chemical production was sought, based on geographic variation.

PROVENANCE - GEOGRAPHY REVIEW STUDY

The study of plants involves variations in their plant chemical production (secondary metabolism), also due to the environmental conditions in which the species to be studied develops: geographic regions, microclimates, soil characteristics, among others (SINGER et al., 2002). It is also known that soils are usually the result of weathering to which rocks, with their geological characteristics, are subjected (EMBRAPA, 2004).

From this review, we returned to each plant individual we studied to establish a geographic correlation. As previously described, the soil on Governador Island, for the most part, is classified as argisol. The university campus of Ilha do Fundão is on Ilha do Governador. Between 1949 and 1952, eight islands in this region were filled in and interconnected for the construction of the University City of the University of Brazil, currently the Federal University of Rio de Janeiro/UFRJ (MENEZES et al., 2005).

The soil of *E. tirucalli*, studied by us, a plant located in the IPPN/UFRJ garden for around 35 years, is located on the shore of Guanabara Bay, whose plant group suggests it can be classified as a halophyte meadow. It was subjected to analysis in the UFRRJ Laboratory, in accordance with EMBRAPA collection recommendations at both depths, and was classified as sandy soil. In the past, Governador Island was called Paranapuãm Island, and the indigenous people who lived there were from the Maracajás tribe. Around the entire Guanabara Bay and where the city of Rio de Janeiro is located today, there was the nation of Tamoios/Tupinambás.

Petrópolis is located in the mountainous region, 68 km from Rio de Janeiro. The central urban area is located at the top of Serra da Estrela, belonging to the Serra dos Órgãos mountain range, a subsector of Serra do Mar. The municipality has extremely rugged terrain, with large differences in level. From the Itaipava district onwards, the relief decreases in altitude. The mountainous

environment, which is almost always humid, allowed the local vegetation to be characterized as Atlantic Forest forest (PMP, 2020).

Until the 18th century, the region was inhabited by the Coroados indigenous people, known by the Portuguese as "Sertão dos Índios Coroados". It was only with the discovery of gold in Minas Gerais and the consequent opening of the Caminho Novo, which passed through Petrópolis, in this century, that the region began to be occupied by non-indigenous people (PMP, 2020).

Recurrent landslides are caused by the steepness of the slopes, the thin thickness of the soil and the configuration of the rocks below the slopes. The region where the Petrópolis Mountain Region Environmental Protection Area - APA Petrópolis-RJ is located is part of the southeastern portion of the Brazilian Platform, represented by the Atlantic Mobile Belt Tectonic Domain. It is located within the Morphostructural Domain of Remobilized Folding Belts, including the Escarpas e Reversos Geomorphological Region of Serra do Mar (FNMA/INSTITUTO ECOTEMA, 2001; BAPTISTA et al., 2005; PMP, 2020).

The coastal region of São Paulo is characterized by a very rugged relief, with the Serra do Mar escarpment advancing towards the coastal plain in the area corresponding to the municipalities of the North Coast (from São Sebastião to Ubatuba), contrasting with the greater dominance of the plain in Baixada Santista and Litoral Sul. The region is marked by the relief of Serra do Mar, which acts as an important factor in orographic intensification and, associated with atmospheric flows originating from the ocean and a zone where atmospheric systems meet, provides a dynamic of high amounts rainfall, with frequent records of increased mass movements (TECHNICAL DIAGNOSIS APAM LITORAL NORTE).

According to Almeida and Carneiro (1998), Serra do Mar is a set of scarps that extends from the coast of Rio de Janeiro to Santa Catarina, where it ceases to exist as an orographic unit with a steep edge of a plateau. A large part of the territory of the North Coast of São Paulo is formed by mountainous escarpments (43%) and mountainous domains (32.4%), located predominantly in areas within the limits of Integral Protection Conservation Units (DIAGNÓSTICO TÉCNICO APAM LITORAL NORTH).

The coastal and fluvio-marine plains, together, correspond to around 15.7% of the region, with a predominance in Caraguatatuba and São Sebastião. The domains of hills and low mountains are distributed throughout the region (except Ilhabela) and predominate in Caraguatatuba (In: DIAGNÓSTICO TÉCNICO APAM LITORAL NORTE).

TEMPERATURE VARIATION OF AQUEOUS EXTRACTS OF TOTAL STEM (AERIAL PARTS AND LATEX) FROM ILHA DO FUNDÃO/RJ, PETRÓPOLIS/RJ AND LITORAL NORTE/SP OVER PP-5 (CORROSION AND SHRINKAGE)

The third context analyzed was the influence of temperature variation of aqueous extracts of the total stem (aerial parts and latex) of *E. tirucalli* from the three regions: mangrove of Guanabara Bay, mountainous region of Serra dos Órgãos and northern coast of SP (Caraguatatuba). There was no corrosive effect on PP-5 until the first 72 hours of observation of the experiment for all solutions tested. Associated with the absence of PP-5 retraction for all solutions tested, after completing the 30-day observation period.

These results with total extracts from stems of different geographic origins (geological and pedological) subjected to temperature variations are different from previous results obtained with *E. tirucalli* bioproducts from both the IPPN garden and Petrópolis (RJ), which were able to perform the retraction of polypropylene (PP - 5), enzymatically digesting it at room temperature from 30 days to 90 days, without apparent degradation, corrosion or damage. The retraction of the plastic surface without breaking may possibly be able to favor its remolding and reuse.

Such bioproducts were obtained from natural fermentation induced by the cultivation of *Vigna unguiculata* (cowpe beans) with elicitor extracts of *E. tirucalli* (MUSMANNO et al., 2019; FREIRE DA SILVA et al., 2019). It also suggested that there was no participation of the endophytic fungus present in *E. tirucalli* in this plastic digestive action (VARRICCHIO, 2005; VARRICCHIO, 2007; VARRICCHIO et al., 2008). In fact, we are interested in the oxidative stress induced by the total extract of aerial parts of *E. tirucalli* on the cowpea skin, which released and stimulated the growth of *Fusarium* spp., a fungus classically described for this bean (MUSMANNO et al., 2019; DRAGO et al., 2019). It is known that the enzymatic digestion of plastic in nature is carried out through the enzyme phosphofructokinase 1 (PFK1).

The hypothesis of the acceleration of the chemical reaction due to the temperature variation of the extracts corresponded to a search for a solution for recycling, as it could accelerate plastic digester processing (ABIQUIM, 2010), since currently this solid waste persists in the environment for hundreds of years (FRANCHETTI & MARCONATO, 2003; CANEVAROLO JUNIOR, 2006; CANEVAROLO JUNIOR et al., 2007).

The thermal conductivity of the extracts previously tested was involved in this continuous heat exchange process and such thermal conductivity had influenced the long cooling time, leading to shrinkage and twisting (FREIRE SILVA et al., 2019). However, the physical variation in temperature of the total extracts investigated in the present experiment was not capable of interfering with the chemical bonds to exert a physical corrosive or shrinkage effect.

The aqueous extract of the crude latex of *E. tirucalli* from Petrópolis/RJ, cultivated by inserting an acupuncture needle into its main internodal segment, suggested that it was capable of stimulating the thickening of the latex and also activated its resin effect during application (0.2 ml) of the extract in chicken egg albumin, making it thick, dry, hard and resistant, like papyrus, making it difficult for sticky materials to adhere. Once again, it suggested the occurrence of natural polymerization, as a likely mechanism for the qualitative observation of this preliminary test (WENDLING DA SILVA et al., 2019, a).

In geobotany, it is known that *E. tirucalli* has been on the planet since Pangea, predominating in the supercontinent of Botswana (VALLE, 2009). Although its main correlation in studies on plant chemistry and pharmacognosy of terpenoids contained in latex, they often refer to the African continent, in a region that was once sea with soil with high salinity, attributing its toxicity to this factor (FURSTENBERGER & HECKER, 1986), the most recent studies show variations in biological activity in addition to diverse uses by indigenous peoples such as glue, rubber and resin (VARRICCHIO, 2008). As an example, the rubber product is obtained through a simple coagulation of the raw material, latex, extracted from rubber trees providing car and airplane tires, eraser rubber, balls, medical items, flooring, condoms, etc.

In the present experiment, only for the stems from Petrópolis (6/12 or 50%) and the north coast of São Paulo (4/12 or 33%) subjected to boiling was the activation of their gummy action observed, acting as glue in PP-5. This glue effect on paper had already been described using a total extract of aerial parts of *E. tirucalli* from Petrópolis/RJ under assisted cultivation, suggestive of natural polymerization for cellulose (SANTOS, 2001 In PINTO, 2019).

Furthermore, phytopathology tests confirmed the biological effects verified through the roots of *E. tirucalli* (VARRICCHIO, 2007) and subsequently, new cultivars developed followed the variation in the release of cyanuric acid into the test environment, a mark of interest since the Cyanuric acid can play a role in soil recovery, in addition to being a herbicide, insecticide and redactor of coliforms population (GASPAR et al., 2017).

As a reminder, phytoremediation is a technique that aims to decontaminate soil and water, using plants as a decontamination agent. It is an alternative to conventional methods of pumping and treating water, or physically removing the contaminated layer of soil, and is advantageous mainly because it has the potential for in situ treatment and is economically viable. Furthermore, after extracting the contaminant from the soil, the plant stores it for subsequent treatment, when necessary, or even metabolizes it, being able, in some cases, to transform it into less toxic or even harmless products (PIRES et al., 2003).

Phytoremediation can be used in soils contaminated by inorganic and/or organic substances. Promising phytoremediation results have already been obtained for heavy metals, petroleum

hydrocarbons, pesticides, explosives, chlorinated solvents and toxic industry byproducts.

Phytoremediation of herbicides shows good results for atrazine, with the species *Kochia scoparia* revealing rhizospheric potential to phytostimulate the degradation of this molecule. Although still incipient in Brazil, there are already studies on some cultivated agricultural species and wild or native species from the contaminated area itself, with the aim of selecting efficient species in soil phytoremediation (PIRES et al., 2003).

The use of phytoremediation is based on the selectivity, natural or developed, that some species exhibit towards certain types of compounds or mechanisms of action. This fact is a common occurrence in agricultural and weed species, tolerant to certain herbicides. Selectivity is due to the fact that organic compounds can be translocated to other plant tissues and subsequently volatilized; they can also undergo partial or complete degradation or be transformed into less toxic compounds, especially less phytotoxic, combined and/or linked to plant tissues (compartmentalization) (Accioly & SIQUEIRA, 2000; SCRAMIN et al., 2001 apud PIRES et al., 2003).

Most organics appear to undergo some degree of transformation in plant cells before being isolated in vacuoles or binding to insoluble cellular structures, such as lignin (SALT et al., 1998). The ability to metabolize the pesticide into a non-toxic (or less toxic) compound for the plant and the environment is the principle of phytodegradation. Another possibility is phytostimulation, in which microbial activity is stimulated, promoted by the release of root exudates, which acts to degrade the compound in the soil, which characterizes, in some plants, the rhizospheric aptitude for the bioremediation of toxic compounds (PIRES et al. al., 2003).

This field of research, due to its complexity, is still very little studied and consistent references are still scarce. However, the test results that determined the beginning of our studies have been systematically repeated, highlighting the potential for phytoremediation (VARRICCHIO, 2007) in soil and water by an indirect mechanism via the release of cyanuric acid. As for water, and as an addendum, scientific research suggested the participation of cyanuric acid compromising the viability of the gram negative bacteria *E. coli* (CAMPOS, 2014), a microorganism with reports of adherence and multiplication in plastics through a mechanism that has not yet been established (FREIRE SOUZA SILVA et al., 2019).

To minimize the impact caused by the release of sewage into water bodies, it is necessary that they go through a disinfection stage, before their final disposal, with the aim of containing the spread of waterborne diseases. In this context, the work of Josimar Campos (2014) aimed to evaluate a chlorination system using trichlorisocyanuric acid tablets, applied to disinfect sanitary effluent from a facultative lagoon, in the municipality of Itirapuã - SP. For the evaluation, an experimental test was used, carried out in the laboratory, where concentrations of 2.5, 3.5, 5, 10, 15 and 20 mg.L⁻¹ of total residual chlorine were tested, in the contact times of 5, 15, 30, 45 and 60 minutes, to define the

dosage; in addition to the full-scale test with the implementation of the system in the sewage treatment plant to analyze performance, which was based on the inactivation of bacteria from the coliform group.

In the experimental test, with the application of 3.5 mg.L⁻¹ of total residual chlorine in a contact time of 30 minutes, which results in a CT factor of 105 mg.min.L⁻¹, inactivation of 5 log and 4.5 log for total coliforms and *E. coli*, respectively. With the system implemented in the sewage treatment plant, at a concentration of 10 mg.L⁻¹ of total residual chlorine applied to the effluent, the inactivation of total coliform was 4.7 log and of *E. coli* 4.6 log. Therefore, the results obtained demonstrated that the system was effective in disinfecting the effluent, enabling its release into class 2 water bodies without compromising bacteriological quality, in addition to being operationally simple (CAMPOS, 2014).

To conclude the evaluation of our experiment, which motivated the writing of this chapter, in fact, natural polymerization was suggestive as already described by SANTOS (2001) and CÂMARA (2003), in the observation of the glue effect of raw latex at room temperature by CAROLINE MACHADO - TUKANO with *E. tirucalli* from Rio Comprido, which belongs to the Tijuca Massif, in the municipality of RJ/RJ. In his project-based learning (MACHADO et al., 2019), he sought raw plant extracts that favored the conservation of stored seeds for urban indigenous crafts, for consequent financial survival, autonomy and promotion of ethnodevelopment (MACHADO et al., 2019a).

Despite all these observations regarding the potential and probable practical, useful and cheap application of this assay aimed at phytoremediation, perhaps bioremediation, on the other hand, it was evident that the crude lattices from the geographical regions tested at different temperatures were not capable of chemically digesting the isopropylene, thus suggesting that the enzyme capable of digesting this plastic effectively participates when the endophytic fungus present in this species finds favorable conditions to develop as discussed by VARRICCHIO (2005; 2007).

A specific protocol is being developed in Plant Biotechnology, as these jobs have the possibility of useful and profitable application for reuse to be carried out by small solid waste recyclers. It will also aim at autonomy for ethnic groups in urban situations, as well as promoting environmental sustainability.

Based on this contribution, new tests will be carried out in order to investigate mechanisms of action in phytoremediation (KATHAR et al., 2023), comparing them with those already preliminarily evidenced in phytoremediation (GASPAR et al., 2017; 2023; 2024) .

There is much to learn from observing nature and the traditional use of natural resources for climate change, environmental health and sustainability of the planet (VARRICCHIO & LAGE, 2020; PYRRHO et al., 2020).



CONCLUSION

The varied total aqueous extracts of *E. tirucalli* latex stem prepared at different temperatures, from different geographic, geological, pedological and climatic regions in Brazil (RJ and SP), at the concentrations/dosages tested, were not capable of triggering immediate corrosion , nor medium-term shrinkage in polypropylene (PP-5). A different result from our previous publications.

They were promising only for their potential biotechnological action as a glue applicable to paper and as a resin, both activities already described in the literature, but verified for all boiled extracts.

REFERENCES

1. ABIQUIM. Available in: <https://abiquim.org.br/> Accessed on September 5, 2020.
2. Abreu, F. O. M., Forte, M. M. C., & Liberman, S. A. (2006). Mechanical Properties and Morphology of Polypropylene Blends with TPEs. *Polymers: Science and Technology, 16*(1), 71-78.
3. Araújo, J. L. de, L.H.C. dos, & Pereira, M. G. (2009). Soil Attributes and Distinction of Pedo Environments for Agriculture on the Mbya Indigenous Land in Ubatuba (SP). *R. Bras. Ci. Solo, 33*, 1765-1776.
4. Baptista, A. C., Calijuri, M. L., Schaefer, C. E. G. R., & Marques, E. A. G. (2005). Susceptibility of Risk Areas to Mass Movements in APA Petrópolis-RJ. *Nature & Development, 1*(1), 51-58.
5. Betancur-Galvis, L. A., et al. (2002). Cytotoxic and antiviral activities of Colombian medicinal plant extracts of the Euphorbia genus. *Memórias do Instituto Oswaldo Cruz, 97*(4), 541-546.
6. Betancur-Galvis, L., et al. (2003). Tiglane diterpenes from the latex of Euphorbia obtusifolia with inhibitory activity on the mammalian mitochondrial respiratory chain. *Journal of Ethnopharmacology, 85*(2-3), 279-282.
7. Brazil. Ministry of the Environment. Last accessed in May, 2020.
8. Câmara, A. L. da. (2003). Use of national talc as an adsorbent additive for tars and sticky materials in the paper manufacturing process. [Master's dissertation, UFMG School of Engineering].
9. Campos, J. A. (2014). Disinfection of facultative lagoon effluent with trichloroisocyanuric acid: Evaluation of coliform inactivation. [Master's thesis, University of Campinas].
10. Canevarolo Junior, S. V. (2003). *Polymer Science: A Basic Text for Technologists and Engineers*. São Paulo: Artliber.
11. Canevarolo Junior, S. V. (2006). *Polymer Science*. São Carlos, SP: Artliber Editora Ltda.
12. Canevarolo Junior, S. V., et al. (2007). *Polymer characterization techniques*. São Carlos, SP: Artliber Editora Ltda.
13. Delaunay, N. (2019). *Euphorbia tirucalli as a paleocontinental indicator in northwestern Bahia and the coastal strip of Angola*. Presentation Extension Course: Geopharmacobotany and Bioproducts, FMPFase Cultural Center.
14. Delaunay, N., Musmanno, P., Silva, S. da, Pyrrho, A. dos S., Kuster, R. M., Varricchio, M. C. B. N., & Castelo Branco, M. T. L. (2019). Euphorbia tirucalli as a paleocontinental indicator in northwestern Bahia and the coastal strip of Angola. *GEOSUDESTE, UNICAMP*.
15. Drago, J. A. A., Musmanno, P., Pinto, M. D. D. C. de A., Pyrrho, A. dos S., Castelo Branco, M. T. L., & Varricchio, M. C. B. N. (2019). Biotechnological potential of activity on fungi by the Euphorbia Genus and Secondary Metabolites: A literature review. *Poster accepted for oral presentation by Alberto A. Drago*. Advisor: Marcia C. B. N. Varricchio. Round table: Neglected Diseases and Oncology & Bioproducts of Euphorbia tirucalli. Discipline of Parasitology and Mycology E. Faculty of Pharmacy, UFRJ.


16. EMBRAPA. (2004). Lumbreras, J.F. & Gomes, J.B.V. Pedological mapping and useful interpretations for environmental planning in the city of Rio de Janeiro.
17. EMBRAPA. (2006). Brazilian system of soil classification. Retrieved from [URL]
18. Franchetti, S. M., & Marconato, J. C. (2003). The importance of the physical properties of polymers in recycling. *New Chemistry at School, (18)*, 42-44.
19. Freire Silva, F., Pinto, M. D. D. C. de A., Silva, A. V. W. da, Machado Tukano, C. V., Brioso, P., Pyrrho, A. dos S., Castelo Branco, M. T. L., & Varricchio, M. C. B. N. (2019). Euphorbia tirucalli, bioproduct and biotechnological potential plastic digester: Preliminary results. Summary. *FMPFase SCIENTIFIC WEEK - BioEconomy: Caring as a life ethic*.
20. Gaspar, S. A., Gualberto, M. J. V., & Varricchio, M. C. B. N. (2017, May). Germination of *Vigna unguiculata* with ultra-diluted and energized solutions. *INFO-SAPB Magazine – Magazine supporting the SAPB-LIPAT/FF/DAC/UFRJ Project, 1*(1). Retrieved from [URL]
21. Gaspar, S. A., Musmanno, P. G., Bellizzi, G. M., Kathar, K. R., Varricchio, M. T., Varricchio, M. C. B. N., Pyrrho, A. dos S., Brioso, P. S. T., & da Silva, S. (2023, Jun). Environmental and Economic Values of salt tolerance. *Euphorbia tirucalli: Phytoremediation potential. *International Journal of Advanced Engineering Research and Science (IJAERS), 10*(6). Retrieved from [URL]*
22. Gaspar, S. A., Nagamatsu, D., Bolognani, F. de A., Castelo Branco, M. T. L., Pyrrho, A. dos S., Silva, S., Brioso, P. S. T., & Varricchio, M. C. B. N. (2024, Apr). Environmental impact of pollutants and the potential contribution to phytoremediation. In *Engineering and its advancements*. Retrieved from [URL]
23. Kathar, K. R., Wasim, N., da Silva, S., Pyrrho, A. dos S., & Varricchio, M. C. B. N. (2023, Apr). Constructed wetlands: Technology for removing drug concentration from water. *International Journal of Advanced Engineering Research and Science (IJAERS), 4*. Retrieved from [URL]
24. Machado - Tukano, C. V. da S., Pinto, M. D. D. C. de A., Lage, C. L. S., Pyrrho, A. dos S., Amaral, M. do, & Varricchio, M. C. B. N. (2019). Quantum philosophical café of the FMPFase Cultural Center as a sensitizer to Bioethics, Diversity, Sustainability, Environmental Health and Spiritual Health. Summary and oral presentation. *ABEM RJ/ES*.
25. Machado - Tukano, C. V. da S., Silva, A. V. W. da, Freire Silva, F., Pinto, M. D. D. C. de A., Brioso, P., Pyrrho, A. dos S., Castelo Branco, M. T. L., & Varricchio, M. C. B. N. (2019). "Euphorbia tirucalli, bioproduct and biotechnological potential plastic digester: Preliminary results" Poster accepted for oral presentation by Caroline V. da S. Machado TUKANO in the FMPFase Extension Course: Semiology: Care, Inter/Transdisciplinarity, Bioethics and Spirituality. Coordination Prof. Dr. Marcia C. B. N. Varricchio. Held in the 7th Ward of HGSCMRJ.
26. Menezes, P. M. L. de, Andrade, L. G. de, Lepore, V. M. G., Silva, B. S. da, & Ferreira, T. de S. F. (2005). Historical-geographic-cartographic evolution of Fundão Island. *Proceedings of the X Meeting of Geographers of Latin America – March 20 to 26, 2005 – University of São Paulo*.
27. Miguel, J. J. P. (2010). Comparative Study of the Thermal and Mechanical Properties of Polypropylene Reinforced with Zinc Oxide, Calcium Carbonate and Talc. Master's thesis, Faculty of Technology SENAI CIMATEC. Retrieved from [URL]

28. Musmanno, P., Pinto, M. D. D. C. de A., Wasim, N., Kreischer, C. R., Delaunay, N., Bufon, A. P. Dal P., Pyrrho, A. dos S., & Varricchio, M. C. B. N. (2019). *Euphorbia tirucalli* and germination of *Vigna unguiculata*: Bioproduct and Biotechnological Potential. Poster presented at the FMPFase Extension Course: Semiology: Care, Inter/Transdisciplinarity, Bioethics and Spirituality, HGSCMRJ.
29. Pereira, R. C. C., Machado, A. H., & Silva, G. G. (2002). (Re)getting to know PET. **New Chemistry at School, 15**, 3-5.
30. Pinto, E. (1968). **Brazilian Ethnology (Fulnio - The Last Tapuias)**. Own edition.
31. Pinto, M. D. D. C. de A. (2019). Comparison of the effect of *E. tirucalli* extracts on the germination of *Vigna unguiculata*. Oral presentation at the I Natural Products and Bioproducts Day, FMPFase Cultural Center, Petrópolis, RJ.
32. Pires, F. R., Souza, C. M., Silva, A. A., Procópio, S. O., & Ferreira, L. R. (2003). Phytoremediation of soils contaminated with herbicides. **Planta Daninha, 21*(2)*. Retrieved from [URL]
33. Petrópolis City Hall. (n.d.). Site. Retrieved from [URL]
34. Puffett, K. (2018). PFK1 and Plastic. **National Geographic**. Retrieved from [URL]
35. Pyrrho, A. dos S., Lage, C. L. S., Gaspar, S. A., Nagamatsu, D., & Varricchio, M. C. B. N. (2020). Medicinal Plants: Bioethics, Legislation, Sustainability. Medicinal Plants Course, Corandoo7 Extension Project, Immunology Laboratory, ICB, HUCFF/UFRJ.
36. Saavedra, M. Noemí González. (2003). New Polyhydroxylated Cytotoxic Steroids from *Isis hippuris* and Serinolipids from *Didemnum* sp. Iogenic studies of diterperpenes from *Gorgonias Eunicea mammosa* and *Briaerum asbestinum*. Department of Fundamental Chemistry, Faculty of Sciences, University of A Coruña.
37. Santos, C. P., Reis, I. N., Moreira, J. E. B., & Brasileiro, L. B. (2001). Paper: how is it manufactured? **New Chemistry at School, 14**, 3-7.
38. Singer, A. C., et al. (2003). Secondary plant metabolites in phytoremediation and biotransformation. **Trends in Biotechnology, 21*(3)*, 123-130.
39. Technical Diagnosis - Product 2 Physical Environment - APAM Litoral Norte – Revision 1. (n.d.). Retrieved from https://sigam.ambiente.sp.gov.br/sigam3/Repositorio/511/Documentos/APAM_LN/APAMLN_Meio%20Fisico_Terrestre_final-p1.pdf
40. Varricchio, M. C. B. N. (2005). Integrated Studies: Biotechnology, Toxicology, Special Metabolites and Antitumor Activity of **Euphorbia tirucalli* L.* Master's dissertation, Federal University of Rio de Janeiro.
41. Varricchio, M. C. B. N. (2007). Preliminary analysis of HUD 30CH **E. tirucalli** (Aveloz) as an action strategy in the Severe Cowpea Mosaic virus. UFRJ/PPGBV Library.
42. Varricchio, M. C. B. N., Ormelez, E. G., Silva, S. D., Sato, A., Henriques, A. B., & Lage, C. L. S. (2008). **Euphorbia tirucalli**: qualitative analysis of vegetable development during in vitro cultivation. **BioFar, 03*(01)*, 1-13.



43. Varricchio, M. C. B. N., Silva, S., Holandino, C., Lage, C. L. S., Kuster, R. M., & Castelo-Branco, M. T. L. (2008). Chromatographic analysis of Aveloz latex and the risks of non-standardized plant extracts. **FOG Archives*, 5*(2), 113-136. Retrieved from [URL]
44. Varricchio, M. C. B. N. (2020). Analysis regarding the effectiveness of legislation on access to Brazilian genetic heritage, protection and access to associated traditional knowledge, as a sustainable use of biodiversity. Postdoctoral Internship Report, National Institute of Industrial Property.
45. Wendling Silva, A. V. da, Machado Tukano, C. V., Brioso, P., Pyrrho, A. dos S., Castelo Branco, M. T. L., & Varricchio, M. C. B. N. (2019). Cultivation of **Euphorbia tirucalli** with Acupuncture: Bioproduct and resinous biotechnological potential (Preliminary results). Poster presented at the FMPFase Extension Course: Semiology: Care, Inter/Transdisciplinarity, Bioethics and Spirituality, HGSCMRJ.
46. Wendling Silva, A. V. da. (2019). **Euphorbia tirucalli**, Bioproduct and Resinous biotechnological potential: Preliminary results. Oral presentation, Faculty of Pharmacy, UFRJ.

Sustainable use of the pseudostem and rachis of banana *Musa sp.*

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ABSTRACT

Currently, plastics are the most diversified materials with the highest volumes of consumption worldwide, reinforced with synthetic fibers. However, the environmental repercussions related to the accumulation of plastics have led to the search for alternatives that allow the establishment of a development attached to sustainability. Around the world, various research is being carried out with the aim of taking advantage of the use of natural fibers as a substitute for plastics. The objective was to establish sustainable techniques for the processing and staining of banana rachis and pseudostem fiber in order to diversify its use. It was found that solar dehydration allows fibers to be obtained with better characteristics than in an electric dryer. The dried fibers are useful for making various handicraft items with decorative, cultural and agricultural uses, compostable. The dyeing of the fibrous pieces was achieved using natural sources. The use of these techniques for the use of by-products of banana production will allow local artisans to have processes that allow them to improve their production and take advantage of the by-products of the environment while being environmentally friendly, which will have an impact on the development of communities dedicated to the elaboration of traditional handicrafts.

Keywords: Agricultural by-products, Bananas, Artisanal, Natural fibers.

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INTRODUCTION

In the last sixty years, the most diversified materials with the highest volumes of consumption worldwide are plastics reinforced with synthetic fibers: thermoplastics and thermosets reinforced with carbon fibers, aramid and glass fibers (Rodríguez *et al.*, 2014). Most of the synthetic polymer fibers used in everyday life are obtained from petroleum; the decline of which has led to increased environmental concern, causing sustainable fibres to become important; leading to further research into materials such as cellulose, lignin and silk, as well as polymeric fibers synthesized from raw materials derived from natural resources (Chang *et al.*, 2017).

In countries such as Brazil, Ecuador and Colombia, fibers from the by-products of the banana agro-industry are used, whose residues are considered organic, since they are mainly composed of cellulose, hemicellulose and lignin; Its management is costly and difficult, as well as being a source of pests that are harmful to crops (Saval, 2012).

An example of these technologies is the production of various products from the use of local resources, such as natural fibers such as juta, sisal, coconut fiber, flax, banana fiber and some other agricultural and industrial waste materials that are being used for many applications due to their advantages over their synthetic counterparts (Rodríguez *et al.*, 2014).

In Mexico, the states of Chiapas, Tabasco and Veracruz together account for 72% of banana production (Agricultural and Fisheries Information Service, 2016), however, these resources have not yet been exploited. The banana is a herbaceous plant of which only 30% of its biomass is used after harvest, being able to find around 625 to 3,030 plants per hectare in one hectare, generating a usable source of resources after the harvest (Álvarez, 2010).

The banana agro-industry generates large amounts of organic vegetable waste made up of the pseudostem, leaves and pinzote (Canché-Escamilla *et al.*, 2005; Sosa *et al.*, 2010; Calle *et al.*, 2014). When the banana bunch is harvested, only 20 to 30% of its biomass is being used (Álvarez, 2010), leaving 70 to 80% to be used. This waste has generated one of the main environmental problems because, in most cases, it is incinerated or dumped into the receiving sources without prior treatment, contributing to the degradation of the ecosystem (Mazzeo, 2010).

Untreated waste deposited in the soil generates leachate that can reach aquifers, favoring the transport of bacteria due to runoff to other areas of the crop (Saval, 2012). The high volume and weight of these by-products also makes them difficult to handle and more expensive to dispose of; while their accumulation contributes to the production of insects, fungi and odors inside or outside the crops when they are stored in an uncontrolled manner (Quinchia and Uribe, n.d.).

Agro-industrial waste represents one of the major problems and challenges faced by banana producing and exporting countries, which generates high costs in terms of the environment and finances (Gaona, 2015). Because Tabasco is one of the three banana-producing states in the country

(Agri-Food and Fisheries Information Service, 2016), it has to solve several challenges, including the negative impact on the environment. For this reason, it is a priority to develop products that do not cause damage to the environment or are made using reusable material, with the aim of having sustainable ecosystems and a society that is more aware of the benefits of a healthy environment today and in the future (Cortés, 2014).

Industries also need to gradually improve their technological development for the use of alternative resources, because of the growing demand for food, energy and other essential needs of the population. In this sense, the Food and Agriculture Organization of the United Nations (FAO, 2015) indicates that it is important to produce more food, but in a sustainable scheme; This implies for industries and producers to generate cleaner technologies and production chains.

Banana-producing regions in Mexico produce a high amount of plant residues (Sosa *et al.*, 2010; Calle *et al.*, 2014; Gaona, 2015), which forces them to look for alternatives for the sustainable use of these by-products, as is the case in other countries such as Colombia, where they are used to make handicrafts and paper, including the textile industry (Artesanías de Colombia, 2008). The use of the pseudostem can contribute to reducing the existence of pests in crops, such as: bacteriosis, screwworm, black or striped weevil (SIAP, 2016).

Considering the importance of developing products with fewer environmental impacts, in order to achieve a more sustainable ecosystem and a society more aware of the benefits of a healthy environment, today and in the future, there is a need to contribute to generating techniques for the use of these materials available in the locality (Cortés, 2014). In this context, this work presents a sustainable alternative for the use of the banana pseudo-stem, through the production of handicrafts, paper, biodegradable packaging and containers for agricultural use, including natural dyeing using available local resources.

THEORETICAL FRAMEWORK

(a) *Agro-industrial by-products*. The presence of man on the planet has caused the generation of various solid, liquid or gaseous wastes, which tend to increase permanently, as well as their quantity and complexity; This is done as the population increases and the development of technology; thus making it more difficult for the environment to degrade, assimilate or reuse the materials that compose them (Quinchia and Uribe n.d.).

In his documents, Saval (2012) describes agro-industrial by-products as: solid or liquid state materials that are generated from the direct consumption of primary products or their industrialization that are no longer useful for the process that generated them, but that are susceptible to use or transformation to generate other products with economic value. of commercial and/or social interest.

The new products generated from agro-industrial waste may have different characteristics, but be composed of similar elements, mainly lignin, cellulose, pectin and hemicellulose, to which they confer the name of *organic waste*; for which there is no adequate management, nor the technological or economic capacity to give them a destination, including a lack of specific legislation to promote the management of this type of waste. waste (Saval, 2012).

Gaona (2015) indicates that banana production produces high pollution due to the harvest waste generated after the fruit is cut, since it is deposited in the soil without any treatment, which does not reduce the impacts on the environment; This is a problem that those who engage in this activity must face.

On the other hand, Canché-Escamilla *et al.* (2005) also agree that there are large amounts of waste in banana crops, after harvest, since only the fruit is used, having to dispose of the other parts of the plant such as pseudostem, leaves and pinzote or rachis (part of the plant that supports the bunches of fruit).

These untreated vegetable wastes cause problems mainly related to their volume and weight, as well as difficulties in handling them, which makes them more expensive to dispose of; while their piling contributes to the production of insects, fungi and odors, specifically when stored in an uncontrolled manner (Quinchia and Uribe n.d.).

b) Morphology of the banana plant. According to Sandoval and Müller (1999), the banana tree is a herbaceous plant of the Musaceae family, which has an underground stem (corm or rhizome) from which an aerial pseudostem is born; the corm emits roots and lateral buds that will form the offspring or offspring (Álvarez, 2010). The root system of the banana tree has the main function of absorbing and transporting water, as well as transferring nutrients from the soil to the plant. Banana plants have both a primary and an adventitious root system. Primary roots originate from the rhizome and secondary and tertiary roots originate from primary roots.

The rhizome is the true stem of the banana plant and is found underground, although it is usually referred to as corm, the correct botanical term is rhizome. The growing point of the rhizome is a flattened dome where the leaves are formed and then the inflorescence arises at the top of the plant.

The pseudostem is the part of the plant that resembles a trunk, it is a false stem formed by a tight set of overlapping leaf sheaths, fleshy in texture, formed mainly by water, which can support a cluster of 50 k or more. As the leaves emerge, the pseudostem continues to grow upward, reaching its maximum height when the true stem, the flowering stem that supports the inflorescence, emerges at the top of the plant.

The inflorescence is supported by the floral stem, a structure that contains the flowers, which will be the future fruits. The flowering stem, produced by the terminal growing point of the rhizome,

grows through the pseudostem and emerges at the top of the plant after the last cigar leaf has sprouted. As the female flowers develop into fruits, the distal portion of the inflorescence elongates and produces a second set of male (staminate) flowers, each under a bract. Male flowers located on the male bud produce pollen, sterile or fertile.

The leaves are the main photosynthetic organ of the plant; These emerge from the center of the pseudostem like a coiled cylinder. The distal end of the elongating leaf sheath contracts to form a petiole, more or less open depending on the cultivar. The upper part of the leaf is called the adaxial surface, while the lower part is called the abaxial surface. The first basic leaves that are born from a growing child are called flakes. Mature leaves, which are called true leaves, consist of sheath, petiole, midrib, and blade.

The cluster is the set of fruits that appear along the rachis. The individual fruits, also called fingers, are grouped into structures called hands. The male bud contains the male flowers enclosed in their bracts, sometimes called "bells", which, together with the rachis, continue to grow as the fruits ripen. In some crops, the male bud stops growing when the fruits have formed and may be more or less exhausted by the time the bunch reaches maturity. The presence or absence of male bud is one of the characteristics used to differentiate between crops.

On the other hand, the rachis is the stem of the inflorescence. Starting from the first fruit to the male bud, it may be devoid or covered with persistent bracts. The spine has nodules; These are scars that indicate where the bracts were attached.

(c) *Banana by-products*. Several studies found (Abad *et al.*, 2012; Canto and Castillo, 2011; Cortés, 2014; Flotats, 2015; Gaitán *et al.*, 2016; Gonzalez *et al.*, 2016; Grisales and Giraldo, 2004; Linares *et al.*, 2008; Mazzeo *et al.*, 2010), among others, propose various alternatives for the sustainable use of these by-products, demonstrating in their work their versatility for the production of components of construction materials, biodegradable packaging, handicrafts and paper.

In the Americas: Brazil and Costa Rica, both banana producing countries, are already making various products based on banana fiber such as: paper, diaries, cargo bags, wallets, mats, bread baskets, dolls, hats, among others. Similarly, in Costa Rica, Japan and Australia in 2015, products obtained from banana fiber were also industrially produced, exporting their production to the markets of Europe and the United States (Gaona, 2015).

At a global level, great advances have been made for the use of bananas and their by-products (peels, leaves, pseudostem, stem and inflorescence) whose applications range from food products for people or animals as well as for non-food products related to the use of natural fibers, natural bioactive compounds and bio-fertilizers (Padam *et al.*, 2014).

One of the current discoveries is the use of the pseudostem for the production of laminate material known as *Green Blade*, discovered in 2016 in France (Ecocosas, 2017). Agro-industrial

banana residues have been evaluated for the production of activated carbon by Quinchia and Uribe (n.d.) in Colombia, whose study concludes that it is feasible for this purpose.

Studies have also been found on the components of the pseudostem juice of the banana known as dominico, carried out by Vargas and Martínez (2015), a residue also studied three years earlier for the production of wine by Guarnizo-Franco *et al.* (2012) in Colombia. Another study by Álvarez (2010) evaluated the feasibility of banana residues for animal feed. In addition, leachates have been shown to be efficient for the control of crop-related diseases and as promoters of plant growth, in addition to not containing pathogenic microorganisms for plants, humans and animals (Blasco *et al.* 2014).

Based on the works found, it is important to emphasize that one of the countries that predominates in the study and use of this waste is Colombia, although some were also found in Venezuela, Ecuador, Brazil and India, countries where it was even found that there are small companies dedicated to the production of paper and handicrafts using these resources. composed mainly of women.

Thus, the alternatives for the use of these by-products for the production of paper, agglomerates, lamination and cellulose extraction require sophisticated equipment and greater financing. In other cases, they can be used in an artisanal way for the production of handicrafts and paper; In both situations, there is the prospect of obtaining economic benefits, taking advantage of a low-cost resource available in banana growing areas.

The recycling of the huge quantities of by-products from this crop represents a valuable source of high-value raw materials for industries, avoiding the waste of this biomass, as well as providing additional income for small-scale agricultural industries, without compromising quality and safety in competition with other commercial products (Padam *et al.* 2014)

The prospects and challenges in the future, in the use of these materials, are the important key factors, given the association with sustainability and the feasibility of the use of these by-products (Padam *et al.*, 2014). As far as Mexico is concerned, few examples of research or the application of technologies for the use of this material have been found:

- Nanocellulose obtained from agro-industrial waste from plantains. Held in Morelos, Mexico, in 2016.
- *Musa balbisiana finzon* and *Musa acuminata* as a source of paper fibers. Held in Jalisco, Mexico, in 2009.
- Elaboration of ecological paper and other products carried out by students of the Instituto Tecnológico Superior de Tierra Blanca in the state of Veracruz, Mexico.

Similarly, in Tabasco, Mexico, work was found carried out by high school students related to the use of banana stem fiber to manufacture biodegradable sheets and tablets and bioplastic by

students from the State Technological University. The few studies found indicate that alternatives for the use of banana residues, considered one of the most important crops in Mexican agriculture, are still being explored in Mexico (García *et al.*, 2013).

At the international level, researchers Armas *et al.* (2016), carried out several tests with different fibers extracted from the banana stem, in combination with polyester resin as a matrix, applying two treatments; one consisting of pre-curing the fibres with 10% sodium hydroxide (NaOH) and the other using the untreated fibre. They found that the mechanical properties of this compound are better compared to the behavior of polyester resin. The fibers that were chemically treated with NaOH in combination with the resin possess improved mechanical properties, including the property of working in saline environments without affecting their properties.

The high strength, compression and tensile strength of polyester resin composites in combination with banana fiber allows their use in multiple applications such as body elements, aircraft or boat parts, insulating structures, tool accessories, among others, based on the fact that the integration of the fiber to the resin increases its mechanical properties by approximately 272.55% at maximum tensile stress. 292.46% in the modulus of elasticity and 442.51% in the average bending stress (Armas *et al.* 2016).

METHODOLOGY

a) *Obtaining banana fibre.* The fiber was obtained based on the techniques described by Abad *et al.* (2012) and Artesanías de Colombia S.A. (2008), according to the following indications:

1. The pseudostem was cut to a height of 80 cm from the corm or base of the plant, depending on its height, pieces of 1 to 1.5 m in length were cut.
2. The surface was cleaned and the layers were separated until the center was reached. Then 4 cm was cut from the edges of each layer.
3. The central part of the layer was filleted to obtain three different textures: mesh-like, hard fiber, and soft layer, as shown in Figure 1.

Figure 1. Pseudostem layers, from top to bottom: mesh type, hard fiber and soft layer.



4. To obtain the dry fiber, two methods were evaluated: solar dehydration and oven drying. Sun drying was carried out during the months of May to September. The mesh-type fibers, silk and those obtained from the edges of each layer, were placed on a circular rod of 4cm in diameter approximately suspended 1.70 cm from the ground, while the rest were laid neatly on a zinc sheet roof; exposed during the day and night, except on rainy days.

6. Oven drying was carried out in the laboratory using an oven at 45°C, with inspections every 30 minutes.

(b) *Fibre dyeing*. Three natural sources of dyes were evaluated: mahogany husk (*Swietenia macrophylla* King), hibiscus flower (*Hibiscus sabdariffa*) and beet tuber (*Beta vulgaris*). The dyeing with the husk of the mahogany stem was carried out cold, as indicated by Martínez *et al.* (2010) proposing a modification at the time of adding the fibers, which were added at the same time as the dyeing material and not after 24 hours. Three treatments and two levels of peel were performed (T1, water at room temperature, 10 and 20% dry peel; T2, Water at room temperature, 10 and 20% green shell; and water at 90 °C, 10 and 20% dry mahogany) and three repetitions of each. 3 strips of each type of fiber of 10 x 1 cm (9 in total) were added for each repetition, weighing approximately 2 to 3 g, leaving at rest for 24 h. They were monitored every 12 h until color change was observed.

For the dyeing of the fibers with hibiscus flower, two treatments were evaluated with three replications: T1, 250 ml of water at room temperature with 6 g of dried hibiscus flower; T2, 250 ml of water at 90 °C with 6 g of dried hibiscus flower. In the dyeing with beets, the pieces of the tuber were added in the container where the strips of fibers were placed. In both treatments, coloration was evaluated in the same way as in mahogany shell treatments.

(c) *Making handicrafts from dry fibre*. The sun-dried fibers were evaluated, and the air was extracted using a glass container used as a roller. Subsequently, they were cut into strips 1cm wide and various fabrics were made, interlaced, and spliced until a handmade product was obtained, as shown in Figure 2. A bioglue-based sealant was applied to the finished handicrafts.

Figure 2. Elaboration of handicrafts with different weaving techniques.



(d) *Papermaking*. The technique proposed by Gaona (2015) was used. The raw material was obtained from the pseudostem, cut into slices and cooked with water for 1.2 hours. The pulp at room temperature was crushed in an industrial blender for 2 min. Four 1 k portions of the paste obtained were weighed and placed in separate containers, where treatments were applied to give color. Mahogany husk (10%), hibiscus flower (10%) and commercial sodium hypochlorite (1%) were evaluated for the dyeing of the paste.

The paper was made by placing water in a container to which the paste was added and dispersed homogeneously. Using a 20 cm x 40 cm frame, covered with metal mosquito net, the fiber contained inside the container was trapped to form a homogeneous sheet (Figure 3). Finally, it was dehydrated in the sun until it was obtained into dry paper sheets.

Figure 3. Paper production from banana pseudostem pulp.



(e) *Production of compostable containers*. For the production of compostable plates, pots and masks, the same procedure used in the production of paper was carried out, until the pulp was obtained. To provide firmness to the fibre paste, a bio glue based on cornstarch was designed, made with 300 ml of water plus 10% of corn starch and 10% of vinegar as a preservative; The mixture was stirred until the ingredients were homogenized, then simmered until it reached a change from white to transparent. For each kilo of dry fiber, 20% bioglue was added and mixed by manual kneading; the paste was molded in the different containers, to which paper or plastic was placed to facilitate unmolding (Figure 4).

Figure 14. Moulding of bio packaging and handicrafts.

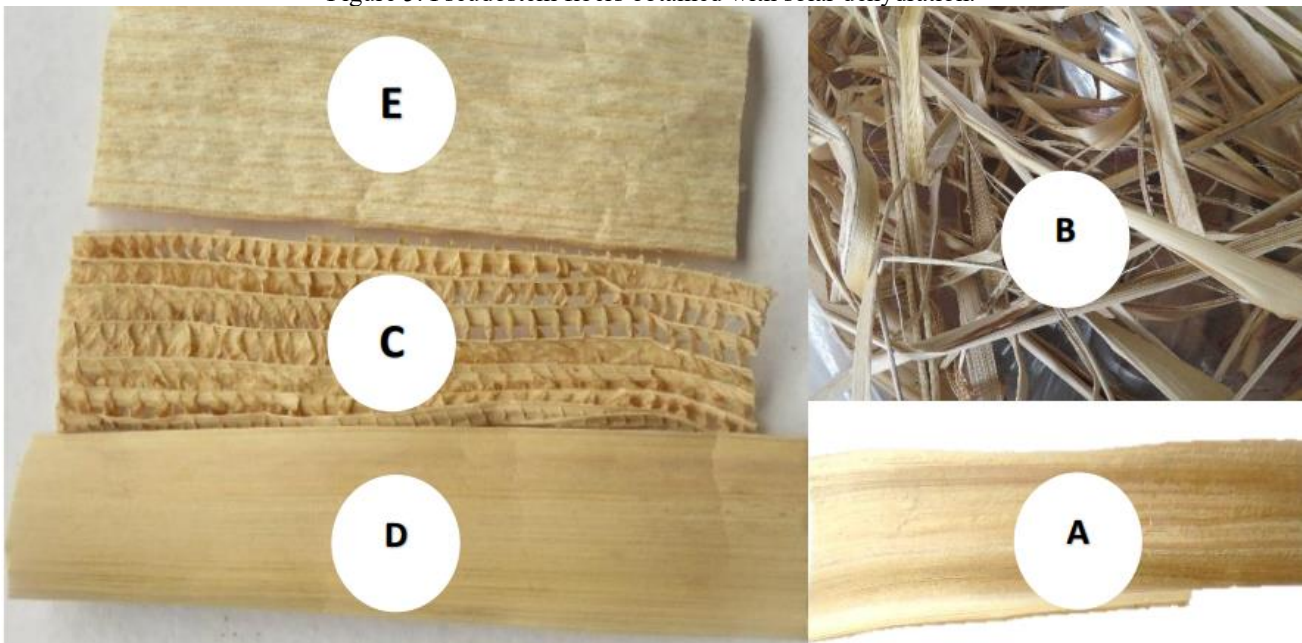


RESULTS AND DISCUSSION

The use of by-products of banana cultivation is an opportunity to contribute to sustainable development by adding value to products made from natural fibers. The objective of this work is to present sustainable alternatives for processing the pseudostem and rachis of the banana plantation; Provide tools that allow artisans to make crafts, paper, packaging and compostable containers that add value, take care of the environment and promote the development of sustainable communities.

a) *Drying*. Two methods of drying, solar dehydration and oven drying were evaluated; Five types of fiber were obtained. With solar dehydration, during sunny days the drying time of the thin and flexible layers was one to two days, while the thick fibers were 3 to 5 days (D, A and B), as shown in Figure 5.

Figure 5. Pseudostem fibers obtained with solar dehydration.



The dry fibers obtained during hot days had a light brown color. On these days, temperatures around 48 °C were reached inside the fiber, with a relative humidity of 72-96%. The dehydrated fibers on sunny and rainy days took 7 to 8 days to dry, presenting a dark brown color and fungal spots on more than 30% of the material. According to Abad *et al.* (2012) indicate that it is possible to remove fungal stains with a 10% chlorine solution, the stains are removed. However, it is not recommended for use on materials with more than 30% stains, as when applied it was observed that the fiber loses its shine and it is more difficult to remove stains.

As for kiln drying, no favorable results were obtained with this method in any of the five types of fibers. The thinnest layers (the mesh and silk fiber) dried after half an hour, however, the flexibility characteristics were not adequate, since they broke when handled during the folds to make the handicrafts; these results are similar to the drying work carried out by Artesanías de Colombia S.

A. (2008). However, the temperature of 45 °C is given as unsuitable for drying. As for the other thicker fibers, they began to dehydrate from the banks after two hours; They became brittle when pressed with the fingers. A change in the color tone of the fibers was also observed, turning dark brown, an effect probably related to the caramelization of sugars or enzymatic browning (Belén-Camacho *et al.*, 2007).

The results obtained in both drying techniques indicate the importance of this step during the process to obtain fibers with suitable characteristics for the elaboration of handicrafts both in color and flexibility; solar dehydration is the technique that makes it possible to obtain fibers with the best characteristics for the production of handicrafts; However, its disadvantage lies in its seasonality, with the months of January to August being the most suitable, while the rest are not recommended due to the problems of fungal appearance. However, tests indicate that it is possible to dry the fibers, but they should be prevented from getting wet with rainwater.

To avoid the inconveniences of the rainy months, it is recommended to dry fiber during the sunny months and store them in closed bags in a dry place. If required, it is recommended to build solar dryers to carry out drying in the rainy months, as is done by working groups in other countries.

(b) *Staining*. Three treatments were evaluated in the mahogany shell staining, the best being the treatment consisting of hot water at 90°C + 10% dry mahogany shell; where a dyeing time of 24 h was obtained, unlike those immersed in cold water that took 48 h. However, after 36 hours, all three treatments added color to the fiber, in visually similar shades. It was observed that the longer the submerged fibers take, the more the color intensifies. It should be noted that only the thinnest fibers, such as mesh and silk, showed more intense homogeneous coloration; unlike the hard fibers, which were only dyed on the edges. Subsequently, Mayan fiber was dyed to make handicrafts, which was observed for a year, a period in which the color remained visually constant.

The results obtained indicate that mahogany shell is a dyeing plant material suitable for dyeing Mayan banana fiber and silk, whose color remains for a long time; which justifies its use to dye materials with rustic textures. Fibers dyed with beets and hibiscus failed to permanently dye the fiber. However, after 24 hours, both added color to the wet fiber.

The fibers of the top layer (hard) when wet gave the appearance of being dyed homogeneously, not just from the edges as in mahogany shell dyeing. Although both provided a rosewood-like color when dried, the beetroot-dyed fiber discolored after a week; Causes of discoloration include lack of pH control and instability to light and oxygen. It was found that the stability of these dyes depends directly on the pH, which ranges from 3 to 7, with an optimal pH between 4 and 5; in addition to being unstable in the presence of light and oxygen (Antigo, 2018).

Likewise, the loss of the color of hibiscus may be due to the use of high temperatures, since the increase causes the loss of glycosylant sugar, resulting in chalcones that are totally colorless, in addition to the presence of oxygen and water activity (Ordoñez & Saavedra, 2016).

(c) *Obtaining paper.* Although initially the production of paper using rachis and pseudostem was considered; The low availability of the spine limited its use in the other products. Handmade paper was obtained using both fibers. Paper made with pinzote was more rustic as the fibers are thicker and shorter than those of the pseudostem (Canche *et al.*, 2005). Figure 6 shows the paper sheets obtained.

Figure 6. Handmade paper obtained from the pseudostem and rachis.



Although there are other methods that contribute to obtaining paper with better textural characteristics, this involves the use of other products that are not environmentally friendly, such as sodium hydroxide, to remove up to 90% of lignine. In rachis paper, even the hairs of the fibers are detached when you run your finger over the surface of the paper. On pseudostem paper, the hairs do not come off and the paper can be folded without difficulty, unlike rachis paper that breaks when folded.

On the other hand, it is possible to dye the paste of the moist banana fiber with beet extract and hibiscus flower. The paste was also bleached using 10% commercial chlorine. However, during drying, the dyes obtained from hibiscus and beets were lost, possibly due to enzymatic reactions or bacterial consortia (Antigo, 2018). The dyeing material that gave color and permanence to both wet

and dry fibers was mahogany shell extract. As for bleaching with chlorine, it is possible to obtain a yellowish paper.

(d) *Handicrafts and compostable packaging.* Handicrafts made of paper pulp and bioglue were made as a new technique for making use of fibres. Compostable pots and masks were obtained and used in the Danza del Pochó, a dance of Mayan origin performed in southeastern Mexico, where around 1,000 dancers participate, during several days of carnival; With this alternative, it is proposed to replace wood to avoid the felling of trees. With this alternative, the elements of the dancers' costumes are provided and the cultural and tourist activity of the municipality is promoted. These elements are shown in Figure 7.

Figure 7. Bio handicrafts obtained from the molding and drying in the sun of pulp for paper.



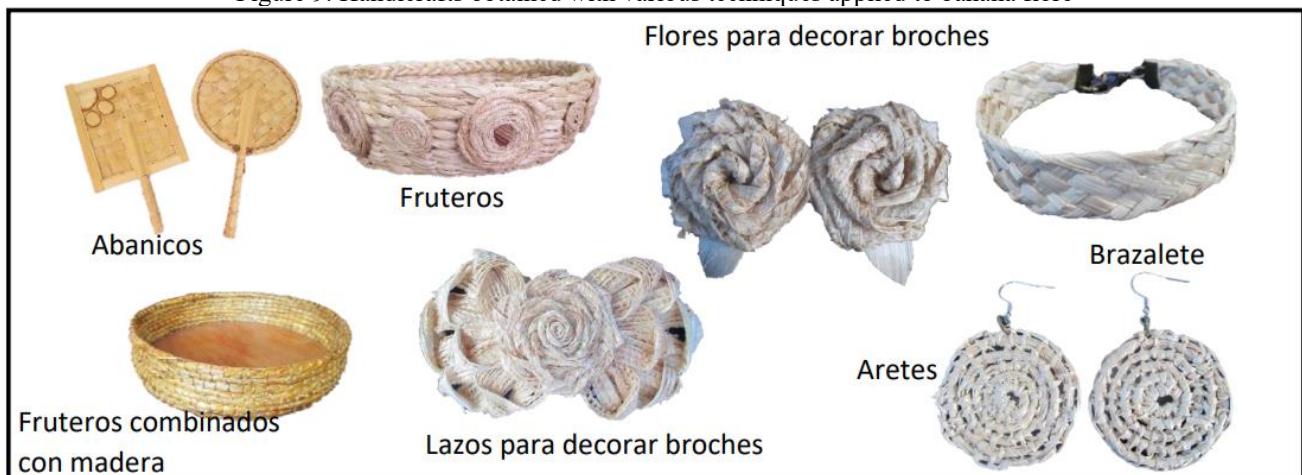
An alternative technique of molding and drying the paper pulp in the sun obtained biopackaging and biodegradable plates (Figure 8). With this, an alternative for the use of paper pulp obtained from the same pseudostem is proposed. Further studies may contribute to consolidating a proposal for biocontainers and biopackaging through the use of banana fibre.

Figure 8. Bio packaging and containers obtained by molding banana fiber paste.



Finally, the five types of dry fibres were used to make various handicrafts (Figure 9), demonstrating the versatility of banana fibre for the production of products in an artisanal way.

Figure 9. Handicrafts obtained with various techniques applied to banana fibre



CONCLUSIONS

From the banana plant, versatile fibers are obtained for the artisanal production of various products. It was found that fibers with better color and flexibility characteristics are obtained when dried in the sun in the months of January to May, from which different types of fiber can be obtained, depending on their final use. Drying times vary from 2 to 4 days depending on the type of fiber. It is not recommended to dry in the rainy season, unless it is avoided to get wet.

Various handicrafts were obtained from the dry fibre by applying different techniques, including weaving. Compostable containers were also made by adding 20% bioglue to support the reduction of plastics in sustainable agriculture. There is also a new proposal for the use of fiber, consisting of the production of masks that promote the culture and tourism of a region.



Of the three natural dyes used in banana fiber, it was found that the only dye material that provided color in the shortest time to the banana fiber was mahogany peel (*Swietenia macrohpyla*) in a concentration of 10%, by immersion in water at 90 °C with a time of 24 hours, followed by immersion at room temperature for 48 hours; demonstrating that the fiber can be dyed with specific natural dyes.

The use of these techniques for the use of by-products of banana production will allow local artisans to have processes that allow them to improve their production and take advantage of the by-products of the environment while being friendly to the environment, which will have an impact on the development of communities dedicated to the production of traditional handicrafts by promoting added value. innovation and waste reduction in the banana production chain.

REFERENCES


1. Abad Barahona, K.D., Mogrovejo Guerrero, X.D., & Rojas Zapata, F. (2012). Posibles Aplicaciones de la fibra del banano en el campo textil. Tesis de licenciatura, Universidad de AZUAY. [Link](<http://dspace.uazuay.edu.ec/bitstream/datos/288/1/09102.pdf>)
2. Álvarez Ríos, S. (2010). Gobierno de Canarias. Aprovechamiento de subproductos de la platanera para alimentación animal. Instituto Canario de Investigaciones Agrarias. Jornadas Biomusa. [Link](<https://www.icia.es/biomusa/es/jornadas-y-actividades/primeras-jornadas-de-transferencia-de-idi/19-de-octubre-de-2010-tercera-sesion/25-aprovechamiento-de-subproductos-sergio-alvarez/file>)
3. Antigo, J.L.D., Bergamasco, R.D.C., & Madrona, G.S. (2018). Effect of ph on the stability of red beet extract (*Beta vulgaris* l.) microcapsules produced by spray drying or freeze drying. *Food Science and Technology, 38*(1), 72-77. DOI: <http://dx.doi.org/10.1590/1678-457X.34316>
4. Armas-Ruiz, D., Ruiz-Galarza, S., Piován, M., Carrión-Matamoros, L., & Narváez-Muñoz, C. (2016). Caracterización de propiedades mecánicas de las fibras de banano de la corteza y el cuerpo del tallo. *Científica, 20*(1), 21-31. [Link](<https://www.redalyc.org/journal/614/61447568003/61447568003.pdf>)
5. Artesanías de Colombia S. A. (2008). Proyecto de mejoramiento en la calidad y certificación de productos de artesanos en 13 comunidades, ubicadas en los departamentos del Atlántico, Antioquia, Boyacá, Caldas, Cauca, Chocó, Santander, Sucre y Valle del Cauca. MN048-7. [Link](<http://www.artesantiasdecolombia.com.co/propiedadintelectual/comunidades/artesantias-colombia-tejeduria-aguadas-caldas.pdf>)
6. Belén-Camacho, D.R., Román, J.C., García Pantaleón, D., Moreno-Álvarez, M.J., Medina Martínez, C., & Ojeda Escalona, C.E. (2007). Efecto del secado solar en los contenidos de humedad, carbohidratos, carotenoides totales e índice de peróxidos del mesocarpio de la palma coroba (*Attalea* spp.). *Interciencia, 32*(4), 257-261. [Link](http://ve.scielo.org/scielo.php?script=sci_arttext&pid=S0378-18442007000400010&lng=es&tlng=es)
7. Blasco López, G., & Gómez Montaña, F.G. (2014). Propiedades funcionales del plátano (*Musa* sp). *Revista Médica UV, 14*(2), 23. [Link](<https://www.medigraphic.com/pdfs/veracruzana/muv-2014/muv142d.pdf>)
8. Calle, E., Fernández, L., Godoy, T., Sempetegui H., & Patiño, M. (2014). Elaboración de papel a partir de fibras vegetales no maderables (pinzote de plátano). [Link](<https://es.scribd.com/document/427635506/Elaboracion-de-Papel-a-Partir-de-Fibras-Vegetales-No-Maderables>)
9. Canché, E.G., De los Santos, H.J.M., Andrade, C.S., & Gómez, C.R. (2005). Obtención de celulosa a partir de los desechos agrícolas del banano. *Información tecnológica, 16*(1), 83-88. [Link](<https://dx.doi.org/10.4067/S0718-07642005000100012>)
10. Canto, C.B.B., & Castillo, A.G. (2011). Un mil usos del plátano. *La ciencia y el hombre, 24*(1). [Link](<https://www.uv.mx/cienciahombre/revistae/vol24num1/articulos/platano/>)
11. Chang, H., Luo, J., Gulgunje, P.V., & Kumar, S. (2017). Structural and functional fibers. *Annual Review of Materials Research, 47*, 331-359.

12. Comisión Nacional Forestal (2013). Sistemas Agroforestales Maderables en México. [Link](https://www.gob.mx/cms/uploads/attachment/file/126296/Sistemas_agroforestales_maderables_en_Mexico.pdf)
13. Cortés Vega, A.E. (2014). Elaboración de papel a base de residuos de banano. Tesis de licenciatura, Universidad Católica de Santiago Guayaquil. Ecuador. [Link](<http://repositorio.ucsg.edu.ec/bitstream/3317/1706/1/T-UCSG-PRE-ESP-CFI-7.pdf>)
14. Ecocosas. (2017). Green Blade, el nuevo panel ético y exótico del caribe francés. [Link](<https://tendencias2009.wordpress.com/2017/05/05/green-blade-el-nuevo-panel-etico-y-exotico-del-caribe-frances/>)
15. Flotats, S. (2015). Los tejidos del futuro se escriben en verde. De ITFASHION. [Link](<HTTP://WWW.ITFASHION.COM/MODA/ECOECO/LOS-TEJIDOS-DEL-FUTUROSEESCRIBEN-EN-VERDE/>)
16. Gaitán, A., Fonthal, G., & Ariza, C.H. (2016). Fabricación y propiedades físicas de aglomerados de Pennisetum purpureum Schum, Philodendron longirrhizum y Musa acuminata. *Revista Ciencias Técnicas Agropecuarias, 25*(1), 5-11. [Link](<http://scielo.sld.cu/pdf/rcta/v25n1/rcta01116.pdf>)
17. Gaona, E.D.E. (2015). Estudio de factibilidad para la elaboración y Comercialización de papel de fibra de banano. Tesis de maestrante, Universidad de Guayaquil. Facultad de Ciencias Agrarias. Guayaquil, Ecuador. [Link](<https://repositorio.ug.edu.ec/items/08d9a970-07d3-43be-a08f-69618d21034a>)
18. García, M., González, M., García, S., Mora, F., González, E., & Martínez, D. (2013). El mercado del plátano (*Musa paradisiaca*) en México, 1971-2017. *Agrociencia, 47*(4). [Link](<http://www.redalyc.org/pdf/302/30226975008.pdf>)
19. González, S., Reyes, A., Gutiérrez, Meráz, F., & Pacheco, V. (2016). Nanocelulosa obtenida de residuos agroindustriales del cultivo de plátano macho (*Musa paradisiaca* L). *Investigación y Desarrollo en Ciencia y Tecnología de Alimentos, 1*(2), 301-306. [Link](<http://www.fcb.uanl.mx/IDCyTA/files/volume1/2/3/53.pdf>)
20. González Velandia, K., Daza Rey, D., Caballero Amado, P., & Martínez González, C. (2016). Evaluación de las propiedades físicas y químicas de residuos sólidos orgánicos a emplearse en la elaboración de papel. *Revista Luna Azul, (43)*, 499-517. [Link](http://www.scielo.org.co/scielo.php?pid=S1909-24742016000200021&script=sci_abstract&tlng=es)
21. Grisales, M., & Giraldo, M. (2004). Empaques biodegradables a partir de fibra de plátano para Los productos agrícolas del departamento de caldas. Trabajo de grado, Universidad Nacional De Colombia, Sede Manizales. [Link](<https://repositorio.unal.edu.co/handle/unal/2675>)
22. Guarnizo-Franco, A., Martínez-Yepes, P., & Pinzón-Bedoya, M. (2012). Azúcares del pseudotallo de plátano: una opción para la obtención de alcohol de segunda generación. *Bistua: Revista de la Facultad de Ciencias Básicas, 10*(1), 39-51. [Link](<https://www.redalyc.org/pdf/903/90326398009.pdf>)
23. Linares, E.L., Galeano, G., García, N., & Figueroa, Y. (2008). Fibras vegetales utilizadas en artesanías en Colombia. Artesanías de Colombia S.A. Instituto de Ciencias Naturales-

Universidad Nacional de Colombia. Bogotá.
[Link](https://www.researchgate.net/publication/279205047_Fibras_vegetales_usadas_en_arterias_en_Colombia)

24. Mazzeo, M.M., León, A.L., Mejía, G.L., Guerrero, M.L., & Diego, B.J. (2010). Aprovechamiento industrial de residuos de cosecha y poscosecha del plátano en el Departamento de Caldas. *Revista Educación en Ingeniería, (9)*, 128-139.
25. Quinchia, F., & Uribe, C. (s.f). Aprovechamiento ambiental de residuos agroindustriales. [Link](<http://www.propiedadpublica.com.co/aprovechamiento-ambiental-deresiduos-agroindustriales/>)
26. Rodríguez, L., Sarache, W., & Orrego, C. (2014). Compuestos de poliéster reforzados con fibra de plátano/banano (*Musa paradisiaca*) modificada químicamente. Comparación con fibra de vidrio y fique (*Furcraea andina*). *Información Tecnológica, 25*(5), 27-34. DOI: 10.4067/S0718-07642014000500005
27. Sandoval, J.A., & Müller, L. (1999). Anatomía y morfología de la planta de banano *Musa AAA*. *Corbana, 24*(51), 43-60. [Link](<https://www.musalit.org/viewPdf.php?file=IN020198.pdf&id=6554>)
28. Saval, S. (2012). Aprovechamiento de residuos agroindustriales: Pasado, Presente y Futuro. *BioTecnología, 16*(2), 14. [Link](http://www.smbb.com.mx/revista/Revista_2012_2/Saval_Residuosagroindustriales.pdf)
29. Servicio de Información Agroalimentaria y Pesquera (2016). Anuario Estadístico de la Producción Agrícola. Avance de Siembras y Cosechas. Resumen nacional por estado. [Link](http://infosiap.siap.gob.mx:8080/agricola_siap_gobmx/AvanceNacionalCultivo.do)
30. Sosa, A., Rivas, J., Mogollón, G., Gutiérrez, I., & Aguilera, A. (2010). Evaluación papelera del pseudotallo de plátano (*Musa paradisiaca*) en formulaciones con *Hevea brasiliensis*, *Eucalyptus urophylla* y *Pinus caribaea* var. *Hondurensis*. *Revista Forestal Venezolana, 55*(1), 9-16. [Link](<http://www.saber.ula.ve/bitstream/handle/123456789/33480/articulo1.pdf;jsessionid=98696D4731549C08E29B713755D4A5C4?sequence=1>)
31. Ordóñez, Z., & Saavedra, R. (2016). Extracción y uso del colorante natural de la flor de jamaica (*Hibiscus Sabdariffa*) como alternativa para la elaboración de salchicha y yogur. Tesis de licenciatura, Universidad de Cuenca. Ecuador. [Link](<http://dspace.ucuenca.edu.ec/handle/123456789/23488>)
32. Padam, B.S., Tin, H.S., Chye, F.Y., & Abdullah, M.I. (2014). Banana by-products: an under-utilized renewable food biomass with great potential. *J Food Sci Technol, 51*(12), 3527-3545. DOI: 10.1007/s13197-012-0861-2.
33. Vargas, S., & Martínez, Y. (2015). Algunas características fisicoquímicas del jugo del pseudotallo de plátano dominico hartón. *Revista de Ciencias, 17*(01). [Link](<http://bibliotecadigital.univalle.edu.co/handle/10893/8792>)

Solid Waste Management of the municipalities of the state of Rondônia in the Western Amazon – Brazil

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ABSTRACT

The approach of this study was the management of urban solid waste in municipalities in the state of Rondônia – Western Amazon – Brazil. The main objective was to analyze the management of solid waste in accordance with PNRS Law 12.305/2010 in municipalities in the State of Rondônia. The research established the Municipal Index (IM) and the General State Index (IGE) for each municipality. In the aspects of Strategic Management and Collection and transportation, the IGE was 0.47 and 0.39 respectively, considered a BAD performance for Rondônia, whereas Sorting and Treatment and Final Destination the IGE was 0.24 and 0.27, classifying them like TERRIBLE. Unsatisfactory results may result from the absence or poor management of the municipal solid waste plan and its resources, inadequate disposal of waste, including open dumps, little investment in a selective and cooperative waste collection system, among others. The main contribution of the research was to observe the critical points that require greater attention so that MSW managers can establish or prioritize the most urgent points that require action, create or improve an Integrated Municipal Solid Waste Plan that meets the demands of society, developing and including cooperatives and associations of collectors, reducing environmental impacts and the health of the population, controlling or minimizing the municipality's costs with landfills and eliminating open dumps.

Keywords: Municipal Management, Solid waste management, National Solid Waste Policy.

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INTRODUCTION

For some time now, there has been a growing concern about the impacts that waste has been causing to society, the economy and the environment, authors such as Leite (2002), argues that different ways of reusing garbage should be adopted, either to produce something new, using garbage as raw material, or with the use of "second-hand" products. Neto and Moreira (2010) describe that the increase in population and migration to cities has changed the consumption profile and, consequently, its disposal.

The issue of solid waste is something that has plagued humanity since antiquity for Pereira (2019), especially the issue of sanitation is often responsible for soil contamination and the proliferation of diseases, affecting people's health. In this regard, Cunha (2018) points out that in Brazil public policies are backward and little has been done for decades. However, the National Solid Waste Policy – PNRS Law 12.305/2010 became a milestone, as it presented guidelines for the better organization of waste and its concept, where waste is considered to be that which no longer presents any possibility of reinsertion into the production cycle again, which ultimately needs environmentally appropriate final disposal.

In Brazil there are more than 5,700 municipalities throughout the territory that need support in the most diverse situations, Tullio (2019) argues that the Municipal Solid Waste Plans are more detailed, as it is necessary to recognize the waste generating agents and differentiate the waste that can be classified as hazardous from non-hazardous. Silveira and Clementino (2017) describe that in PNRS Law 12.305/2010, it was provided that by the year 2012 all municipalities in the country should have prepared their plans and that by 2014 all open waste disposal would be eradicated. Most Brazilian cities have not complied with this law. The IBGE (2019) shows that only 54.8% of municipalities effectively have an Integrated Solid Waste Management Plan.

Therefore, the questions about the problem of solid waste in Brazil are to find adequate solutions to the dilemma of this century, the destination of waste from consumption. For this, it was necessary to know how the municipalities in the State of Rondônia – Western Amazon/Brazil, manage Urban Solid Waste in accordance with the National Solid Waste Policy – PNRS, Law 12.305/2010. To this end, the general objective of this study was to analyze the management of solid waste according to PNRS Law 12.305/2010 in the municipalities of the State of Rondônia - Western Amazon/Brazil. The specific objectives were: to raise with the municipalities the adoption of solid waste management policy measures in attention to local demands in waste management, in line with Law 12.305/2010 of the municipalities of the State of Rondônia - Western Amazon/Brazil (a); identify the existence of actions that involve the community and people's sensitization to the problems related to GRSU in the municipalities of the State of Rondônia - Western Amazon/Brazil (b); and to seek, under the analysis of the urban solid waste manager of the municipalities of the

State of Rondônia - Western Amazon/Brazil, the conditions of strategic management, collection and transportation, sorting and final disposal of MSW in each city studied (c).

An inductive method supported by Medeiros (2018), Gil (2019, p. 12), Lakatos (2018) was used, and a descriptive method was based on Vergara (2010), Kauark, Manhães, Medeiros, (2010) and (Andrade, 1997), having qualitative and quantitative. Data were collected using a semi-structured form adapted from Ferraz (2008) in his model for the evaluation of integrated municipal management of urban solid waste and Barroso (2013) in Contributions to Solid Waste Management in the State of São Paulo, the research was applied to those responsible for solid waste management in all municipalities with a population above 20,000 inhabitants, totaling 21 in the state of Rondônia. The study took place during the Covid-19 Pandemic period. The research was characterized as being Census, as Gil (2009) and Lakatos (2018) discuss, in a census survey, sampling does not occur.

The contribution of this study was to establish for each municipality the Municipal Index (MI) and the General State Index (IGE), making it possible to quantify and qualify the situation of each one considering the aspects of Strategic Management, Collection and transportation, sorting and treatment and the final destination.

THEORETICAL-EMPIRICAL FRAMEWORK

The main theoretical bases that support this study are presented especially in this chapter. Thus, a presentation is initially made on the main previous studies developed on the National Solid Waste Policy, which includes the Municipal Plans for Urban Solid Waste. Next, the main Laws, resolutions and Decrees that serve as a contribution for all municipalities in the Brazilian territory in the construction of management strategies to give an adequate final destination to the waste produced daily, in order to reduce, mainly, the impacts on the environment and the health of the population. The chapter also covers the contents of the National Solid Waste Plan, State Solid Waste Plans, and the Municipal Plan for Integrated Solid Waste Management.

CONCEPTS AND DEFINITIONS: GARBAGE AND MUNICIPAL SOLID WASTE

Before defining solid waste, it is necessary to understand some concepts that may facilitate its conceptualization, for some, waste, garbage, remains, rubble, debris and/or leftovers. There are several words used for its name. For Aurelius (2020), The Garbage refers to any Material without value or utility, or waste from domestic, industrial and other work that is thrown away, or even everything that is removed from a place to leave it clean. The fact is that humanity's relationship with its biosphere has been progressively transforming over time in the same proportion as production and consumer growth to meet people's needs. After the Industrial Revolution began in the mid-eighteenth century, the creation of machinery and equipment that provided an exponential increase in waste

became a major problem in society. MAGERA (2003)

The big bottleneck is in the scenario that most of this waste is not even sent for these purposes, such as reuse or recycling. According to studies presented by UN-Habitat (2018), more than 2 billion tons of waste are produced worldwide every year, at the meeting that took place on October 1, 2018, energetic changes in the consumption pattern were demanded to combat excess garbage in cities, highlighting the importance of "Municipal Solid Waste Management". Another alarming fact from the same survey is that 99% of the products that are purchased are thrown away in 6 months, and to accommodate 7.6 billion inhabitants in the world, supply the use of resources and absorb the garbage generated, it would be necessary to have 70% of another planet like ours. That is why it is necessary for countries, states and municipalities around the world to jointly seek urgent solutions for effective waste management.

Currently, billions of people do not have access to public basic sanitation services, such as drinking water supply, collection, transport and their final disposal. Much of this same population suffers from diseases related to the inadequate distribution of water and sewage. Issues related to this theme have been shown to be one of the most backward public policies. WEDGE (2018)

SOLID WASTE

The definition of Solid Waste is basically represented by the materials discarded by people, where they can be recycled and/or partially used, having as main benefit the protection of health, economy as well as the preservation of the environment.

The PNRS (2010) also introduced a new concept of "tailings", where, according to the text, they are solid waste that, after exhausting all possibilities of treatment and recovery by available and economically viable technological processes, presented no other possibility than environmentally appropriate final disposal. To this end, the PNRS addresses a set of characteristics and properties listed in the table below. Although the term emphasizes the adjective solid to the term waste, the PNRS includes other states of matter in the definition of solid waste.

Table 1: Characteristics and properties of Solid Waste according to the PNRS

Feature	Property
Discarded material, substance or good.	It requires action, a positive act that involves the disposal of something that is under your administration, use, power;
Resulting from human activity in society.	If it is not something resulting from human activity in society, it cannot be understood as waste, like animal excrement in the jungle;
If it proceeds, if it proposes to proceed or if it is obliged to proceed with its final disposal.	From disposal follows the need for final destination, whether by voluntariness (proceeds and proposes to succeed) or by obligations
There are no solid, semi-solid states, gases contained in containers and liquids that cannot be disposed of in the public sewage system or bodies of water.	Despite the term emphasizing the adjective solid to the term exclusion, the PNRS includes other states of matter in the definition of solid elimination.

Source: Silva Filho and Soler (2012), adapted.

For the Brazilian Association of Technical Standards – ABNT: Solid waste is waste in solid and semi-solid states, which result from community activities, of origin: industrial, domestic, health services, commercial, agricultural, services and sweeping. (ABNT, 2004)

Law 12.305 of August 2, 2010 defines it as: "Material, substance, object or discarded good resulting from human activities in society, and which need to be disposed of". The legal framework for basic sanitation in Brazil was instituted by the National Basic Sanitation Law (LNSB), Federal Law No. 11,445, of January 5, 2007 and regulates years later through Federal Decree No. 7,217 of June 21, 2010, and brings that basic sanitation is a set of infrastructures and operational facilities: (i) drinking water supply; (ii) sanitary sewage; (iii) urban cleaning and solid waste management; drainage and rainwater management, preventive cleaning and inspection of urban networks. MARCHI (2018)

Only after 20 years of discussion in Brazil was Federal Law No. 12,305 of August 2, 2010, called the National Solid Waste Policy (PNRS), which establishes principles, objectives, instruments, guidelines related to integrated management and management of solid waste (it also includes hazardous waste, with the exception of radioactive waste that has its own legislation). as well as the responsibility of those who generate, the public authorities and some applicable economic instruments. The PNRS is part of the National Environmental Policy, which is articulated with the Environmental Education Policy, the Federal Basic Sanitation Policy and the Public Consortium Law.

It is important to understand that the Law that establishes the PNRS are a set of provisions, principles, objectives and guidelines, however, the normative issue is not exclusively hers, it is necessary to observe some instruments and guidelines as listed in the following table.

Chart 2: Laws, guidelines, regulations preceding the PNRS/2010

Laws/Decrees	Goal
Law no. 11,445 of January 5, 2007	Establishes national guidelines for basic sanitation and federal basic sanitation policy.
Federal Law no. 6,938, of August 31, 1981.	Provides for the National Environmental Policy, its purposes and formulation and application mechanisms;
Federal Law no. 9,605, of February 12, 1998.	Provides for criminal and administrative sanctions arising from conduct and activities harmful to the environment;
Federal Law no. 9,795, of April 27, 1999.	Provides for environmental education, establishes the National Environmental Education Policy;
Federal Law no. 10,605, of April 16, 2003.	Provides for public access to data and information existing in bodies and entities that are part of Sisnama;
Federal Law no. 11,079, of December 30, 2004.	Establishes general rules for bidding and contracting public-private partnerships within the scope of public administration;
Federal Law no. 11,107, of April 6, 2005.	Provides for general rules for contracting public consortia;
Complementary law no. 101, of May 4, 2000.	Establishes public finance standards aimed at responsibility in fiscal management;
Complementary law no. 123, of December 14, 2006.	Establishes the National Statute for Microenterprises and Small Businesses;
Federal Decree no. 6,514, of July 22, 2008.	Provides for environmental infractions and administrative sanctions, establishes the federal administrative process for investigating these infractions;
Federal Decree no. 7,217, of June 21, 2010.	Feature
Property	Material, substance or discarded good.

Source: Silva Filho and Soler (2012), adapted.

The topic of solid waste is carried out through various legal and normative instruments. In addition to the laws and decrees mentioned, there are also some standards that are established by agencies such as: the National Environmental System (Sisnama), the National Health Surveillance System (SNVS), the Unified System of Agricultural Health Care (Suasa) and the National System of Metrology, Standardization and Industrial Quality (Sinmetro).

CLASSIFICATION OF WASTE

There are several classifications for solid waste that are basically determined by their characteristics or the identification of properties, and these are determinant for the choice of management strategies appropriate to each one. NBR 10004/2004 classifies solid waste according to its degree of hazard, that is, according to its physical, chemical and infectious properties, as well as the possible risk to people's health and the environment. Table 3 below shows the classifications according to the hazardousness of solid waste.

Table 3: Classification of solid waste according to its hazardousness

It demands action, a positive act that implies the disposal of something that is under its administration, use, power;		Resulting from human activity in society.
If it is not something resulting from human activity in society, it cannot be understood as waste, like animal excrement in the jungle;	If it proceeds, if it proposes to proceed or if it is obliged to proceed with its final destination.	From the disposal onwards, the need for final destination follows, either by voluntariness (proceeds and proposes to succeed) or by obligation
In the solid, semi-solid state, gases contained in containers and liquids that cannot be disposed of in the public sewer system or in water bodies.	Although the term emphasizes the adjective solid to the term waste, the PNRS includes other states of matter in the definition of solid waste.	-
Class II A	Not Inert	They have biodegradability, combustibility and water solubility properties.
Class II B	Inert	Those considered inert or non-combustible.

Source: NBR 10004/2004.

The PNRS of Law 12.305/2010 also provides a classification regarding the origin and its dangerousness, as presented below.

Table 4: Classification of solid waste according to its origin

Laws/Decrees	Objective
a) Law No. 11,445 of January 5, 2007	Establishes the national guidelines for basic sanitation and federal basic sanitation policy.
b) Federal Law No. 6.938 of 31 August 1981.	Provides for the National Environmental Policy, its purposes and mechanisms for formulation and application;
c) Federal Law No. 9,605, of February 12, 1998.	Provides for criminal and administrative sanctions derived from conducts and activities harmful to the environment; <i>a e b</i> ;
d) Federal Lions n. 9,795, of 27 abril of 1999.	Provides for environmental education, institutes the National Policy for Environmental Education; <i>b, e, g, h e j</i> ;
e) Federal Lions n. 10,605, of 16 abril of 2003.	Provides for public access to existing data and information in the bodies and entities that are part of Sisnama; <i>c</i> ;
f) Federal Law No. 11,079, of December 30, 2004.	Establishes general rules for bidding and contracting of public-private partnerships within the scope of public administration;
g) Federal Lions n. 11.107, of 6 abril of 2005.	Provides for general rules for contracting public consortia;
h) Complementary Law No. 101 of May 4, 2000.	Establishes public finance standards aimed at responsible fiscal management;
i) Complementary Law No. 123 of December 14, 2006.	Establishes the National Statute of Micro and Small Enterprises;
j) Federal Decree No. 6,514, of July 22, 2008.	Provides for environmental infractions and administrative sanctions, establishes the federal administrative procedure for the investigation of these infractions;
k) Federal Decree No. 7,217, of June 21, 2010.	Regulates Law 11.445, of January 5, 2007, which establishes national guidelines for basic sanitation.

Source: PNRS/2010, Law 12.305, adapted.

In addition to classifying the PNRS Law, it also distinguishes between hazardous and non-hazardous waste, as provided in the table, namely:

Table 5: Classification of solid waste according to hazardousness

Federal Decree No. 7,704, of December 23, 2010.	Regulate Law No. 12,305, of August 2, 2010, which establishes the National Solid Waste Policy and the Committee Oriented to the Implementation of Reverse Logistics Systems.
a) Hazardous waste	Those that, due to their characteristics of flammability, corrosiveness, reactivity, toxicity, pathogenicity, carcinogenicity, teratogenicity, mutagenicity, present a significant risk to public health or environmental quality, in accordance with the law, regulation or technical standard;
b) Non-hazardous waste	Those not included in paragraph a;

Source: PNRS, Law 12.305/2010, adapted.

One of the objectives of the Law is to reduce the volume and hazard of hazardous waste, precisely because of the imminent risk to people (public health) and the environment. However, there are more objectives that are part of it, such as: adoption of development and improvement of clean technologies, in order to minimize environmental impacts; encouraging the adoption of sustainable patterns of production and consumption of goods and services; protection of public health and environmental quality; non-generation, reduction, reuse, recycling and treatment of solid waste, as well as environmentally appropriate final disposal of waste; encouraging the recycling industry, with a view to promoting the use of raw materials and inputs derived from recyclable and recycled materials; and put an end to integrated solid waste management. SILVA FILHO AND SOLER (2012)

Integrated Solid Waste Management: National, State and Municipal

Currently, IBGE (2020) shows that 68% of Brazilian cities have less than 20 thousand inhabitants, where 80% of them live in urban areas. The PNRS (2010), Section IV, article 19, item IX, paragraph 2 of the Municipal Solid Waste Plans states that "*§ 2 For municipalities with less than twenty thousand inhabitants, the municipal plan for integrated solid waste management shall have simplified content, in the form of the regulation.*" This opening of the Law, together with the Brazilian reality in relation to the substantial number of municipalities with smaller populations, raises concerns about urban environmental problems, including the management of solid waste, which is the responsibility of municipal public administrations.

Therefore, on August 3, 2012, the elaboration of Integrated Solid Waste Management Plans was foreseen: National, State and Municipal, where these should be in accordance with the terms of the PNRS Law. SANTAELLA (2014)

National Solid Waste Plan

The National Solid Waste Policy (PNRS), which was regulated by Decree No. 7,404 of 2010, created an important instrument, which was the National Solid Waste Plan, and established the Interministerial Committee (IC), coordinated by the MMA. This plan has a close relationship with the National Climate Change Plan (PNCM), Water Resources Plan (PNRH), Basic Sanitation Plan

(Plansab), and Sustainable Production and Consumption Plan (PPCS). They contain, according to the aforementioned Law, the proposals for various sectors of the economy, making economic growth and environmental preservation compatible.

The National Solid Waste Plan shall be prepared by the Federal Government under the coordination of the Ministry of the Environment (MMA), which shall be valid for an indefinite period, with a horizon of 20 years and updated every 4 (four) years. Article 15 of Section II, items I to XI of the PNRS/2010, assigns a minimum content of:

Briefly, the National Plan includes guidelines, strategies, goals with indications of actions necessary for the implementation of the national objectives as well as their priorities, serving as a guide for other public responsibility plans, including solid waste plans. IBAM (2001)

It is important to emphasize that planning must exist at all levels, from the national to the local, to the planning and management of different types of waste, and must contain the National Plan, State Plan and Municipal Plans. Also at the municipal level, there may be, if necessary, Intermunicipal, Micro-regional, Metropolitan Regions and Urban Agglomeration Plans, as can be seen in figure 4 below.

Figure 1: Hierarchical Structure of the Solid Waste Plans according to PNRS/2010.

ESFERA	Plano	PRAZOS			
		Elaboração	Vigência	Horizonte de atuação	Atualização ou Revisão
Federal	Plano Nacional de Resíduos Sólidos	Versão preliminar até junho de 2011	Indeterminado	20 anos	A cada 4 anos (previsão)
Estadual	Plano Estadual de Resíduos Sólidos	Agosto de 2012	Indeterminado	20 anos	A cada 4 anos (previsão)
	Plano Microrregional de Resíduos Sólidos	A elaboração é condição para o acesso dos Estados aos recursos da União, ou por ela controlados.			
	Plano de Resíduos Sólidos de Regiões Metropolitanas ou Aglomerações Urbanas				
Municipal	Plano Municipal de Gestão Integrada de Resíduos Sólidos	Agosto de 2012	Indeterminado	20 anos	Prioritariamente, no máximo a cada 4 anos, junto com a revisão do plano plurianual. <i>Esta exigência, para o âmbito local, faz do PGRS uma peça viva, que se reinventa a cada nova discussão pública, renovando o repertório de conhecimento sobre o assunto por parte da comunidade; incorporando novas tecnologias nos processos de gestão, manejo, processamento e destinação final; incorporando novos procedimentos e descartando os que já não mais se mostrem eficientes ou viáveis.</i>
	Plano Intermunicipal de Resíduos Sólidos	A elaboração é condição para o acesso dos Municípios aos recursos da União, ou por ela controlados.			
	<i>Municípios com menos de 20 mil habitantes poderão adotar planos simplificados de gestão de resíduos sólidos.</i>				

Source: MMA (2012, p. 45)

The Federal Constitution (1988), in its article 30, item V, provides for the competence of municipalities to "organize and provide, directly or under a concession or permission regime, public services of local interest, including public transport, which has an essential character". The characterization of the definition of "local interest" is the predominance of the interests of the municipality over the interests of the State or the Union. Thus, among these interests are urban

cleaning, which can be managed directly by the municipality; by a specific public company or through a mixed-capital company acting specifically to act in this function.

Also, without mentioning the word "garbage", the Federal Constitution of 1988, articles 196, 225 and 23, items VI, IX, and X, respectively in its wording states that, "health is a right of all and a duty of the State, guaranteed through social and economic policies aimed at reducing the risk of disease and other health problems and universal and equal access to actions and services for its promotion, protection and recovery", another part, "Everyone has the right to an ecologically balanced environment, a good for the common use of the people and essential to a healthy quality of life, imposing on the Public Power and the community the duty to defend and preserve it for present and future generations", finally, "It is the common competence of the Union, the States, the Federal District and the Municipalities: protect the environment and combat pollution in any of its forms; promote housing construction programs and the improvement of housing conditions and basic sanitation; tackling the causes of poverty and the factors of marginalization by promoting the social integration of disadvantaged sectors."

Therefore, the Integrated Management of the Urban Cleaning System involves the population and the systematic political exercise that are linked to the municipal, state and federal spheres. In Brazil there is a vast collection of Decrees, Laws, Resolutions and norms that highlight the concern with the environment, some of which are specific to the maintenance of the environment, however forceful actions are needed in relation to them. IBAM (2015)

State Solid Waste Plan

The elaboration of the State Solid Waste Plan (PERS) is provided for in Article 16 of Law No. 12,305/2010, and is an essential condition for the states to have access to federal resources and projects related to solid waste management. Sebrae (2012) mentions that, in essence, the PERS have the same instruments as at the federal level, however, what differs are those of observing the territorial aspects of each state, giving greater emphasis to the definition of guidelines for planning and other solid waste management activities in metropolitan regions, agglomerations and micro-regions.

After the establishment of these micro-regions, the states must coordinate the plans aimed at the municipalities in the way they are organized. It is necessary to carry out studies that define the best locations for the treatment of solid waste and the final disposal of tailings, as well as the recovery of areas affected as a result of inappropriate use.

Article 17 of Section III mentions the scope and validity of the State Plans, a horizon of action that is 20 (twenty) years and a review time of 4 (four) years, and provides the minimum contents of the PERS to be observed in the plans of each state, provided for in items I to XII in Law

No. 12,303/2010 (2017a). The State Solid Waste Plans (PERS) must be based on guidelines that integrate environmental policies, with the policies of the most diverse sectors of the government, the productive sector and civil society, with transparency in order to give legitimacy to the process. SEMAS (2012)

Municipal Plan for Integrated Solid Waste Management

For Tullio (2019), public policies linked to laws, norms and guidelines, inspection bodies are essential for organizing the waste structuring process in Brazil, but there are more than 5,700 municipalities throughout the territory that need to be supported in the most diverse situations. There is a lot of complexity when it comes to correctly disposing of solid waste, starting with handling, packaging and storage. It continues in relation to collection, types of transport, industrial organization for reuse and recycling, even though there are numerous legislations some for individuals and others for legal entities, it is essential that the manager prepares a management plan of which the actors work together to give correct destination to the waste.

The Municipal Solid Waste Plans (PMRS) are more detailed, as they require the identification of favorable areas for adequate final disposal and with less impact on the environment, it must also contain the identification of possible solutions consortium or shared with other municipalities that can be implemented. At this point in the plan, it is necessary to recognize on site the waste generating agents that must present particular plans, in case they produce specific waste (such as construction remains, hospital waste, among others), or hazardous waste.

Data provided by IBGE (2017) through the Ministry of the Environment show that (54.8%) of the municipalities have an Integrated Solid Waste Management Plan. The article published by the MMA website (2019), reinforces that "the presence of the plan is greater in municipalities with larger populations, ranging from 49% of municipalities with 5 thousand to 10 thousand inhabitants, to 83%, in those with more than 500 thousand inhabitants" and when related to the regions of the country highlight that, "Among the regions, the highest percentages are the municipalities in the South (78.9%), Midwest (58.5%) and Southeast (56.6%). Below the national average are the North (54.2%) and Northeast (36.3%) regions." Monteiro (2006) observes that there are numerous deficiencies in the conduct of waste plans (planning and programming) in the medium to long term. Municipalities, particularly the smaller ones, suffer in their economic and managerial capacity, which prevents them from carrying out an adequate work of solid waste management. The same author clarifies that legislation aimed at environmental conservation is abundant, but what prevents it from proceeding most of the time is the interpretation and compliance by public authorities.

Data from ABELPRE (2019) show that almost three-quarters of Brazilian municipalities carry out some type of selective collection, however, in most of them they are not able to serve all neighborhoods, according to data shown in the table below.

Table 1: Number of municipalities with selective collection

Regions	North		North East		Midwest		Southeast		South		Brazil	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Yes	270	286	902	978	209	227	1.464	1496	1.078	1.083	3.923	4.070
No	180	164	892	816	258	240	204	172	113	108	1.647	1.500
Total	450		1.794		467		1.668		1.191		5.570	

Source: Abrelpe (2019, p. 15).

It is possible to notice that although many municipalities still do not offer collection services, on the other hand, in all regions there was an increase between the years 2017 and 2018, with emphasis on the northeast and midwest regions of the country. Being more specific in the North Region, Abelpre (2019) in its report shows that the number of municipalities with selective collection in 2017 was 270 and in 2018 this data rose to 286 out of a total of 450 municipalities, even with an advance many localities still do not have any selective collection system.

METHODOLOGY

In this chapter, the methodological design used for the development of the research of this article is described, such as: approach, scientific method, application of the research, application of the research form, data collection and the criteria for analysis and interpretation of the data. For analysis, charts, graphs and tables were made, later interpreted and discussed in the form of text. For the municipal and state indexes, the formula developed by the author was used.

Table 6: Methodological description of the research

Those not covered by point	Description
Approach	Regarding the approach to the problem, the work was characterized as qualitative and with quantitative aspects and described. Contributed by Severino (2016, p. 125), Figueiredo et al. (2014), (Gerhardt & Silveira, 2009, p.32) and Oliveira (2002).
Scientific Method	Documentary research, bibliographical research and semi-structured form conceptualized by Lakatos (2018), Santos (2000); Gil (2009).
Application of research	It was a census survey, as Gil (2019, p. 102) explains, since the form was applied in all municipalities in Rondônia with a population above 20,000 inhabitants in accordance with PNRS Law 12,305/2010. Lakatos (2018), adds that in a census survey there is no sampling.
Application of the survey form	Semi-structured form adapted from Ferraz (2008) in his model for evaluating integrated municipal management of urban solid waste and Barroso (2013) in Contributions to Solid Waste Management in the State of São Paulo.
Data collect	Procedure for collecting data through the application of already tested instruments, applied to MSW managers in 21 municipalities in the state of Rondônia. The interviews took place via telephone calls, virtual meetings via Google Meeting, video and telephone calls via WhatsApp due to the Covid-19 pandemic period.
Analysis and interpretation and presentation of data	For analysis, a chart, graphs and tables were created, later interpreted and discussed in text form. For municipal and state indices, the formula developed by the author was used.

Source: Prepared by the authors, (2024).

To contemplate each technique selected for the survey and investigation process, it was necessary to establish the categories to be analyzed in the research form, which were: Strategies/Actions; Collection and transportation; Screening and Treatment and Final Disposal. Each category/criterion was divided into subcategories so that it was possible to better enter into the solutions and problems by city, established in the table below:

Table 7: Research categories and subcategories.

Nº	Category/criteria	Subcategory
01	Strategies/Actions	Master plan
		Execution plan
		Institutional Structure
		Organizational Structure/Resource Allocation
		Human Resources Training
		Financial Management and Costs
		Social inclusion policy
02	Collection and Transport	Environmental education
		Waste characterization and analysis
		Domestic Waste Collection System
		Health Waste Collection System
		Construction Waste Collection System
		Bulky Waste Collection System
		Hazardous and Special Waste Collection System
		Sweeping, pruning and Urban Cleaning System
		Maintenance and conservation of equipment
		Human Resources, hygiene and safety
03	Screening and Treatment	Assessment of performance, quality and productivity
		Selective Collection – Qualitative and Quantitative Analysis
		Sorting Plant Qualitative and Quantitative Analysis
		Composting Plant
		Civil Construction Waste Recovery Plant: qualitative and quantitative
		Health Waste Treatment System
		Operating Conditions of Waste Treatment and Recovery Plants
04	Final destination	Operational support for waste picker and scrap dealer cooperatives
		Environmental Licensing
		Environmental Impacts: Domestic Waste Landfill
		Operational Conditions for Final Disposal of Domestic Waste
		Operational Conditions for Final Disposal of RSS Waste
		Operational Conditions for the Disposal of Civil Construction Waste - Rubble
		Operational Conditions for the Disposal of Bulky and Unusable Waste
		Operational Conditions for the Disposal of Special and Hazardous Waste
Maintenance of Machines and Equipment		

Source: Prepared by the authors, (2022), based on Ferraz, (2008).

With the score of each municipality, we sought to establish the municipal index of each city in relation to the analysis carried out by its managers, to measure the municipal performance resulting from the management of the MSW.

a) To arrive at the index for each municipality, the following equation was used:

- PM = Maximum possible score of the municipality
- MI = Index of the municipality
- T = Total score achieved by the municipality

Then:

$$IM = T/PM$$

b) To arrive at the **General Sum in the State (SGE)**, the score of each criterion in each municipality studied was added. To find the **General State Index (GSI)**, the following was adopted:

- IGE = General State Index
- SGE = General Sum in the State
- *PMG = Maximum Overall Possible Score
- NIA = Number of criteria analyzed

* To find the **Overall Maximum Score (PMG)**, the maximum score that each municipality can achieve is multiplied by the number of municipalities. This includes:

$$\text{IGE} = (\text{SGE}/\text{PMG})/\text{NIA}$$

After finding the index of each municipality and state, which can vary from 0.00 to 1.00, a simple scale was established to determine the condition of each one, enabling an analysis of the general (state) or individual (municipality) performance using:

- **Terrible:** 0.00 to 0.29
- **Poor:** 0.30 to 0.49
- **Regular:** 0.50 to 0.69
- **Good:** 0.70 to 0.89
- **Optimal:** 0.90 to 1.00

Table 8 - Description of the hypotheses proposed for the study

Hypotheses	Director
<p>H1 - The municipalities in the State of Rondônia - Western Amazon/Brazil in their Integrated Municipal Solid Waste Plans do not meet local demands in waste management caused by the inefficient management of their plans.</p>	
<p>H2 - The municipalities in the State of Rondônia - Western Amazon/Brazil, in their Integrated Municipal Solid Waste Plans, partially meet local waste management demands due to lack of technical knowledge.</p>	
<p>H3 - The Integrated Municipal Solid Waste Plans in the municipalities of the State of Rondônia - Western Amazon/Brazil do not meet the guidelines established in the National Solid Waste Policy.</p>	<p>1.1 1.1 National Solid Waste Policy Law 12,305/2010.</p>
<p>H4 - Most of the municipalities in the State of Rondônia - Western Amazon/Brazil do not have a solid waste management plan and therefore do not comply with PNRS Law 12,305/2010.</p>	

Source: Prepared by the authors (2024).

PRESENTATION OF THE RESEARCH OF THE RESULTS

In this chapter, the collected data will be presented, as well as the results from the study, focused on meeting the objectives listed, as well as the research problem, the validation and/or refutation of the hypotheses. It was sought to identify, from the manager's own point of view, the conditions of urban solid waste management, focusing on Strategic Management, Collection and Transportation, Sorting and treatment and Final Disposal in compliance with Law 12.305/2010 of the National Policy on Urban Solid Waste in the State of Rondônia.

CHARACTERIZATION OF THE MUNICIPALITIES SURVEYED

The study was concentrated in 21 of the 52 municipalities in the state of Rondônia, since Law 12.305/2010, in section IV, art. 19, § 2, says that "For municipalities with less than twenty thousand inhabitants, the municipal plan for integrated solid waste management will have simplified content, in the form of the regulation." Currently, according to the survey, more than 70% of Brazilian cities currently have less than 20 thousand inhabitants, where 80% of them live in urban areas.

Thus, all the other municipalities were surveyed, considering that the estimated population of each one is above 20,000 people and that, therefore, all of them should already have an Integrated Municipal Plan for Solid Waste in compliance with the aforementioned Law, making the survey a census since it contemplated 100% of the cities with these characteristics.

According to IBGE (2021), the municipalities of the State of Rondônia are: Porto Velho (state capital) with 548,952 inhabitants, Ji-Paraná with 131,026, Ariquemes with 111,148, Vilhena with 104,517, Cacoal with 86,416, Rolim de Moura with 55,748, Jaru with 51. 469, Guajará-Mirim with 46,930, Machadinho D'Oeste with 41,724, Buritis with 41,043, Pimenta Bueno with 37,098, Ouro Preto D'Oeste with 35,445, Espigão D'Oeste with 33,009, Nova Mamoré with 32,184, Candeias do Jamari with 28,068, Cujubim with 27,131, São Miguel do Guaporé with 23,147, Alta Floresta D'Oeste with 22,516, Alto Paraíso with 22,258, São Francisco do Guaporé with 21,088 and finally Nova Brasilândia D'Oeste with 20,504 representing 40.38% of the municipalities in the State of Rondônia.

ANALYSIS OF THE MANAGEMENT AND MANAGEMENT OF URBAN SOLID WASTE EVALUATED BY MUNICIPAL MANAGERS IN THE FOLLOWING DIMENSIONS: STRATEGIC MANAGEMENT, COLLECTION AND TRANSPORT SYSTEM, SORTING AND TREATMENT AND FINAL DISPOSAL.

We sought to collect the information under the evaluations of the municipal managers in their respective secretariats aspects of urban solid waste management in each municipality surveyed.

STRATEGIC MANAGEMENT DIMENSION

PNRS 12.305/2010 establishes in its Article 18 that the elaboration of the Integrated Municipal Plan for Solid Waste is the condition for the Federal District, as well as the municipalities, to have access to resources from the Union, intended for projects aimed at urban cleaning, solid waste management, as well as financing to federal credit entities or even promotion for such purpose. In view of this, the first criterion for the analysis of the Strategic Management dimension is the municipal solid waste plan, when all managers were asked if they had a plan, 12 municipalities answered that they did not have one, with a score of 0 (zero) in this item, including the most populous municipality, which is Porto Velho.

Among those that have plans, such as the city of Ariquemes, a score of 5 (five) was assigned in several other items, which shows that the plan requires adjustments. However, two municipalities have an index of 1.00 with EXCELLENT performance, which are Candeias do Jamari and Pimenta Bueno, followed by Cacoal with 0.87 and Nova Brasilândia with 0.78, both on the scale can be classified with GOOD performance, the city of Vilhena also draws attention to the fact that despite

having a Municipal Plan, its index was very low because in the items, defined evaluation indicators, establishes a work plan, defines projects to be implemented, establishes priorities and defines an execution schedule if evaluated with a grade of 0 (zero) lowering its Municipal Index (IM) to 0.21 having VERY POOR performance. Also due to the high number of municipalities with an index of 0.00, the General State Index (IGE) was 0.29, with VERY POOR performance in this criterion.

Another 7 criteria that are related to the understanding of what concerns the execution of the plan, shows that although 12 municipalities have declared that they do not have PMIRS, many of them have some type of informal planning of the activities to be carried out about the MSW in their cities. Now, not all cities have a professional exclusively dedicated to the implementation and monitoring of the plan or even the activities related to MSW.

Regarding the evaluation and updating of the plan, only 3 municipalities evaluated themselves with a score of 10 respectively, the massive majority self-evaluated with 0 (zero), that is, they do not do so, the recommendation of PNRS 12.305/2010 is that the PMIRS be updated together with the municipality's master plan that occurs every 4 (four) years, usually from the beginning of a municipal management. In the general analysis of this criterion, the best **IM** of 0.85 were from Espigão D'Oeste and Ariquemes and 9 (nine) municipalities had **IM** equal to 0 (zero) because they do not have an effective plan, among those who declared to have the **IM** the lowest was Vilhena with 0.35 considered a POOR performance. Or **IGE** in the topic execution of the plan was 0.22, denoting a level of performance classified as VERY POOR for the state of Rondônia.

Following the analysis of the Strategic Management dimension, we sought to understand the way in which the solid waste sectors among the surveyed municipalities are formatted, the criterion institutional structure brought data about the responsible manager, his technical profile, autonomy in decision-making, policies and guidelines, among others. In this criterion, there was no municipality that was evaluated with a score of 0 (zero), and the lowest MI of 0.33 with POOR performance was the municipality of Ouro Preto D'Oeste, where only in the items "adequate allocation" of the sector and "is there a responsible manager" it obtained, suggesting that in this aspect it still has some structuring challenges where it possibly brings negative impacts on the management of MSW. However, two municipalities had an index of 1.00, which were Cacoal and Nova Brasilândia, 0.91 Ariquemes and another 6 had MI of 0.83, which in the performance scale are considered EXCELLENT and GOOD, respectively. However, it should be noted that 8 presented the result with MI between 0.5 and 0.67, considered a REGULAR performance. The IGE also obtained a timid result of 0.69, i.e., a REGULAR performance for the state of Rondônia.

There were 10 municipalities with MI ranging from 1.00 to 0.91 with an EXCELLENT performance index, and 6 with MI results between 0.75 and 0.83 configuring GOOD performance, i.e., the vast majority of managers have a very adequate degree of satisfaction in relation to the

physical facilities of the sector. Only the municipality of Candeias do Jamari obtained a MI of 0.41 considered a POOR performance, although Guajará Mirim, Alto Paraíso and Machadinho D'Oeste had a Regular performance with a MI between 0.5 and 0.58. With the high general municipal indexes, there was an increase in the General State Index – IGE, which stood at 0.82, with GOOD performance.

The training of employees in the MSW sector is of paramount importance for the proper development of work and with quality, both in the administrative sector of the MSW as well as operational, which deals directly with waste and needs technical training as well as preventive training that minimizes risks of work accidents, so the interviewees analyzed three basic aspects that were training and qualification, accident prevention and career plan. It is noteworthy that 3 municipalities that are Guajará Mirim, Ouro Preto D'Oeste and São Miguel did not score in any of these aspects, with a MI of 0.00 and Candeias do Jamari with 0.17, that is, with a VERY BAD performance. The best IMs were Espigão D'Oeste, Pimenta Bueno, Rolim de Moura and Buritis with 1.00 with GREAT performance. However, 9 municipalities had their MI between 0.5 and 0.66, i.e., 42.86% have a REGULAR performance condition, which if added to the 28% already mentioned, creates a precarious scenario regarding investment in people. Again, the IGE had a REGULAR performance with 0.57. It is necessary to develop and create policies in the state of Rondônia and work together with municipalities on the importance of investing in people development.

The cleaning services provided by the municipalities are financed by the collection rates carried out in more than 76% together with the IPTU, according to data collected in chart 12 above. Thus, understanding how these values are managed and monitored was one of the points evaluated by the MSW managers, considering the following aspects: financial control of fees, rationalization and reduction of costs, search for increased collection, application of resources through other financing and monitoring through management reports.

Thus, 4 municipalities such as Guajará Mirim, Ouro Preto, São Francisco and São Miguel had MI equal to 0 (zero) and another two such as Candeias do Jamari and Cujubim with MI of 0.16, indicating a VERY POOR performance. Another 11 municipalities had a Municipal Index between 0.33 and 0.66, indicating a performance between POOR and REGULAR, so that of the 21 cities, 17 or 80.95% have a performance below average when it comes to aspects related to financial management and cost. A worrisome result, as it is an important part of municipal management strategies, knowing how much is collected, how to apply the resource, where and how it will be done, has a positive and substantial effect on cities. Only the municipalities of Ji-Paraná, Pimenta Bueno and Vilhena had MI with EXCELLENT performance, between 1.00 and 0.91. The state's result was 0.43, which denotes a BAD GIE for Rondônia.

According to Monteiro (2001), recycling generates jobs, income and reduces the amount of waste that can be disposed of in the soil and in landfills, all of which can be considered an alternative choice of treatment for garbage. Thus, the stimulus to the creation or development of waste pickers' cooperatives not only generates income for families, but also reduces costs for the municipal government itself, since it reduces the amount of tons sent to landfills, reducing the amount paid, especially to outsourced companies that give the proper destination to the waste. WEETMAN (2019)

Thus, with MI 0.00 or VERY BAD are the cities of Guajará Mirim, Cadeia do Jamari, Machadinho D'Oeste and São Miguel do Guaporé, another 9 municipalities had MI between 0.3 and 0.6, being between BAD or REGULAR, so in these aspects it is still necessary to make many advances. However, most managers justified that at the current moment, due to COVID-19, many projects in schools were suspended since the students were in prison until the time of the interview. *homeschooling*, but even so, no work was developed in this direction in the neighborhoods either, even though most of the municipalities indicated that the MSW sector was properly installed within the Department of the Environment.

The best indicators between 1.00 and 0.80 were for the cities of Espigão D'Oeste, Ji-Paraná and Jaru, with performance between EXCELLENT and GOOD. The GIE in Rondônia was 0.56 or REGULAR. In article 19 of the PNRS, Law 12.305/2010, item X of the PMIRS, it states that "environmental education programs and actions that promote the non-generation, reduction, reuse and recycling of solid waste" must be developed;" reinforcing the importance of all municipalities developing their Integrated Municipal Solid Waste Plans so that they establish real goals and can not only have access to resources that allow their applications in environmental education actions but that allow a more strategic performance of the management of MSW.

DIMENSION: PICK-UP AND TRANSPORT SYSTEM

NBR 10004/2004 classifies solid waste according to its degree of hazard, that is, according to its physical, chemical and infectious properties, as well as the possible risk to people's health and the environment. On the other hand, PNRS Law 12.305/2010 states that, for the purposes of the law, solid waste can be classified according to its origin, which can be urban solid waste, which includes domestic and urban cleaning waste, waste from commercial establishments, basic sanitation waste, industrial waste, health service waste, civil construction waste, agrosilvopastoral waste, waste from transportation services and mining waste. They can also be classified when their hazard is divided into hazardous and non-hazardous waste.

The criterion addressed sought information about studies to characterize the MSW of each municipality, it is considered important to know the conditions, volume, among others, to establish its chemical and biological composition, so that managers can plan what type of vehicle as well as

the quantity needed to meet the demand of each location. Specifying this is not only important for safety, but especially for cities that outsource collection and transportation, to be able to hire the correct number of vehicles without waste or damage to the public treasury and that adequately serve the community. Thus, 14 municipalities had a MI equal to 0.00, which leads to the assumption that they do not have any study to qualify their urban solid waste, a worrying fact, as it is an important indicator that could provide subsidies for an adequate planning to the municipality, both in terms of the number of vehicles needed for transport as well as the qualification due to the risk of contamination of the soil and people.

The fact is that, adding the MI between 0.00 and 0.2, which configures a TERRIBLE performance in relation to this criterion, having a representativeness of 80.95% among those who do not know the type of MSW they carry. Only the municipalities of Pimenta Bueno and Nova Mamoré had a MI of 0.75 considered GOOD. The IGE was 0.14, indicating a VERY POOR performance for the state of Rondônia, considering that in the State Solid Waste Plan, the state must have a diagnosis that includes the identification of the main waste streams in the state and their socioeconomic and environmental impacts. PNRS (2010)

An analysis of the system of collection and transportation of household waste was proposed to the managers, which are basically those produced in the residence of each family. The following aspects were considered: study on the choice and types of collection vehicles, amount of equipment, optimization of collection routes and use of software, frequencies and schedules, determination of volume and weight and the scope of collection within each municipality.

Thus, in the first analysis, the municipalities of Guajará-Mirim, Jaru, and São Miguel do Guaporé, did not score, with a MI equal to 0.00, two more, such as Candeias do Jamari and Nova Brasilândia D'Oeste, presented MI of 0.11 and 0.27, respectively, giving them a VERY BAD performance classification. Another 12 had MI between 0.33 and 0.61, which indicates a performance between POOR and FAIR. The system of collection and transportation of domestic waste is considered the most basic and also necessary activity of urban solid waste management, 15 out of the 21 cities presented inadequate conditions and low performance according to the evaluations of the managers themselves, the inefficient management can lead to dissatisfaction of the consumer who pays taxes to have this service, It can be seen that they are made available to the community, but they are not managed, because for the vast majority there are no studies that serve as metrics. The highest MI were in the cities of Pimenta Bueno with 0.83, Ji-Paraná with 0.77, Ariquemes and Porto Velho with 0.72, indicating a GOOD performance. The IGE was 0.46, that is, BAD for the general panorama of the State of Rondônia.

The next analysis on solid health waste (HSW), which also has characteristics regarding its hazardousness due to the risk of contamination it can represent, they come from hospital and

laboratory activities and cannot under any circumstances be discarded as household waste, requiring an adequate container, safe handling and proper transportation. All municipalities outsource in the state of Rondônia the collection and transportation of this type of material and collect it only in their laboratories and public hospitals, they do not do it in private companies considered generators, since these are the ones that are required by Law 12.305/2010 to give the proper destination to the RSS as defined in regulation or in rules established by the Sisnama and SNVS bodies.

The system of collection of health services as explained above is not executed by the municipalities, but they are inspected and have teams to investigate complaints of inadequate disposal when they occur, which if proven are notified and fined, so most of the municipalities had their aspects analyzed with MI equal to 1.00 considered an OPTIMAL performance indicator, with the exception of São Miguel do Guaporé, which obtained 0.87. The state's IGE was 0.99, a result considered EXCELLENT for Rondônia.

Another aspect analyzed within the dimension of collection and transportation system is the collection system from civil construction, which is derived from the waste produced by constructions and renovations of both companies and individuals. This is an activity within the solid waste sector that is poorly developed and it may be possible to say that it is not considered a priority within solid waste management in the municipalities of Rondônia. It can be seen that according to the interviewees, 15 municipalities have MI from 0.00 to 0.4, denoting a performance indicator between VERY BAD and BAD, with emphasis on two municipalities, Guajará-Mirim and São Miguel do Guaporé, which did not score in any aspect, getting 0.00. The best IMs were from the city of Cacoal and Ariquemes, with 0.7 having a GOOD performance. The IGE for Rondônia was 0.4, considered to have a POOR performance for the state.

The municipalities of Guajará Mirim, Candeias do Jamari, Cacoal, Ouro Preto D'Oeste, Jaru, Buritis, Machadinho D'Oeste and São Miguel do Guaporé had MI equal to 0.00, that is, they do not have a collection and transport system, do not carry out any control and inspection action and also do not have solutions for this type of disposal to the population, others in similar conditions are the cities of Alto Paraíso, Pimenta Bueno and Vilhena, despite having scored, still have a TERRIBLE performance indicator. The best IM went to the city of Porto Velho, with 0.87, a result considered GOOD.

However, there is little management in this aspect, the incentive of both waste pickers' cooperatives as well as scrap dealers could be a benefit for both parties, since it generates income for these workers, brings a solution to the MSW sector and the population that needs to dispose of this material. In Section II Shared Responsibility PNRS Law 12.305/2012 in art. 30 "Shared responsibility for the life cycle of products is instituted, to be implemented in an individualized and chained manner, covering manufacturers, importers, distributors and traders, consumers and holders

of public urban cleaning and solid waste management services, according to the attributions and procedures provided for in this section." Still, the CONAMA No. 416/2009 provides for the prevention of environmental degradation caused by scrap tires and their environmentally appropriate disposal. The IGE of the state of Rondônia was 0.29, indicating a TERRIBLE performance.

Almost no municipality has an adequate system for collecting this type of material and only 7 of them, such as Espigão D'Oeste, Ji-Paraná, Pimenta Bueno, Rolim de Moura, Ariquemes, São Francisco, Porto Velho and Vilhena, have recycling bins. Thus, 13 cities had MI equal to 0.00, indicating VERY POOR performance in this regard, with the best result being 0.75 for Ji-Paraná and Porto Velho considered GOOD. The state's IGE was 0.29, which is considered VERY POOR.

In order to carry out the tasks related to the collection and transportation system, it is necessary that the municipal solid waste management is properly equipped with vehicles, equipment and all other resources for such activity. In the survey, only the municipalities of Guajará-Mirim, Rolim de Moura, Ariquemes, Machadinho D'Oeste and Vilhena did not score, getting 0.00 having a TERRIBLE performance, however it is important to point out that Rolim de Moura and Vilhena, do it outsourced, however, it still generates a loss not to have a place for maintenance because the vehicles can be stopped for a period, If you don't have the budget for the repair or even, you need to wait for the pricing process to solve the equipment problem. In a general context, most of them had a performance that oscillated between REGULAR and EXCELLENT. The state's IGE was 0.6, indicating a REGULAR performance for Rondônia.

It is noteworthy that almost no municipality makes use of any type of indicator, 17 having a score equal to 0.00, two others had 0.12 and 0.25, so 90.47% of the municipalities had VERY POOR performance in this aspect. It is understood that decisions are not based on the monitoring of any of the points evaluated, be it productivity, user satisfaction, number of user complaints or number of work accidents that may occur. Not knowing the scenario also reduces the possibility of assertiveness, management capacity, planning and organization of the sector. The municipality of Pimenta Bueno was the only one that declared to monitor all these aspects by means of indicators, being 1.00 or EXCELLENT performance. The state's IGE was 0.15, which represents a TERRIBLE result for Rondônia.

SCREENING AND TREATMENT SYSTEM DIMENSION

The Sorting and treatment system dimension addresses the aspects of selective collection, sorting plant, composting plant, civil construction recovery plant, health waste treatment plant, operational conditions of treatment and recovery plants, and support for waste pickers' and scrap metal cooperatives. In the first aspect of this dimension, information was collected on: whether the municipality has a selective collection system, whether it is carried out with the participation of

waste pickers and scrap dealers, whether there is collection of cooking oil, whether there is control of the amount collected and whether there is control of the number of cooperative waste pickers.

In article 18, item XIV of the PNRS/2010, the minimum content of the PMIRS is the incentive to "programs and actions for the participation of interested groups, especially cooperatives or other forms of association of collectors of reusable and recyclable materials formed by low-income individuals, if any." However, in the survey, it can be seen that few municipalities were able to organize or prioritize the selective collection system, where 13 had a MI of 0.00 to 0.13, having as an indicator a VERY POOR performance. Only the municipalities of Vilhena had an indicator of 1.00 or EXCELLENT, Pimenta Bueno, Ariquemes and São Francisco were 0.80 or GOOD for this aspect. In view of this, the IGE for Rondônia was 0.27, indicating a TERRIBLE performance for the state.

No municipality has any mechanism for sorting waste in the municipalities, leading to the conclusion that all waste is sent to its final destination, which can be landfills, ditches or dumps. Thus, their IM was 0.00, indicating a TERRIBLE performance. The best MIs were from Ouro Preto and Porto Velho with 0.62 having a REGULAR performance, both in the previous table indicated that they do not have selective collection, but they make investments in screening, another situation is that of Pimenta Bueno with MI 0.62. The state's IGE was 0.29, a TERRIBLE performance for Rondônia.

Regarding the composting plant and its aspects, only Pimenta Bueno and Alto Paraíso have this type of plant, with a MI equal to 0.37, considered a BAD performance. The remaining 19 cities had their MI equal to 0.00 or a VERY BAD performance indicator. The lack of management and the lack of solutions on the part of the MSW management can cause more problems to the municipality, since the fact is that this waste exists and if the population does not have an adequate place to dispose of it, it will possibly be thrown in places that are inappropriate for this waste. Many managers mentioned that when they are collected, they are disposed of on the dump grounds. The IGE for the state of Rondônia was 0.03, a VERY BAD result for the state.

In the aspect that deals with civil construction plants, no municipality indicated that it has any recovery system, despite the fact that it is a very common and common waste, even with an aggravating factor due not only to the diversity of materials, but also to the volume it generates. Thus, 100% of the cities had a MI of 0.00 in this aspect, indicating a VERY POOR performance, including the IGE of the state of Rondônia.

FINAL DESTINATION DIMENSION

The PNRS Law 12.305/2010 in Chapter II, which deals with the definitions related to urban solid waste, item XV says that "tailings: solid waste that, after exhausting all possibilities of treatment and recovery by available and economically viable technological processes, presents no

other possibility than environmentally appropriate final disposal". Thus, according to the law, only after exhausting the possibilities of recovering this waste, the waste must be sent to the appropriate final destination, that is, a place that allows its disposal according to the type of waste, in order to reduce the effects of its disposal on society and the environment as much as possible. In relation to final destination, 15 municipalities have MI between 0.2 and 0.4, establishing a performance condition that varies between VERY BAD and BAD for these cities. Thus, there is a recognition on the part of municipal managers that they still do not meet the minimum requirements of regulatory and inspection bodies, and some do not even have a license to dispose of the tailings in the place they use for final disposal. Only the tailings from the RSS were considered adequate by all cities. The highest DI were from the municipalities of Alto Paraíso, Alta Floresta D'Oeste, Cacoal, Pimenta Bueno, Ariquemes and Vilhena, which ranged from 0.8 to 0.6, with a performance between regular and good. The IGE for the state was 0.42 BAD result for the state, it is important to highlight the relevant role of the state government in the environmental licensing process, in addition to the predictability in the PNRS/2010 itself, in which the states in their state solid waste plan must contemplate studies, diagnoses and goals throughout their region, including the elimination of dumps as a final destination area for tailings, so that the poor performance of the municipalities reflects the poor performance of the State of Rondônia and requires the creation of better policies and guidelines.

Aspects related to technical studies on the final destination site, appropriate location, monitoring of impacts on groundwater and surface water. For municipalities that have a final disposal system in sanitary landfills and, in the case of Rondônia, the largest portion does so through outsourced companies with an operating license, these studies are part of the protocol for them to continue operating, with the exception of Porto Velho, which has a municipal landfill and passes with conduct adjustment, according to previous data already presented.

It is not up to the municipal managers of the MSW to carry out this type of analysis unless the landfill is under the management of the secretariat linked to the solid waste sector, in the latter case these studies must be carried out by the responsible municipality itself and presented to the competent inspection body that will give the operating license. However, managers can sue for the fact that in the case of outsourced landfills, they only have an operating license when they meet the criteria established by the state department of the environment. Thus, due to the fact that most of them dispose of their household waste in landfills, the MI of most cities was 1.00, indicating an OPTIMAL performance. However, seven had a MI between 0.00 and 0.25, indicating VERY POOR performance, as expected, as they still dispose of their destination in open dumps, so they do not carry out any type of monitoring on the impacts caused to the environment. The IGE for Rondônia was 0.65, which is considered REGULAR for the state.

According to Santaella (2014), the appropriate (desired) final destination, where there is: reuse; recycling; composting; recovery; energy use and disposal of waste in landfills. However, as already demonstrated in this study, 66.67% of the 21 municipalities surveyed use landfills as final destinations, another 14.29% use open dumps, 14.29% a combination of landfills and dumps, and 4.76% have ditches as a disposal resource for domestic waste.

The worst indices refer to the municipalities of Guajará-Mirim, Candeias do Jamari, Jaru, São Miguel and Porto Velho with MI ranging from 0.06 to 0.33, with a performance indicator classified as VERY POOR. The condition of Porto Velho is highlighted, which, despite having a landfill, the operating conditions are terrible and analogous to a dump, not being able to score in important aspects that impacted a very low MI. However, a considerable part or 14 municipalities had a MI of 0.93 considered an OPTIMAL performance. It is noticeable that, as much as the municipalities present serious flaws in relation to the previous dimensions, which aggravates the general condition of urban solid waste management in the state of Rondônia, the fact that part of its waste is disposed of in landfills considerably reduces the impacts on society and the environment.

Thus, 17 municipalities had MI between 0.00 and 0.25, indicating a VERY POOR performance for this aspect. The highest MI was 0.87 for Nova Brasilândia and 0.75 for Ariquemes was considered GOOD. The state's IGE was 0.16, considered VERY BAD for Rondônia. In general, among the 21 municipalities surveyed, only the conditions for the final disposal of domestic waste have a GOOD concept, so that MSW managers need to seek solutions for other types of waste with well-established actions that mobilize the population through environmental education programs in schools and neighborhoods and partner companies that lead to an improvement in the indicators of CCR and Special and Hazardous Waste.

CONCLUSION

The research was carried out in the State of Rondônia, belonging to the Western Amazon, Northern Region of Brazil. The main objective was to analyze solid waste plans and management in accordance with PNRS Law 12.305/2010. It was possible to perceive, through the theoretical contribution and recent studies, that Urban Solid Waste (MSW) is a problem that is still very far from being solved. There are many challenges related to waste, such as: sharp growth in the world population, exaggerated consumption, lack of consistent public policies and even lack of priority of public administrations for this issue. Solid waste in Brazil had its National Solid Waste Policy Law enacted only in 2010, although this thesis developed its research in 2021, the vast majority of Brazilian municipalities do not dispose of their waste in sanitary landfills, a considerable part still does so even in open dumps, currently banned in Brazil. The PNRS provided for the extinction of this type of final waste disposal by the year 2015, that is, five years after the enactment of the Law.

The State of Rondônia, in turn, presented a panorama very close to the reality of other Brazilian regions, both in the amount of garbage produced, where the national average according to the latest survey by Abelpre (2021) was 1,100 kg/day per person and for the state of Rondônia the average is close to 1kg. As well as the problems and difficulties in collecting, transporting and disposing of waste correctly.

According to the survey information more than 66% of the municipalities surveyed stated that they did not have any evaluation tool that could serve as a performance indicator for MSW, assuming that managers can hardly say whether there are advances, stagnation or even setbacks when it comes to urban solid waste management in the state of Rondônia.

Regarding the conditions of strategic management, collection and transportation, sorting and final disposal of MSW in each city studied, the first point was to survey the conditions of each municipality, established by the Municipal Indices (IM), the results were given according to the degree of commitment, level of investment, difficulties, knowledge and experience and structure available in each place. However, in summary, the condition and performance of the Strategic Management system of the State of Rondônia through its General State Index (IGE), the result of the average of the Municipal Indices (IM) was only 0.47, demonstrating a BAD performance for the state, that is, there is much to be done in terms of Strategy and conduction of management activities, which involve: Preparation of Solid Waste Plan, Plan Execution, Institutional Structure, Organizational Structure, Employee Training, Financial and Cost Management, Social Inclusion Policies and Environmental Education of each city, so that the IGE consequently increases and improves the classification at the state level, hence the need to have indicators and monitor them periodically.

For the Collection and Transportation System, the General State Index (IGE) was 0.39, a result that leads to a POOR performance for Rondônia. With the exception of the transportation of Health Waste, which predominantly in all the cities surveyed is carried out by outsourced companies, the other types of waste in the 21 municipalities surveyed, with special attention to the study of waste characterization, collection of household waste, construction waste, etc. bulky waste, hazardous waste collection (practically non-existent), hygiene and safety of workers and creation of performance indicators, for effective management in the transport collection system.

In the sorting system, the General State Index was 0.24, considered a VERY BAD condition or performance for Rondônia, a result that reflects the lack of adoption of measures that will directly impact the costs related to the Final Destination of each municipality, since the less investments directed to sorting plants, the more garbage is discarded or sent to landfills. Increasing the amount paid to landfills, worse than the high costs, are the amounts of waste sent to open dumps, in operation in many cities in the state of Rondônia, leading to an even greater environmental and social impact.

In addition, investments in sorting bring comfort and dignity to the population, who often dump their waste from tree pruning, construction debris and others on sidewalks and/or vacant lots, precisely because there are no places indicated by the municipalities for this purpose, and it is worth emphasizing that the population pays for the collection through taxes or fees. Another point to consider is that the absence or little investment in selective collection excludes workers, often self-employed, from improving their income, caused by the lack of a point of consolidation of waste, having to do it from door to door, rummaging through household garbage in search of recyclable material.

The last point of the research on Final Destination, that is, the final point for the waste produced by each municipality in Rondônia, which according to the PNRS/2010, should only be sent to the final destination, to that which has no possibility of use or reuse, called tailings. In the research it was possible to perceive that what reaches landfills, ditches or even dumps is an immense amount of garbage that could at some point have been transformed into other products, through recycling, if the process that started back then, with Strategic Management, collection and transport and sorting had been planned, organized, controlled for efficient execution, it would be sent as little as possible to landfills. The state's IGE for Final Destination is 0.27, denoting a VERY POOR condition or performance for the State of Rondônia. Therefore, when it comes to complying with the National Solid Waste Policy LAW 12.305/2010, the municipalities of Rondônia urgently need to organize themselves to comply with this law.

Regarding the hypotheses (a) The municipalities of the State of Rondônia - Western Amazon/Brazil in their Integrated Municipal Solid Waste Plans do not meet the local demands in waste management caused by the inefficient management of their plans was refuted, (b) The municipalities of the State of Rondônia - Western Amazon/Brazil in their Integrated Municipal Solid Waste Plans, meet the local demands in waste management in a partial way due to lack of technical knowledge was confirmed, (c) The Integrated Municipal Solid Waste Plans in the municipalities of the State of Rondônia - Western Amazon/Brazil, do not meet the guidelines established in the National Solid Waste Policy was confirmed and (d) The municipalities of the State of Rondônia - Western Amazon/Brazil in their majority do not have a solid waste management plan, so they do not comply with the PNRS Law 12.305/2010 was confirmed.

The main contribution of the research was to observe the critical points that need greater attention so that MSW managers can establish or prioritize the most urgent actions that can be solved with simpler activities, create or improve an Integrated Municipal Solid Waste Plan that meets the demands of society, developing and including cooperatives and associations of waste pickers, reducing environmental impacts and the health of the population, controlling or minimizing the municipality's costs with sanitary landfills and eliminating open dumps. In addition, through the



preparation of plans, cities can seek financial resources from the Union to be applied in the projects of each municipality.

REFERENCES


1. ABRELPE. Panorama dos Resíduos Sólidos no Brasil 2018/2019. [PanoramaAbrelpe]. Acesso em 15/01/2020.
2. Andrade, M. M. (1997). Como preparar trabalhos para cursos de pós-graduação: noções práticas. São Paulo: Atlas.
3. Aurélio, B. de H. F. (2020). *Míni Aurélio: O Dicionário Da Língua Portuguesa* (8ª ed.). São Paulo: Editora Maralto Edições.
4. Barroso, L. F. de L. (2013). Contribuições aos Resíduos Sólido do Estado de São Paulo. Recuperado de <www.teses.usp.br> Acesso em 05/01/2020.
5. Brasil. (2019). Constituição Federal Brasileira de 1988. (1ª ed.). Editora D.O.U. Online. (Original publicado em 25 janeiro 2019). Ebook Kindle.
6. Brasil. (2017). Lei n. 12.305, de 2 de agosto de 2010. Política Nacional de Resíduos Sólidos. (3ª ed., reimpr.). Brasília: Câmara dos Deputados, Edições Câmara. (Série legislação; n. 229 PDF).
7. Brasil. Ministério do Meio Ambiente. (2019). Contexto e principais aspectos: A problemática “resíduos sólidos”. Recuperado de <www.mma.gov.br/cidades> Acesso em 06/02/2019.
8. Filho, C. R. V. da S., & Soler, F. D. (2012). *Gestão de Resíduos Sólidos: o que diz a lei*. São Paulo: Trevisan Editora Universitária.
9. Figueiredo, A. M. B., et al. (2014). Metodologia da pesquisa. In: _____. *Pesquisa Científica e Trabalhos Acadêmicos* (2ª ed. revisada). Chapecó, SC: Uceff.
10. Gerhardt, T. E., & Silveira, D. T. (2009). *Métodos de pesquisa*. Porto Alegre: UFRGS.
11. Gil, A. C. (2009). *Como elaborar projetos de pesquisa* (5ª ed.). São Paulo: Atlas.
12. Gil, A. C. (2019). *Métodos e técnicas de pesquisa social* (7ª ed.). São Paulo: Atlas.
13. IBAM - Instituto Brasileiro de Administração Municipal. (2015). Programa Lixão Zero: estratégias, limitações e desafios. *Revista de Administração Municipal – RAM*. Texto: Zveibil, V. Z.
14. IBAM. (2001). *Manual de Gerenciamento Integrado de resíduos sólidos*. Monteiro, J. H. P., Zveibil, V. Z. (Coord.). Rio de Janeiro: IBAM.
15. IBGE. Instituto Brasileira de Geografia e Estatística. Brasil/Rondônia. Recuperado de <www.cidades.ibge.gov.br/brasil/ro/panorama>. Acesso em 05/03/2020.
16. IBGE. (2020). IBGE divulga estimativa da população dos municípios para 2020. Agência IBGE Notícias. Recuperado de <www.agenciadenoticiasibge.gov.br> Acesso em 21/10/2021.
17. IBGE. (2021). Instituto Brasileiro de Geografia e Estatísticas. *Informações Ambientais*. Recuperado de <www.ibge.gov.br> Acesso em 26/10/2021.
18. IBGE. Ministério das Cidades. Município dos Estado de Rondônia. IBGE.gov.br. 2019.

19. Kauark, F., Manhõe, F. C., & Medeiros, C. H. (2010). Metodologia da pesquisa: guia prático. Itabuna: Via Litterarum.
20. Lakatos, E. M. (2018). Metodologia do trabalho científico: projetos de pesquisa/ pesquisa bibliográfica/ teses de doutorado, dissertações e mestrado, trabalho de conclusão de curso (8ª ed.). São Paulo: Atlas. (Marconi, M. A., & Lakatos, E. M.).
21. Leite, P. R. (2002). Logística Reversa: Nova área da Logística Empresarial. Revista Tecnologista – São Paulo, Ed. Publicare.
22. Leite, P. R. (2002). Logística Reversa: a complexidade do retorno de produtos. Revista Tecnologista, São Paulo.
23. Magera, M. (2003). Os empresários do Lixo: um paradoxo da modernidade. Campinas, SP: Ed. Átomo.
24. Marchi, C. M. D. F. (2018). Gestão dos resíduos sólidos: conceitos e perspectivas de atuação. Curitiba: Appris.
25. Medeiros, J. B. (2019). Redação Científica: prática de fichamentos, resumos, resenhas (13ª ed.). São Paulo: Atlas.
26. Monteiro, J. H. P. (2006). Manual de Gestión integrada de residuos sólidos municipales em ciudades da la América Latina y el Caribe. Rio de Janeiro: IBAM.
27. MMA, Ministério do Meio Ambiente. (2012). ICLEI - Brasil Planos de gestão de resíduos sólidos: manual de orientação, apoiando a implementação da Política Nacional de Resíduos Sólidos – do Nacional ao Local. Coord. Pinto, T. de P. Brasília.
28. Neto, P. N., & Moreira, T. A. (2010). Política nacional de resíduos sólidos - reflexões a cerca do novo marco regulatório nacional. Revista Brasileira de Ciências Ambientais, 15.
29. Oliveira, S. L. de. (2002). Tratado de metodologia científica (2ª ed.). São Paulo: Pioneira Thomson Learning.
30. ONU. (2018). Programa das nações unidas para assentamentos humanos (ONU-HABITAT). Recuperado de <www.nacoesunidas.org> Acesso em 13/01/2020.
31. Santaella, S. T., et al. (2014). Resíduos Sólidos e a atual política ambiental brasileira. Fortaleza: UFC / LABOMAR / NAVE. (Coleção Habitat, v. 7)
32. SEBRAE-MS. (2012). Gestão de resíduos sólidos: uma oportunidade para o desenvolvimento municipal e para as micro e pequenas empresas. São Paulo: Instituto Envolverde: Ruschel & Associados.
33. Severino, A. J. (2016). Metodologia do Trabalho Científico (24ª ed. rev. e atual.). São Paulo: Cortez.
34. Silveira, R. M. da C., & Clementino, M. do L. M. (2017). Novas Regras, Velhos Entraves: o Desafio da Gestão dos Resíduos Sólidos nos municípios Brasileiros. In: XVII ENANPUR. Anais. São Paulo. 2017.



35. Tullio, L. (2019). Gestão de resíduos sólidos 3 [recurso eletrônico]. Organizador Leonardo Tullio. Ponta Grossa (PR): Atena Editora. (Gestão de Resíduos Sólidos; v. 3)
36. Vergara, S. C. (2010). Projetos e Relatórios de Pesquisa em Administração (12ª ed.). São Paulo: Atlas.

Respirable particles, the influence of the tropical climate and the importance of monitoring air quality in the city of Manaus-AM

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ABSTRACT

With the creation of the Manaus Free Trade Zone in 1967, the growth of the city of Manaus accelerated rapidly, increasing the consumption of materials and energy. The number of vehicles also increased, and traffic became chaotic, contributing to high emissions of greenhouse gases and particulate matter. The city does not have a public policy for monitoring atmospheric air quality, but some pioneering initiatives have been implemented by researchers at the Federal University of Amazonas (ENERAR Project/NIEMA/UFAM, 2005-2012) and more recently by the Amazonas State University (EducAIR Project). This paper analyzes inhalable particle data from the Air Quality Monitoring Station acquired under the ENERAR project developed by NIEMA/UFAM and considers the influence of the equatorial climate on emissions, analyzing the number of particles suspended in the air in relation to rainfall levels at the time of data collection. It also includes current air quality data published by the Electronic Environmental Surveillance System (SELVA) created by the Amazonas State University. The results suggest that the frequent tropical rains, which are a feature of the local climate, help to disperse the pollutants, but also underline the fact that in the dry season, when rainfall is very low and wind speed is practically non-existent, the pollutants remain in the air for much longer periods.

Keywords: Particulate material, Air quality, Monitoring, Climate change.

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INTRODUCTION

Located close to the equator (latitude 03°07'00"S, longitude 59°57'00"W), at an altitude of 67 meters above sea level and covering an area of 11,401km², Manaus has a population of 2,063,547 inhabitants (IBGE, 2022). The city's growth increased dramatically after the creation of the Manaus Free Trade Zone (ZFM) in 1967. The largest city in the north of Brazil, it was listed as the ninth largest city in the country in 2000, became the eighth largest in 2004 and is now the seventh largest, according to the latest data released by the Brazilian Institute of Geography and Statistics (Torres and Martins, 2005). As a result of this growth, there has been a corresponding increase in the consumption of goods and services and in the size of the vehicle fleet, ultimately leading to a growing demand for matter and energy (Cartaxo, et.al., 2018).

Evaluating these conditions, one can understand why the accelerated process of urbanization in the capital of Amazonas was probably one of the most damaging transformations to the city, causing potentially disastrous results in the energy balance, climate, socio-spatial distribution, and economy of the region. The growth process of the city of Manaus was guided by confidence in the "hypothetical" inexhaustibility of nature. By treating nature as an inexhaustible source of resources, independent of human relations, capital dragged society into the uncontrolled exploitation of natural wealth and unbridled consumerism which, in the end, collided with the limitation of its own resources. (Valois and Cartaxo, 2022, p. 202)

When it comes to air pollution, atmospheric particulate matter (PM) directly affects the climate by scattering and absorbing solar radiation and indirectly by acting as a condensation nucleus in cloud formation processes. As air pollutants, PM₁₀ and PM_{2.5} particles have received the most attention due to the problems they cause for human health. Considered according to their size (average aerodynamic diameter of the particles), coarse inhalable particles (PM₁₀) are those with an average aerodynamic diameter in the range of 2.5 to 10 μm and fine or respirable particles (PM_{2.5}) are those smaller than 2.5 μm . (Freitas and Solci, 2009)

And even if emission levels were maintained, air quality would vary according to the greater or lesser dilution of pollutants, which is determined by meteorological, topographical, and urban conditions. There is scientific evidence that the Amazon could be very close to breaking point. Deforestation rates accelerate a process of "savannization" of the rainforest that could become irreversible if these rates exceed 20% to 25% of the entire forested area of the Amazon basin. Currently, we have already lost 18% and a possible "savannization" of the Amazon is likely to cause new CO₂ emissions into the atmosphere and significantly alter the rainfall regime, affecting food production in South America and the country's water and energy security. (WRI Brazil, 2022, cited by Valois and Cartaxo, 2022)

In a pioneering initiative, researchers from the Federal University of Amazonas installed an



Air Quality Monitoring Station (EMQA) in the eastern region of the city, with the aim of analyzing and measuring the level of atmospheric pollutants, especially in the areas near the thermoelectric plants, where emissions from burning fossil fuels are concentrated. Mobile emissions represented by motor vehicles circulating in the urban perimeter were also investigated, as the issue of transport and air quality is paradoxical. On the one hand, the increase in the number of vehicles meets the growing demand for mobility, but on the other hand, the effects on society in terms of environmental pollution are important. Consequently, transportation represents a significant contribution to the rise in air pollution, especially in the most populous cities, emerging as the largest source of urban air pollution in the developing world. These measurements are obviously necessary to determine whether the concentration levels of pollutants are within the limits set by the World Health Organization (WHO) and/or the National Environment Council (CONAMA). (Cartaxo et.al., 2018)

This work used the data available from the Air Quality Monitoring Station⁵ to develop a preliminary estimate of air pollution in terms of inhalable particles (PM10) and to consider the contribution of fixed and mobile emission sources, as well as the influence of tropical rains, which are frequent in the Amazon region. The data was updated in relation to the new CONAMA Resolution 491/2018, noting a persistent lag when compared to the recommendations issued by the World Health Organization (WHO).

Recently, the Electronic Environmental Surveillance System developed by the University of the State of Amazonas has filled in some gaps in information about air quality in the city of Manaus, data that is published here showing the climate severity experienced by the people of Amazonas in the year 2023.

PARTICULATE MATTER

The term "particulate matter" is generally used to refer to a mixture of small solid or liquid particles of different diameters (aerodynamic diameter) suspended in the atmosphere. They have different chemical compositions and are capable of absorbing toxic substances such as SO₂, whose harmful effects are intensified in the presence of these particles. They come from different sources, both natural and anthropogenic, and when released directly into the atmosphere, they are referred to as primary particles; when they are formed in the atmosphere from chemical reactions between the primary particles and species present in the air, they are referred to as secondary particles.

The impact of particulate matter on human health and ecosystems depends on its chemical composition, size, and suspension time in the atmosphere. The larger the particle, the shorter its residence time in the atmosphere, but fine particles can be transported long distances by air currents,

⁵ Acquired by the ENERAR/NIEMA/UFAM project with funding from CNPq (2011)

with a chemical and physical impact on the atmosphere, not only locally but on a regional and global scale, due to their longer residence time (Barbosa, 2007).

Until 1989, air pollution legislation in Brazil sought to regulate only particles with a diameter greater than 10 micrometers (μm). However, it was later shown that particles with diameters of less than $10\mu\text{m}$, known as PM10, pose a greater risk to human health, as they penetrate further into the respiratory tract, hence the term "inhalable particles". The presence of these particles in the atmosphere also increases the speed of atmospheric chemical reactions, as the particles act as catalysts in the transformation of primary pollutants into secondary pollutants.

Smaller particles, with potentially even greater health risks, such as particles smaller than $2.5\mu\text{m}$ (PM_{2.5}), due to their tiny size, penetrate the respiratory system deeply, reaching the pulmonary alveoli. They are mainly produced by combustion: fires, industrial activities, motor vehicles, fuel burning and even domestic activities such as cooking. In the case of fires in the Amazon rainforest, winds can carry PM_{2.5} particles hundreds of kilometers, with consequences for human health such as cancer, respiratory and cardiovascular diseases.

In May 2018, the World Health Organization released alarming estimates: Every year, around 7 million people die on the planet because of exposure to airborne microparticulate pollutants. Recent studies carried out in 2019 by researchers at the Max Planck Institute indicate an even higher figure: 8.8 million deaths a year worldwide. In Brazil, it is estimated that 50,000 deaths a year result from air pollution (Maia, 2019, p. 12).

AIR QUALITY STANDARDS AND THE EFFECTS OF AIR POLLUTION

According to the World Health Organization (WHO), air quality standards vary depending on the approach taken to balance health risks, technical and economic feasibility, as well as political factors related to national capacity to manage air quality. In short, it's a question of choosing priorities and, in this sense, the WHO recommends that governments formulate air quality policies and adopt values as national standards considering their local circumstances.

In Brazil, air quality standards are established by CONAMA Resolution No. 491/2018, which repealed and replaced CONAMA Resolution No. 03/90. (Figure 1)

Figure 1 - Air quality index

Classificação	Concentração ($\mu\text{g}/\text{m}^3$)					
	MP ₁₀ 24h	MP _{2,5} 24h	O ₃ 8h	CO 8h	NO ₂ 1h	SO ₂ 24h
BOA	0 – 50	0 – 25	0 - 100	0 - 9	0 - 200	0 – 20
MODERADA	>50 – 100	>25 – 50	>100 - 130	>9 – 11	>200 – 240	>20 – 40
RUIM	>100 – 150	>50 – 75	>130 – 160	>11 – 13	>240 – 320	>40 – 365
MUITO RUIM	>150 – 250	>75 – 125	>160 – 200	>13 – 15	>320 – 1130	>365 – 800
PÉSSIMA	>250 - 600	>125 - 300	>200 - 800	>15 - 50	>1130 - 3750	>800 - 2620

Source - IEMA, 2023

Recent studies have shown that even at concentrations considered "safe" by current legislation, the effects on the health of individuals can be serious, demonstrating that the recommended air quality standards are still inadequate, especially for vulnerable populations (Steffens and Steffens, 2013).

The new legislation, therefore, despite the advances, is still far from meeting the WHO recommendations, which can be seen in Table 1, which shows the WHO standards and the current CONAMA standards in the first stage of its implementation:

Table 1: WHO standards and CONAMA No. 491/2018 standards

Poluentes	Tempo de amostragem	OMS 2005 ($\mu\text{g}/\text{m}^3$)	Resolução CONAMA nº 491/2018
Partículas inaláveis (PM10)	24 horas	50	120
	Média anual	20	40
Partículas respiráveis (PM2,5)	24 horas	25	60
	Média anual	10	20
Ozônio	8 horas	100	140

Source: Adapted from Breder et. al (2020)

For Felini and De Simoni (2021), air pollution is a silent epidemic that kills 51,000 Brazilians every year and for which the vaccine would be public policies if well implemented. Despite this destructive potential, only 1.7% of Brazilian cities monitor air quality, meaning that most Brazilians, and here we can include the people of Amazonas, have no information about the quality of the air they breathe and, consequently, face an unknown enemy.

And even considering these 1.7% of municipalities where air monitoring is carried out, it can be seen from the data in Table 1 that Brazil does not monitor the air in an acceptable way, because the standards established in Brazilian legislation are more permissible than those recommended by the WHO and there are no penalties for non-compliance. (Felini and De Simoni, 2021)

The study, carried out by 14 experts and coordinated by WRI Brasil, comprehensively synthesized knowledge about air quality in the country and denounced the negligence of Brazilian



environmental policies. "The State of Air Quality in Brazil", as the research was called, reveals, above all, how the impacts of air pollution reach other sectors besides the environment and health, as they also affect the economy, agriculture, climate change and others. In the developing world, this is a reality that exposes inequality, as it affects the most vulnerable populations more intensely. Apparently, everyone is subjected to the same atmospheric air, but for some (the sick, children, the elderly and the poor) the effect of pollution is greater (Felin and De Simoni, 2021; Valois and Cartaxo, 2022).

According to the Pan American Health Organization (OPAS, 2019) air pollution and household air pollution (from cooking) "cause more than 50% of acute lower respiratory tract infections in children under 5 in low- and middle-income countries". (Figure 2)

Figure 2: Mortality rate per 100,000 children attributable to the joint effects of air and household pollution in 2016 - by WHO region and income level

	Nível de Renda	Crianças <5 anos	Crianças de 5-14 anos
África	PBMRs*	184,1	12,9
	PRAs**	4,3	1,4
Américas	PBMRs	14,2	0,7
	PRAs	0,3	0,0
Sudeste Asiático	PBMRs	75,0	2,5
Europa	PBMRs	8,8	0,6
	PRAs	0,3	0,0
Mediterrâneo Oriental	PBMRs	98,6	3,6
Pacífico Ocidental	PRAs	5,3	0,4
	PBMRs	20,5	1,0
Todas	PRAs	0,3	0,0
	PBMRs	88,7	4,5
	PRAs	0,6	0,1

*PBMRs: low- and middle-income countries; **PRAs: high-income countries.

Source: OPAS, 2019, p.16, cited by Raposo, et.al., 2021

In the Amazon region, the impacts go beyond urban centers, as the frequent wildfires and forest fires generate pollutants whose levels of particulate matter reach 500 micrograms per cubic meter of PM10, around 25 times more pollution than the historical average for the region (20 micrograms per cubic meter). "With increased exposure to pollution, there has been an increase in the number of preventable deaths from non-communicable diseases in Brazil, especially in urban regions and in states with a high number of fires". (Raposo, et. al., 2021)

These particles move along with the air currents in the Amazon, carrying humidity to the Midwest, South and Southeast (the flying rivers). They also carry pollution to other regions of the country, affecting the climate and air quality.

THE INFLUENCE OF WEATHER CONDITIONS

It is known that the dispersion rate of particulate matter is a function of both topography and meteorological conditions. (Lyra et.al., 2011) When relative humidity is high enough, inorganic aerosols dissolve, while in conditions of low humidity, they form salts in the solid state and



sometimes in the hydrated form. These conditions (topographical and meteorological) are indicators that combine unfavorable climatic and geographical conditions with relatively still air, constituting one of the greatest threats of air pollution to public health and national economies (Seinfeld, 2004).

When the gases released by chimneys and vehicle discharges enter the atmosphere, external conditions such as wind speed, wind direction, amount of precipitation, precipitation rate, air instability, temperature, atmospheric pressure and many others begin to affect them, favoring not only the accumulation of pollutants in the atmosphere, but also the formation of secondary compounds. All these meteorological factors, which vary in time and space, combined with topographical factors, directly affect the dispersion and transportation of pollutants. In addition, the earth's atmosphere is in constant movement, mainly because of sunlight passing through, which generates a non-uniform thermal balance. Meteorological parameters therefore vary considerably with location, height, and time (STERN et al. 1984).

Monitoring data and studying as many variables and their effects as possible is important for understanding potential environmental impacts on a local, regional, and global scale (Guerra and Miranda, 2011; Kay, et al, 2007).

Therefore, when examining the problems of air pollution in Manaus, meteorological conditions such as precipitation, temperature, humidity, and sunshine is clearly important. The city of Manaus is hot all year round, and the high temperatures and strong sunshine present are therefore likely to favor the photochemical reactions that lead to the formation of secondary particles. The topography, buildings, type and use of the land and the scarcity or abundance of plant species are also characteristics that can determine the course of pollutants released into the atmosphere, as they modify the microclimate and contribute to the formation of "heat islands" (Guerra and Miranda, 2011). Precipitation also interferes with the speed with which particles are removed from the atmosphere, as it promotes the removal of pollutants, since a significant part of the pollutants is incorporated into the rainwater (Barbosa, 2007; Kay, et al., 2007).

Just as meteorological variables can determine the degree to which pollutants are dispersed, the opposite can also occur, i.e., meteorological conditions can be affected by the presence of pollutants in the atmosphere over prolonged periods. For example, the number of particles in the urban atmosphere is directly proportional to the increase in fossil fuel consumption. This, in turn, can reduce insolation due to the increased concentration of condensation nuclei, can intensify precipitation and, consequently, can induce the formation of photochemical smog. In addition, and more generally, since polluting particles cause and accelerate chemical reactions, the presence of particles in the air aggravates the impacts of other greenhouse gases.

Some of the conditions for the formation of photochemical smog are clearly present in Manaus, especially in the hottest and driest months of August and September. Manaus reaches



temperatures of 40°C in these months, and the high level of sunlight provides the energy needed for photochemical reactions. The limited movement of air masses also limits the dispersion of pollutants (INMET, 2011).

In addition to the critical conditions of high temperatures and light, and the limited movement of the air mass, Manaus also has intense vehicle traffic. Traffic and traffic jams on the busiest roads are constant every day throughout the year and the weather conditions facilitate the evaporation of hydrocarbons and photochemical reactions. During the rainy months of the year, although much higher levels of precipitation reduce the risk of smog, the likelihood of "acid rain" forming increases.

THE WEAKNESSES OF ENVIRONMENTAL LEGISLATION

Given the situation described above, it is not possible to think about improving air quality without defining a solid legal framework that can be aligned with the technologies available on the world market and adapted to the national reality. The fact is that Brazil has a series of environmental laws and regulations that set standards for air pollution control, but most of these regulations are infralegal and therefore do not have the power to generate rights or impose obligations. This has led to major weaknesses in air quality management policy.

The parameters regulated by environmental legislation (CONAMA No. 491/18) are as follows: Total Suspended Particles (TSP); Inhalable Particles (PM₁₀); Respirable Particles (PM_{2.5}); Smoke; Sulphur Dioxide (SO₂); Carbon Monoxide (CO); Ozone (O₃); Nitrogen Dioxide (NO₂) and Lead. Compared to CONAMA Resolution No. 03/90, there has been an advance in relation to the permitted limits, in addition to the fact that Respirable Particles were not regulated in the previous legislation.

The new air quality standards are divided into two categories:

- I - Intermediate air quality standards - PI: standards established as temporary values to be met in stages; and
- II - Final air quality standard - PF: guide values defined by the World Health Organization - WHO in 2005.

These parameters must be adopted in 4 stages: PI-1, PI-2, PI-3 and PF. Figure 3 compares the previous standards defined in CONAMA Resolution 03/90 with those of CONAMA Resolution 491/18 in force, with regard to particulate matter, PM₁₀ and PM_{2.5}:

Figure 3: Air quality standards (PM₁₀ and PM_{2.5})

RES. 03/1990				RES. 491/2018					
POLUENTE	PERÍODO	µg/m ³	ppm	POLUENTE	PERÍODO	PI-1	PI-2	PI-3	PF
						µg/m ³	µg/m ³	µg/m ³	µg/m ³
MP10	24 h	150	—	MP10	24 h	120	100	75	50
	Anual ¹	50	—		Anual ¹	40	35	30	20
MP 2.5	24 h	—	—	MP 2.5	24 h	60	50	37	25
	Anual ¹	—	—		Anual ¹	20	17	15	10

Source: Ferreira (SISEMA, 2019)

The first stage of the new legislation came into force with the publication of CONAMA Resolution 491/18 and comprises Intermediate Air Quality Standards PI-1. The Intermediate and Final Air Quality Standards (PI-2, PI-3 and PF) will each be adopted subsequently, taking into account the Atmospheric Emissions Control Plans and Air Quality Assessment Reports drawn up by the state and district environmental agencies.

It can be seen from figure 3 above that CONAMA Resolution 491/2018 aims to achieve the parameters recommended by the WHO in the final standard (FP) but does not set a precise deadline for the entry into force of the subsequent intermediate stages or the final stage. Under these conditions, instead of helping to achieve more restrictive limits, the legislation encourages inertia in any attempt to reach these limits. "After all, the reason for the existence of intermediate standards is that they effectively function as temporary objectives, leading in a staggered manner to the achievement of final standards." (Raposo et. al., 2021)

According to CONAMA Resolution No. 491/18, state and district environmental agencies must draw up an Atmospheric Emissions Control Plan within 3 years (from the publication of the Resolution) (Art. 2, item VI) defined in their own regulations, and every 3 years present a report on monitoring the plan, indicating any need for reassessment, ensuring that it is publicized. The plan must be submitted to the Ministry of the Environment in the first quarter of the fifth year following the publication of CONAMA Resolution 491/18 and must include a scope, identification of sources of atmospheric emissions, guidelines and actions with respective objectives, targets, and implementation deadlines, aimed at controlling air pollution in the state or district territory, observing the strategies established in the National Air Quality Control Program - PRONAR.

Despite the above determinations, the evolution of intermediate standards may stagnate in the first stage, since according to paragraph 4 of the Resolution, "if migration to the later standard is not possible, the standard already adopted shall prevail". (CONAMA 491/2018)

MATERIAL AND METHODS

This article compares the results, published in 2012 in Manaus by the ENERAR project, with the new legislation in force in Brazil on air quality standards (Resolution 491 of November 19, 2018)

and with WHO recommendations. Given that Brazilian limits are more liberal, it is clearly prudent to relate the results to WHO standards, since, according to the WHO's own assessment of diseases due to air pollution, avoiding pollution means avoiding millions of premature deaths attributed annually to the effects of air pollution (WHO, 2005).

A monitoring station was installed in the eastern part of the city, at a site located 1.72 km from the Mauá thermal power plant, 2.72 km from the Breitener thermal power plant (UTE Breitener Tambaqui) and 2.84 km from the Manaus Refinery (REMAM), which between them are considered the city's main fixed sources of pollution (Figure 4).

Figure 4 - Location of the Monitoring Station in relation to fixed emission sources.



Source - Valois, 2012

Emissions from sources other than thermoelectric plants and cars were clearly incorporated into the samples, although together they were not considered to have a major impact on the selected area, especially since there are no significant potential sources, such as waste incineration, laundries, bakeries, and motels (known as non-industrial pollution sources (Cavalcanti, 2010).

The station used was a fully automated station that simultaneously collects and analyzes pollutants using spectroscopic methods. The use of this method is justified because it is reliable and sensitive for monitoring trace components, a requirement imposed by the growing concern for environmental quality, without, however, dispensing with knowledge about the components of the air and their chemical and physical behavior in the atmosphere.

To study the concentrations of particulate matter (Total Suspended Particles and PM10) and analyze air quality standards during the research period, a Continuous Environmental Particle Monitor (FH 62 C14 Series) manufactured by Thermo Fisher Scientific was used. This monitor uses continuous and simultaneous particle collection associated with beta ray attenuation, the radiation source being Carbon-14 due to its long half-life. As the name suggests, it works on a continuous cycle, generating pollutant concentration data every 30 minutes.

The results were stored, and the data was then used to calculate hourly averages of pollutant concentrations. Some measures were adopted to avoid errors that could compromise the interpretation of the results. These were based on the same measures used by the São Paulo State

Environmental Company (CETESB), as follows:

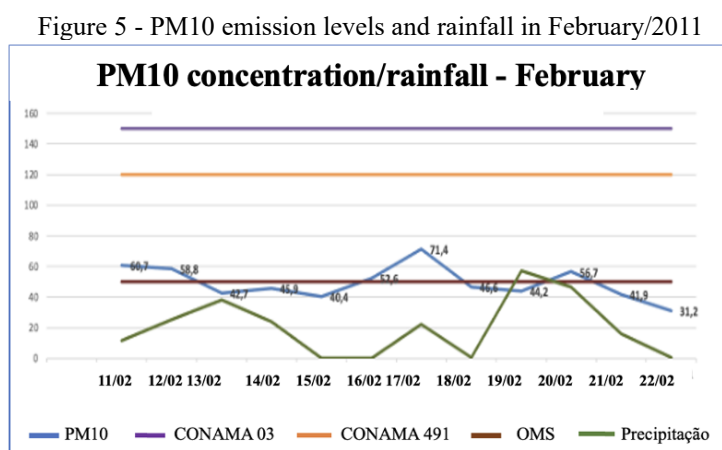
- For the hourly average, 75% of the valid hourly measurements were used.
- For the daily average, 66% (2/3) of the valid daily measurements were used.
- For the monthly average, 66% of valid monthly measurements were used.

The data was collected from February to September 2011 and compared with meteorological data for the same period provided by the National Meteorological Institute (INMET). The wettest months were examined to consider the influence of tropical rains and, at the same time, facilitate comparison with the months of the dry season, which may be associated with a greater risk to public health.

RESULTS OF THE ENERAR PROJECT

The activities of the ENERAR project (NIEMA/UFAM) began on February 11, 2011. It can be seen (Figure 5) how permissible the CONAMA standards (n° 03/90 and n° 491/2018) are, discouraging air quality control and even encouraging polluting anthropogenic activities.

The values found for the daily concentrations of the pollutant PM10, released into the atmosphere during the month of February, did not exceed the standards then established by CONAMA n° 03/90 (150 $\mu\text{g}/\text{m}^3$), nor the new CONAMA n° 491/2018 standards in the initial stage (120 $\mu\text{g}/\text{m}^3$), but were above the standards recommended by the WHO on some days of the month. It is important to note, based on Figure 5, that the days with the heaviest rainfall corresponded to the lowest concentrations of the pollutant.

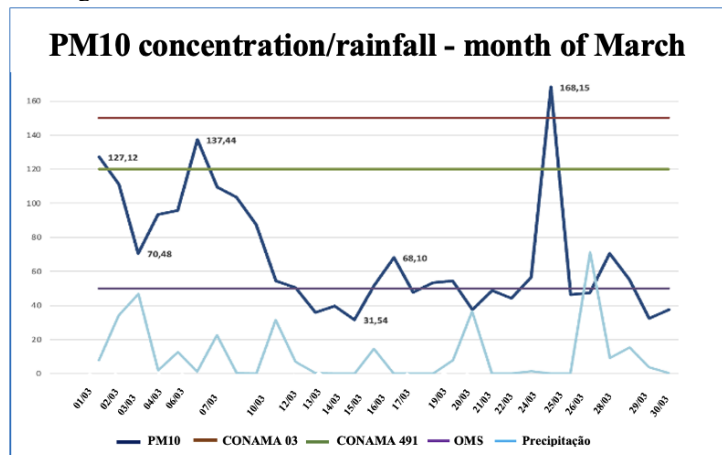


Source - Adapted from ENERAR Project Report, 2011

Rainfall is a very important parameter, as low concentrations of particles in the rainy season mean that they have been expelled from the atmosphere by rainwater. In this case, rain reduces the presence of the pollutant in the atmosphere by depositing it on the surface of the earth and transferring the pollution problem from one ecosystem to another.

Throughout the collection period, there were days of high rainfall and zero rainfall, even during the months of the "rainy season". The months with the highest concentrations of the pollutant in the air were February and March. We can observe the Figure 6 that shows March followed the same pattern as February: daily concentrations of the pollutant PM10 exceeded CONAMA standards (03/90 and 491/2018) on only 3 days. They were, however, above the WHO recommended standards on several days in March. In addition, as in February, on rainy days, the atmosphere cleared.

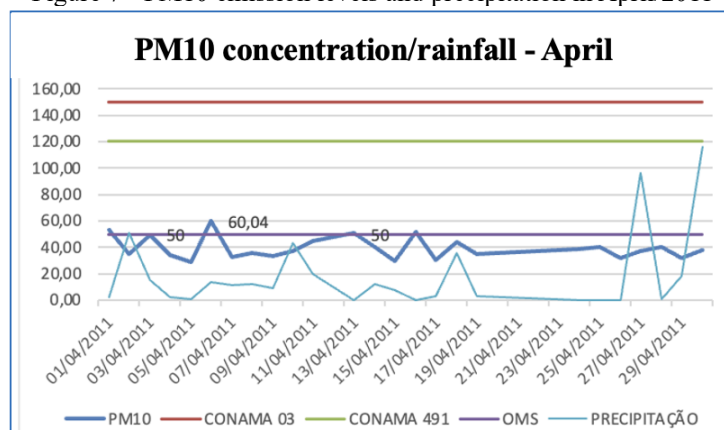
Figure 6 - PM10 emission levels and rainfall in March/2011



Source - Adapted from ENERAR Project Report, 2011

Figures 7 and 8 show the day-by-day behavior of PM10 emissions in April and May. April, which was particularly rainy, showed PM10 concentrations in the atmosphere below the standards regulated by the WHO.

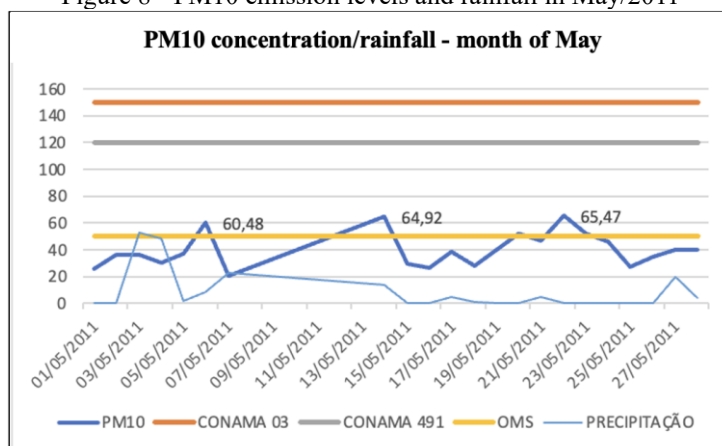
Figure 7 - PM10 emission levels and precipitation in April/2011



Source - Adapted from ENERAR Project Report, 2011

The same behavior was observed in May (Figure 8). The standards recommended by the World Health Organization were exceeded in just three days.

Figure 8 - PM10 emission levels and rainfall in May/2011

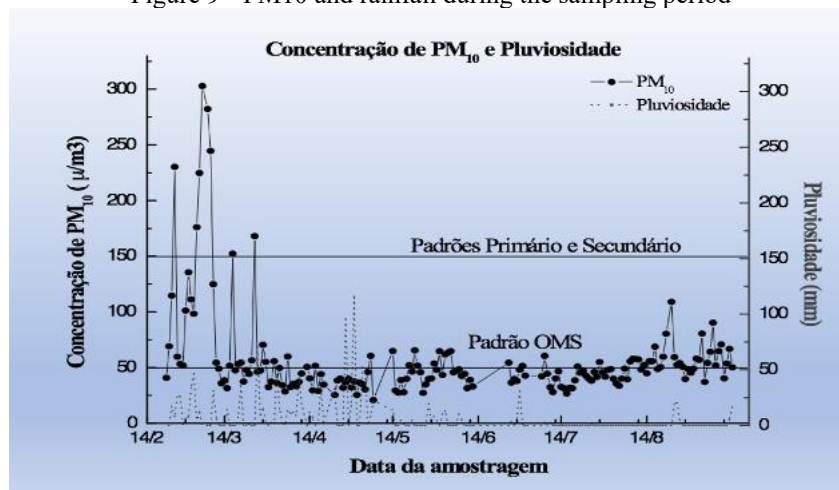


Source - Adapted from ENERAR Project Report, 2011

Although there are only two seasons, one dry and the other rainy, rainfall is not uniform either spatially or seasonally, and there is variability in the volume of rainfall from one year to the next, or even different intensities in the duration of rainfall in these seasons.

To analyze the contribution of tropical rainfall throughout the sampling period, figure 9 lists the variation in PM10 concentration, the standards regulated at the time by CONAMA (RE-03/90), and the standards recommended by the World Health Organization (WHO)

Figure 9 - PM10 and rainfall during the sampling period



Source: ENERAR, 2012

The months of February and March had the highest pollutant concentration peaks and rainfall was less intense. The wettest month was April and, proving our hypothesis, it was also the month with the lowest emissions of PM10 particulate matter into the atmosphere.

The number of times the limits of each standard (CONAMA 03 and WHO) were exceeded is shown in Table 3 and serves to illustrate the significant divergence of the respective air quality standards.

TABLE 3: Number of days when limits were exceeded.

Poluente	n	Número de ultrapassagem dos limites	
		CONAMA	OMS
PM10	181	8	30

Source: Adapted from ENERAR Project, 2011

The ENERAR project ended its activities in 2012 and since then the city of Manaus no longer has any parameters for assessing atmospheric air quality. The city has continued to grow, and its population has increased. In 2010 the population was 1,802,014 inhabitants and today, in 2023, according to the Census (2022) the number has reached 2,063,547 inhabitants.

AMAZON 12 YEARS LATER

In addition to emissions from vehicles and thermoelectric power stations, the pattern of land use in the Amazon region is also responsible for climate change. Deforestation and fires emit aerosol particles and alter the rainfall regime, prolonging the dry season, a phenomenon that is repeated year after year in Brazil, especially in the Amazon biome. In particular, 2023 was a very difficult year for the people of the Amazon, with deforestation and fires reinforced by the El Niño phenomenon and interfering with rainfall dynamics. As a result, air quality in the largest city in the state of Amazonas, Manaus, reached alarming levels.

As mentioned above, Manaus still has no air quality monitoring station equipped with automatic analyzers capable of reliably providing the concentration levels of all the pollutants regulated by CONAMA Resolution 491. The advantage of monitoring stations is that they allow a more interactive study of pollutant levels with meteorological conditions and anthropogenic activities (deforestation and fires) and in this sense, the ENERAR and QUAREMA projects, funded by CNPq, were the last experiments carried out with this profile in the city of Manaus.

Attempts to fill these gaps and send information on the state of the city's atmospheric air have been made by the State University of Amazonas (UEA) which, through the Educ-AIR project, has created an electronic environmental surveillance system (SELVA), based on low-cost air quality sensors, data from environmental satellites and estimates from numerical air quality models. The system sends real-time information on PM2.5 levels and the occurrence of fires (Ferreira, 2023).

According to the World Air Quality Index, a database that monitors air quality at a global level, considering only PM10 and PM2.5 particles, the capital of Amazonas is considered one of the worst places in the world to breathe today. "The current concentration of PM2.5 in Manaus is 2.7 times higher than the limit recommended by the WHO for 24-hour air quality." (AQI, October 4th, 2023)

Figure 10 provides information on air quality in the city of Manaus during the period from October 13 to November 13, 2023.

Figure 10: Air quality in Manaus/Am. PM2.5 levels



Source: Adapted from <https://www.aqi.in/dashboard/brazil/amazonas/manaus>

We can see that November 4 was the most critical day, as the air quality in the city reached the worst levels according to the website "AQI.in".

Only 10 Brazilian states and the Federal District monitor atmospheric air using automatic analyzers. According to Vormittag et. al. (2021), there are 371 active stations, 80% of which are in the southeast of the country and 41.2% of the national stations are private. Particulate matter PM10 is the most monitored pollutant in 62.8% of the stations and PM2.5 in only 25.9% of them. And only in 5 states are real-time monitoring data communicated to the population, making it impossible to know about air quality and hindering defensive actions in relation to exposure to pollutants.

Despite being created in 1989, the National Air Quality Network is still not complete and, where it exists, it is not sufficiently implemented, making it impossible for environmental agencies to properly manage air quality. "There is, therefore, damage to: i) the diagnosis of air pollution; ii) information about it to Brazilian society and iii) the proper protection of health - which constitute violations of fundamental rights to health and the environment." (Vormittag, 2021, p. 17)

DISCUSSION

The abundance of rain is a distinctive feature of the hot and humid equatorial climate. In the Amazon there are only two seasons: summer with rain and summer without rain. However, rainfall in the wet season is not uniform and varies in terms of quantity and intensity. Stillness and intense sunshine are also characteristic conditions of the Amazon dry season. These conditions are most

extreme in the months of August and September but can occur on any day of any month of the year, with heavy rainfall followed by intense sunshine being common for distinct and prolonged periods (Valois, 2012).

The year 2011 was particularly wet, with the highest rainfall occurring in the months of February to May. April was the wettest month with 515.90 mm of rain, significantly above the climatological average of 396 mm (INMET, 2011). The fact that this month provided the lowest readings for PM₁₀ (Figure 4) suggests that abundant rainfall tends to dilute the pollutants, transferring them to another ecosystem and leaving a purified atmosphere. However, even with the effects of abundant rainfall throughout the wettest period, the limits recommended by the WHO for inhalable particles were exceeded on 16.57% of days in the first 4 months and, if we consider the whole period, this percentage rises to 40.6%.

It was also possible to observe that the limits of the CONAMA legislation are much less strict than the WHO limits, producing results that can mask reality and lead to questionable, if not dangerous, conclusions. The results, when compared with the particulate limit suggested by the WHO of 50 μ g/m³, indicate the need for special attention on the part of the environmental authorities and suggest the need to improve air quality monitoring and control. Compared to Resolution 491/2018, the contrasts are greater if we consider the uncertainties related to the timeframes in which the intermediate air quality standards will come into force.

More than a decade after the monitoring carried out by the ENERAR project, the Amazon is facing the worst drought in its history. The results have been exacerbated by the El Niño phenomenon and by forest fires and burn-offs. The SELVA (Electronic Environmental Surveillance System) program, created by the Educ-AIR project at the State University of Amazonas, has helped to show that the current levels of particulate matter concentration in Manaus reached alarming limits during the drought period in 2023 (4.5 times higher than the limit recommended by the World Health Organization for air quality in 24 hours).

As well as reliable information, the population needs to be equipped with safe and efficient legislation to deal with drastic climate change. This is now a global concern, as air pollution is set to become one of the most alarming issues for humanity's survival.

Finally, it is clearly necessary for any national environmental legislation to be effectively enforced throughout the country and, in Brazil, this certainly includes the Amazon region: Manaus, although it may be surrounded by the largest tropical rainforest on the planet, is by no means free from the effects of pollution. The year 2023 is proving that.

CONCLUSIONS

The atmosphere of the city of Manaus has been a neglected subject, partly due to its

privileged location in the middle of a tropical rainforest abundant in animal and plant species. Hence the concept of a limitless surrounding forest ecosystem, which for a long time contributed to the idea of endless natural resources. To corroborate this concept, the city of Manaus has not previously been included among the most polluted cities on the planet. The significant levels of daily rainfall seemed to work in such a way as to prevent the accumulation of air pollution over long periods. However, these rains, although abundant, do not fall evenly and, during the dry season, are much less frequent and intense.

Air quality was monitored throughout 2011 by researchers from the Federal University of Amazonas, linked to the Interdisciplinary Center for Energy, Environment and Water (NIEMA). At the time this data was collected, air quality limits in Brazil were established by CONAMA No. 03/90. In 2005, the World Health Organization published a study (Air Quality Guides) recommending stricter concentration limits for atmospheric pollutants. According to this study, the suggested limits would imply a "lower risk to health" and should therefore guide the development of national air quality standards. However, despite the urgency of an immediate review of the standard then in force in the country, it was only changed in 2018, when new standards were set.

The new reference standard for monitoring air quality, CONAMA Resolution 491/18, still has limits that are not in line with the parameters of the World Health Organization and is the subject of criticism from various experts. One major criticism, which we consider to be the most important, is the lack of a deadline. As we have seen, the air quality standards are to be achieved in 4 stages, with the first stage coming into force immediately after the publication of the Resolution. As for the intermediate and final air quality standards, the regulation states that they should be adopted subsequently "taking into account the Atmospheric Emissions Control Plans and the Air Quality Assessment Reports drawn up by the state and district environmental agencies. It has been established, however, that if migration to the subsequent standard is not possible, the standard already adopted prevails. Under these conditions, cities that do not monitor air quality are also not obliged to draw up control plans or evaluation reports.

This study analyzed the relationship between concentrations of inhalable particles in the atmosphere of the city of Manaus and levels of rainfall. The data obtained in 2011 showed the influence of rainfall on air quality as it promotes the dilution of pollutants. On the other hand, periodic droughts have the opposite effect.

The year 2023 proved how much the historic drought in the region, aided by fires and the El Niño phenomenon, affected the climate and the quality of life of the Amazonian population, registering high levels of pollutants per cubic meter in the atmosphere. However, it is not only rainfall that influences atmospheric conditions: the movement of air masses, high humidity and high temperatures can also act to disperse pollutants.




Wind speed and direction directly affect the concentration, dispersion and trajectory of pollutants at or from the source, and all these factors must be taken into account in any analysis. This is why we insist on the importance of monitoring air quality in correlation with meteorological parameters in the city of Manaus.

REFERENCES

1. AQI, World Air Quality Index. Histórico da qualidade do ar em Manaus. [Link](<https://www.aqi.in/dashboard/brazil/amazonas/manaus>), 2023.
2. Barbosa, A.M. (2007). Caracterização Elementar Sazonal do PM10 e a Influência das Condições Meteorológicas em Cuiabá-MT. Universidade Federal do Mato Grosso. Programa de Pós-Graduação em Física e Meio ambiente (Tese de Mestrado), 104f.
3. Breder, L.A., et al. (2020). A EVOLUÇÃO DO MONITORAMENTO DA QUALIDADE DO AR E DESAFIOS PARA ATENDIMENTO DOS PADRÕES DA ORGANIZAÇÃO MUNDIAL DE SAÚDE (OMS). *Revista Tecnológica da Universidade Santa Úrsula, 3*(1), 128-146.
4. Cartaxo, E., Valois, I.M., Miranda, V., & Costa, M. (2018). Issuances of automotive vehicles and the impacts on air quality in the largest city in the Brazilian Amazon. *Sustainability, 10*(11), 4091.
5. Cavalcanti, P.M.P.S. (2010). Modelo de Gestão da Qualidade do Ar: Abordagem Preventiva e Corretiva. Universidade Federal do Rio de Janeiro, Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa de Engenharia - COPPE. Tese de Doutorado.
6. Felin, B., & De Simoni, W. (2021). Estudo revela estado da qualidade do ar e mostra como o tema é negligenciado no Brasil. WRI BRASIL. [Link](<https://www.wribrasil.org.br/noticias/estudo-revela-estado-da-qualidade-do-ar-e-mostra-como-o-tema-e-negligenciado-no-brasil>)
7. Ferreira, E. (2023). Pesquisadores da UEA criam sistema para medir a qualidade do ar que respiramos. *Jornal do Comércio*. [Link](<https://www.jcam.com.br/noticias/pesquisadores-da-uea-criam-sistema-para-medir-a-qualidade-do-ar-que-respiramos/>)
8. Freitas, A.M., & Solci, M.C. (2009). Caracterização do MP10 e MP2, 5 e distribuição por tamanho de cloreto, nitrato e sulfato em atmosfera urbana e rural de Londrina. *Química Nova, 32*, 1750-1754.
9. Guerra, F.P., & Miranda, R.M. (2011). Influência da Meteorologia na Concentração do Poluente Atmosférico PM2,5 na RMRJ e na RMSP. *II Congresso Brasileiro de Gestão Ambiental*.
10. IBGE, Cidades. (2022). Manaus. População. Censo 2022. [Link](<https://cidades.ibge.gov.br/brasil/am/manaus/panorama>)
11. IEMA. Instituto do Meio Ambiente e Recursos Hídricos. Índice da qualidade do ar. [Link](<https://iema.es.gov.br/qualidadedoar/indicequalidadedoar>)
12. INMET, Instituto Nacional de Meteorologia. Ministério de Agricultura, Pecuária e Abastecimento. Estações Convencionais, Gráficos. [Link](<http://www.inmet.gov.br/html/observacoes.php>)
13. Kay, Z., Tianxue, W., Yousef, M., & Frank, M. (2007). Properties of Nitrate, Sulfate and Ammonium in Typical Polluted Atmospheric Aerosols (PM10) in Beijing. *Atmospheric Research, 84*, 67-77.
14. Lyra, G.B., Oda-Souza, M., & Viola, D.N. (2011). Modelos lineares aplicados à estimativa da concentração do material particulado (PM10) na cidade do Rio de Janeiro, RJ. *Revista Brasileira de Meteorologia, 26*(3), 392-400.

15. Maia, L.M. (2019). Ministério Público Federal. Procuradoria Geral da República. Ação Direta de Inconstitucionalidade, N.º 287/2019 – SFConst/PGR Sistema Único n.º 149.483/2019. [Link](<https://criancaenatureza.org.br/wp-content/uploads/2021/Peticao-Inicial-ADI-6148.pdf>)
16. OMS. Organización Mundial de la Saúde. (2005). Guias de Calidad del aire de la OMS relativas al material particulado, el ozono, el dióxido de nitrogeno, y el dióxido de azufre. Resumen de evaluación de los riesgos. Atualización mundial.
17. OPAS. Organização Pan-Americana da Saúde. (2019). POLUIÇÃO DO AR E SAÚDE INFANTIL: prescreve do ar puro. Resumo. Brasília: Organização Pan-Americana da Saúde. Licença: CC BY-NC-SA 3.0 IGO.
18. Raposo, A., de Assis, W.L., & Norton, S.R. (2021). Revisão bibliográfica dos efeitos da poluição do ar sobre a saúde humana e uma breve análise crítica da atual legislação brasileira sobre os padrões de qualidade do ar (CONAMA 491/2018). *Cadernos do Leste, 21*(21).
19. São Paulo. (2002). Caracterização das Estações da Rede Automática de Monitoramento da Qualidade do Ar na RMSP. Estação São Caetano do Sul. Diretoria de Recursos Hídricos e Engenharia Ambiental. Departamento de Qualidade Ambiental. Divisão de Qualidade do Ar. Fevereiro, 2002.
20. Seinfeld, J.H. (2004). Air Pollution: A Half Century of Progress. *American Institute of Chemical Engineers Journal, 50*(6), 1096-1108.
21. Steffens, J., & Steffens, C. (2013). A Poluição Atmosférica e a qualidade de vida da população. *Unoesc & Ciência - ACET, 4*(1), 85-96.
22. Stern, N. (2010). O Caminho para um Mundo Sustentável. Rio de Janeiro: Elsevier.
23. Torres, F.T.P., & Martins, L.A.A. (2005). Caminhos de Geografia, 16–23p.
24. Valois, I.M., Cartaxo, E., & Char, J. (2012). A mudança na matriz energética e o potencial impacto dos NOx na atmosfera urbana da cidade de Manaus. *T&C Amazônia, 22*, 36-40.
25. Valois, I.M. (2012). Estudo das concentrações de óxidos de nitrogênio em área urbana do município de Manaus por analisadores automáticos. Programa de Pós-Graduação em Química da Universidade do Amazonas. Tese de Doutorado.
26. Valois, I.M., & Cartaxo, E.F. (2022). Amazon cities and climate change. *International Journal for Innovation Education and Research, 10*(11), 189.
27. Vormittag, E. da M., et al. (2021). Análise do monitoramento da qualidade do ar no Brasil. *Estudos Avançados, 35*, 7-30.

Thermal performance of liquid metal phase heat exchanger used in hydrogen production by thermal efficiency method

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ABSTRACT

The main objective of the work is to apply the thermal efficiency method to analyze the heat exchange process in a heat exchanger used in a nuclear power plant to produce hydrogen. The fluids that exchange heat are superheated Helium and the liquid metal Sodium, the first used as the primary refrigerant and the second as the secondary heat exchanger refrigerant. The presented solution is restricted to the heat exchange and considers the two-phase heat exchange process as a nucleated boiling heat exchange for Sodium. The quantities determined for global heat transfer process analysis are thermal efficiencies, thermal effectiveness, heat transfer rates, and fluid exit temperatures in the three heat exchange regions by the liquid metal Sodium: subcooled fluid, saturated steam, and superheated steam. The theoretical analysis is a powerful tool that makes it possible to analyze situations under different operating conditions, which are not permissible through experimental means due to the high cost involved. The results are compared with the literature, and the absolute deviation for the quantities under analysis does not exceed 13%. The use of the equation developed by Rhosenow in 1963 for nucleated boiling heat exchange proved consistent in the simulation presented.

Keywords: Liquid metal, Heat exchanger, Produce of hydrogen, Nuclear power plant, Thermal efficiency.

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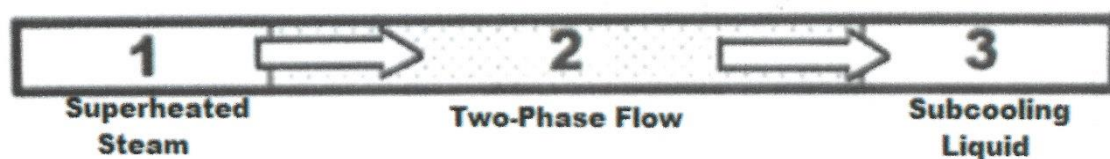
INTRODUCTION

The main objective of the work is to apply the thermal efficiency method to analyze the heat exchange process in a heat exchanger used in a nuclear power plant to generate electricity and produce hydrogen. During hydrogen production, it becomes necessary to use a heat exchanger to transfer heat from the Nuclear Power Plant (NPP) to the hydrogen plant efficiently. For this purpose, phase change heat exchangers are the most suitable due to the high enthalpy transfer. This energy transfer includes the heat associated with the superheated vapor, the latent heat of vaporization, and the liquid's sensible heat. The fluids that exchange heat are Helium and Sodium, the first used as the primary refrigerant and the second as the secondary heat exchanger refrigerant.

Sodium is a liquid metal that behaves like a Newtonian fluid. It is desirable for transferring energy to process plants as a secondary medium since it has high thermal conductivity and allows high heat transfer coefficients. Another advantage of Sodium is that it can act close to atmospheric pressure due to its high standard boiling point. The saturation temperature of Sodium in the two-phase heat exchange region equals 833 °C.

In this work, Helium superheated by the nuclear reactor enters the heat exchanger at 1027 °C. Sodium enters the heat exchanger from the opposite end at 120 °C as a subcooled liquid. The Liquid Metal Phase Heat Exchanger - LMPHE under analysis is a counterflow heat exchanger with three distinct sections: the superheated helium vapor inlet Region 1, Region 2, where the sodium convective boiling process occurs, and the subcooled liquid of sodium inlet Region 3, as schematically shown in Figure 1. Arrows indicate the direction of the helium flow.

Figure 1 – Liquid Metal Phase Heat Exchanger Process



The theoretical analysis is a powerful tool, making it possible to analyze situations under different operating conditions, which are not permissible through experimental means due to the high cost involved. The analytical solution is restricted to the heat exchange aspect and considers the two-phase heat exchange process as a nucleated boiling heat exchange for Sodium. The quantities determined for global heat transfer process analysis are thermal efficiencies, thermal effectiveness, heat transfer rates, and fluid exit temperatures in the three regions described above.

Piyush Sabharwall et al.^[1] developed a design for a heat exchanger coupled to a nuclear reactor and associated with a hydrogen production plant. The reactor supplies energy in heat to the primary helium coolant, heated to outlet temperatures of 1100 to 1300 K and flowing through a high-

temperature heat exchanger, where heat exchange with Sodium occurs. The heat exchanger studied is a way to efficiently transfer thermal energy from the Nuclear Power Plant to the hydrogen production facility. The authors perform a detailed analytical solution for the phase change heat exchanger and determine the global heat transfer coefficients and pressure drop for the three phases associated with Sodium: subcooled liquid, saturated steam, and superheated steam. Sodium is the most promising for heat transport among alkali metals because it has high thermal conductivity and heat transfer coefficients and behaves like Newtonian fluids. They clarify that the difference between liquid metals and non-metallic fluids is that the former have high boiling points, can operate close to atmospheric pressure, and are more sensitive to boundary conditions. They determine that the global heat exchange coefficient in the saturated vapor section equals $228.38 \text{ W}/(\text{m}^2 \text{ K})$ when operating at a speed equal to half the sonic velocity and in the subcooled liquid area, similar to $338.19 \text{ W}/(\text{m}^2 \text{ K})$. When the operating speed in the saturated vapor region equals $1/4$ of the sonic velocity, the heat transfer coefficient equals $272.27 \text{ W}/(\text{m}^2 \text{ K})$. They use the well-known Chen correlation to calculate the global heat transfer coefficient in the saturated vapor region, which considers micro and macro heat exchange mechanisms. However, they conclude that the overall heat transfer coefficient is more influenced by helium vapor. They believe the study could be helpful in experimental work related to phase change heat exchangers.

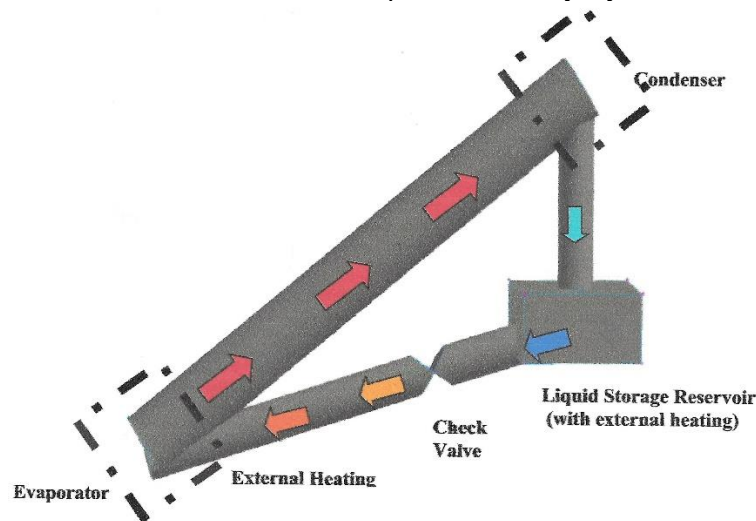
Idaho National Laboratory (United States)^[2] presents a report on designing, constructing, and operating a prototype nuclear reactor to produce hydrogen. The prototype aims to provide an economically competitive nuclear heat source with minimal risk and regular hydrogen production capacity. The reactor outlet temperature is between 800 and 950°C . The development of hydrogen production facilities is of comparable complexity to that of the nuclear reactor, and, in this sense, it is necessary to isolate the two systems using an alternative high-temperature heat source before coupling them. The heat from the high-temperature helium coolant will be used to produce hydrogen. The heat from the high-temperature helium refrigerant will produce hydrogen from heat exchange with liquid metal sodium.

Piyush Sabharwall^[3] argues that a viable option for long-distance thermal energy transport is a single-phase forced convection device mechanically pumping fluid between heat exchangers. This option presents excellent challenges due to the high temperatures involved but can be carried out using a high-temperature thermosiphon, which uses phase change for high temperatures. In this sense, he presents a feasible study for implementing a system that allows thermal energy transfer to a hydrogen production facility relatively far from a nuclear reactor. However, he argues, thermosiphons have operational limitations as they depend on gravitational or centrifugal force to drive the subcooled liquid to the evaporator. Furthermore, the gravitational force is only one of the requirements, as thermosiphon performance depends on the properties of the working fluid,

geometry, temperature, or saturation pressure. In this sense, the two-phase thermosiphon is an ideal candidate where the temperature difference between the fluids is relatively small, as the heat transfer rate per unit of temperature difference, i.e., the heat transfer coefficient, is very high.

Piyush Sabharwall et al.^[4] present a preliminary analysis of the thermal performance of a two-phase thermosiphon (Figure 2) for various types of alkali metals. In the thermosiphon, the working fluid is recirculated with the help of gravitational force, which allows heat transfer to be transported over appreciable distances without the need for external pumping. They clarify that the analysis aims to select high-efficiency compact heat exchangers that work at high temperatures. Furthermore, they present an analysis of a spiral plate heat exchanger and state that this type of heat exchanger is less susceptible to fouling and has never been considered in processes that occur phase change. They believe that the research developed will provide valuable elements for decision-making related to the heat transfer system between the nuclear reactor and the hydrogen production plant.

Figure 2 – Schematic Two-Phase Thermosiphon idealized by Piyush Sabharwall et al.^[4]



Shanbin Shi et al.^[5] argue that heat pipes and thermosiphons are widely used in engineering applications due to the almost isothermal phase change heat transfer mechanism and because they are passive devices. They clarify that modeling the complex phenomena that occur internally to the device is essential for project execution and security analysis. They present a two-phase, one-dimensional flow model developed to study heat pipes that work in steady and transient regimes. Apply specific constitutive equations related to interfacial heat, mass transfer, and film thickness to annular flow for wickless thermosiphons. They recommend future research and new experiments to validate the model developed for high-temperature heat pipes.

Élcio Nogueira^[6] presents thermal and viscous irreversibility concepts, applying the thermal efficiency method and the second law of thermodynamics. He used the thermodynamic Bejan

number in a typical example of a problem related to heat exchange between two fluids by a dimensionless solution for counterflow and parallel flow. Numerical results for thermal efficiency, thermal effectiveness, thermal irreversibility, and viscous irreversibility were used to discuss the procedure's advantages. He argues that the system has been applied to many associated heat exchanger problem solutions over the last three years.

Nogueira, É.^[7] presents theoretical work with localized application of the thermal efficiency method to save energy in air conditioning systems with heat pipes with individual fins. The performance analysis uses the number of fins per heat pipe, the number of heat pipes, and fluid inlet temperatures as input parameters. Freon 404A is a working fluid for energy absorption in the evaporator and energy recovery in the Condenser. The theoretical results obtained by the theoretical model located in the Evaporator, Condenser, and globally for the heat exchanger regions are compared with experimental results. Air velocities, Nusselt numbers, thermal efficiencies, heat transfer rates, and exit temperatures were obtained for theoretical-experimental comparison. Global comparisons showed excellent agreement, demonstrating that the localized theoretical approach is a consistent analysis tool for applying finned heat pipes to heat exchangers.

Andrijana D. Stojanović et al.^[8] reaffirm the importance of understanding the heat transfer process in nucleated boiling and accurately predicting the conditions that lead to the critical flow situation, mainly for safety reasons in nuclear power plants. They present a comprehensive review of heat transfer in nucleated boiling and discuss the results of studies related to the heat transfer coefficient in boiling processes and the characteristics associated with the phenomenon. They analyze aspects related to bubble exit diameter, bubble exit frequency, nucleation density, and bubble growth period and the impact reflected in the nucleated boiling process.

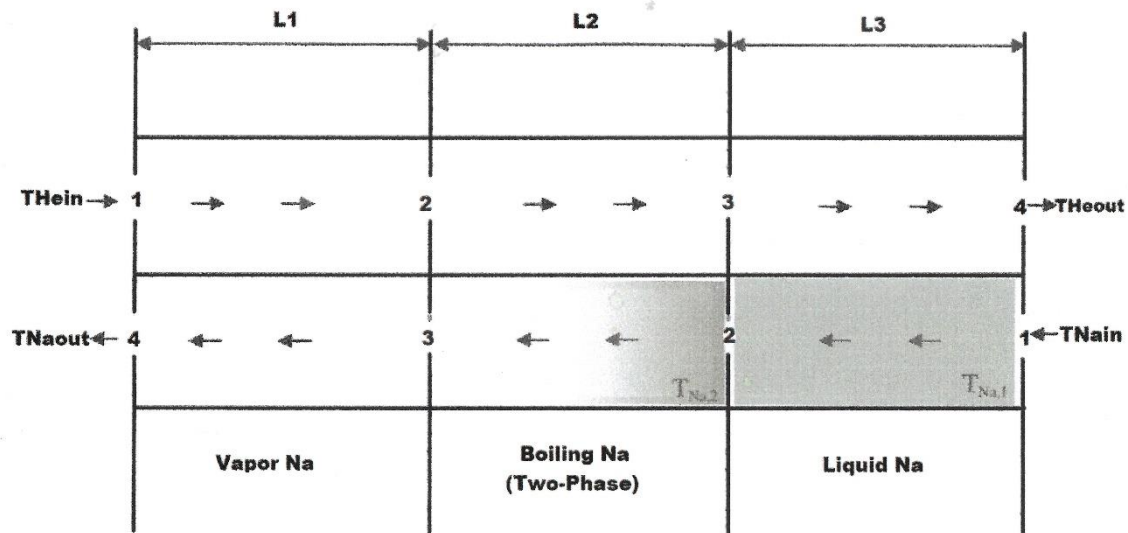
David Taler^[9] proposes new heat transfer correlations in the turbulent flow of liquid metals in tubes with constant heat flow boundary conditions. He used models developed by several researchers in the analysis. He considered the energy conservation equation integrated with the universal profile experimentally determined by Reichart and the different relations for the Prandtl number. He calculated the Nusselt numbers associated with the Reynolds and Prandtl numbers using Lyon Integral. He compared experimental results and adjusted the coefficients to obtain good agreement.

Lei Ren [10] conducted an experimental study on liquid metal as a working fluid. He suggests that large-scale turbulent circulation occurs near the beginning of the convection process. It determines that the evolution in the turbulent flow regime is characterized by the Nusselt number and that the temperature probability density function of the temperature fluctuation in the center of the cell evolves in a Gaussian manner before the turbulent transition to an exponential form in an utterly turbulent regime.

METHODOLOGY

The heat exchange process between the superheated Helium and changing phase sodium is simulated in a heat exchanger composed of three regions, as shown in Figure 3.

Figure 3 – Schematic of Liquid Metal Phase Heat Exchanger (Adapted by Piyush Sabharwall et al.^[1])



The heat exchanger is of the counterflow type, with superheated Helium entering at one end and Sodium as a subcooled liquid in another. The tubes are concentric, and Sodium flows through the inner tube. The saturation temperature of Sodium equals 833 °C and serves as a reference for the three regions. Two different diameters were used for analysis in the saturated vapor region for Sodium. The minor diameter is related to half the speed of sound in the pipe, and the largest diameter is to $\frac{1}{4}$ the speed of sound. It is assumed that the thermal resistance associated with the tube surface is negligible compared to the thermal resistance related to the fluids and flow regime. The properties of the fluids are obtained approximately through the mixing temperatures in the regions under analysis.

The physical quantities that remain constant during the analyses are the fluid inlet temperatures, the internal and external diameters in regions 1 and 3, the sodium saturation temperature, and the flow rates. For safety reasons, the inner diameter in the two-phase flow region depends on the assumed speed, which must be lower than the speed of sound associated with sodium^[4].

$$T_{sat} = 833.0 \text{ } ^\circ\text{C fixed}$$

(1)

The saturation temperature of Sodium, T_{sat} , is equal to 833 °C.

$$T_{He_{in1}} = 1027 \text{ } ^\circ\text{C fixed}$$

(2)

THe_{in1} is the inlet temperature of the helium vapor in the heat exchanger.

$$TNa_{in3} = 120 \text{ }^{\circ}\text{C} \text{ fixed}$$

(3)

TNa_{in3} is the temperature at which Sodium enters the heat exchanger.

$$TNa_2 = T_{sat} \text{ fixed}$$

(4)

The saturation temperature of Sodium in region 2 is equal to 833 °C.

$$\dot{m}_{He} = 81.59 \text{ kg/s}$$

(5)

$$D_{He} = 1.551 \text{ m}$$

(6)

The mass flow rate of Helium is 81.59 kg/s, and the external diameter is 1.551 m.

$$\dot{m}_{Na} = 9.794 \text{ kg/s}$$

(7)

$$D_{Na1} = 0.122 \text{ m}$$

(8)

$$D_{Na3} = 0.122 \text{ m}$$

(9)

The mass flow rate of Sodium equals 9.794 kg/s, and the internal diameter in regions 1 and 3 equals 0.122 m.

The properties associated with Helium depend on the vapor mixing temperature in the region under analysis.

$$\begin{aligned} \rho_{Hei} = & 0.1717547693d0 - 0.0005024738072 * THe_i + 9.528424492d - 7 * THe_i ** 2. d0 \\ & - 1.020764019d - 9 * THe_i ** 3. d0 + 5.538255567d - 13 * THe_i ** 4. d0 \\ & - 1.177254392d - 16 * THe_i ** 5. d0 \quad 1 \leq i \leq 3 \end{aligned}$$

(10)

The density of helium vapor is equal to ρ_{Hei} . The Helium mixing temperature in the region under analysis is represented by THe_i , where the index varies from 1 to 3. Petersen, H. ^[11], Vincent D. Arp, and Robert D. McCarty^[12] provide the properties of Helium.

$$k_{Hei} = 0.148407961d0 + 0.0003254147293d0 * THe_i - 4.305657603d - 8 * THe_i ** 2. d0$$

(11)

$$\mu_{Hei} = (1.929583717d0 + 0.004096498682 * THe_i - 5.313746426d - 7 * THe_i ** 2. d0) * 1. d - 5 \quad (12)$$

k_{Hei} is the thermal conductivity of helium vapor in region i. μ_{Hei} is the dynamic viscosity of helium vapor in region i.

$$Pr_{Hei} = 0.6725624682d0 - 2.199176297d - 5 * THe_i + 2.590560079d - 8 * THe_i ** 2. d0 - 2.328029436d - 11 * THe_i ** 3. d0 + 1.17454495d - 14 * THe_i ** 4. d0 - 2.431817654d - 18 * THe_i ** 5. d0$$

(13)

The Prandtl number of Helium in region i is represented by Pr_{Hei} .

$$\nu_{Hei} = \frac{\mu_{Hei}}{\rho_{Hei}}$$

(14)

ν_{Hei} is the dynamic viscosity associated with helium vapor in region i.

$$\alpha_{Hei} = \frac{\mu_{Hei}}{Pr_{Hei}} \quad (15)$$

$$Cp_{Hei} = \frac{\nu_{Hei}}{\alpha_{Hei}} \quad (16)$$

α_{Hei} is the thermal diffusivity of helium vapor in Region i. The specific heat of helium vapor in region i is represented by Cp_{Hei} .

The properties of Sodium in the two-phase flow region are associated with the properties of saturated liquid, related to the index l, and saturated vapor, related to the index v. The properties of Sodium are provided by Joanne K. Fink and Leonard Leibowitz^[13] and by G. H. Golden and J. V. Tokar^[14].

$$\rho_{Nal} = -0.2382637363d0 * TNa_2 + 951.134744d0$$

(17)

$$\rho_{Nav} = (-1942.324038d0 + 9.805341382d0 * TNa_2 - 0.01643668511d0 * TNa_2 ** 2. d0 + 9.251732712d - 6 * TNa_2 ** 3. d0) * 1. d3$$

(18)

$$k_{Nal} = 91.21074266d0 - 0.04824000559d0 * TNa_2 + 6.873126873d - 7 * TNa_2 ** 2. d0$$

(19)

$$k_{Nav} = -0.00578082968d0 + 6.85950024d - 5 * TNa_2 + 6.578942795d - 8 * TNa_2 ** 2. d0 - 1.208200401d - 10 * TNa_2 ** 3. d0 + 4.632867133d - 14 * TNa_2 ** 4. d0$$

(20)

$$\mu_{Nal} = (7.549325321d0 - 0.02161616967d0 * TNa_2 + 3.465090376d - 5 * TNa_2 ** 2. d0 - 3.030746977d - 8 * TNa_2 ** 3. d0 + 1.361249488d - 11 * TNa_2 ** 4. d0 - 2.453808446d - 15 * TNa_2 ** 5. d0) * 1. d - 4$$

(21)

$$\mu_{Nav} = (933.0641319d0 + 1.555217815 * TNa_2 + 0.0003932320867d0 * TNa_2 ** 2. d0 - 1.716200466d - 7 * TNa_2 ** 3. d0) * 1. d - 8$$

(22)

$$Cp_{Na1} = 2.022230309d0 - 0.005312730163d0 * TNa_2 + 1.501227267d - 5 * TNa_2 ** 2. d0 \\ - 2.13879551d - 8 * TNa_2 ** 3. d0 + 1.514270833d - 11 * TNa_2 ** 4. d0 \\ - 4.166666667d - 15 * TNa_2 ** 5. d0$$

(23)

$$Cp_{Nav} = (0.1013238839d0 + 0.002248844802d0 * TNa_2 + 2.089437138d - 5 * TNa_2 ** 2. d0 \\ - 4.723338971d - 8 * TNa_2 ** 3. d0 + 3.569885839d - 11 * TNa_2 ** 4. d0 \\ - 9.307692308d - 15 * TNa_2 ** 5. d0) * 1. d2$$

(24)

$$v_{Na1} = \frac{\mu_{Na1}}{\rho_{Na1}}$$

(25)

$$v_{Nav} = \frac{\mu_{Nav}}{\rho_{Nav}}$$

(26)

$$Pr_{Na1} = \frac{v_{Na1}}{\alpha_{Na1}}$$

(27)

$$Pr_{Nav} = \frac{v_{Nav}}{\alpha_{Nav}}$$

(28)

The density of Sodium is represented by ρ_{Na} , the thermal conductivity by k_{Na} , the dynamic viscosity by μ_{Na} , the specific heat by Cp_{Na} , the kinematic viscosity by v_{Na} , and the Prandtl number by Pr_{Na} . The thermal diffusivity is given by $\alpha_{Na} = \frac{k_{Na}}{\rho_{Na}Cp_{Na}}$.

The energy per unit of mass exchanged between the fluids during two-phase flow in Region 2 is given by:

$$h_{Na1v} = (4771.697082d0 - 1.000857055d0 * TNa_2 - 0.0001022855894d0 * TNa_2 ** 2. d0 \\ + 9.906759907d - 8 * TNa_2 ** 3. d0) * 1. d3$$

(29)

The properties of Sodium in Regions 1 and 3 are obtained by:

$$\rho_{Na1} = -0.2382637363d0 * TNa_1 + 951.134744d0$$

(30)

$$k_{Na1} = 91.21074266d0 - 0.04824000559d0 * TNa_1 + 6.873126873d - 7 * TNa_1 ** 2. d0$$

(31)

$$\mu_{Na1} = (7.549325321d0 - 0.02161616967d0 * TNa_1 + 3.465090376d - 5 * TNa_1 ** 2. d0 \\ - 3.030746977d - 8 * TNa_1 ** 3. d0 + 1.361249488d - 11 * TNa_1 ** 4. d0 \\ - 2.453808446d - 15 * TNa_1 ** 5. d0) * 1. d - 4$$

□

(32)

$$Cp_{Na1} = 2.022230309d0 - 0.005312730163d0 * TNa_1 + 1.501227267d - 5 * TNa_1 ** 2. d0 \\ - 2.13879551d - 8 * TNa_1 ** 3. d0 + 1.514270833d - 11 * TNa_1 ** 4. d0 \\ - 4.166666667d - 15 * TNa_1 ** 5. d0$$

(33)

$$v_{Na1} = \frac{\mu_{Na1}}{\rho_{Na1}}$$

(34)

$$Pr_{Na1} = \frac{v_{Na1}}{\alpha_{Na1}}$$

(35)

$$\rho_{Na3} = (-1942.324038d0 + 9.805341382d0 * TNa_3 - 0.01643668511d0 * TNa_3 ** 2. d0 \\ + 9.251732712d - 6 * TNa_3 ** 3. d0) * 1. d3$$

(36)

$$k_{Na3} = -0.00578082968d0 + 6.85950024d - 5 * TNa_3 + 6.578942795d - 8 * TNa_3 ** 2. d0 \\ - 1.208200401d - 10 * TNa_3 ** 3. d0 + 4.632867133d - 14 * TNa_3 ** 4. d0$$

(37)

$$\mu_{Na3} = (933.0641319d0 + 1.555217815 * TNa_3 + 0.0003932320867d0 * TNa_3 ** 2. d0 \\ - 1.716200466d - 7 * TNa_3 ** 3. d0) * 1. d - 8$$

(38)

$$Cp_{Na3} = (0.1013238839d0 + 0.002248844802d0 * TNa_3 + 2.089437138d - 5 * TNa_3 ** 2. d0 \\ - 4.723338971d - 8 * TNa_3 ** 3. d0 + 3.569885839d - 11 * TNa_3 ** 4. d0 \\ - 9.307692308d - 15 * TNa_3 ** 5. d0) * 1. d2$$

(39)

$$v_{Na3} = \frac{\mu_{Na3}}{\rho_{Na3}}$$

(40)

$$Pr_{Na3} = \frac{v_{Na3}}{\alpha_{Na3}}$$

(41)

The temperatures TNa_1 and TNa_3 are mixing temperatures in the regions under analysis.

$$A_{Hei} = \frac{\pi(D_{He}^2 - D_{Nai}^2)}{4} \quad 1 \leq i \leq 3$$

(42)

The helium flow area is represented by A_{Hei} .

$$Per_{Hei} = \pi(D_{He} + D_{Nai}) \quad 1 \leq i \leq 3$$

(43)

$$Dh_{Hei} = \frac{4A_{Hei}}{Per_{Hei}} \quad 1 \leq i \leq 3$$

(44)

Dh_{Hei} is the hydraulic diameter associated with Helium.

$$Re_{Hei} = \frac{\dot{m}_{He} Dh_{Hei}}{A_{Hei} \mu_{Hei}} \quad 1 \leq i \leq 3$$

(45)

$$V_{Hei} = \frac{\dot{m}_{He}}{\rho_{Hei} A_{Hei}} \quad 1 \leq i \leq 3$$

(46)

The Reynolds number associated with Helium is represented by Re_{Hei} , and the velocity by V_{Hei} .

$$Nu_{Hei} = 0.022 Re_{Hei}^{0.8} Pr_{Hei}^{0.5} \quad 1 \leq i \leq 3$$

(47)

Nu_{Hei} is the Nusselt number associated with helium vapor given by W. M. Kays and M. E. Crawford^[15].

$$h_{Hei} = \frac{Nu_{Hei} k_{Hei}}{Dh_{Hei}} \quad 1 \leq i \leq 3$$

(48)

The convection heat transfer coefficient is represented by h_{Hei} .

$$A_{Nai} = \frac{\pi D_{Nai}^2}{4} \quad 1 \leq i \leq 3$$

(49)

The sodium flow area is represented by A_{Nai} .

$$Per_{Nai} = \pi D_{Nai}^2 \quad 1 \leq i \leq 3$$

(50)

$$Dh_{Nai} = \frac{4A_{Nai}}{Per_{Nai}} \quad 1 \leq i \leq 3$$

(51)

Dh_{Nai} is the hydraulic diameter associated with Sodium.

$$Re_{Nai} = \frac{\dot{m}_{Nai} Dh_{Nai}}{A_{Nai} \mu_{Nai}} \quad 1 \leq i \leq 3$$

(52)

$$V_{Nai} = \frac{\dot{m}_{Nai}}{\rho_{Nai} A_{Nai}} \quad 1 \leq i \leq 3$$

(53)

The Reynolds number associated with Sodium is represented by Re_{Nai} , and the velocity by V_{Nai} .

$$Nu_{Nai} = 6.3 + Re_{Nai}^{0.85} Pr_{Nai}^{0.93} \quad i = 1 \text{ or } i = 3$$

(54)

Nu_{Nai} is the Nusselt number associated with Sodium in the single-phase region given by W. M. Kays and M. E. Crawford^[1;15].

$$h_{Nai} = \frac{Nu_{Nai}k_{Nai}}{Dh_{Nai}} \quad i = 1 \text{ or } i = 3$$

(55)

The convection heat transfer coefficient is represented by h_{Nai} .

$$Uo_i = \frac{1}{\frac{1}{h_{Hei}} + \frac{1}{h_{Nai}}} \quad i = 1 \text{ or } i = 3$$

(56)

The global heat transfer coefficient in the single-phase region, disregarding the thermal resistance associated with the separation surface between the fluids, is represented by Uo_i .

$$h_{boil} = \mu_{Nai} h_{Nai} \left(g \frac{(\rho_{Nai} - \rho_{Nai v})}{\sigma_{Na}} \right)^{0.5} \left(\frac{Cp_{Nai}}{Csf h_{Nai} Pr_{Nai}} \right)^3 \Delta T_{sat}^2 \quad i = 2$$

(57)

In the two-phase flow region, Region 2, the boiling coefficient, h_{boil} , used in the simulation is associated with the nucleated boiling process, determined experimentally by W. M. Rohsenow^[16], which presumably can be applied to processes related to liquid metals, according to Piyush Sabharwall et al.^[1]. The Rohsenow equation is more uncomplicated and contains parameters that do not consider some complex effects, such as those occurring in convective boiling, such as that developed by J. C. Chen^[17] and used by Piyush Sabharwall et al.^[1].

$$\Delta T_{sat} = T_{He2} - T_{Na2}$$

(58)

ΔT_{sat} is called the saturation temperature difference.

$$\sigma_{Na} = -0.1000989011d0 * T_{Na2} + 204.8458973d0$$

(59)

The surface tension associated with Sodium is represented by σ_{Na} and can be found in a numerical table obtained by Joanne K. Fink and Leonard Leibowitz^[13].

$$Csf = 0.006 \quad \text{fixed!}$$

(60)

The parameter Csf is used in the work developed by W. M. Rohsenow^[16].

$$Uo_i = \frac{1}{\frac{1}{h_{Hei}} + \frac{1}{h_{boil}}} \quad i = 2$$

(61)

The above global heat transfer coefficient, Uo_i , is associated with the boiling process occurring in Region 2.

$$A_{Tri} = \pi D_{Nai} L_i \quad 1 \leq i \leq 3$$

(62)

A_{Tri} is the area of heat exchange between fluids.

$$C_{Nai} = \dot{m}_{Na} C_{p_{Nai}} \quad \text{Region 2}$$

(63)

$$C_{Nav} = \dot{m}_{Na} C_{p_{Nav}} \quad \text{Region 2}$$

(64)

$$C_{Nai} = \dot{m}_{Na} C_{p_{Nai}} \quad i = 1 \text{ or } i = 3$$

(65)

$$C_{Hei} = \dot{m}_{He} C_{p_{Hei}} \quad 1 \leq i \leq 3$$

(66)

$$C_i^* = \frac{C_i^{min}}{C_i^{max}} \quad 1 \leq i \leq 3$$

(67)

C_i^* is the relationship between the fluids' minimum and maximum thermal capacities in region i .

$$NTU_i = \frac{U_o A_{tri}}{C_i^{min}} \quad 1 \leq i \leq 3$$

(68)

The number of thermal units in region i is represented by NTU_i .

$$Fa_i = \frac{NTU_i(1-C_i^*)}{2} \quad 1 \leq i \leq 3$$

(69)

Fa_i is the factor called "Fin Analogy Number" presented in the pioneering work of Fakhri A.^[18] and used in papers developed by Nogueira, É.^[6-7]

$$\eta_{Ti} = \frac{Tanh(Fa_i)}{Fa_i} \quad 1 \leq i \leq 3$$

(70)

The thermal efficiency in region i is given by η_{Ti} .

$$\varepsilon_{Ti} = \frac{1}{\frac{1}{\eta_{Ti} NTU_i} + \frac{1+C_i^*}{2}} \quad 1 \leq i \leq 3$$

(71)

ε_{Ti} is the thermal effectiveness in region i .

$$\dot{Q}_i = \varepsilon_{Ti} C_i^{min} (T_{Heini} - T_{Naini}) \quad 1 \leq i \leq 3$$

(72)

The heat transfer rate between the fluids in region i is obtained by \dot{Q}_i .

$$\dot{Q}_i^{Max} = C_i^{min} (T_{Heini} - T_{Naini}) \quad 1 \leq i \leq 3$$

(73)

\dot{Q}_i^{Max} is the maximum heat transfer rate between the fluids in region i .

$$THe_{outi} = THe_{ini} - \frac{\dot{Q}_i}{C_i^{min}} \quad 1 \leq i \leq 3$$

(74)

THe_{outi} is the vapor helium outlet temperature in region i.

$$TNa_{outi} = TNa_{ini} + \frac{\dot{Q}_i}{C_i^{min}} \quad i = 1 \text{ or } i = 3$$

(75)

TNa_{outi} is the sodium outlet temperature.

RESULTS AND DISCUSSION

The results obtained through the simulation are divided into three parts associated with Sodium: superheated vapor region (Region 1), saturated vapor region (Region 2), and subcooled liquid region (Region 3).

The data stipulated at the entrances and exits of the regions are represented numerically in red.

SUPERHEATED STEAM REGION – REGION 1

Figure 4 – Thermal efficiency in the region 1 (Superheated Steam)

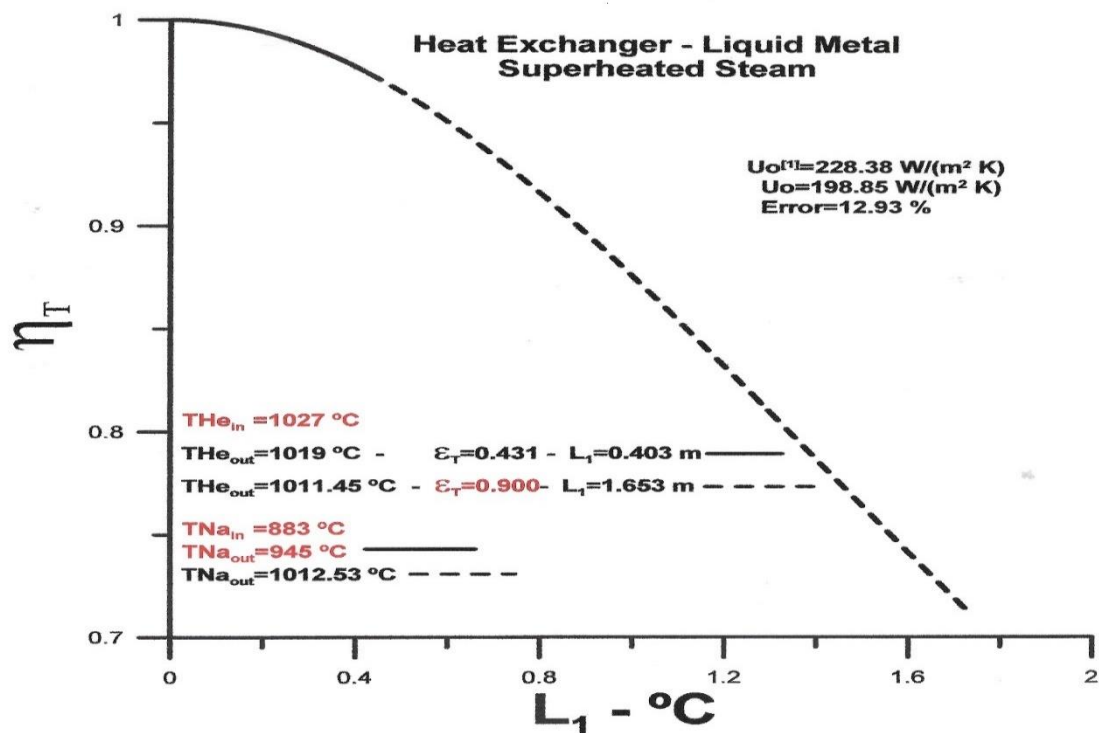


Figure 4 presents values obtained for thermal efficiency in the superheated steam region.

During the simulation, the length of the heat exchange section varies until the exit temperature value stipulated for Sodium is obtained ($T_{Na_{out}}=945\text{ }^{\circ}\text{C}$). In this first imposed situation, the required length of section 1 corresponds to 0.403 meters, and the thermal effectiveness associated with this length is equal to 0.431. In this case, the helium vapor's exit temperature reaches $1019\text{ }^{\circ}\text{C}$. This result is quite conservative since there is a wide margin for improving heat exchange between the fluids, increasing the size of the heat exchange section.

The second situation imposed in the simulation is to increase the thermal efficiency value, improving the heat exchange between the fluids to obtain a higher sodium outlet temperature. In this second simulation, the value imposed for thermal effectiveness is equal to 0.9. The exit temperature of the sodium vapor corresponds to $1012.53\text{ }^{\circ}\text{C}$, and the value for the length of section 1 corresponds to 1.653 m. In this case, the helium vapor's exit temperature reaches $1011.45\text{ }^{\circ}\text{C}$.

There is an effective gain when the demand for heat exchange increases, but in compensation, there is a significant increase in the section length when comparing the first simulation with the second. An essential observation concerning Figure 4 is that the deviation obtained in section 1 for the global heat transfer coefficient equals 12.93%. Note that the section length does not influence the value of the global heat transfer coefficient. The absolute deviation is the result of the simulation concerning the results presented by Piyush Sabharwall et al.^[1].

Figure 5 – Thermal effectiveness in the region 1 (Superheated Steam)

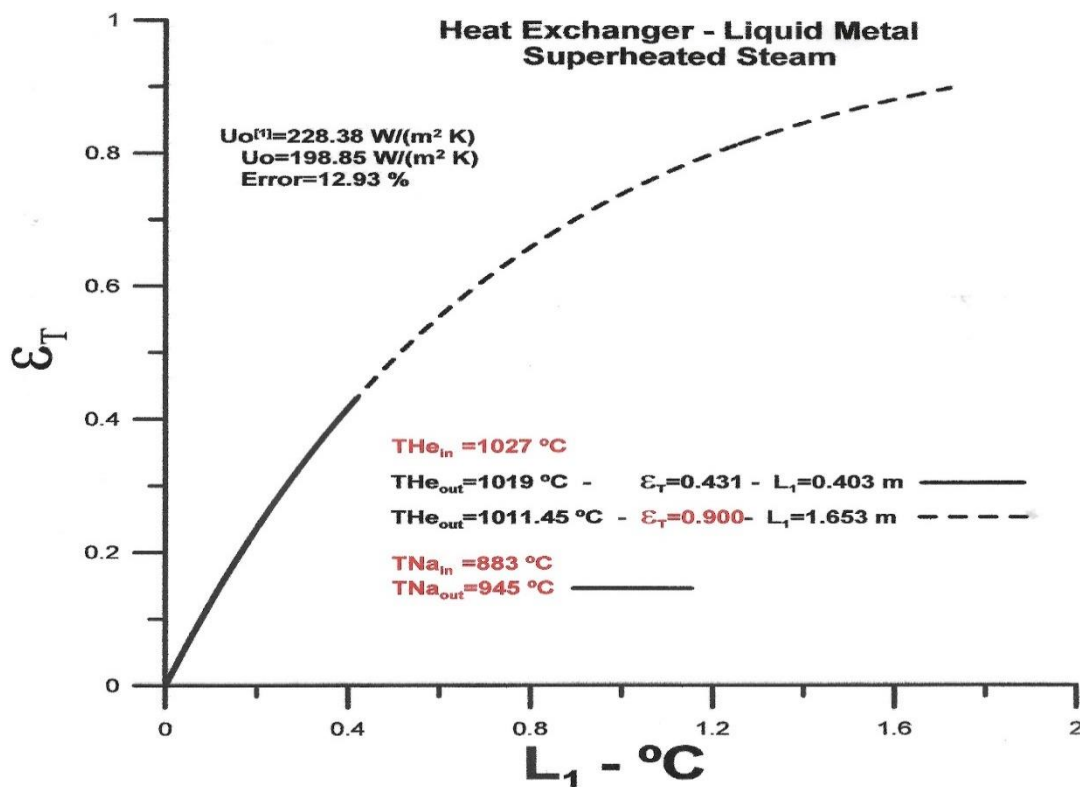


Figure 5 presents values obtained for thermal effectiveness in the superheated steam region.

The results are coherent with the conditions in the simulations related to Figure 4. When the sodium exit temperature is equal to 945 °C, the section length is equal to 0.403 m, and when the effectiveness is equal to 0.9, the section length is equal to 1,657 m.

Figure 6 presents values obtained for heat transfer rate in the superheated steam region.

There is coherence between the results presented for thermal effectiveness and those obtained for the heat transfer rate in Region 1. In the first condition imposed, the heat transfer rate obtained is relatively low when compared to the maximum heat transfer, which depends only on the difference between the inlet temperatures of the helium and sodium fluids. When the effectiveness is set equal to 0.9, the heat transfer rate approaches the maximum, as expected.

Figure 7 presents values obtained for Helium and Sodium outlet temperatures in the superheated steam region.

Again, the exit temperatures for both fluids, Helium and Sodium, are consistent with the conditions imposed in Region 1. When the length of section 1 is equal to 0.403 m, the sodium exit temperature is equal to 945 °C; when the length is equal to 1.653 m, the sodium outlet temperature is equal to 1012.53 °C. The helium temperatures in both conditions equal 1019 °C and 1011.45 °C.

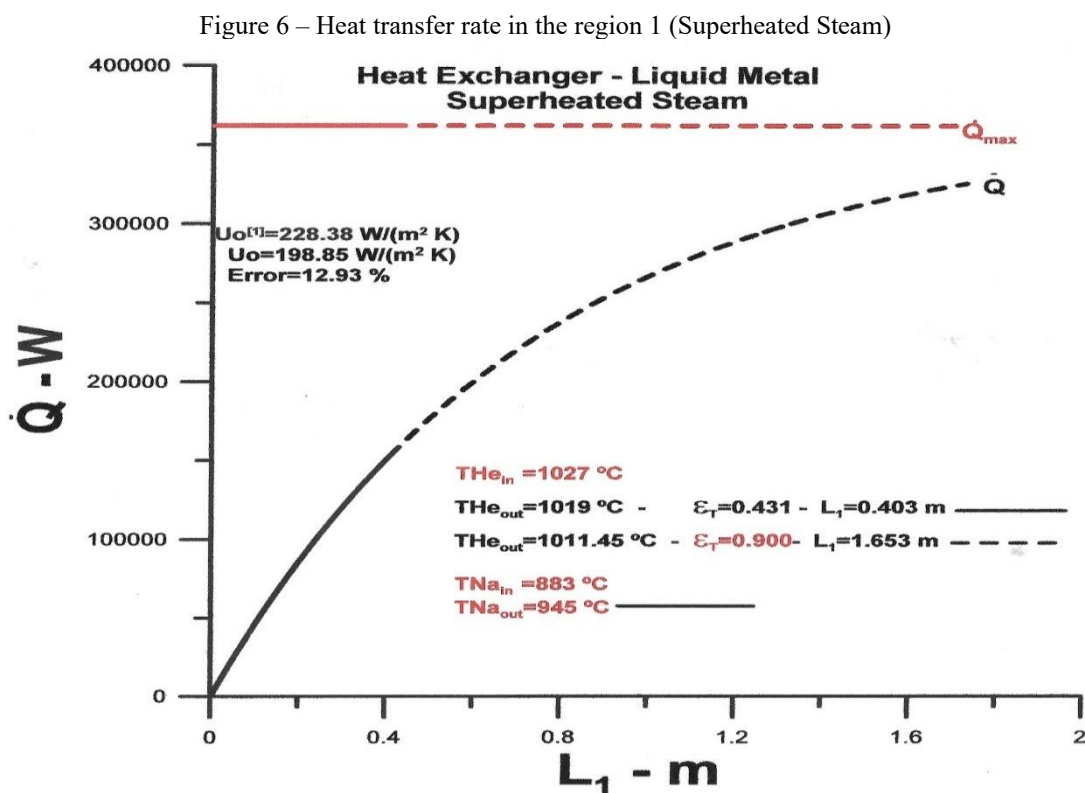
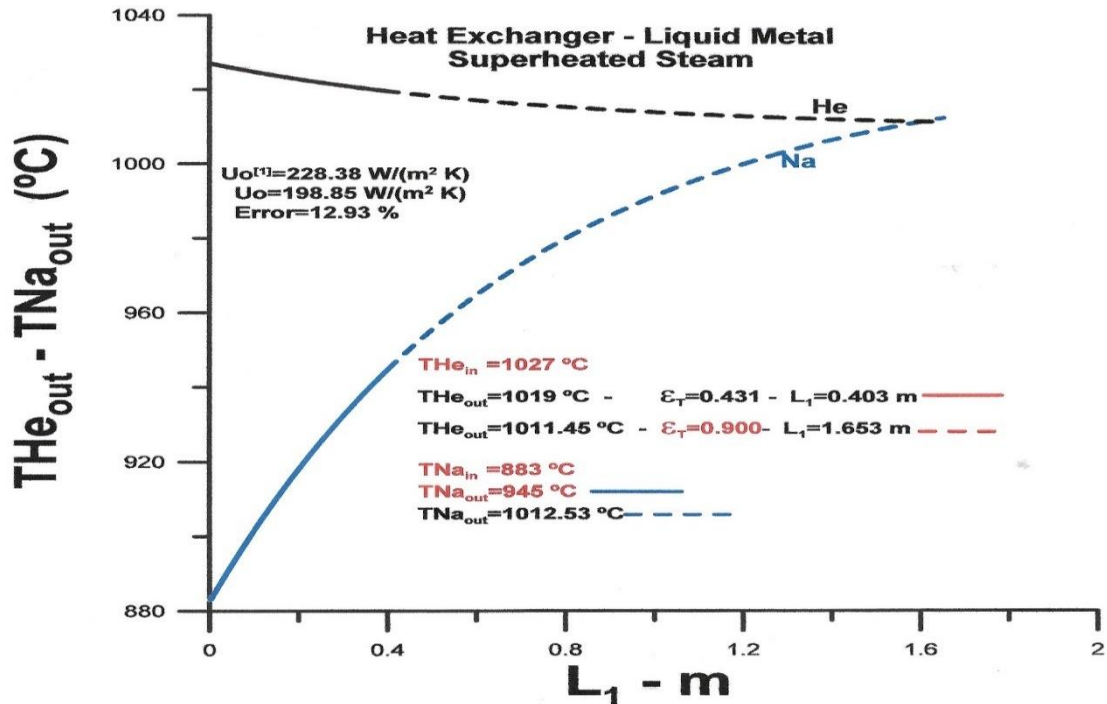


Figure 7 – Outlet temperatures of Helium and Sodium in the region 1 (Superheated Steam)



The helium exit temperatures will influence the results of thermal quantities in Region 2, where Sodium is a saturated vapor.

SATURATED STEAM REGION – REGION 2

In Region 2, saturated vapor for Sodium, the sodium inlet temperature is set equal to 1019 °C, and the sodium temperature is equal to the saturation temperature, equal to 833 °C. However, two new conditions related to the diameter of the tube through which the sodium flows are to be implemented. The speed of sodium vapor cannot exceed the speed of sound, and for safety, the tube diameters must satisfy two conditions: $D_{Na2}=0.1797 \text{ m}$, which corresponds to half the sonic speed, and $D_{Na2}=0.2542 \text{ m}$, which corresponds to $\frac{1}{4}$ of the sonic speed.

Figure 8 presents values obtained for thermal efficiency in the saturated steam region.

In addition to the pipe diameter in region 2 being imposed, a second condition must be set to obtain results that allow Sodium to be heated in region 3. The second condition implemented in the simulation relates to the pipe length in Region 2. The size chosen in the implementation must be consistent with the helium exit temperature, and the imposed value equals 0.2 m.

When the imposed diameter corresponds to $\frac{1}{2}$ the speed of sound in the tube, that is, $D_{Na2}=0.1797 \text{ m}$, the helium exit temperature corresponds to 945 °C, and the exit temperature is 927 °C for a diameter equal to $D_{Na2}=0.2542 \text{ m}$, which corresponds to $\frac{1}{4}$ the speed of sound. The corresponding values obtained for thermal efficiency are, respectively, 0.544 and 0.678. The higher effectiveness value corresponds to greater heat exchange for the larger diameter. Consistent result with greater heat exchange area.

When comparing the values of the global heat transfer coefficient, there is a deviation of 6.64% related to $\frac{1}{2}$ the speed of sound and 9.05% for $\frac{1}{4}$ the speed of sound. The value used for comparison corresponds to the average value of the global heat transfer coefficient obtained by Piyush Sabharwall et al.[1] in Region 2.

Figure 9 presents values obtained for thermal effectiveness in the saturated steam region.

The thermal effectiveness corresponds to 0.544 in the saturated vapor region when the adopted diameter corresponds to 0.1797 m and 0.678 when the adopted diameter corresponds to 0.2542 m.

Figure 10 presents results for the heat transfer rate in the saturated vapor region, which is compatible with the results shown in Figure 9. In comparison with the maximum heat transfer rate, it is possible to see that the heat exchange is underestimated. However, as there is a need for heating in Region 3, the values obtained are the most realistic possible, considering that the subcooled liquid enters Region 3 at a temperature equal to 120 °C.

Figure 11 shows the temperature profile of Helium in the saturated vapor region associated with Sodium. The outlet temperature corresponds to 945 °C for a diameter of the tube that transposes the Sodium equal to 0.1797 m and is 927 °C for a diameter equal to 0.2542 m. The helium exit temperature values will impact heat transfer in region 1 of subcooled fluid.

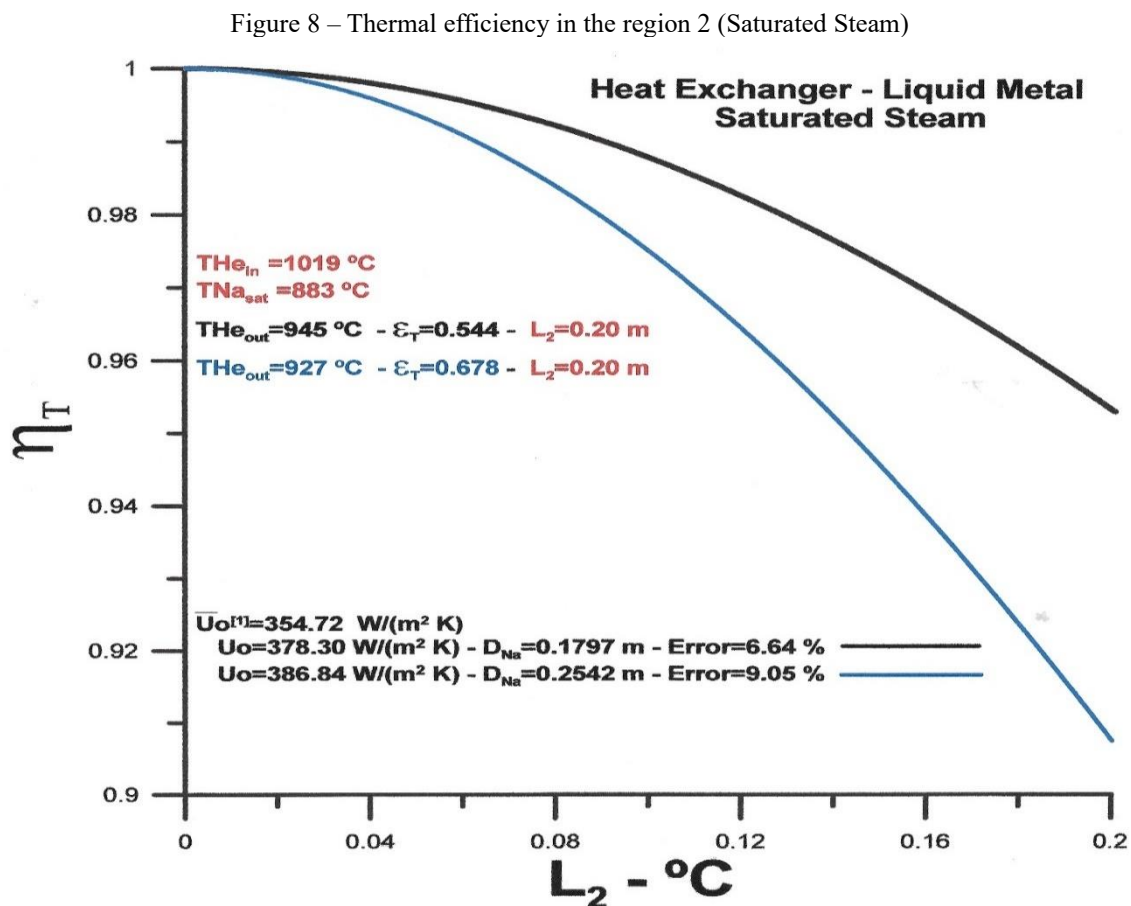


Figure 9 – Thermal effectiveness in the region 2 (Saturated Steam)

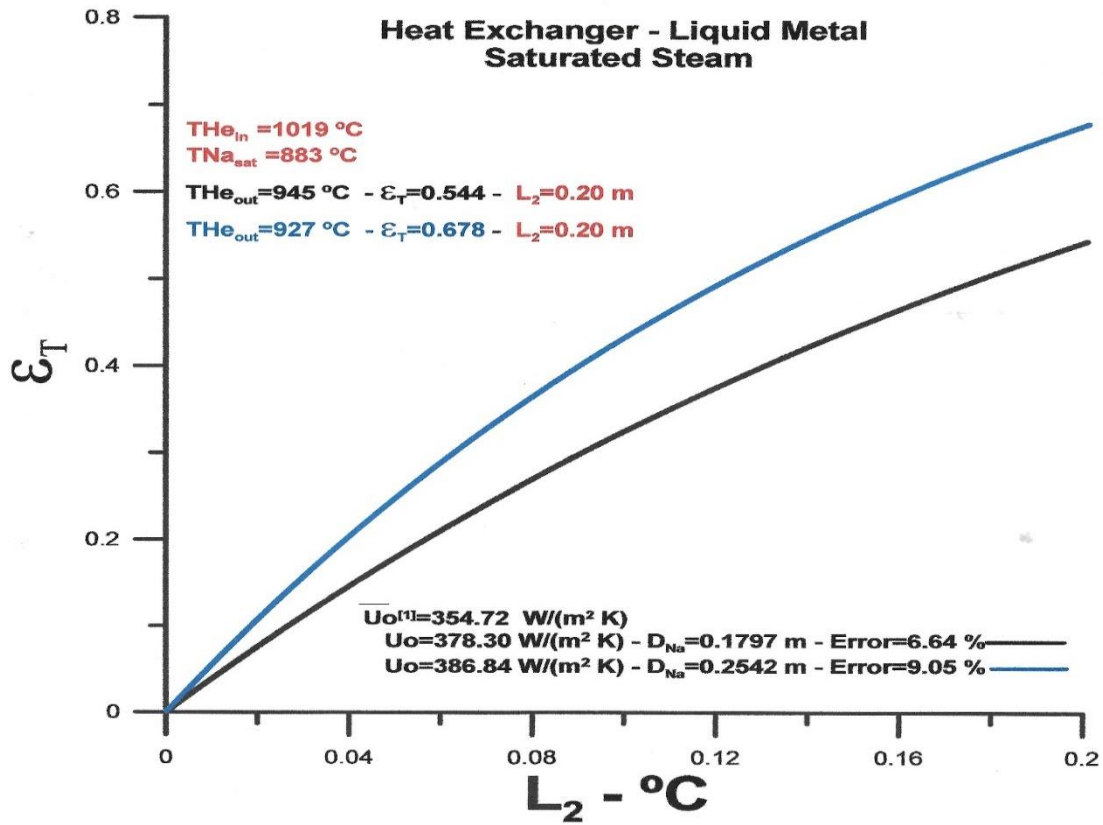


Figure 10 – Heat transfer rate in the region 2 (Saturated Steam)

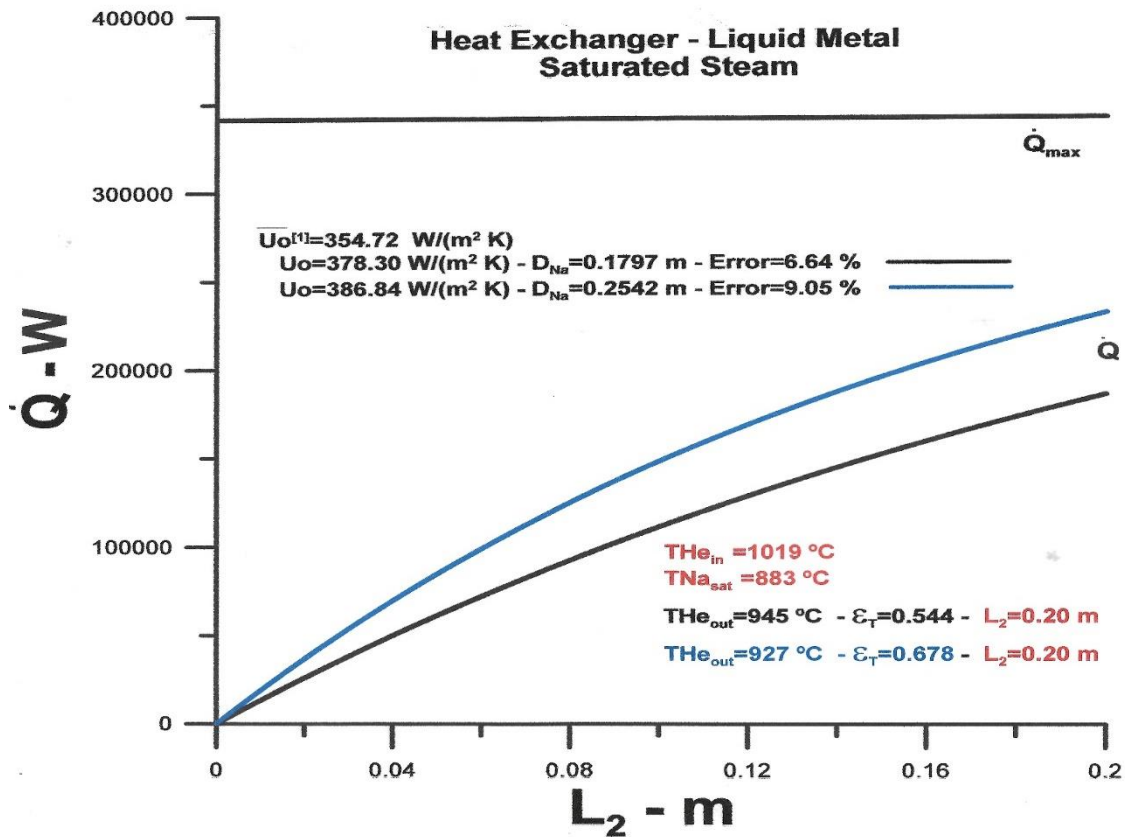
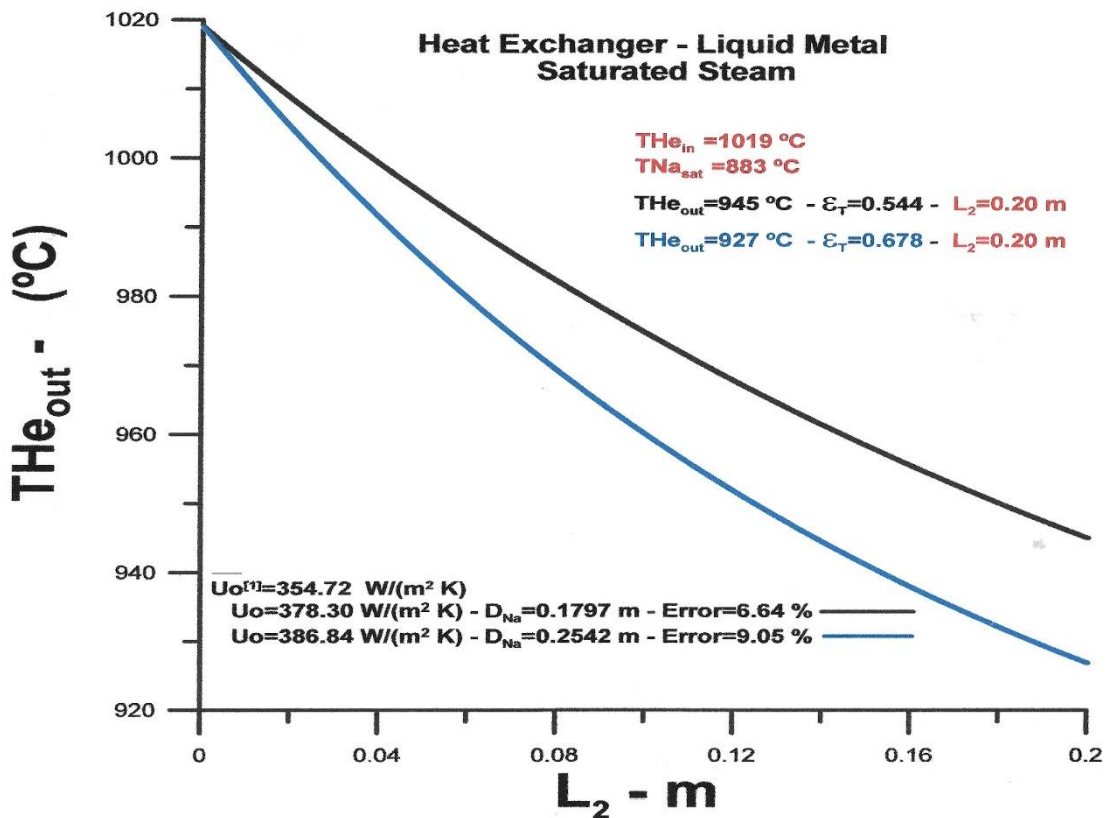


Figure 11 – Outlet temperatures of Helium at the region 2 (Saturated Steam)



SUBCOOLED LIQUID REGION – REGION 3

In region 3, Sodium in the subcooled liquid state enters at a temperature of 120 °C, and Helium enters with a temperature equal to 945 °C when the diameter of the tube associated with Sodium in the saturated vapor region is equal to 0.1797 m, and with a temperature equal to 926 °C for diameter equal to 0.2542.

The absolute deviation obtained for the global heat transfer coefficient in the subcooled liquid region equals 4.43%.

Figure 12 presents results for thermal efficiency in the cooled liquid region, with helium inlet temperatures equal to 945 °C and 926 °C, with values respectively equal to 0.763 and 0.736. The length of the pipe in the cooled liquid region corresponds to 0.80 meters for the first temperature mentioned and 0.86 meters for the second temperature. These results indicate greater heat exchange for the helium inlet temperature equal to 926 °C due to the larger diameter and length of the pipe.

The thermal effectiveness corresponds to 0.884 and 0.864 for the two helium vapor entry conditions, as shown in Figure 13. The highest value obtained for effectiveness corresponds to the largest diameter associated with the saturated vapor region, equal to 0.2542, and an inlet temperature of the helium vapor in the subcooled liquid region equal to 926 °C.

Figure 12 – Thermal efficiency in the region 3 (Subcooling Liquid)

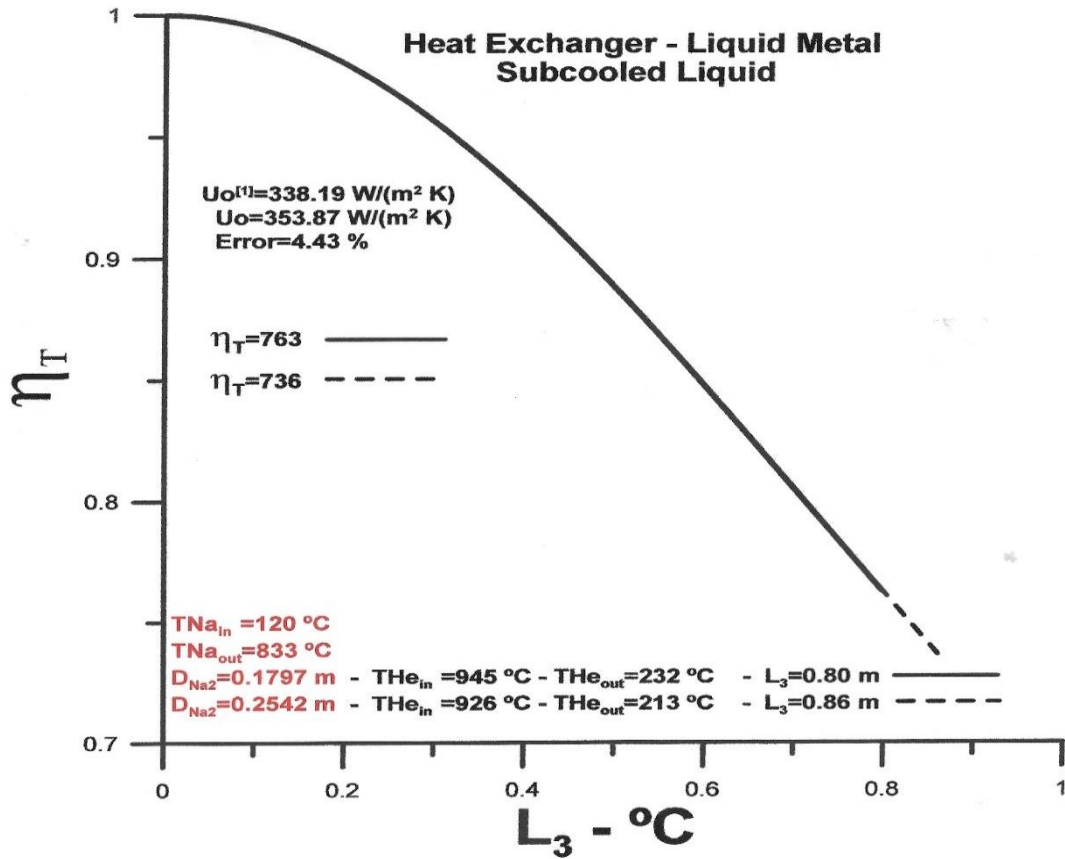


Figure 13 – Thermal effectiveness in the region 3 (Subcooling Liquid)

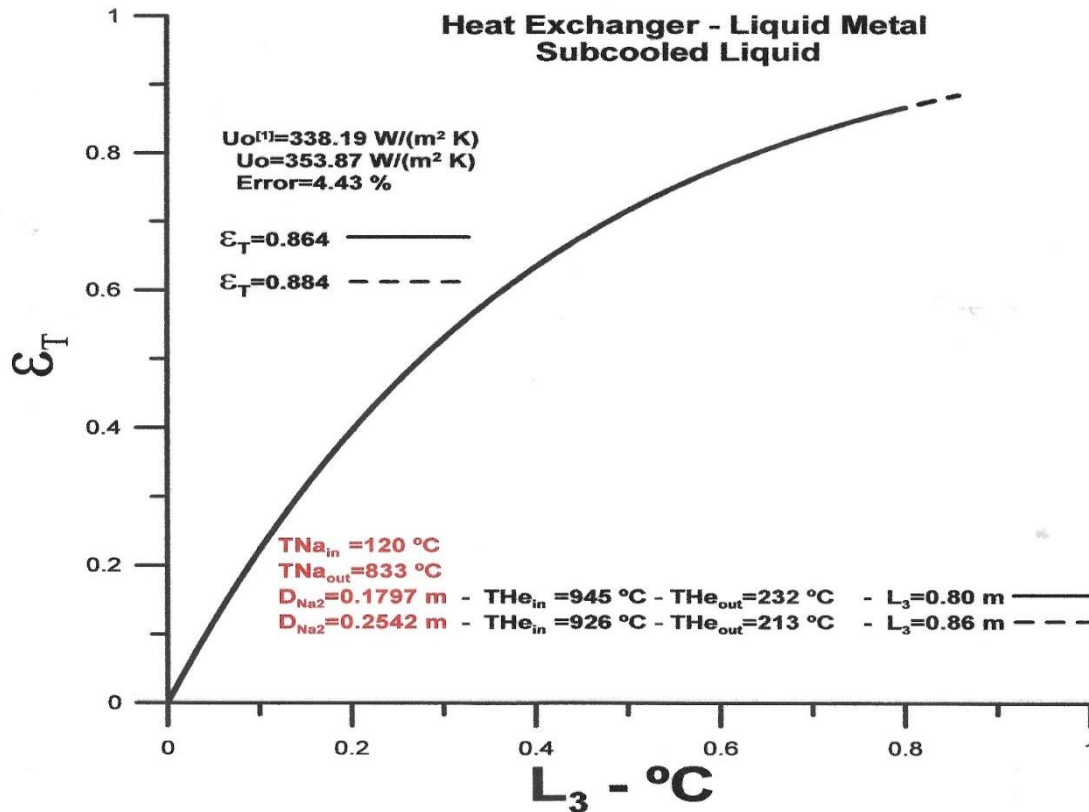


Figure 14 – Heat transfer rate in the region 3 (Subcooling Liquid)

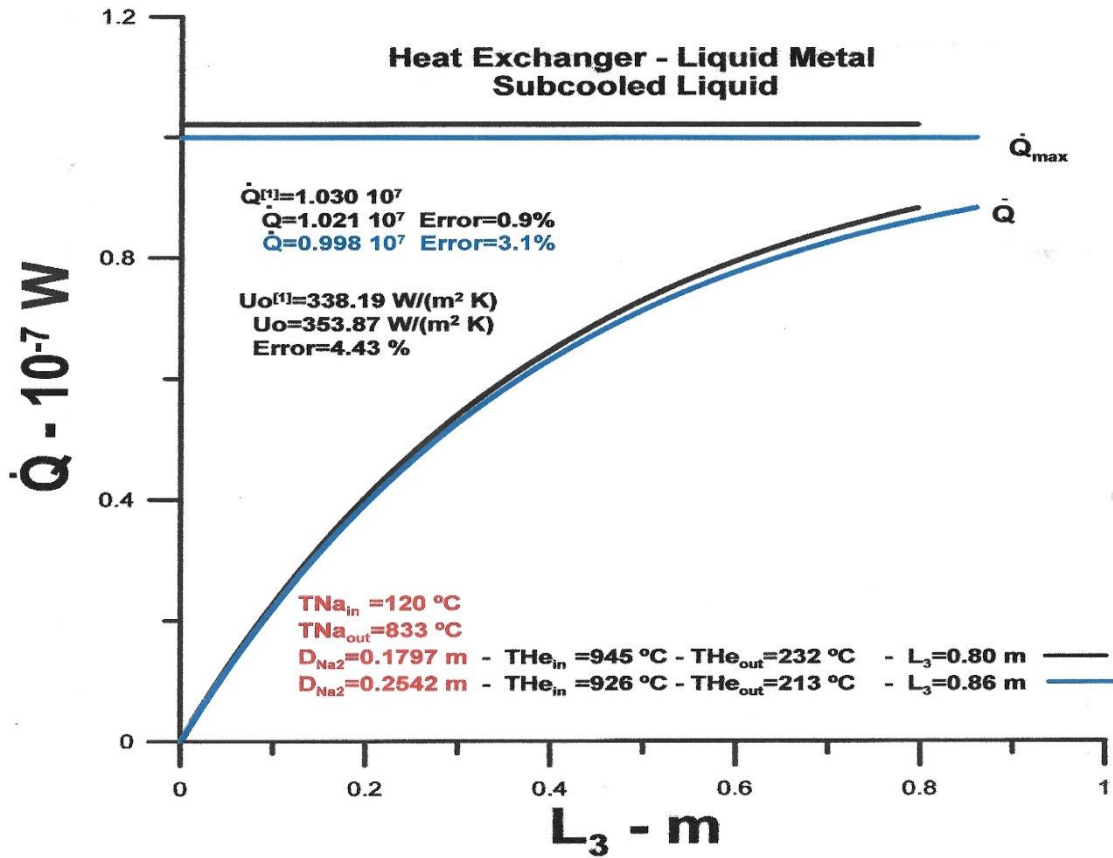
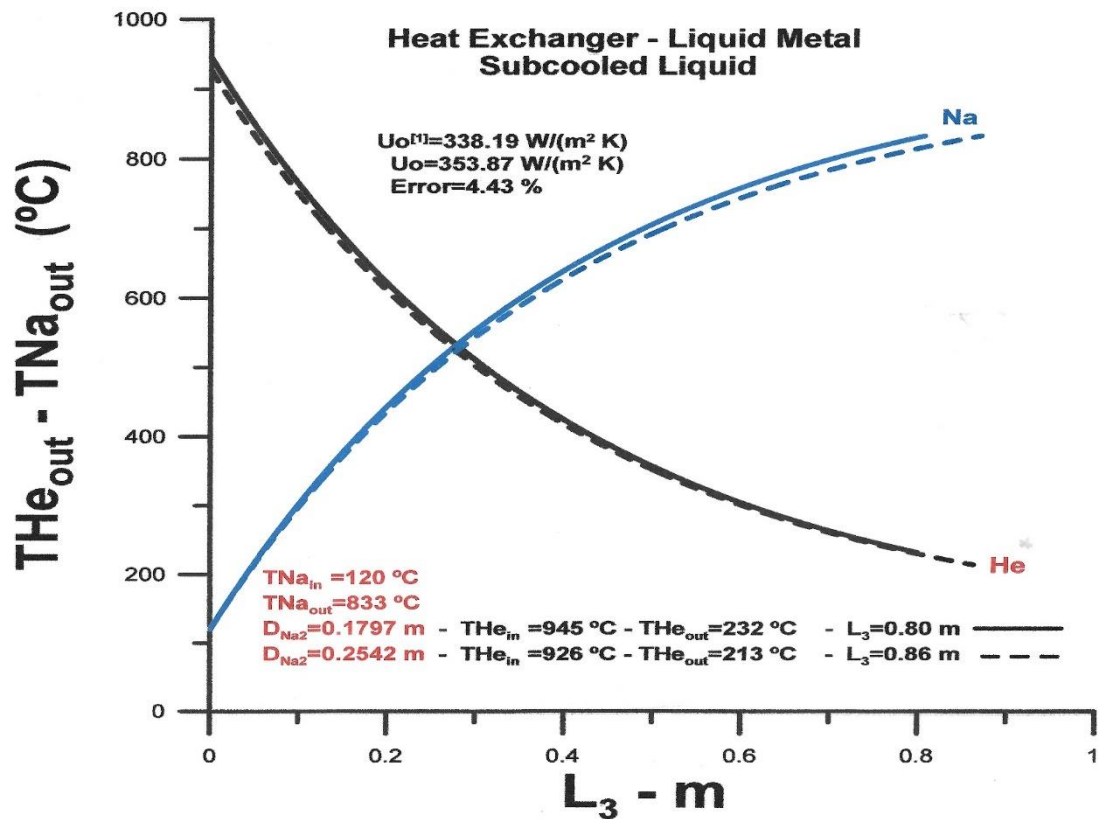


Figure 15 – Outlet temperatures in the region 3 (Subcooling Liquid)



The heat transfer rate in the subcooled liquid region is shown in Figure 14. The absolute deviation determined for the heat transfer rate in region 3, when the helium vapor inlet temperature equals 945 °C, corresponds to 0.9% and is equal to 3.1% when the helium inlet temperature equals 926 °C. Note that the maximum values for heat transfer shown in Figure 14 depend on the difference in inlet temperature between the two fluids that exchange heat and that the sodium inlet temperature value is fixed, equal to 120 °C.

The exit temperatures of the helium and sodium fluids are represented in Figure 15. The sodium exit temperature, equal to 833 °C, determines the other associated quantities. The helium vapor outlet temperatures depend on the stipulated inlet temperatures. The same happens with the length of the pipe. When the sodium inlet temperature is set to 945 °C, the values obtained for the helium outlet temperature and tube length are equal to 232 °C and 0.80 m. When the inlet temperature is 926 °C, the helium outlet temperature is 213 °C, and the section length is 0.86 m.

CONCLUSION

The counterflow Liquid Metal Phase Heat Exchanger was used to simulate the heat exchange process used in a nuclear power plant to produce hydrogen.

The heat exchange process between superheated Helium and liquefied Sodium is carried out in three stages related to Sodium: subcooled liquid stage, saturated steam stage, and superheated steam stage. Helium's inlet temperature equals 1027 °C, and Sodium is 120 °C. The sodium outlet temperature equals 945 °C, and the helium outlet temperature depends on the conditions imposed in regions 2 and 3. The helium outlet temperatures in the simulation correspond to 232 °C and 213 °C.

Comparisons were made with a previously developed model using a different numerical procedure, and the deviations presented did not exceed 13%.

The use of the equation developed by Rhosenow for the nucleated boiling process proved consistent in the simulation presented.

The analytical efficiency method is a powerful tool that makes it possible to analyze situations under different operating conditions, which are not permissible through experimental means due to the high cost involved.

A similar analytical procedure can simulate thermal and viscous irreversibilities using the Bejan number to determine the best configuration for the system in terms of cost-benefit.

NOMENCLATURE

A_{tr} – heat transfer area, [m^2]

C_p – specific heat, [$\frac{J}{kg K}$]



C – thermal capacity, $[\frac{W}{K}]$

C_{\min} – minimum thermal capacity, $[\frac{W}{K}]$

$$C^* = \frac{C_{\min}}{C_{\max}}$$

D_h – hydraulic diameter, $[m]$

Fa – fin analogy number

g – acceleration of gravity

h – coefficient of heat convection, $[\frac{W}{m^2K}]$

He - Helium

k – thermal conductivity, $[\frac{W}{mK}]$

K - Kelvin

L – vertical or horizontal length, $[m]$

\dot{m} – mass flow rate, $[\frac{kg}{s}]$

Na - sodium

Nu – Nusselt number

Pr – Prandtl number

\dot{Q} – actual heat transfer rate, $[W]$

\dot{Q}_{\max} – maximum heat transfer rate, $[W]$

Re – Reynolds number

T – temperatures, $[^{\circ}C]$

U_o – global heat transfer coefficient, $[\frac{W}{m^2K}]$

SUBSCRIPTS

boil – boiling

i – region 1, 2 or 3

in – inlet

out – outlet

sat - saturation



GREEK SYMBOLS

α – thermal diffusivity, $[\frac{m^2}{s}]$

ρ – density of the fluid, $[\frac{kg}{m^3}]$

μ – dynamic viscosity of the fluid, $[\frac{kg}{m s}]$

ν – kinematic viscosity of the cold fluid, $[\frac{m^2}{s}]$

ε_T – thermal effectiveness

η_T – thermal efficiency

ΔT – a difference of temperatures, $[^\circ C]$

ACRONYMS

NTU – number of thermal units


REFERENCE

1. Sabharwall, P., Utgikar, V., Tokuhiko, A., & Gunnerson, F. (2009). Design of Liquid Metal Phase Change Heat Exchanger for Next-Generation Nuclear Plant Process. *Heat Application, Journal of Nuclear Science and Technology*, 46(6), 534-544. DOI: 10.1080/18811248.2007.9711559
2. Idaho National Laboratory. (2008). Next Generation Nuclear Plant Project Preliminary Project Management Plan. PLN-2489 (INL/EXT-05-00952) Revision 1 [Dennis J. Harrell (2006)]. Retrieved from <http://www.inl.gov>
3. Sabharwall, P., Gunnerson, F., Tokuhiko, A., Utgiker, V., Weaver, K., & Sherman, S. (2007). Theoretical Design of a Thermosyphon for Efficient Process Heat Removal From Next Generation Nuclear Plant (NGNP) for Production of Hydrogen. INL/EXT-07-13433. Retrieved from <http://www.inl.gov>
4. Sabharwall, P. (2009). Engineering Design Elements of a Two-Phase Thermosyphon to Transfer NNGP Thermal Energy to a Hydrogen Plant. INL/EXT-09-15383 Revision 0.
5. Shi, S., Liu, Y., Yilgor, I., & Sabharwall, P. (2022). A Two-Phase Three-Field Modeling Framework for Heat Pipe Application in Nuclear Reactors. INL /JOU-21-64836-Revision-0. Retrieved from <http://www.inl.gov>
6. Nogueira, É. (2023). A Theoretical Approach to be Applied in Heat Exchangers by Using the Thermal Efficiency Concept and the Second Law of Thermodynamic. *Mechanical Engineering Advances*, 1(1), 92. <http://dx.doi.org/10.59400/mea.v1i1.92>
7. Nogueira, É. (2023). Localized Theoretical Analysis of Thermal Performance of Individually Finned Heat Pipe Heat Exchanger for Air Conditioning with Freon R404A as Working Fluid. *Journal of Materials Science and Chemical Engineering*, 11, 61-85. <https://doi.org/10.4236/msce.2023.118005>
8. Stojanović, A. D., Belošević, S. V., Crnomarković, N. D., Tomanović, I. D., & Milićević, A. R. (2022). NUCLEATE POOL BOILING HEAT TRANSFER Review of Models and Bubble Dynamics Parameters. *THERMAL SCIENCE*, 26(1A), 157-174. <https://doi.org/10.2298/TSCI200111069S>
9. Taler, D. (2016). Heat Transfer in Turbulent Tube Flow of Liquid Metals. *Procedia Engineering*, 157, 148–157. doi: 10.1016/j.proeng.2016.08.350
10. Ren, L., Tao, X., Zhang, L., Ni, M.-J., Xia, K.-Q., & Xie, Y.-C. (2022). Flow States and Heat Transport in Liquid Metal Convection. *J. Fluid Mech.*, 951, R1. doi:10.1017/jfm.2022.866
11. Petersen, H. (1970). *The Properties of Helium: Density, Specific Heats, Viscosity, and Thermal Conductivity at Pressures From 1 To 100 Bar and From Room Temperature to About 1800 K.* Risø National Laboratory. Denmark. Forskningscenter Risoe. Risoe-R No. 224.
12. Arp, V. D., & McCarty, R. D. (1989). *Thermophysical Properties of Helium-4 From 0.8 to 1500 K With Pressures to 2000 M Pa.*
13. Fink, J. K., & Leibowitz, L. (1979). *Thermophysical Properties of Sodium.* Chemical Engineering Division, Argonne Laboratory, ANL-CEN-RSD-79-1.



14. Golden, G. H., & Tokar, J. V. (1967). Thermophysical Properties of Sodium. Argonne National Laboratory, ANL—7323 Chemistry (TID-4500), AEC Research and Development Report.
15. Kays, W. M., & Crawford, M. E. (1993). Convective Heat and Mass Transfer. McGraw-Hill, Inc., New York.
16. Rohsenow, W. M. (1952). Heat transfer, a Symposium. Engineering Research Institute, University of Michigan, Ann Arbor, Michigan (1952).
17. Chen, J. C. (1963). A Proposed Mechanism and Method of Correlation for Convective Boiling Heat Transfer with Liquid Metals. Brookhaven National Laboratory, BNL 7319 (1963).
18. Fakheri, A. (2007). Heat Exchanger Efficiency. *Journal of Heat and Mass Transfer*, 129(9), 1268–1276. doi: 10.1115/1.2739620

Implementation of lean manufacturing in the cake mix production line and its effects on *Overall Equipment Effectiveness*

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ABSTRACT

The present work aimed to apply the Lean Manufacturing methodology in the cake dough production line of a food industry located in the Northwest of the state of Paraná. The Study of Methods and Times, Poka-Yoke and Kaizen methodologies were applied to obtain information about the process and verify changes through the construction of an action plan for improvements in the mixture filling machine. All tools were supported by brainstorming, carried out at the beginning of the study, to collect previous data and possible improvements, as well as during the application of Lean Manufacturing, aiming for continuous improvement. The results, expressed in packaging losses, demonstrated that, after applying the methodologies that supported the action plan, the percentages of packaging losses were reduced and remained constant in productions with and without setup for product exchange on the production line. Such results were evidenced with the significant increase in OEE, rising from 27% to 62% after the application of Lean Manufacturing in the production line. It is worth noting that some information was removed from the text due to the company's commitment to reliability.

Keywords: Continuous improvement, General Equipment Efficiency, Quality tools, Waste reduction, Toyota Production System.

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INTRODUCTION

After the Second World War, in the mid-1950s, engineers Taiichi Ohno and Eiji Toyoda adopted, at the Toyota factory, located in Japan, a more current approach to the production line, with the aim of eliminating waste. Taiichi Ohno is considered the creator of the Toyota Production System (*Just in Time*), and responsible for developing the Kanban System, which is based on the following principles: leveled production, reduction of preparation time, machine layout, work standardization, improvement of activities and automation (Black, 1991; Monden, 1984)

The concepts developed by Taiichi Ohno were based on two conceptions: the first, the perception of Henry Ford, founder of the Ford Motor Company, the first to integrate the entire production process, starting mass assembly in automobile manufacturing, and the second, by own observation of the dynamics in North American supermarkets, on a visit in 1956. In a book published by Ohno, entitled “The Toyota Production System: Beyond Large-Scale Production”, the author brings his experiences in the industrial scenario, in addition of the changes that led to the application of his methodology on a global scale. We call this context of applying changes to production processes *Lean Manufacturing* or Lean Manufacturing (ME) (Womack; Jones, 1998).

At the beginning of the 21st century, with the expansion of markets and technological needs, companies that began to deal with a new customer, demanding high-level products and services, began to look for an innovative management style, redefining their notions about quality. This imposed the search for continuous improvements and improvement of products, seeking the almost total elimination of waste (Brito; Dacol, 2008). Thus, to meet the demand for more flexible and lean production systems, the different industrial sectors continue to evolve with the application of practices proposed by Ohno, that is, Lean Manufacturing. Even though it was developed with an industrial focus, lean manufacturing can be defined as a “business system for organizing and managing product development, operations, suppliers and customer relationships”, being capable of application in any sector, including the of services, as it allows achieving high levels of quality, low costs and adequate delivery times (Womack; Jones; Roos, 1992).

For the creator of lean manufacturing, the elimination of waste and unnecessary elements, in order to reduce costs, consists of the basic idea that only what is necessary should be produced, at the time necessary and in the quantity required, as production occurs according to the demand of market, but this does not limit losses (Ohno, 1997). Lean manufacturing is the result of eliminating seven types of waste, also called losses, existing within a company, such as :

1. Loss due to overproduction, which is production beyond the scheduled or anticipated volume;
2. Loss due to waiting time, which consists of the time in which no processing, transportation or inspection is carried out;

3. Transport loss, which is the loss caused by unnecessary movements or temporary stocks;
4. Processing loss, in which machines or equipment are used inappropriately in terms of their ability to perform an operation;
5. Loss due to movement in operations, in which there is unnecessary agitation carried out by operators when carrying out an operation;
6. Loss due to defective products or rework, when products do not meet the requirements for use, requiring disposal or reprocessing;
7. Inventory loss, which consists of loss in the form of raw material inventory, work-in-process and finished product.

The Lean Manufacturing methodology has certain tools to be applied according to the needs of the industry to be analyzed. It is worth remembering that the analyzed scenario demands a set of observations until data is obtained so that action plans can then be carried out within the limits established by the company, as it is worth highlighting that the methodology is moldable to the reality in which it is being worked on. . The main tools used in the application of Lean Manufacturing are:

METHOD AND TIME STUDIES

The application of Method and Time Studies is essential for using the tools, in order to observe the current manufacturing environment and note what modifications will be necessary. Along with observation, counting time is essential to assess how much is being spent unnecessarily influencing the process. Both are related to the company's costs, which may be negatively influenced by bottlenecks. This visualization is extremely important, as it influences the entire modification process and any detail must be analyzed individually in order to characterize the damage that has been caused to the company and how to reverse this scenario.

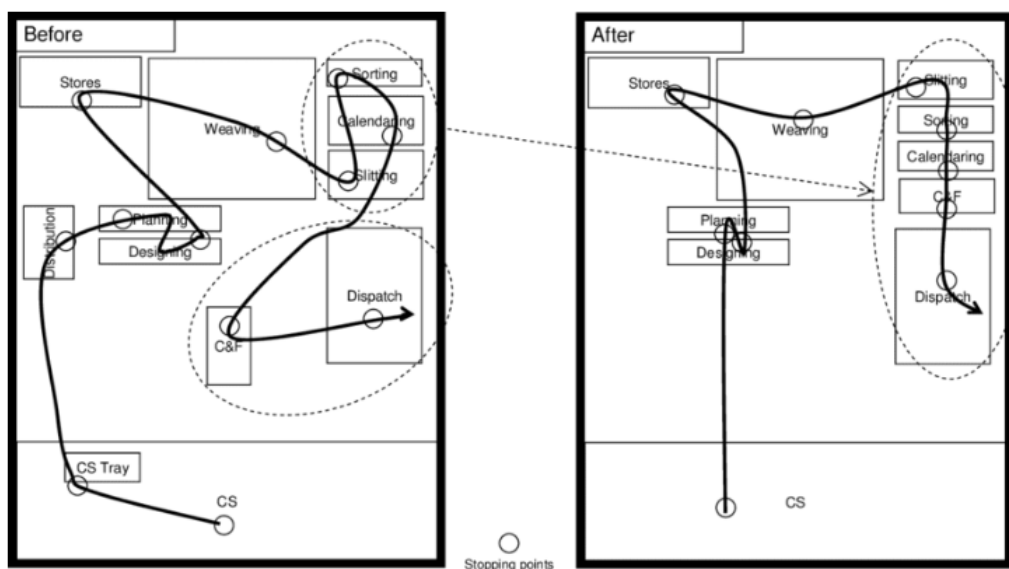
SMED (SINGLE MINUTE EXCHANGE OF DIE)

The SMED (*Single Minute Exchange of Die*) or Quick Tool Change methodology is applied when there is a need to diversify products in low production volumes, increasing the number of equipment involved in so-called *setups* . For the authors Sharma (2001), Agustin and Santiago (1996), Severson (1988), Moxham and Greatbanks (2001), Shingo's methodology is about reducing *setup* . This reduction is based on converting, as much as possible, internal *setup* , when carried out with the machine stopped, into external *setup* , carried out with the machine running, that is, activities in a factory environment, during rapid product change, present better results. results when the machine is not stopped for possible modifications, or when it is impossible not to have stops, this time is minimized (Shingo, 1988, 1989) . Monden (1994) proposed the presentation of a set of

techniques to achieve *setup reduction* using SMED, such as: knowing the real conditions of *setup activities* , filming to better understand time and movement restrictions and documenting the standard operations routine. With the SMED implementation, the Spaghetti Diagram appears as a tool to visually assist with changes in the process and in the layout of the environment, allowing to reduce the movement of employees and, consequently, bottlenecks, as previously mentioned.

Coutinho (2020), defines that the spaghetti diagram consists of displaying the routes, times and flows of movement on the factory floor. It is done using as a basis the local layout where the movements of each employee, the product and the time it takes to move are drawn. This diagram is of great importance for reducing time and standardizing movement. Figure 01 shows a Spaghetti Diagram before and after applying Lean Manufacturing.

Figure 01 - Spaghetti Diagram before and after applying the Lean Manufacturing methodology (Coutinho, 2020)



5'S

The 5'S methodology brings the idea of “senses” and basically consists of people's commitment to organizing the workplace by maintaining only what is necessary, cleaning the environment, standardization and discipline in carrying out work, with a minimum of supervision possible. The 5'S are the initials of five Japanese words, *Seiton*, *Seiri*, *Seiso*, *Seiketsu* and *Shitsuke* , translated as organization, use, cleaning, hygiene and discipline respectively. According to Egoshi (2006), this methodology was the basis of total quality in Japanese companies, and should also be considered as one of the basic philosophies to support Lean Manufacturing.

KANBAN

The Kanban system is another branch of the Toyota production system, which proposes, in an agile way, the formation of a *Post-it flowchart* aiming to make visible the way in which one is

working and the way in which one should work, in addition to what the work will look like after the modifications are completed. For Ohno (1997), the Kanban system is based on the standardization of the layout of equipment and workspaces, avoiding unnecessary movements of employees and wasted time, in other words, another methodology that can be evaluated using the Spaghetti Diagram.

FLOW MAPPING

To map the process, it is necessary to follow the production flow, observing its particularities, the aggregates or not that each operation contributes, as well as the time that the product remains in each of them (RIVERA; CHEN, 2007). In this sense, Lean Manufacturing seeks balance between production time and *Takt*, which is the available production time divided by the customer demand index.

Production time can be defined as the maximum time allowed at each workstation to complete tasks, before moving work to the next station. Along with production time, there is cycle time, a variable that establishes the production speed of a line (STEVENSON, 2001), determined according to the needs of the operation, such as checking the machine configuration, respecting its limits, prior to the start of production, correctly directed labor, as well as the availability of equipment. Thus, the application of process mapping is aimed at the proper functioning of the process, as the greater the demand, the more care must be taken with the flow time, so that the production line functions efficiently.

POKE-YOKE

Shimbun (1998) defines the term *Poka-Yoke* as a method that initially aimed to prevent human error at work, considered the main cause of defects, but which always aimed to obtain zero defects in the production line and eliminate inspections of quality. The implementation of *Poka-Yoke* is linked to the implementation of the kaizen philosophy, which has continuous improvement as its principle.

All the tools mentioned above have similar bases and aim, at continuous improvement, to reduce costs, correct bottlenecks and organize the process, undergoing changes only in the way and situations in which they are applied. The results of applying these tools can be expressed through the OEE (*Overall Equipment Effectiveness*) index, a measure of the effectiveness of equipment in the industry. For Garza et. al (2008), the OEE index, also known as General Equipment Efficiency, has been increasingly used in industry not only to control and monitor the productivity of equipment in the production line, but also as an indicator and engine for process improvement. and performance. Thus, the OEE is able to measure performance, identify development opportunities and direct the focus of improvement efforts in areas with specific demands. Therefore, associating the Lean

Manufacturing methodology with the OEE index results in noticeable changes on the “factory floor”, generally expressed in graphic form or percentages of production/productivity (GARZA et al., 2010).

However, for Jeong and Phillips (2001), there is a limitation on the types of losses that the system considers, and the assessment using the OEE index may cause distortions, such as attributing responsibility to production for losses that are not controlled by it. Losses resulting from supplier packaging problems or due to restarting the process after a power outage are examples of failures that have as their root cause problems external to a production process, but which can be commonly associated with production areas. Ljungberg (1998) defends the thesis that the losses considered by OEE must be associated with production or maintenance areas and not external areas.

To apply the tools of the Lean Manufacturing methodology, the cake mix production line with added fat in its composition was used as a source of study. According to ABIMAPI (2021), in a study carried out by Ital (Institute of Food Technology), cakes tend to be central foods for celebrations and domestic hospitality, associating the pleasure provided by the great diversity of recipes, with their nutritional value formed by composition that, in addition to flour, fats and sugar, usually includes eggs, milk, cocoa, fruits, nuts, seeds, among other very nutritious foods. Due to the wide variety of recipes, cakes can have very different amounts of calories and nutrients.

In Brazil, according to Nielsen/ABIMAPI data, in 2020, the total consumption of industrialized cakes was 0.042 million tons, with per capita consumption estimated at 0.196 kg. According to Resolution RDC n° 383, from Anvisa, of August 5, 2005, establishes the “Technical regulation that approves the use of food additives, establishing their functions and maximum limits for food category 7 - bakery products and biscuits”. Specifically, in item 7.3.2 - “Cakes, pies, sweets and confectionery dough, with chemical yeast, with or without filling, with or without topping, ready for consumption or semi-ready” of the table attached to the Resolution, are placed the limits for additives and adjuvants used for this group of products. In addition to RDC n° 383, of August 5, 1999, there is only RDC n° 285, of May 21, 2019, which prohibits the use of food additives containing aluminum in several food categories (ABIMAPI, 2021).

In recent years, trends in the consumer market have led to the launch of new products with ingredients that are better known to consumers and with fewer additives. However, the reformulation of traditional products, which are considered safe by Anvisa and the Ministry of Agriculture, Livestock and Supply (MAPA), is often not an easy task from technological and economic aspects (ABIMAPI, 2021).

Therefore, the present work presents an analysis of the implementation of Lean Manufacturing in the cake mix production line in a food industry located in the Northwest of Paraná, aiming at continuous improvement, reducing waste and increasing the OEE of the machine used to fill this product. mixture.

METHODOLOGY

On-site research, enabling interviews with different sectors involved in the cake mix production line (Selltiz et al., 1967).

The research took place with two main focuses: the first was a general observation throughout the production sector, especially the cake mix production line, seeking to identify and analyze losses during the process and the second aimed to evaluate the data and manuals from the company. The information was collected through operational data and the system used in the tactical management area with leaders, supervisors and collaborators in the sector. Subsequently, the results were evaluated and measured in the form of graphs, which were segregated according to each bottleneck present in the machine in question. The analyzes were carried out during the month of September 2023.

The study began with the choice of the company, which adopts the Lean Manufacturing methodology in its production process system. After the interview with the sector leader, she guided the data collection points, intended for the case study. The formulation was the first step towards better understanding the process. The formulation consists of three processes: weighing the components present in the cake mix, stipulated by the company's quality control, inserting the raw materials into the mixer, where fat is added and, finally, sieving. Figure 02 shows all the previously mentioned steps in the filling machine for the production of cake mix.

Figure 02 – Weighing, mixing and sieving steps in the filling machine of the cake mix production process.

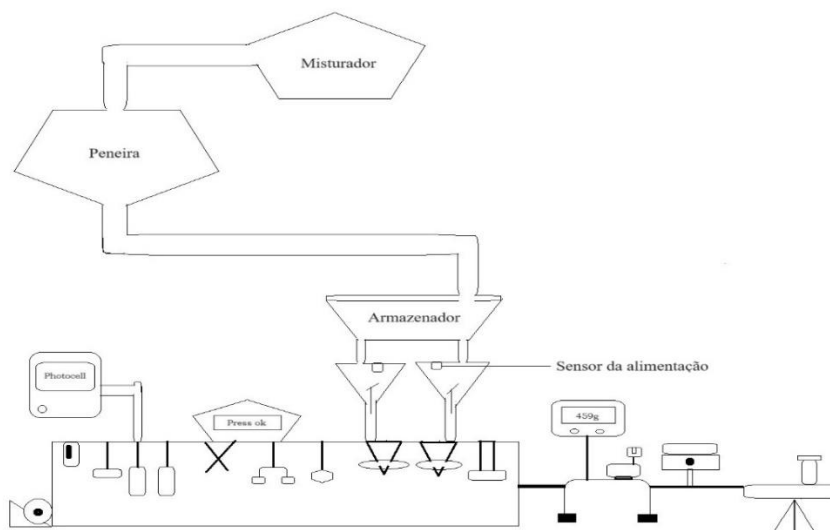
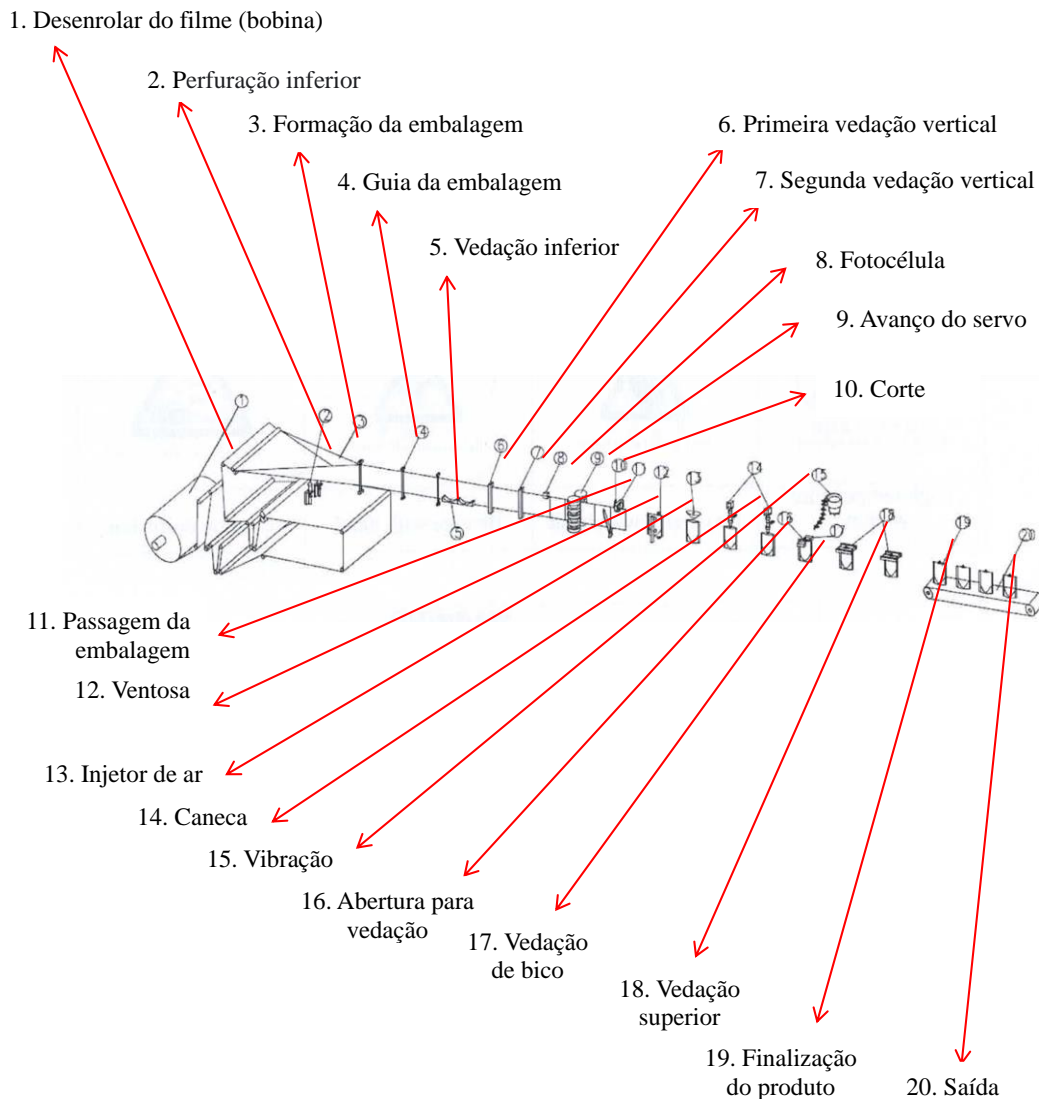


Figure 03 shows the flowchart of the internal part of the filling machine. Empty packages are formed at points 1 to 13, where the coil unwinds following the pattern configured on the machine panel. The mug (14) is responsible for filling the product into the package, which undergoes vibration (15) to accommodate the mixture, as from points 16 to 20, adjustments take place at the top

of the package. This vibration is important so that the product is not retained when sealed, as if it is poorly sealed, reprocessing and loss of packaging will occur. The packages containing 500 g of cake mix are sent to the secondary package, cardboard boxes, where 12 packages are manually stored by line employees.

Figure 03 – Flowchart of the internal part of the filling machine.



Colauto and Beuren (2004) express that the interview is a technique for obtaining information in which the researcher personally presents himself to the sample of the selected population and formulates questions, with the objective of obtaining data necessary to answer the question studied. Therefore, any understanding of the process was essential for the course of the study, both observation and dialogue.

When observing the machine, demonstrated by Figures 02 and 03, information was sought through interviews with employees on the production line to better understand the problems, attracting the team's attention to correct errors. Through dialogue, questions were raised regarding

the work instructions applied and the machine's installation history, raising key points for understanding the process. During the course of the research, methods and questions were created that led to challenges in the company's mechanical sector, where it was noted that the parameters were different from the manual studied to carry out the case study. Through discussions, based on experience and the methodology applied, new measures were identified to be taken during the process.

The *brainstorming* carried out led to the search for data prior to the beginning of the application of the methodology, such as graphs, the global efficiency index, justifications for machine stops, behavior of the entire manufacturing environment in the face of the problem encountered, spreadsheets of values involving the entire process, in addition to the machine manual, for a better mechanical understanding of the machine. The objective of analyzing spreadsheets, efficiency indices and graphs prior to the application of lean manufacturing is to compare values after the action plans adopted, proving or not the effectiveness of the study.

In the case study, the following tools of the Lean Manufacturing methodology were applied: Study of Methods and Times, *Poka-Yoke* and Kaizen.

RESULTS AND DISCUSSION

Using Lean Manufacturing tools, such as Study of Methods and Times, *Poka-Yoke* and Kaizen, action plans began, aiming to correct the process, using the methodology, generating tables and using measuring devices for collection of the data. Table 01 shows the results generated after applying the tools mentioned above.

Table 01 – Results of applying the Lean Manufacturing methodology tools

APPLICATION OF THE LEAN MANUFACTURING METHODOLOGY

WASTE	ACTION PLAN	DESCRIPTION	RESULT
Machine interfering with the top of the packaging during the filling process	The researcher and machine operator began correcting the packaging nozzles within their reach.	Using a pointed tool and applying a circular motion, the packages were opened manually.	Significant reduction in packaging loss and reprocessing.
Expulsion of good packages for passing alongside non-conforming packaging on the scale	Analyze the weight at the end of the filling process or collect the non-conforming package.	At the end of the filling process, it must be weighed using a table scale whether the package that was expelled next to the empty one is actually compliant or the empty package must be collected before the machine's scales reach it, taking it to the packing table.	Significant reduction in packaging loss and reprocessing.
Product interfering with the identification of the machine's power system (sensor)	Constant cleaning of the sensor.	Check if there is any product dirt on the sensor and, by tapping the machine with a tool, remove the residue.	Significant reduction in packaging loss and reprocessing.
Excess weight caused by defects in the dosers	Constant correction on the machine panel.	The cake mix is stored in mugs, not filled into packaging due to machine failures, so correction becomes constant through observations.	Significant reduction in packaging loss and reprocessing.
Top of the machine without wind seal cover	Change in wind flow at the top of the machine.	The sector's ventilation system was positioned differently, so that the air did not go towards the top of the machine.	Significant reduction in packaging loss and reprocessing.
Dater failure	Constant observation of the date device and changes to the configuration panel.	When the panel points out the lack of standardization of the date, the operator promptly makes adjustments.	*The time stipulated for the research was not enough to present relevant results
Scissors fail when cutting packaging	Measuring packaging thickness	Using the thickness measuring device found in quality control, the research began with ten packages each production, having a visualization of the standards.	*The time stipulated for the research was not enough to present relevant results
Product Feature	Analysis of the moisture content of the product to be packaged.	Using the moisture measuring device found in quality control, one package per production is taken to the counter that expresses the humidity every one minute, totaling ten. The last value expressed is the quantified one and must therefore be inserted into a spreadsheet to create a standard and compare it to the theoretical values of methodologies.	*The time stipulated for the research was not enough to present relevant results, but significant values were found.
Machine traction out of parameters	Panel adjustment.	Using a ruler, the beginning of the package is measured to the white stripe, where the pattern is coded by the photocell and estimated. With the value found, adjustments were made to the panel. Another action plan adopted was the translation of the manual for better understanding.	Significant reduction in packaging loss and reprocessing.
Sensor light identifying fault	Constant observation of the light sensor.	Research still to be developed.	*The time stipulated for the research was not enough to present relevant results

With the information in Table 01, it was possible to create tables and graphs that showed the reality of the process, making it possible to identify, more easily, the problems associated with it. Table 02 had the purpose of collecting data regarding process errors and waste classification.

Table 02 - Descriptive table of observed waste and causes.

WASTE IN THE PACKAGING PROCESS						
DESCRIPTIVE	CAUSE					
	PACKAGING	ADDITION	WAIT	MOVEMENT	MACHINE DEFECTS	PRODUCT LOSS
Machine interfering with the top of the packaging during the filling process	X				X	X
Expulsion of good packages for passing alongside non-conforming packaging on the scale					X	
Product interfering with the identification of the machine's power system (sensor)	X	X			X	X
Excess weight caused by defects in the dosers	X	X			X	
Loss of cake mix due to excess product in the dispensers					X	X
Top of the machine without wind seal cover	X					X
Scissors fail when cutting packaging	X				X	X
Product Feature	X	X				X
Machine traction out of parameters	X				X	X

Table 02 presents a description of the waste in the cake mix packaging process. The table was filled in with “x” in the causes of waste corresponding to each of the descriptions in the table. It appears that the selected causes are: loss of packaging (PACKAGING), the addition of product during packaging (ADD), waiting for the procedure carried out to take place, such as the formulation of the raw material, mixing time, arrival of the product to the production line, the starting of the machine, the organization of the process, among others (WAIT), how much is necessary for the activity carried out and whether there is dispersion of employees during that moment (MOVATION), the defects presented by the machine during processing (DEFECTS) and reprocessing and/or rejects during process failure (PRODUCT LOSS). Therefore, through the analyzes of Table 02, the problems to be analyzed were formulated, possible changes were constructed, the tool to be used was identified, the variations in the process that were presented daily were observed, and significant strategies were drawn up. to obtain data that leads to the result.

According to the results presented in Table 02, it is evident that packaging loss is the biggest problem in the cake mix production line. The data was promptly processed and possible bottlenecks were identified. Packaging is used to package products for transportation and storage in order to

protect and maintain product quality. According to Arnold (2015), they can be divided into two parts: primary packaging and secondary packaging. Primary packaging is directly linked to the product, secondary packaging groups and stores product units. During the analysis it was noted that the loss started from the primary packaging, which occurred through machine failures, incorrect adjustment by operators and even characteristics of the packaged product. Losses in general are the major problems in production processes, which are embedded in complexity, mainly in controlling losses and reducing process costs, often being a point of difficulty for the manager (COSTA, 2012).

Using the description in Table 02, we can individually address each of the problems involved in the loss of packaging in the production process. Regarding problem 1, machine interfering with the top part of the packaging during the filling process, when questioning the operator, he mentioned that it was a suction cup problem (Item 1- Figure 02), which did not open the top part of the packaging to insert the product . By viewing the process, it was observed that the bottleneck in question was the air injector of the packaging, which mistakenly rested on the opening of the packaging, causing folding, and thus generating reprocessing through the mugs (Item 14 - Figure 02). This observation stage was essential for obtaining the first results, as after observation, the openings were made manually, between the air injector and the mugs, finally resulting in the product being packaged, carrying out the first action plan to contain losses. .

For problem 02, “Expulsion of good packages due to passing alongside non-conforming packaging on the scale”, indicated that packages filled correctly, suffered interference, through the total mass, when passing through the scale next to packages filled outside of standards. In several situations, non-standard packaging, which was generally empty packaging, levitated, due to the sector's ventilation, and fell close to correctly packaged packages, indicating a non-standard mass on the scale. Upon observing this situation, the comparison between machine scales and table scales began. The solution was obtained by confirming, using a table scale, that the package was compliant. When this happened, it went to packing; if it didn't happen, it was destined for reprocessing.

Problem 3, “Sensor interfering between the machine's power supply communication and the storage box”, occurred when the cake mix itself caused dirt to accumulate on the filling machine's sensor. The purpose of the feed sensor (Figure 02) is to identify whether there is product in the package feed or not. From observation, it was noted that the storage box (Figure 02) did not communicate with the feeder, reducing the filling of the product through the mug (Item 14 - Figure 03). This perception was also evident when noticing that the light point, attached to the sensor, was unregulated, because, according to the correct functioning of the machine, the red light expressed that the power supply was full and the same light was off, which was necessary. complete the machine with the product.

During observation, it was observed that the light remained on (red) while the feed was empty, initiating a failure process in the machine, called “sieve return”, in which even though the filling request was made by the machine, this was not done. corresponded because the sensor continued to identify that there was product in the supply. When the red light turned off, the product went down from the storage box to the feeder, returning to the correct filling process. Until communication was established, packets were lost. To minimize this problem, manually tap the sensor or quickly configure the machine.

Interconnected with problem 3, there are problems 4 and 5, “Excess weight caused by defects in the dosers” and “Loss of cake mix due to excess product in the dosers”, respectively, in which when regularizing the feed of the machine, due to the problem with the red or off light, the commands were obeyed quickly, filling the packages with an additional amount of product, filling more than necessary. The action plan was to translate the machine manual for operators and employees, providing reading as a better understanding of the process.

Problem 6, “Top part of the machine without a wind seal cover”, occurred externally to the machine, due to the ventilation of the sector which, as it was located above the machine, caused the packages to bend in the nozzle, interfering with the standard weight. The direction of ventilation was then changed to resolve this problem.

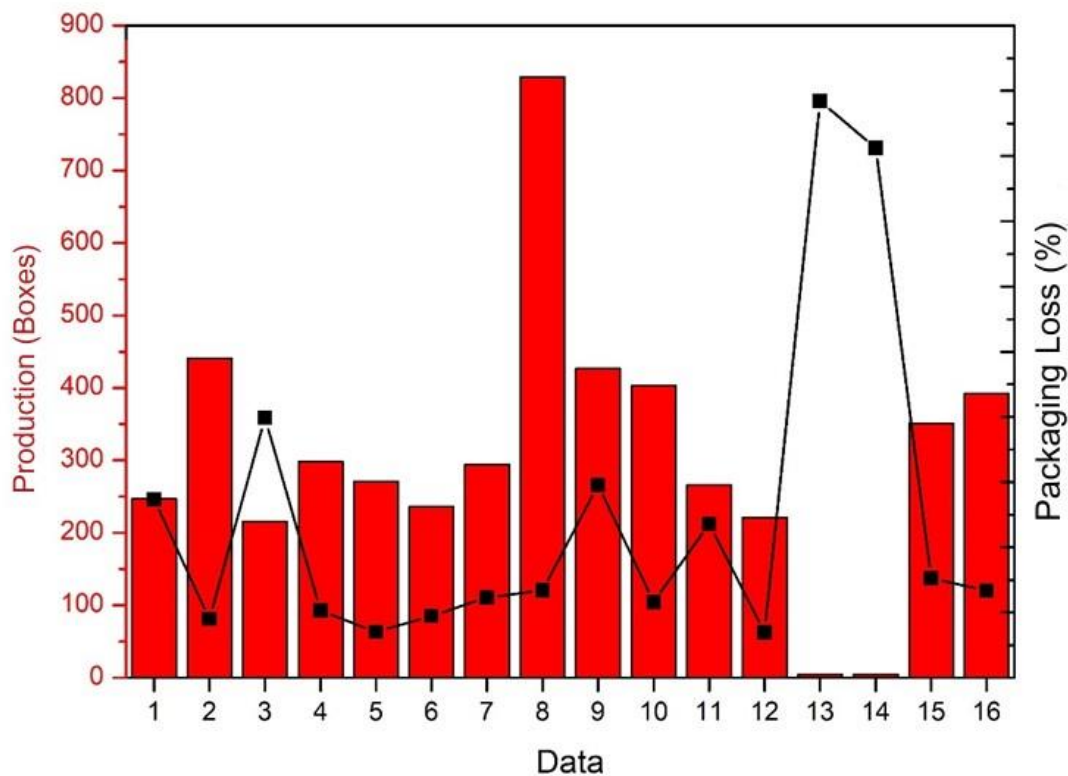
Problem 7, “Scissors failed when cutting packaging”, was verified when the packaging that, when going through the cut (Item 10 – Figure 03), suffered damage. The corrective action began with measuring the thickness of the packages, a method used for quality control in continuous processes. At each processing, a sample of 10 empty and completely clean packaging was collected, so that the thickness could be measured using a thickness gauge. This data collection was used by quality control, which did not yet contain adequate standardization of the coil.

Another approach was problem 8, “ Product characteristic”, a point that clearly demonstrates that the variables of a process shape the application of the Lean Manufacturing methodology, given that this case study has a food product as its commodity, which suffers physicochemical changes. In this case, the consistency of the product in relation to ambient temperature was taken into account, which significantly changed the process. The product contains fat in its composition, which, due to the heat in the sector, modified the characteristics of the product. The action plan began with the moisture analyzer, a device that prints out the moisture content of the food for ten minutes. Another approach was to identify the supplier and standardize the raw material in question, applying flow mapping. It was noted that it would be necessary to use internal ventilation in the machine, which would not interfere with other problems. The company's maintenance sector performed in accordance with what was analyzed.

Finally, problem 9, “Machine traction outside of parameters”, tried to analyze the machine display, noting that the settings were in another language, leading to a translation of the manual for better understanding by the operators. Another action plan was the observation of numerical values, bringing standardization. When contacting the maintenance sector, they inquired about the existence of a mathematical method or method of measuring this traction that interfered with the length of the packages (Item 03 Figure 03). The packaging obtains an appropriate length for packaging, therefore, through measurements taken with a 30 cm ruler, these parameters were established according to the coil of the respective flavor to be packaged, as each one had its own characteristics of thickness and stripe that they were identified by the photocell (Item – 08 Figure 03).

All descriptions highlight the loss of packaging and product as the biggest marker of error during the process, caused by machine defects. Soon, the action plans detailed in Table 01 began, segregating the tables to obtain specific values and providing visual graphics that demonstrate the results. Figure 04 shows the loss of packaging in relation to the daily production of boxes, with 12 packages each.

Figure 04 – Loss of packaging in relation to the production of cake mix boxes.



To better understand Figure 04, some points must be addressed, such as: identifying the date with numerical values from 1 to 16, as during the research period there was a *setup application on the same day* , which consists of the period in which the Production is interrupted so that equipment can be adjusted to change the product. Table 03 expresses the production values, in boxes, for the dates indicated by 1 to 16 in Figure 04.

Table 03 - Production referring to the day for *setup analysis* .

PRODUCT	DATE	DAY	PRODUCTION (boxes)
Ready party cake mix	1	09/05/2023	247
Ready-made anthill cake mix	two	09/06/2023	441
Ready-made corn and cheese flavored cake mix	3	09/11/2023	216
Ready cassava flavor cake mix	4	09/11/2023	298
Ready-made lemon flavor cake mix	5	09/12/2023	271
Ready-made cornmeal flavored cake mix	6	09/12/2023	236
Chocolate flavored cake mix	7	09/12/2023	294
Chocolate flavored cake mix	8	09/13/2023	829
Carrot flavored cake mix	9	09/18/2023	427
Vanilla flavored cake mix	10	09/19/2023	403
Coconut flavored cake mix	11	09/19/2023	266
Pineapple flavored cake mix	12	09/20/2023	221
Ready-made cassava flavor cake mix (export)	13	09/20/2023	5
Ready-made cornmeal cake mix (export)	14	09/20/2023	5
Ready-made anthill cake mix	15	09/20/2023	351
Ready chocolate cake mix	16	09/22/2023	392

Another approach is that the percentages obtained are real values, but will not be demonstrated in the relevant work due to an ethics agreement with the company. Therefore, through visualization it is clear to see the proportion of waste caused in relation to each day of production. From Figure 04 and Table 03 , it can be seen that there was no standardization between production and packaging losses, as waste was greater in expressly small processes. It was then associated with the adjustment of the machine, which can be linked to a considerable percentage when examined individually in relation to the total loss of the process. On dates 13 and 14, which refer to September 20, 2023, the production of just 5 boxes for export represented the biggest packaging loss in the entire month. The percentage calculation of packaging loss occurs through the production carried out, quantity per box, packaging weight and waste, then obtaining the necessary values.

Table 04 shows the dates and days on which the machine was set up, that is, when the machine was adjusted to produce a new flavor cake mix.

Table 04 - Date of data collection with segregation of losses during the process.

PRODUCT	DATE	DAY
Ready-made corn and cheese flavored cake mix	1	09/11/2023
Ready cassava flavor cake mix	two	09/11/2023
Ready-made cornmeal flavored cake mix	3	09/12/2023
Chocolate flavored cake mix	4	09/12/2023
Carrot flavored cake mix	5	09/18/2023
Pineapple flavored cake mix	6	09/20/2023
Ready-made cornmeal flavored cake mix	7	09/20/2023
Ready-made anthill flavored cake mix	8	09/20/2023

From Table 04, it is possible to see that in four days production had to be stopped to adjust the machine to produce another flavor of cake mix, which could lead to packaging and product losses due to the new adjustment. Aiming to demonstrate the segregation of these losses, Figure 05 shows the values of packaging losses segregated into three different causes, namely the adjustment of the machine, the production process itself and defects found in the machine during the processing of cake dough packaging.

Figure 05 - Loss of packaging due to machine adjustment, process and defects.

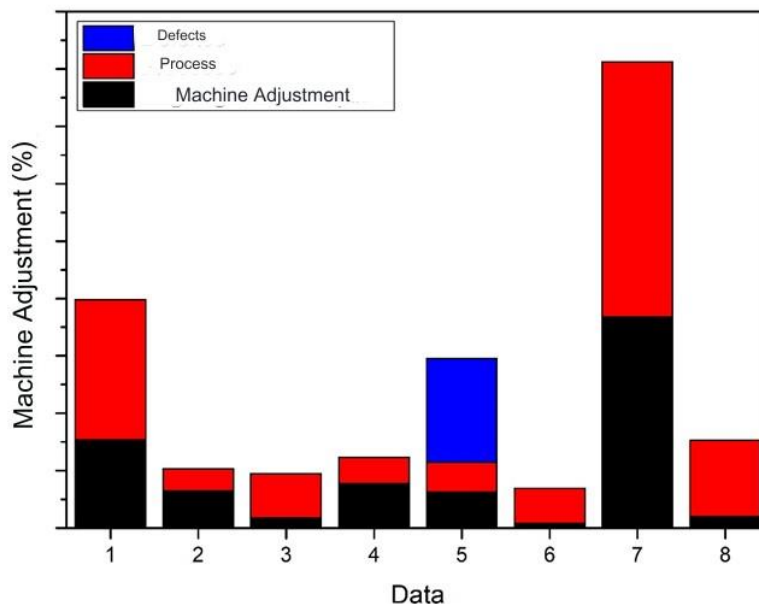


Figure 05 shows that, on most days, the main causes of packaging loss are due to machine adjustment and the process, involving the internal part of the machine (Figure 03), power supply (Figure 02) and physical characteristics. product chemicals. Only on date 5, referring to September

18, 2023, the defects could be seen as a cause of packaging loss, being determined by the lack of standardization of the machine system, which had not been correctly installed since its purchase by the sector. The lack of support from the supplier led to all errors in standardization and understanding of the machine, as no training was applied to line, operator and maintenance employees. It is also worth highlighting that there is a difference in the analysis of the two main reasons for waste, because while the loss during the process can be considered high in comparison with the adjustment of the machine, it is worth remembering that the process time is much longer than the machine adjustment time, that is, losses due to machine adjustment have a much greater impact on the total, highlighting the points mentioned above regarding the lack of correct parameters. Waste due to adjustment occurs in a few minutes, while losses in the process occur over seven hours of production. Again, it is worth highlighting that the percentage values were removed from the graph due to the ethics contract with the company.

Thus, using the data in Figures 04 and 05 and Tables 03 and 04, it is possible to verify that the application of the Lean Manufacturing methodology took place efficiently in the period from September 11 to 13 (dates 4 to 8 – Figure 03) because, after a high value of packaging loss, there was a considerable drop and maintenance of these values in a range below that practiced by the company. In Table 01, it is possible to verify that an action plan was to correct the packaging nozzles within the reach of the operator and the researcher and that the description of this action plan was that, using a pointed tool and applying circular movement, The packages were opened manually, generating less lost packaging and reprocessing. The values for the drop and maintenance of packaging loss are a reflection of this action plan, applied both to the process day without and to the process day with setup, as demonstrated by Table 04 and Figure 05 because, exactly dates 2, 3 and 4, which present the lowest values of combined losses, are the dates on which the action plan, described previously, was applied to the process. However, it is worth highlighting that the process is dynamic and problems become evident during it, interfering with loss control, which can be demonstrated by the increase, shortly afterwards, in the percentage of packaging loss in the cake mix production process. .

To analyze the reasons caused during the process, the loss by scale was prepared, demonstrated by Table 05, in which the percentage values were expressed on a scale from 1, which means a negligible loss of packaging, to 5, whose loss was considered criticism

Table 05 - Packaging loss by scale.

PACKAGE LOSS							
PRODUCT	DATE/DAY	LOSS SCALE					REASONS RELATED TO PRODUCTION
		1	two	3	4	5	
Party flavored cake mix	(1) 5/sep			x			Opening of the top packaging with deformation Photocell failure
Tingling flavor ready mix	(2) 6/sep	x					Identification error in the power sensor
Ready-made corn and cheese flavored cake mix	(3) 11/Sep					x	Feed doser reaching edge of packaging Dater failure
Ready cassava flavor cake mix	(4) 11/Sep	x					Machine interference when opening packaging for filling Inadequate packaging for filling
Lemon flavored cake mix	(5) 12/Sep	x					No apparent cause
Ready-made cornmeal flavored cake mix	(6) 12/Sep	x					Identification error in the power sensor Loss due to regulation Machine interference when opening packaging for filling
Chocolate flavored cake mix	(7) 12/Sep	x					The sieve return does not match the sensor Drop in the machine's light panel
Chocolate flavored cake mix	(8) 13/Sep	x					The sieve return does not match the sensor Machine deconfiguration
Carrot flavored cake mix	(9) 18/Sep					x	Cut without parameter Machine defect Photocell failure
Vanilla flavored cake mix	(10) 19/Sep	x					Physicochemical characteristic of the product interfering in the process Misaligned pull length Photocell failure
Coconut flavored cake mix	(11) 19/Sep					x	Non-standard date Misaligned pull length Physicochemical characteristic of the product interfering in the process
Pineapple flavored cake mix	(12) 20/Sep	x					Proper process.
Ready-made anthill flavored cake mix	(15) 20/Sep		x				Machine interference when opening packaging for filling
Chocolate flavored cake mix	(16) 22/Sep	x					Identification error in the power sensor Machine interference when opening packaging for filling

The range of 5 classifications was carried out from the highest value collected during the study to the lowest, clearly bringing the results obtained, since, after applying the methodology, the vast majority remained on scale 1 of losses, demonstrating that the observation and application within the scope of the research had effects.

An addendum to the case study carried out, quality control research was developed, such as controlling the humidity of the food using the moisture analyzer device and measuring the thickness of the packaging, using the Specimeter Micrometer Thickness Gauge, to control the physical-chemical characteristics of the product and for cutting analysis, respectively. In addition to translating the machine manual, for better understanding of the parameters.

The OEE projection showed that after the improvements implemented there was a significant increase from the percentage of 27% to 62% contained in the system and demonstrated in a meeting with the sector, however all data projections will not be expressed graphically as they are internal



control of the company, in addition to maintaining the ethics contract with the company that provided conditions for the research to be carried out.

CONCLUSION


Based on the analysis of the case study, the *Lean Manufacturing methodology* is a satisfactory concept for implementation in the processing of the food industry, resulting in an increase in the global efficiency index (OEE) from 27% to 62%, in addition to reducing waste. , which were demonstrated in internal factory graphics for employees. The action plans based on the tools used, including Study of Methods and Times, *Poka-Yoke* and Kaizen, were possible from *brainstorming* and observation. The application is adaptable to the scenario found, protecting the limits of the company, in which all sectors are involved, such as maintenance, leaders and employees, as each administration presents its own way of managing beyond Lean Manufacturing.

REFERENCES

1. ABIMAP, Associação Brasileira das Indústrias de Biscoitos, Massas Alimentícias e Pães & Bolos Industrializados. (2010). Disponível em: <http://www.abimapi.com.br/>. Acesso em: 18 de setembro, 2023.
2. AGUSTIN, R.; SANTIAGO F. (2006). Single-Minute Exchange of Die. In: IEEE/SEMI ADVANCED SEMICONDUCTOR MANUFACTURING CONFERENCE, 1996. Proceedings.. Piscataway, NJ: IEEE Conference. p. 214-217.
3. ARNOLD, J. R. T.; RIMOLI, C.; ESTEVES L. R. (2015). Administração de Materiais: uma introdução. 1º Edição, Editora Atlas, São Paulo.
4. BLACK, J. T. (1991). The design of the factory with a future. Nova Iorque.
5. BRITO, F. O.; DACOL, S. (2008). A manufatura enxuta e a metodologia Seis Sigma em uma indústria de alimentos. Rio de Janeiro.
6. COLAUTO, R. D.; BEUREN, I. M. (2004). Coleta, Análise e Interpretação dos Dados. Como elaborar trabalhos monográficos em contabilidade: teoria e prática. 2 ed. São Paulo.
7. CONNOR, G. (2006). Poka-yoke: Human-Proof your Process. Journal of Industrial Maintenance e Plant Operations, p.12-14.
8. COSTA, J. E. L. (2007). Gestão em processo produtivo. Ibplex. Curitiba.
9. COSTA, J.E.L. (2012). Gestão em processos produtivos. 1ºEdição, Editora Inter Saberes. Curitiba.
10. COTRIM, S. L. et al. (2019). Implantação do programa 5S em uma fábrica de vassouras de garrafa PET a partir do Diagrama Espaguete. v. 16, n. 3.
11. COUTINHO, T. (2006). O diagrama de espaguete atua como grande aliado nos projetos de otimização de layout. Disponível em: <https://www.voitto.com.br/blog/artigo/diagrama-de-espaguete>. Acesso em: 15 de setembro, 2023.
12. EGOSHI, K. (2006). Os 5'S da administração japonesa. Artigo disponível em http://www.infobibos.com/Artigos/2006_2/5S/Index.htm.
13. FURLANI, K. (2022). Estudos de Tempos e Métodos. Disponível em: <https://furlani.eng.br/2022/10/23/estudo-de-tempos-e-metodos/>. Acesso em: 19 de setembro, 2023.
14. GHINATO, P. (1996). Sistema Toyota de Produção: mais do que simplesmente Just-in-time. EDUCS. Caxias do Sul.
15. GIL, A. C. (2002). Como elaborar projetos de pesquisa. 4. ed. São Paulo.
16. IMAI, M. (1990). Kaizen a Estratégia para o Sucesso Competitivo. IMAM São Paulo.
17. JEONG, K. Y.; PHILLIPS, D. T. (2001). Operational efficiency and effectiveness measurement. International Journal of Operations and Production Management, v. 21, n. 11, p. 1404-1416.

18. LIAN, Y.; LANDEGHEM, H.V. (2002). An application of simulation and value stream mapping in Lean Manufacturing. Department of Industrial Management, Ghent University, Technologiepark, 903, B-9052, Belgium.
19. LIKER, J. K.; MEIER, D. (2007). O modelo Toyota: Manual de Aplicação. Porto Alegre: Bookman.
20. LIMA, S. (2005). A Ferramenta 5S e suas Implicações na Gestão da Qualidade Total. Academia: Accelerating the world's research.
21. LJUNGBERG, O. (1998). Measurement of overall equipment effectiveness as a basis for TPM activities. *International Journal of Operations and Production Management*, v. 18, n. 5, p. 495-507.
22. MONDEN, Y. (1984). Sistema Toyota de produção. São Paulo: IMAM.
23. MONDEN, Y. (1994). Toyota Production System: An integrated approach to just-in-time. London: Chapman e Hall.
24. MOXHAM, C.; GREATBANKS, R. (2001). Prerequisites for the implementation of the SMED methodology. *International Journal of Quality e Reliability Management*, v. 18, n. 4, p. 404-414.
25. OHNO, T. (1997). O Sistema Toyota de Produção: Além da Produção em Larga Escala. Porto Alegre: Bookman.
26. REYS, G. (2010). Uma abordagem sistemática para diagnosticar o status atual dos sistemas de gestão da qualidade e processos de negócios. *Business Process Management Journal*, Vol. 16 N° 1.
27. RIVERA, L.; CHEN, F. F. (2007). Measuring the impact of Lean tools on the cost–time investment of a product using cost–time profiles. *Robotics and Computer-Integrated Manufacturing*, v.23, n.6, p.684-689.
28. ROTHER, M. & SHOOK, J. (1999). Aprendendo a enxergar. Lean Institute Brasil. São Paulo.
29. SELTZ, et al. (1967). Métodos de pesquisa nas relações sociais. São Paulo.
30. SEVERSON, D. (1988). The SMED system for reducing changeover times: an exciting catalyst for companywide improvement and profits. *P&IM Review with APICS News*, v. 8, n. 10, p. 10, 15-16.
31. SHARMA, V. (2001). SMED for high-mix assembly. *Circuits Assembly*, v. 12, n. 1, p. 62, 64-68.
32. SHIMBUN, N. K. (1988). Poka-yoke: improving product quality by preventing defects. Portland.
33. STEVENSON, W. J. (2001). Administração das operações de produção. Rio de Janeiro: LTC.
34. WOMACK, J. P.; JONES, D.T.; ROOS, D. (1992). A mentalidade enxuta nas empresas: elimine o desperdício e crie riqueza. Rio de Janeiro: Campus.

Management of urban solid waste in the city of Manaus-AM. Thermal characterization for power generation

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ABSTRACT

With a population of two million inhabitants, Manaus – AM has undergone a considered industrial development and consequent urban development, resulting in a significant increase in the need for urban energy and in the control of waste generated. All municipal solid waste (MSW) is currently deposited in landfills, causing health problems to the population, contamination of soils, rivers, and groundwater. This article proposes the use of incineration to recover energy from urban solid waste to produce electricity in the metropolitan region of Manaus - AM. Energy characterization tests were carried out on MSW collected from various neighborhoods of the city, such as: gravimetry, thermogravimetry (TGA), immediate analysis, elemental analysis and superior calorific value (PCS) tests. Finally, the lower calorific value (PCI) was determined. The high percentages of recyclable materials, above 50%, combined with PCI values, presenting values between 15,000 and 19,000 kJ/kg on dry days, calorific value equivalent to the fuels cataloged in the bibliography such as lignite, kiln-dried firewood and coconut shells (17,000 kJ/kg), Coal, (15,000 KJ/Kg), showed promise in a future decision-making for the treatment of MSW by incineration.

Keywords: Municipal solid waste, Waste incineration, Energy recovery, Sustainable energy generation, Energy potential of solid waste.

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INTRODUCTION

Nowadays, controlled dumps and landfills occupy large areas in large urban centers, contaminating soils and groundwater, attracting animals and insects, increasing the risks to the health of the population and increasing the emission of greenhouse gases. A considerable portion of this MSW ends up in the beds of rivers and streams, clogging rainwater systems and causing flooding. These social and environmental benefits alone justify the need to solve this problem. Federal Law No. 12,305/10, which instituted the National Solid Waste Policy (PNRS), gave a period of 10 years for the problems arising from MSW to be extinguished. By the end of the deadline, approximately 60% of the country's cities had not yet achieved this goal.

Between 2010 and 2022, MSW generation in Brazil registered a considerable increase of 20.90% (from 67 million to 82 million tons per year), three times the population growth rate of 6.46% in the same period. In turn, per capita generation increased from 348 kg/year to 381 kg/year (ABRELPE, 2022). On the other hand, there would be economic and sustainable benefits if there were energy recovery through the thermal treatment of MSW, since there is a viable and attractive possibility of integration with other processes, such as recycling and composting, as well as with the reduction of waste disposal in landfills and dumps and its consequences (ABREN, 2020).

In the city of Manaus, capital of the state of Amazonas, the largest state in Brazil, with its ecological and environmental riches, there is no thermal treatment of solid waste. 2,800 tons of MSW collected every day are landfilled at the site. The city has no area or interest in building another landfill, and must hire these services from private companies. In addition, the IBGE classified Manaus as the fourth worst city in Brazil with garbage accumulation in public places. Approximately 6.2% of the surroundings of the households have accumulated garbage. Just near the creeks there are 108,000 residents affected by unpleasant odor, diseases and a lot of dirt. A total of 345,000 families are affected by the dirt in the streams of Manaus (SEMULSP MANAUS, 2021).

Currently, the situation of MSW management in Manaus - AM Almost all MSW is paid to be filled in (98%), occupying an area of 66 hectares that has been in operation since 1985 and is due in 2024. The technology for solid waste management was only used in 2006, that is, for more than 20 years it operated as an open-air dump, which resulted in contamination of some streams such as the Bolivia and Conceição bridge, and the Alta do Tarumã waterfall. The landfill also generates greenhouse gas emissions and a bad smell at the site. The low recycling rate (1.68%) negatively impacts the income expectations of collectors' cooperatives and other related activities (ABRELPE, 2022).

Abren (2019) reveals that the waste sector is responsible for 11% of the total greenhouse gases emitted into the atmosphere. The methane (CH₄) emitted is 25 times more harmful than carbon dioxide (CO₂). And the construction of landfills is continuous, every ten years a sanitary landfill is

increased in the world. Landfills are still used all over the world as a waste destination. The global overview of MSW destination can be shown in Figure 1. It can be seen that adding up all the existing types of landfills results in a total of 70% and the composting, recycling and incineration processes add up to 30% (ABREN, 2019).

Figure 1. Destination of MSW in the world. Adapted from ABREN, 2019.

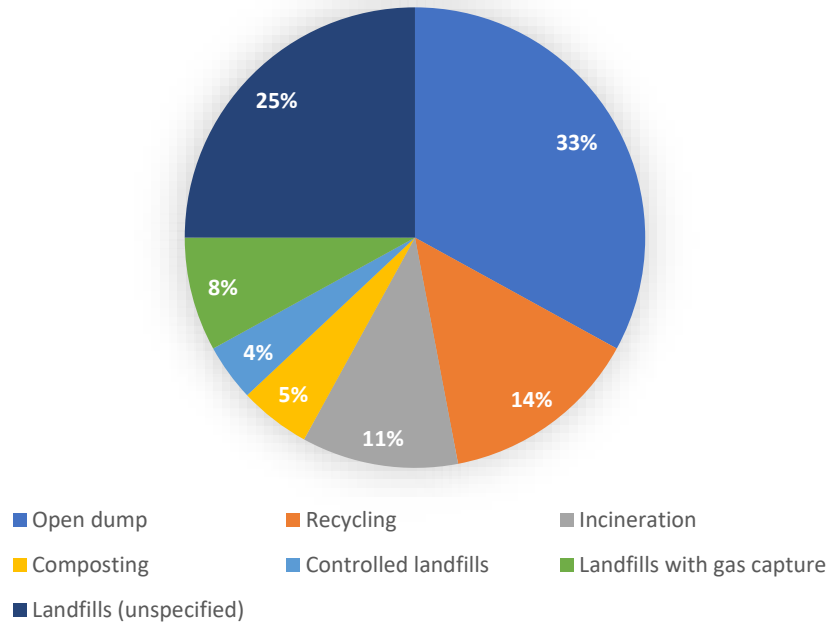
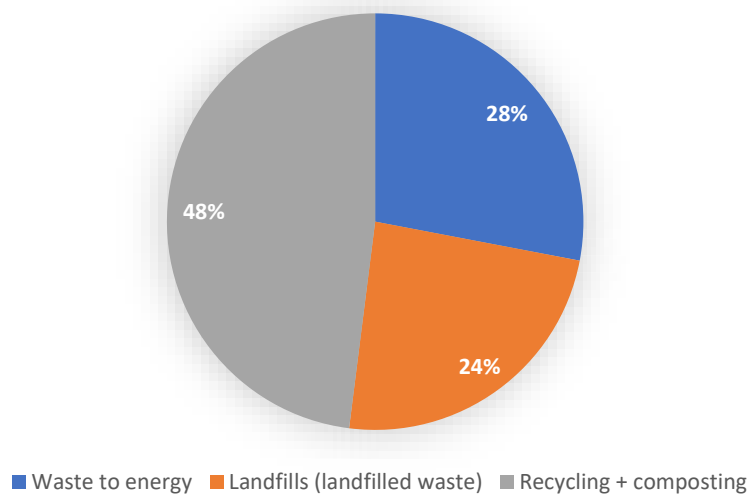


Figure 2 illustrates the European Union's overview of MSW destination. In several countries there are laws prohibiting the construction of landfills. In places where they still exist, the tendency is to decrease (ABREN, 2019).

Figure 2. Overview of the European Union destination of MSW – EU28.



Source: Adapted from CEWEP. 2018.

Research has been carried out in recent years, such as Lino and Ismail (2017, 2018), Lino

(2014), Rada (2014), Jones (2010), Maize (2016), Fonseca (2017), Kuhl (2015), Paulo, Dalbosco & Leites (2013), Andrade (2019) and many others have published the MSW treatment technique for energy production and as a mechanism for social inclusion. Menezes (2000), Morgado & Ferreira (2017) conducted studies on incineration as a heat treatment for MSW. Brietzke (2016) studied the feasibility of composting in the treatment of MSW. Poli (2014) and Queiroz (2014) recorded research on the PCI of USW.

ENERGY USE OF URBAN SOLID WASTE.

In recent years, the term circular economy has been widely used, an alternative to the traditional linear economy based on production-use-disposal, whose objective is to reduce the use of new resources through the reuse and valorization of end-of-life products and materials, and thus avoid the generation of waste, pollution and greenhouse gas emissions (ABREN, 2020).

According to Abren (2020), there are more than 2,430 plants worldwide, but Brazil still does not have any ERU, revealing that our country is still far below what is desirable in terms of MSW management, allocating 96% to landfills and dumps, and the vast majority of landfills would not be licensed with international standards. However, several actions have been taken to make this a reality. The new sanitation framework brings the obligation of bidding through public-private partnerships (PPPs) and allows the collection of tariffs on the consumption bill, such as the water bill, for example. The Ministry of Mines and Energy recently announced that it will hold a regulated auction for the contracting of electricity from URE (ABREN, 2020).

A new WTE plant currently produces an average of 600 kWh of electricity per ton of MSW, while landfills with biogas collectors produce an average of 65 kWh per ton, i.e., a WTE plant is almost ten times more energy efficient, not to mention that the electricity generated from waste in a landfill environment is, in this case, it is extracted slowly over time, while in WTE energy is generated immediately (ABREN, 2019).

Thus, Waste-to-Energy (WTE) can be defined as the generation of electricity from biodigestion or heat treatment of waste, whether organic or inorganic, through the use of several existing technologies. The implementation of these WTE plants has been the solution found in some countries for the final destination of MSW that was not used in the recycling or composting process, that is, MSW that would be sent to landfills, and these, even sanitary ones, bring risks of irreversible contamination to the environment. Member countries of the European Union, the United States, China, India, among others, have included WTE as a priority in the treatment of this waste, which, in addition to obtaining a sustainable destination, contributes to the generation of clean, renewable and firm electricity, attributing greater reliability and stability to the electrical system. The number of WTE heat treatment plants in operation in Europe reaches 522, not including incineration of

hazardous waste (medical, radioactive, etc.), the amount of heat treated waste in millions of tons, which represents a total of 522 plants in operation and 263,314 tons/day (tons per day) processed in 2016 (ABREN, 2019).

In Brazil there are no WTE plants in operation, only the CS Bioenergia biodigestion plant in Curitiba, some small R&D plants, and some landfill gas capture plants. However, the country has the potential to generate up to 5.4% of the national demand through MSW heat treatment plants, with 106 units generating 236,520 GWh/year and a total installed capacity of 3,176 MW. There is also the potential to generate 1.5% of the national demand through accelerated anaerobic biodigestion, with a total installed capacity of 868 MW, generating 6,701 GWh/year. In total, it is estimated that MSW can generate up to 7% of national demand. It is estimated that the country will be able to receive the approximate amount of R\$ 28 billion in investments and, thus, result in the generation of employment and income, and by 2031, R\$ 11.6 billion/year in infrastructure investments will be necessary to ensure the universality of sustainable solid waste management in Brazil (ABREN, 2019).

HEAT TREATMENT

Heat treatment is one in which the waste receives a certain amount of heat for a certain time, they are called respectively reaction temperature and reaction time. The objective is the reduction of volume with the physicochemical processes. Currently, in relation to the thermal treatment system of municipal solid waste, different techniques are applied: drying, pyrolysis, gasification, microwave treatment, plasma and incineration (LINO & ISMAIL, 2018). In many parts of the world, a combination of two or more techniques is applied, mainly to obtain thermal energy and electrical energy.

Energy recovery consists of the technologies and industrial processes that make it possible to recover part of the energy contained in MSW. Among the existing methods, the most commonly used use incineration by combustion process. The composition of MSW also influences the efficiency of the energy recovery system, depending on the location and how they are generated, especially on the composition, whether it has more or less organic residue, calorific value, humidity, etc.

INCINERATION

An MSW incineration plant operates on a similar operating principle to a typical thermal power plant, with the main difference being the combustion of MSW, or a combination of MSW and another fuel, serving as the primary heat source for the boiler. (ADNAN ET AL., 2021)

Waste incineration reduces the large volume of waste generated and consequently increases the useful life of the landfill. This waste treatment technique occurs very quickly and enables the

generation of energy (VG RESIDUALS, 2020).

Incineration can be a form of technology to solve this problem of MSW, as this treatment reduces the volume of waste by up to 90% and the weight to a range of 20 to 30%, also highlighting the two types of ashes produced in this process, namely: solid ash and light suspended ash. The light suspended ash is treated and removed from the exhaust gases. Solid ash is usually inert and typically reused in the manufacture of concrete artifacts, building material, ceramics, etc. (LINO & ISMAIL, 2018).

First, the MSW was burned in the primary chamber ($T = 500$ to 900 °C). Waste turns into gases and small particles. This prevents volatilization of metals. The second process takes place in the secondary chamber: the gases and small particles formed are burned at higher temperatures (750 to 1250 °C) until complete combustion. Usually the time is 30 min in the first phase and three seconds in the second. After incineration, the solid part is removed from the grate. The amount of this solid material after the incineration process varies from 12 to 30% by mass (from 4 to 10% by volume) of the original material and has the appearance of gray, being a clean, inert material suitable for application to civil construction in the manufacture of bricks, sidewalks, pavements, etc. (MENEZES, GERLACH & MENEZES. 2000).

Morgado & Ferreira (2017) surveyed the possibility of the existence of an incinerator with cogeneration of energy in the city of Goiânia. There, the population was 1,897,957 people, who generated 1,583.50 t/day of MSW, of which 92.50% are disposed of in landfills. They estimate that if they were incinerated, there would be a 90% reduction in volume and a 15% reduction in weight. It would also be possible to generate up to 791.75 KWH, or 289 MW per year.

Lino & Ismail (2018) recorded that solid waste is a renewable energy resource, with the capacity to generate energy in the range of 8 to 11 MJ/kg, while Waste Derived Fuel (RDF) composed of dry MSW has a calorific value ranging from 12 to 17 MJ/kg. From this they concluded that one ton of MSW and one barrel of oil both release almost the same amount of heat, about 7 GJ.

One of the countries that manufactures and uses incinerators for solid waste treatment is Japan. The country incinerates about 80% of MSW in about 1172 incinerators, where 24.5% of them have energy recovery, reaching 1770 MW. On average, the energy conversion rate of these incinerators is about 200 kWh/t MSW. In Tokyo, the electricity conversion rate is about 390 kWh/t of MSW, in Osaka, 320 kWh/t of MSW, while Kobe has a production rate of about 300 kWh/t of MSW. In the latter, incineration supplies 16.2% of the electricity demand and 25% of the hot water demand. Singapore has four incineration plants to handle a load of 1700 t/day. Treated MSW is sourced from households and industry with lower calorific value (PCI) around 6 MJ/kg. Each boiler generates 42

t/h of steam and generates 30 MW (LINO & ISMAIL, 2018).

PYROLYSIS

Pyrolysis is a form of thermochemical treatment of organic material developed entirely without the presence of oxygen, with the possibility of oxidation of a small fraction of residue due to the presence of some oxygen contained in the reactor. This technology is used to destroy volatile organic compounds, fuels, and pesticides in the soil. This is an old technology, but for heat treatment of biomass and MSW it is an innovative technique. The products resulting from pyrolysis can be in liquid, solid, or gaseous states, depending on the composition of the residue and parameters such as temperature, pressure, and burning time. During processing, the organic material is transformed into syngas or syngas (a mixture of flammable gases such as CO, H₂, CH₄) and other volatile organic compounds (VOCs) with a calorific value ranging from 10 to 20 MJ/Nm³. A part of these volatiles can be condensed, producing oil, wax and tar, collected in the cooling phase of the syngas and used as liquid fuel. The remaining residue is a type of ash and charcoal. Each ton of solid waste contains 11 kg of ammonium sulfate, 12 liters of tar, 9.5 liters of oil, among others (LINO, 2014). The gas fraction can also be distilled to obtain various hydrocarbons (gasoline, kerosene, and diesel) either burned in boilers or to generate electricity, or partially oxidized to obtain syngas, as occurs in gasification (ABREN, 2019).

The problem is that the syngas generated needs to be purified, for example, through a washing process, only then, without contaminants, this gas can be used, both for electrical and thermal generation, in gas generator sets, or even use it in thermal processes to generate heat (steam, hot water, hot air. For the pyrolysis process to occur, energy from an external source is required, which many consider unfeasible and has not been applied on an industrial scale for MSW processing (ABREN, 2019). The operation of this technology takes place at temperatures ranging from 300°C to 1600°C. Therefore, it is observed that any thermal process at temperatures above 300°C and in the absence of oxygen are considered pyrolysis methods. The advantage is that pyrolysis has proven to be an energy-, economically, socially and environmentally viable technology, being a highly sustainable system, due to the energy generated from 500 kWh/t of MSW, and low levels of atmospheric emissions. (KÜHL, et al. 2015).

GASIFICATION

Gasification is the process of converting organic material into combustible gas in the presence of air in a controlled quantity and high temperature. It also results in syngas gas and has combustible characteristics. It is an endothermic thermal conversion technology for energy extraction from different types of organic materials (LINO, 2014). The principle of this energy conversion process is

based on the use of a raw material, called pre-treated biomass, that is, with a low moisture content, converting it into gas, through gasification reactions, consequently this gas is cooled and purified (KÜHL, et al. 2015).

In general, in both processes, gasification as in pyrolysis, the MSW undergo a pre-treatment, in order to create a more homogeneous and dry mass. Subsequently, they are subjected to heat treatment at high temperatures and in an oxygen-poor environment, a situation in which the gases generated in the combustion process also need environmental control systems to eliminate pollutants. In terms of energy, gasification has a lower net energy use (ABREN, 2019).

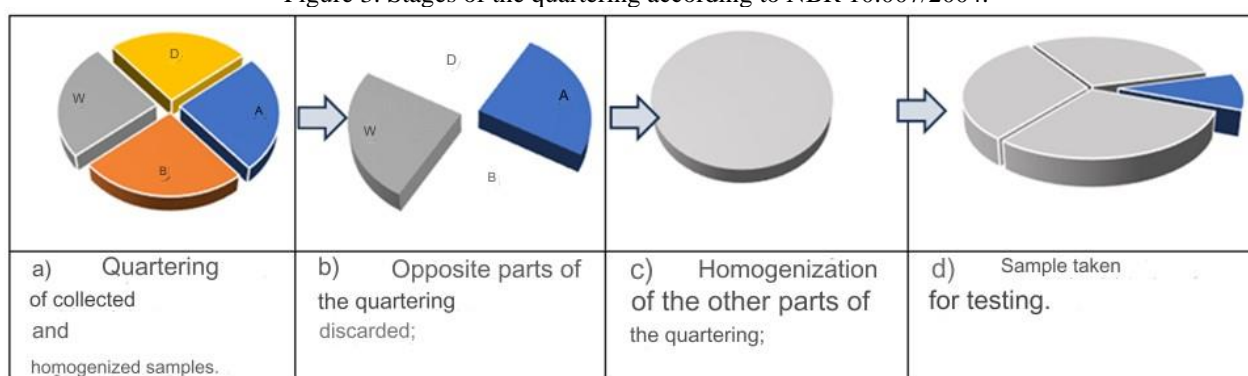
Several gasification processes for heat treatment of solid waste are being developed as an alternative to incineration. The biggest challenge of this technology is to obtain acceptable efficiency due to the high energy consumption in the pre-processing of waste, consumption of large amounts of pure oxygen and cleaning of the syngas. These are the factors that affect the efficiency of converting syngas to electrical energy. Several MSW gasification processes have been proposed, but very little has been built and tested (LINO, 2014).

METHODOLOGY

GRAVIMETRIC COMPOSITION OF MSW

MSW were collected from 18 neighborhoods of the city for gravimetry. The activities developed are carried out in three stages: quartering, identification and weighing of the categories of each type of waste. It is regulated by ABNT - NBR 10.007/2004. The quartering is explained in figure 3.

Figure 3. Stages of the quartering according to NBR 10.007/2004.



With these data, the percentages of each type of existing material were determined, according to Equation 1, by dividing the percentage of the mass of each material by the total mass of the sample, as well as the calculation of the apparent specific weight - direct division of the total mass by the total volume. After the total weighing of the sample, the waste was sorted on the plastic tarpaulin

as follows: Paper/cardboard, wood, metals, glass, hard plastic (HDPE), soft plastic (LDPE), PET plastic, PP plastic, Styrofoam, rejects and organic material. Again, each type of material was properly weighed separately to obtain the representativeness in weight of each one. The percentages of each type of material in that 1000-liter sample were then determined, according to Equation 1.

Equation 1. It allows you to calculate the percentage of each type of material after sorting.

$$\text{Percentual de cada categoria (\%)} = 100 * \frac{\text{peso de cada fração (kg)}}{(\text{peso total da amostra (Kg)})} \quad (1)$$

Where:

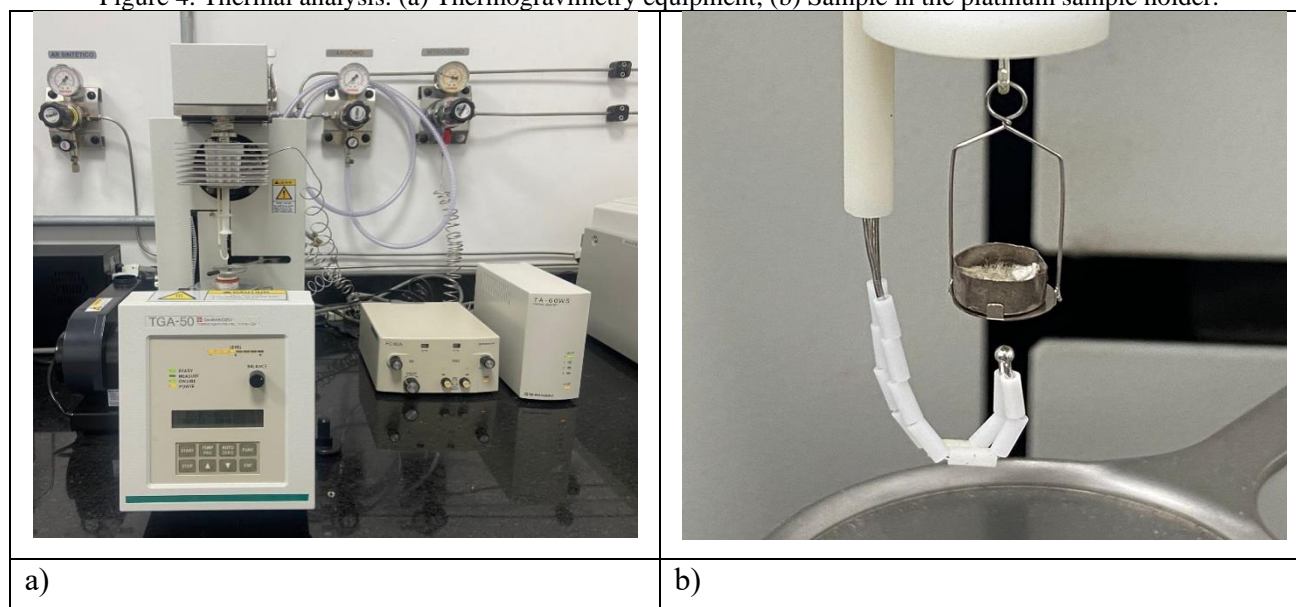
Percentage of each category = percentage of each class/type of waste present in the sample;

Weight of each fraction = weight of each class/type of waste after sorting.

TGA/DTG THERMAL ANALYSIS

The thermal behavior of MSW was evaluated by Thermogravimetry Analysis (TGA) and Thermogravimetry Derivative (DTG). The analyses were carried out at the Laboratory of Synthesis and Characterization of Nanomaterials, of the Federal Institute of Amazonas (LSCN/IFAM), with the aid of the Shimadzu thermogravimetry analyzer, model TGA-50, shown in Figure 4. To perform the analyses, 1.0 mg were deposited in a platinum crucible, without a cap. This sample holder was inserted into the equipment, which in turn operated at a heating rate of 10 °C per minute, until it reached a temperature of 1000 °C, with a nitrogen gas flow of 50 milliliters per minute.

Figure 4. Thermal analysis: (a) Thermogravimetry equipment; (b) Sample in the platinum sample holder.



IMMEDIATE ANALYSIS: MOISTURE, ASH, VOLATILE MATERIAL AND FIXED CARBON.

The values of moisture, volatile material and fixed carbon, determined by heating in muffle to 950 ± 10°C for the samples collected in the summer period and in the Amazonian winter period and

were performed in duplicates. The humidity corresponds to the amount of water present in the sample, the volatile material is that substance that evaporates more easily and the ashes correspond to the inorganic fraction of the MSW sample, aggregating in its constitution the chemical elements that are inert to combustion reactions, among them are phosphorus, potassium and calcium. The amount of carbon that does not volatilize is called fixed carbon.

ELEMENTAL ANALYSIS: CARBON, HYDROGEN, AND NITROGEN.

CHN Elemental Analysis is a technique for determining the percentages of Carbon (C), Hydrogen (H) and Nitrogen (N) in a sample, and is generally performed for organic materials. Its operation is based on the Pregl-Dumas method, in which samples are subjected to combustion in an atmosphere of pure oxygen, and the gases resulting from this combustion are quantified in a TCD detector (thermal conductivity detector). Its main applications involve the study of liquid and solid samples, resulting from organic synthesis and formation of complexes, synthesis of polymers, geological and environmental samples and petroleum derivatives, among others. They are indispensable in the calculation of the lower calorific value of a sample.

CALORIFIC VALUE - PC

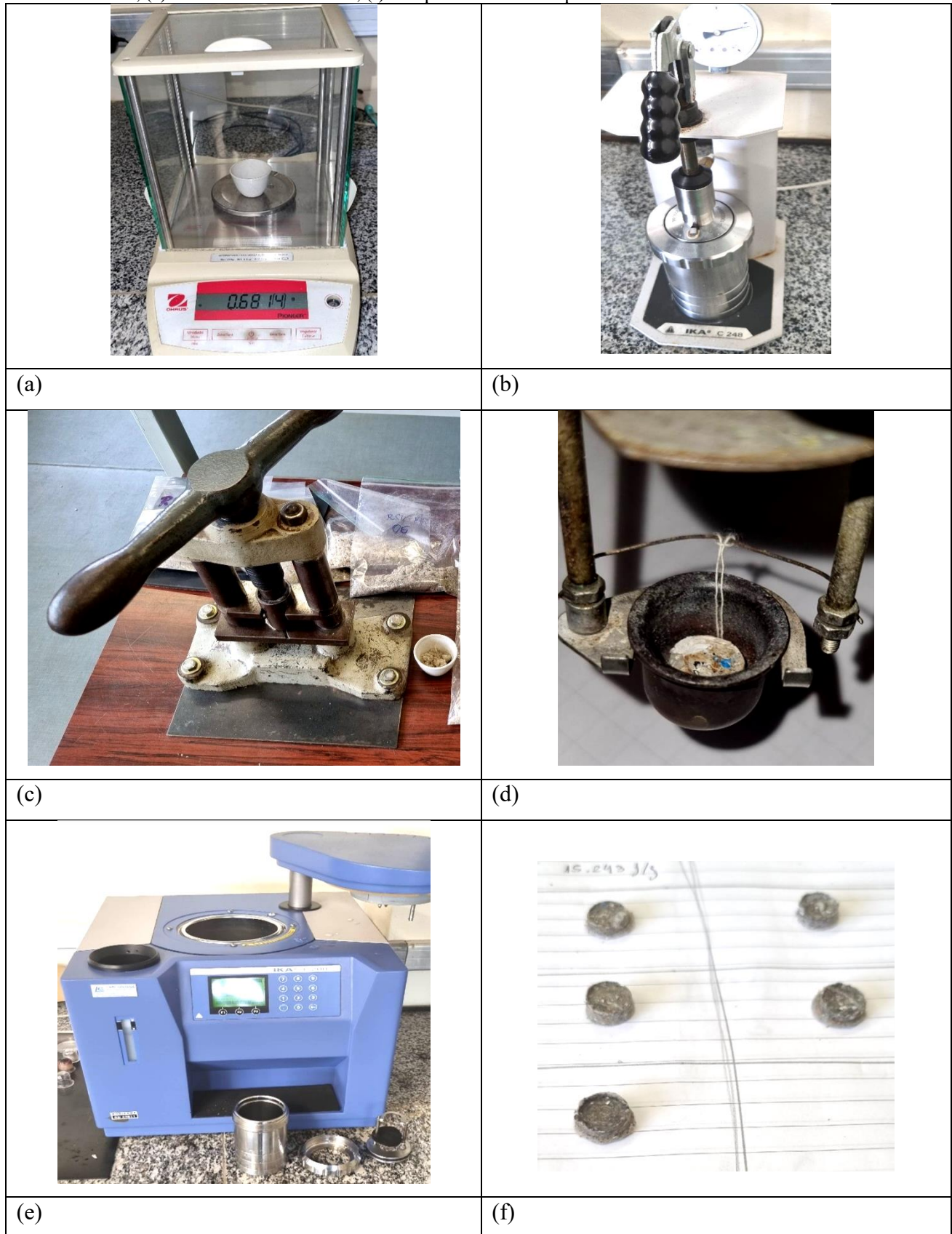
The study of the calorific value of MSW allows the analysis of the feasibility of using this material as an energy source, which will serve as a strong argument for a possible decision by the authorities for the development of projects and execution of one or more plants for the transformation of MSW into energy, which will result in the reduction of landfills and dumps. and will result in the various benefits generated by an energy matrix (QUEIROZ, 2014).

Superior Calorific Value - PCS

The equipment that measures the superior calorific value of a sample is the calorimetric pump. It is able to measure the amount of heat released or absorbed in a chemical or physical reaction. It is basically composed of a combustion chamber, isolated by cold water, where the reaction of oxygen at high pressure with the sample to be analyzed occurs. Combustion begins with the heating of the sample by means of an electric current that burns the ignition wire in contact with the electric current conductor and the sample in the metal crucible.

The residue sample pressed in the form of a tablet or tablet is placed in a metal crucible mounted inside a pressure vessel, with a volume of 350 ml, equipped with an ignition device through electric current. The mass of the sample is approximately 1.0 g. After the sample is placed, the pump is hermetically sealed and pressurized with pure oxygen at about 30 bar, as detailed in Figure 5.

Figure 5. Determination of PCS: (a) Analytical balance; (b) decomposition vessel or pressure vessel; (c) sample press; (d) metallic crucible; (e) combustion calorimeter; (f) Sample in the form of pressed inserts.



Soon after, the pressure vessel is carefully placed inside the equipment, which is filled with water and has an agitator so that the temperature of the set is homogenized and a thermometer that

measures the temperature variation throughout the process. At the beginning, the aim is to balance the temperature of the set between 20°C and 23°C. The calorimeter is configured by entering the mass of the sample. Then an electrical pulse is emitted to the ignition wire which causes the sample to combust, raising the temperature of the system. The equipment's high-precision thermometer measures temperature variation, which is accurate to +/- 0.0001 K (Kelvin) and is recorded minute by minute. At the end of 15 minutes or 16 minutes, the gain in the upper calorific value of the sample is also recorded, in j/g. This is only achieved due to the previous calibrations carried out automatically by the equipment and the various corrections due to the water masses, the calorimeter, ignition energy, etc., as well as the energy gain in the entire process in relation to the mass of the sample measured and typed in the initial phase, on an analytical balance with an accuracy of 0.0001 g. results in Higher Calorific Value.

After muffle drying at 105 °C, the moisture content of each sample was determined and it was possible to determine the value of the dry PCS according to Eq. 2:

Equation 2. It allows you to calculate the upper calorific value of each sample in the dry state.

$$PCS_{seco} = \frac{PCS_w}{1-w} \quad (3)$$

Where:

PCS_{seco} : Calorific value of fully dried sample (Joules/Kg);

PCS_w : Superior calorific value of MSW, in the humidity condition "w" (Joules/Kg);

w : Moisture content at the time of the laboratory test (% by mass).

According to Poli, et al (2014) most fuels have hydrogen in their composition, which, during combustion, reacts with oxygen, generating an additional amount of water. If this hydrogen generates water, then it should be considered in a more precise relationship between PCI and PCS. Assuming that all Hydrogen converts into water and that each gram of Hydrogen in the fuel generates 9.0 g of water stoichiometrically, the ratio is as described in Eq. 3:

Equation 3. It allows you to calculate the lower calorific value of each MSW sample.

$$PCI_w = (1 - w) * PCS_{seco} - [(1 - w) * 9 * H + w] * 2449,38 \quad (4)$$

Where:

PCI_w : Lower calorific value of MSW, at the time of humidity w (joules/Kg);

PCS_{dry} : Calorific value of fully dry sample (Joules/Kg);

w : Moisture content at the time of the laboratory test (% by mass).

H : Hydrogen content, on a dry basis (% by mass, expressed between 0 and 1);

2449.38: Enthalpy of vaporization of water at 22°C (joules/Kg).

RESULTS

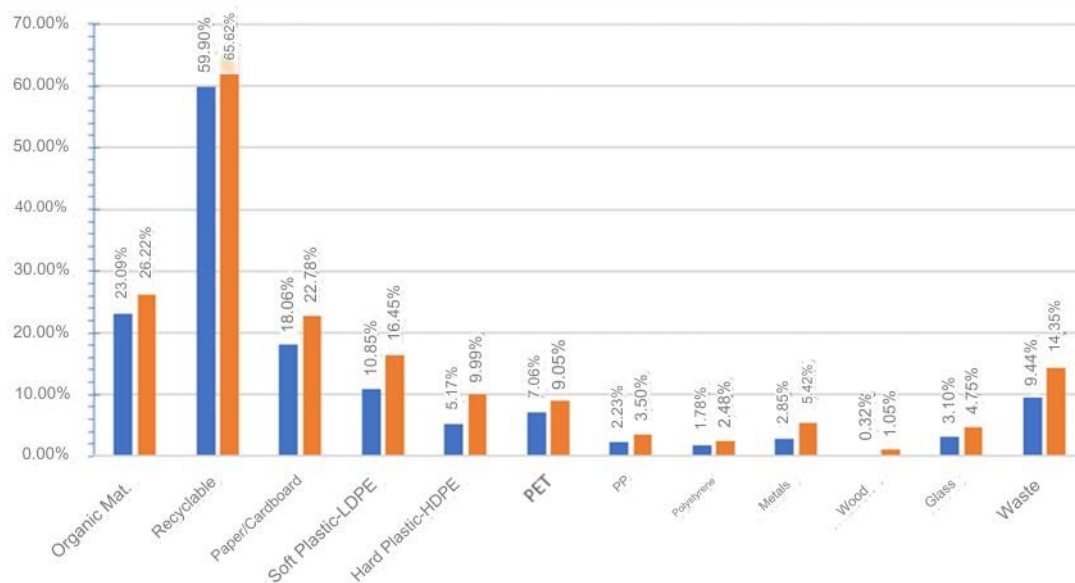
GRAVIMETRIC COMPOSITION OF MSW

Detailed samplings of the gravimetric profile of urban solid waste from each of the neighborhoods were performed. The mean and standard deviation of the sample were calculated. The results indicated a partial variation in certain materials when compared to the national average. The waste profile differs in that it presents a higher amount of recyclable materials such as paper, cardboard and plastics, in relation to the national average, while organic waste is shown in a higher percentage. This is due to the separation carried out in this work between tailings and organic material whose destination can easily be biodigestion or composting, as summarized in Table 1 and summarized in Figure 6.

Table 1. Percentage fractions by administrative area and weighted average of each material comprising the MSW.

COMPONENTS	PERCENTAGE FRACTION						AVERAGE	WEIGHTED AVERAGE
	NORTH	SOUTH	EAST	WEST	SOUTH CENTER	MIDWEST		
Organic Mat.	23,25%	24,5%	24,3%	28,1%	25,3%	24,3%	24,96%	24,66%
Total recyclables	64,24%	58,47%	65,81%	58,61%	62,55%	64,15%	62,31%	62,76%
Paper/Cardboard	20,92%	20,7%	18,6%	18,3%	23,4%	24,5%	21,04%	20,42%
Soft Plastic:LDPE	10,61%	14,3%	18,5%	13,5%	11,0%	11,1%	13,16%	13,65%
Hard Plastic:HDPE	10,60%	3,7%	5,3%	7,9%	9,3%	9,2%	7,69%	7,58%
PET	9,70%	6,9%	7,7%	6,8%	8,3%	7,8%	7,86%	8,05%
PP	2,00%	2,7%	3,3%	3,1%	3,3%	4,0%	3,06%	2,87%
Polystyrene	2,44%	2,1%	2,4%	1,5%	1,7%	2,0%	2,02%	2,13%
Metals	4,36%	3,1%	6,1%	3,1%	3,1%	2,5%	a)	b)
Wood	1,20%	0,0%	0,6%	0,5%	0,8%	0,8%	0,64%	0,69%
Glass	3,60%	5,0%	4,0%	4,4%	2,6%	3,1%	(a)	(b)
Waste	11,31%	(c)	(d)	12,8%	11,4%	(e)	(f)	11,90%
TOTAL	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
Weighting factor	0,2799	0,1600	0,2502	0,1417	0,0853	0,0829	-	-

Figure 6. Final gravimetry of the city of Manaus -AM.



In the research, it was evidenced that the greater representativeness of recyclable waste (59% to 65%) and the small proportional reduction of organic waste (23% to 26%) and waste (10% to 14%), while the national average these values are 28%, 50% and 22% respectively, are possibly consequences of the excessive use of packaging, due to the number of people who start to live in the vicinity of the Manaus Industrial Pole and the commercial and service area existing in the urban area of the city. In the field analysis, it was found that at least 50% of this plastic material comes from recyclable packaging (or with easy commercial value in the market), evidencing the possibility of selective collection if a sorting plant is installed before the waste is landfilled. Such characteristics may possibly be a consequence of the increasing use of packaging, evidencing the need for local public policies of post-consumption responsibility, product life cycle analysis and priority marketing of products with sustainable packaging.

One of the consequences of the presence of a high percentage of packaging and recyclable materials is the average value of apparent specific weight, 73.68 Kg/m^3 , approximately one third of the national average, confirming the large amount of light materials containing air inside, such as packaging and enabling a high degree of compaction when dimensioning the route and the number of waste compactor collection trucks.

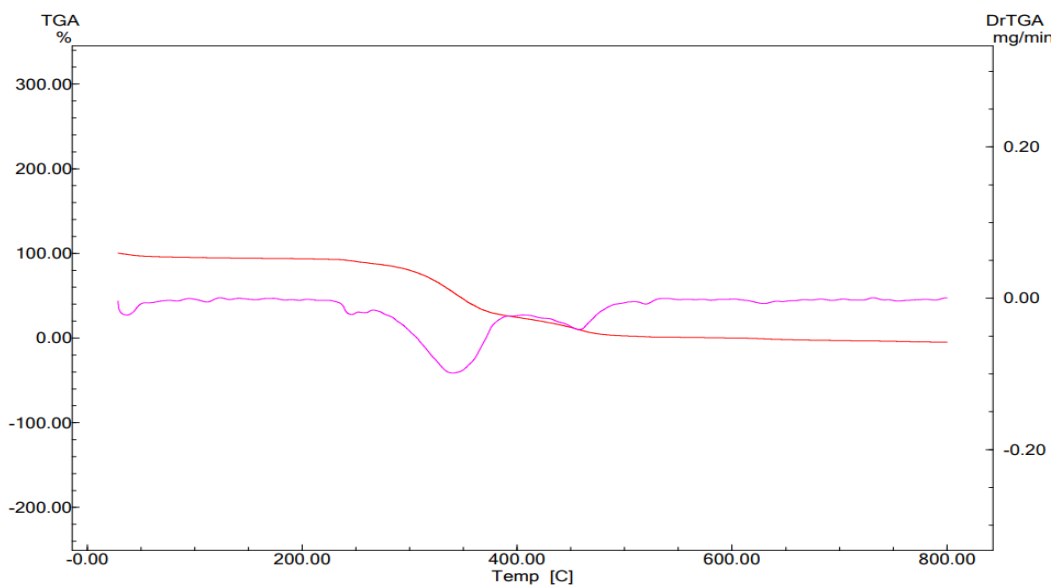
The studies carried out in these neighborhoods were fundamental for the collection of initial and updated data, which enabled the gravimetric characterization of solid waste in the city of Manaus, state of Amazonas, and will enable other studies. For the time being, there has been a large amount of material with the capacity to be recycled (62% + 2%), despite the publicity campaigns of the public authorities, with a low apparent specific weight, confirming little organic matter and a lot of light material that can be recycled, leading to the thought of installing a sorting plant as an

alternative to reduce the waste destined to the city's landfill. increasing its useful life and the reuse of recyclable materials, bringing economic, social and environmental benefits to the city and its inhabitants.

TGA/DTG THERMAL ANALYSIS

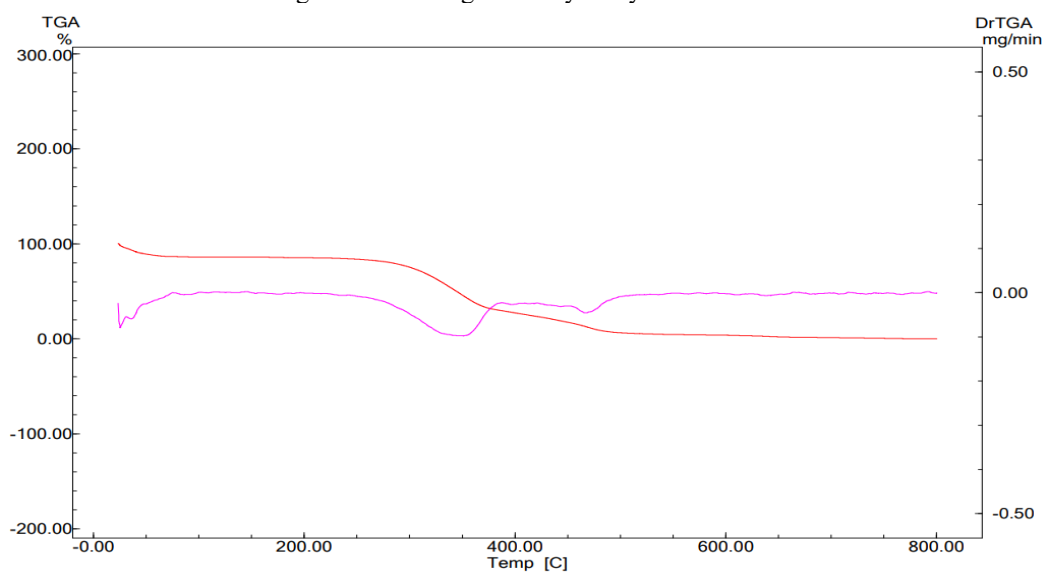
To verify the thermal behavior of the MSW sample, Thermogravimetry (TGA) and Thermogravimetry Derivative (DTG) analyses were performed. Three of these TGA curves are shown in Figures 7, 8 and 9.

Figure 7. Thermogravimetry analysis of MSW.



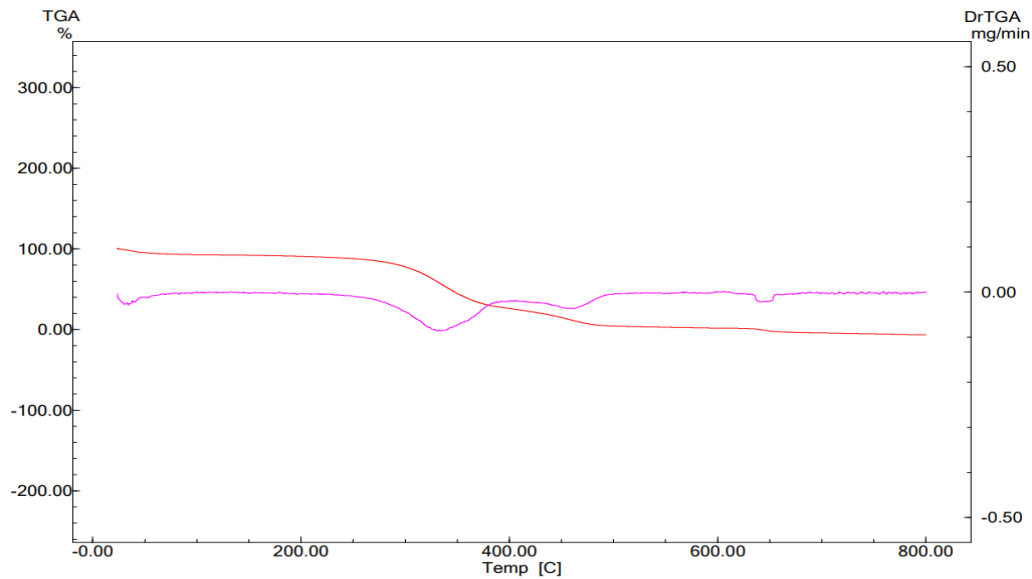
Source: Author.

Figure 8. Thermogravimetry analysis of MSW.



Source: Author.

Figure 9. Thermogravimetry analysis of MSW.



Source: Author.

It is verified that the MSW samples submitted to the tests remain constant until approximately 250 °C, where it began its deterioration process that was up to approximately 500 °C and from that point on the degradation of the polymeric chains or the process of rupture of primary bonds due to thermal energy occurs, where practically all the material has already been consumed.

IMMEDIATE ANALYSIS: MOISTURE, ASH, VOLATILE MATERIAL AND FIXED CARBON.

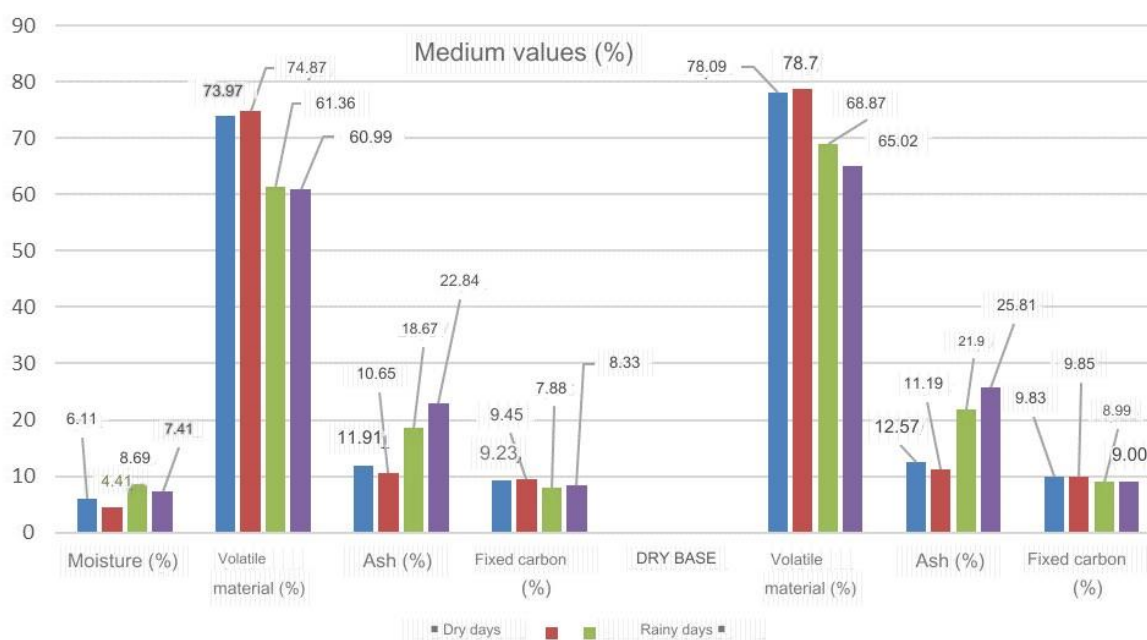
The values of moisture, volatile material and fixed carbon can be seen in Table 2 for the samples collected in the summer period and in Table 3 for the samples collected in the Amazonian winter period and duplicate tests were performed. Figure 10 shows the mean values of these properties.

Table 2. Immediate analysis of MSW in administrative regions on dry days

Experiment 1							
Dry Days	ZONE	NORTH	SOUTH	EAST	WEST	SOUTH CENTER	MIDWEST
WET BASE							
Moisture (%)	w	6,03	6,18	6,23	4,39	5,92	8,12
Volatile material (%)	v	76,31	72,65	71,73	75,29	77,76	55,90
Ash (%)	c	8,36	11,07	12,78	12,75	7,12	29,31
Fixed carbon (%)	FC	9,30	10,09	9,26	7,57	9,20	6,67
Total		100,00	100,00	100,00	100,00	100,00	100,00
DRY BASE							
Volatile material (%)	vs	81,21	77,44	76,50	78,75	82,65	60,84
	cs	9,90	10,75	9,87	7,92	9,78	7,26
Fixed carbon (%)	FCs	8,89	11,80	13,63	13,33	7,57	31,90
Total		100,00	100,00	100,00	100,00	100,00	100,00
Experiment 2							
Dry Days	ZONE	NORTH	SOUTH	EAST	WEST	SOUTH CENTER	MIDWEST
WET BASE							
Moisture (%)	w	4,17	3,78	5,55	3,98	4,66	6,61
Volatile material (%)	v	75,49	62,82	74,26	76,46	78,64	58,45
Ash (%)	c	10,91	23,72	10,39	10,10	8,05	27,64
Fixed carbon (%)	FC	9,44	9,68	9,80	9,46	8,65	7,30
Total		100,00	100,00	100,00	100,00	100,00	100,00
BASE SECA							
Volatile material (%)	vs	78,77	65,29	78,63	79,63	82,48	62,59
Fixed carbon (%)	FC	9,85	10,06	10,37	9,86	9,08	7,81
Ash (%)	cs	11,38	24,65	11,00	10,52	8,44	29,60
Total		100,00	100,00	100,00	100,00	100,00	100,00
Experiment 1							
Rainy days	ZONE	NORTH	SOUTH	EAST	WEST	SOUTH CENTER	MIDWEST
WET BASE							
Moisture (%)	w	6,54	10,97	18,13	8,84	7,72	8,54
Volatile material (%)	v	60,13	62,50	55,29	65,58	69,99	60,21
Ash (%)	c	25,02	18,44	18,90	17,01	15,19	24,07
Fixed carbon (%)	FC	8,30	8,09	7,68	8,58	7,10	7,18
Total		100,00	100,00	100,00	100,00	100,00	100,00
DRY BASE							
Volatile material (%)	vs	64,34	70,20	67,54	71,93	75,85	65,83
Fixed carbon (%)	FC	8,88	9,09	9,38	9,41	7,69	7,85
Ash (%)	cs	26,78	20,71	23,08	18,66	16,46	26,32
Total		100,00	100,00	100,00	100,00	100,00	100,00
Experiment 2							
Rainy days	ZONE	NORTH	SOUTH	EAST	WEST	SOUTH CENTER	MIDWEST
WET BASE							
Moisture (%)	w	4,93%	7,56%	15,47%	7,39%	5,48%	7,43%

Volatile material (%)	v	61,26%	57,96%	53,70%	67,90%	70,61%	60,73%
Ash (%)	c	25,13%	27,56%	22,23%	16,45%	17,85%	23,45%
Fixed carbon (%)	FC	8,68%	6,92%	8,61%	8,26%	6,06%	8,40%
Total		100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
DRY BASE							
Volatile material (%)	vs	64,43%	62,70%	63,52%	73,32%	74,70%	65,60%
Ash (%)	cs	26,43%	29,81%	26,29%	17,77%	18,89%	25,33%
Fixed carbon (%)	FCs	9,13%	7,49%	10,19%	8,92%	6,41%	9,07%
Total		100,00%	100,00%	100,00%	100,00%	100,00%	100,00%

Figure 10. Mean of the values obtained in the immediate analysis on dry and rainy days



The lower moisture and ash contents of the MSW samples are concentrated in those collected on dry days, while the volatile material contents are in those samples collected on dry days, an indication that MSW on dry days have advantageous characteristics for the production of thermal energy in relation to those of rainy days. The samples have similar fixed carbon contents, with a tendency to be slightly higher on dry days. However, the fixed carbon/volatile materials ratio was higher for materials collected on rainy days, possibly due to lower volatile material contents on rainy days.

According to Pereira (2014), the lower the moisture content, the lower the amount of energy spent in the carbonization process of the material and the higher the calorific value of the material. Some biomasses such as rice husks, sugarcane bagasse and soybean meal have 64.10%, 80.42% and 80.00% of volatile materials, respectively, which when compared with the MSW samples analyzed make it possible to classify them as alternatives for energy use based on the averages found,

especially on dry days that present less amount of substances to be released as gases during the carbonization process. and, therefore, it has a lower ash content than the MSW on rainy days. The volatile and fixed carbon materials had their values very approximate, with their FC/Volatiles ratios being very close, indicating a good capacity of both types of materials to be destined for combustion processes. Thus, the materials collected on dry days have a higher proportion of minerals in their composition with greater ease of burning and burning, but for the material collected on rainy days, in a possible work of sorting on conveyor belts and with consequent decrease in humidity, it also becomes of good combustion and thus the first a possible source of energy use.

ELEMENTAL ANALYSIS: CARBON, HYDROGEN, AND NITROGEN.

The elemental analyses of the samples were performed in duplicates at the Analytical Center of the Institute of Chemistry of the University of São Paulo (IQ-USP), using the equipment Elemental Analyzer - Perkin Elmer 2400 series II. These values will be used together with those obtained by the upper calorific value test in the methodology to determine the value of the lower calorific value of each of the samples

Table 4. CHN elemental analysis of MSW samples from Manaus. Medium values

AVERAGE	DRY	ZONE	H (%)	C (%)	N (%)
	1	WEST	6,405	43,31	0,35
	3	SOUTH	6,035	41,79	0,235
	6	NORTH	4,475	35,04	1,34
	RAINY				
	1	NORTH	6,135	38,78	1,685
	2	EAST	5,745	38,33	1,825
	3	MIDWEST	5,645	39,62	1,245

CALORIFIC VALUE – PC

Table 5 shows some PCI values, in joules and calories per kilogram of material.

Table 5. Calorific value of some fuels. Source: ANDRADE, 2019.

FUEL	PCS (KJ/Kg)	PCI (Kcal/Kg)
Paraffin	39.000	9.321
Fuel oil	35.000	8.365
Charcoal	31.000	7.409
Agricultural waste charcoal	26.000	6.214
coconut shells	17.000	4.063
Kiln-dried firewood	17.000	4.063
Lignite	17.000	4.063
Mineral coal	15.000	3.585
Biomass 50% humidity	8.326	1.990
Biomass 10% humidity	17.029	4.070

Superior Calorific Value - PCS

The calorific value analyses were carried out at the Thermal Laboratory of the Faculty of Mechanical Engineering of the State University of Campinas (UNICAMP), with the aid of the IKA C-200 Calorimetric Pump, which performs analyses of gross calorific values of liquid and solid samples. To perform the analyses, each sample should be weighed between 0.5 and 0.7g in a porcelain crucible, without a lid. The analytical balance used was PIONEER OHAUS.

The analyses of the upper calorific value carried out at the Thermal Laboratory of the Faculty of Mechanical Engineering of the State University of Campinas (UNICAMP), with the aid of the IKA C-200 Calorimetric Pump, resulted in the values described in Table 6 for rainy days and in Table 7 for samples collected in the administrative zones of Manaus on dry days.

Table 6. Determination of MSW PCS in administrative regions on rainy days.

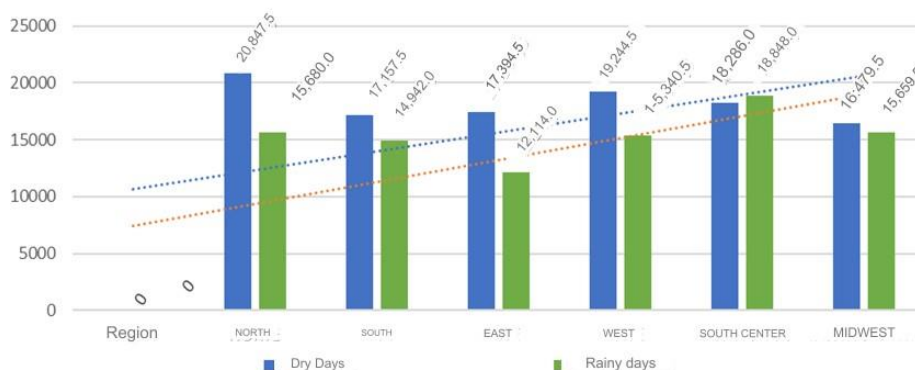
Sample	PCS-1	PCS-2	Average	Standard deviation	Minimum	Maximum
RSU-M07	15.243,0	15.438,0	15.340,5	2001,95	13.339	17.342
RSU-M08	15.147,0	14.737,0	14.942,0		12.940	16.944
RSU-M09	15.690,0	15.670,0	15.680,0		13.678	17.682
RSU-M10	11.994,0	12.234,0	12.114,0		10.112	14.116
RSU-M11	17.885,0	19.811,0	18.848,0		16.846	20.850
RSU-M12	15.543,0	15.776,0	15.659,5		13.658	17.661

Table 7. Determination of MSW PCS in administrative regions on dry days

Sample	PCS-1	PCS-2	Average	Standard deviation	Minimum	Maximum
RSU-M01	20.086,0	21.609,0	20.847,5	1547,66	19.300	22.395
RSU-M02	16.925,0	17.390,0	17.157,5		15.610	18.705
RSU-M03	16.955,0	17.834,0	17.394,5		15.847	18.942
RSU-M04	18.672,0	19.817,0	19.244,5		17.697	20.792
RSU-M05	17.685,0	18.887,0	18.286,0		16.738	19.834
RSU-M06	16.236,0	16.723,0	16.479,5		14.932	18.027

Figure 11 shows the mean values of the PCS of the MSW samples from the six zones on the city's summer and winter days. Possibly due to the naturally increased humidity due to the exposure of the residues to the rains that occurred on rainy days, the values will naturally be lower than on dry days, with the exception of the central-south zone where probably on the day of collection there was no rainfall, making the average value similar to the average value resulting from dry days.

Figure 11. Average PCS of MSW in Manaus-AM on dry and rainy days



Dry Upper Calorific Value - PCSseco

In the previous item, the sample was in thermal equilibrium with the environment and exposed to the humidity of the place, and the amount of additional water formed by the hydrogen in the fuel, as well as the water in the relative humidity of the combustion air, were not considered. In this case, it was necessary to obtain the dry PCS values, in joules/Kg, using equation 2 and obtaining the values in Table 8:

Table 8. Dry PCS of Manaus MSW samples on dry and rainy days

ADMINIST REGION.	Dry		Rainy		Dry	Rainy	Dry		Rainy	
	PCS-1	PCS-2	PCS-1	PCS-2	w	w	PCS _{seco} 1	PCS _{seco} 2	PCS _{seco} 1	PCS _{seco} 2
NORTH	20.086,0	21.609,0	15.690,0	15.670,0	6,02	6,54	21.372,63	22.993,19	16.787,93	16.766,53
SOUTH	16.925,0	17.390,0	15.147,0	14.737,0	6,18	10,97	18.039,86	18.535,49	17.013,37	16.552,85
EAST	16.955,0	17.834,0	11.994,0	12.234,0	6,23	18,13	18.081,48	19.018,88	14.650,05	14.943,20
WEST	18.672,0	19.817,0	15.243,0	15.438,0	4,38	8,84	19.527,30	20.724,74	16.721,15	16.935,06
SOUTH CENTER	17.685,0	18.887,0	17.885,0	19.811,0	5,92	7,72	18.797,83	20.075,47	19.381,23	21.468,36
MIDWEST	16.236,0	16.723,0	15.543,0	15.776,0	8,12	8,54	17.670,88	18.200,91	16.994,31	17.249,07

Lower Calorific Value - PCI

After the calculation of the dry PCS, it was possible to determine the values for PCI, using Equation 3 and considering the hydrogen content extracted from the CHN elemental analyses performed on the samples of municipal solid waste. The values calculated for PCI, in joules/kg, are described in Table 9. Mean PCI and standard deviation values are also presented.

Table 9. PCI of Manaus MSW samples on dry and rainy days.

Region	Dry Days			Rainy days			DP		Weighting %	Weighted PCI – by region	
	H (%)	PCI-1	PCI-2	H (%)	PCI-1	PCI-2	Dry	Rainy		Dry Days	Rainy days
N	6,405	18.611,60	20.134,60	6,135	14.265,83	14.245,83	761,5	10	0,2799	5.422,53	3.990,21
S	6,035	15.448,94	15.913,94	6,135	13.674,24	13.264,24	232,5	205	0,16	2.509,03	2.155,08
L	6,405	15.478,42	16.357,42	5,745	10.442,70	10.682,70	439,5	120	0,2502	3.982,66	2.642,79
O	6,405	17.214,62	18.359,62	6,135	13.793,60	13.988,60	572,5	97,5	0,1417	2.520,43	1.968,37
C-S	6,405	16.211,64	17.413,64	6,135	16.447,89	18.373,89	601	963	0,0953	1.602,24	1.659,26
C-O	6,405	14.739,82	15.226,82	5,645	14.096,89	14.329,89	243,5	116,5	0,0829	1.242,12	1.178,29
									Média	17.279,02	13.593,99

The calorific value of MSW is immediately influenced by the increase in the moisture content of the material, and any variation of this property in any sample changes the result. This is because the higher the moisture content, the greater the energy expenditure to evaporate the water present in the sample and the more water, the smaller the other components, reducing the calorific value of the material present as fuel. Figure 12 explains the above.

Figure 12. Average PCI of MSW in the administrative areas of Manaus-AM.



CONCLUSION AND FUTURE WORK

The characterization of a city's waste is of paramount importance for government decision-making on the type of treatment to be carried out at that site. Knowing that there is Law 12.305 (PNRS) in the country, which requires a form of waste treatment before final disposal, and knowing the thermal treatments, whose techniques are safer and more innovative, increase the range of options available in the market. The values obtained in the tests, such as apparent specific weight, 73.68 Kg/m^3 , indicate the presence in a high percentage of packaging and recyclable materials, approximately one third of the national average, confirming the large amount of light materials and containing air inside, allowing a high degree of compaction when dimensioning the route and the number of waste compactor collection trucks. The gravimetry studies will enable other studies. For the time being, a large amount of material with the capacity to be recycled ($62\% + 2\%$) has been found, despite the publicity campaigns of the public authorities, indicating little organic matter and a lot of material that can be recycled, leading to the thought of installing a sorting plant as an alternative to reduce waste destined to the city's landfill, increasing its useful life and the reuse of recyclable materials. bringing economic, social and environmental benefits to the city and its inhabitants. The high percentages of recyclable materials, combined with lower calorific value (PCI) values, presenting values between 15,000 and 19,000 KJ/Kg on dry days, calorific value equivalent to the fuels cataloged in the bibliography such as lignite, kiln-dried firewood and coconut shells (17,000 KJ/Kg), Coal, (15,000 KJ/Kg), showed promise in future decision-making for MSW treatment by incineration. Currently, approximately 83 thousand tons of MSW are generated per month in the city of Manaus. Most of these wastes (98%) are landfilled, occupying a large area and causing environmental impacts. The researches show the feasibility of increasing recycling, composting a part of these and the rest going through thermal treatment by incineration and



consequently the generation of electricity.

FUTURE WORK

The proposed management plan for the city of Manaus-AM aims at adequate treatment and final disposal of MSW to reduce dependence on landfill and electricity generation. An economic analysis should be presented in the future, taking into account some scenarios of recycling percentages, the amount and cost of fuel spent in incineration, the energy consumed in the process, as well as the gas emissions and financial impacts that may be caused. Finally, the calculation of the actual mass to be deposited in landfills, which includes the solid ash from incineration and the possible use of this in the composition of cementitious material to be used in civil construction.


REFERENCES

1. Abegas: Associação Brasileira das Empresas Distribuidoras de Gás Canalizado. (s.d.). WEG aposta na gaseificação do lixo para geração. Recuperado de <https://www.abegas.org.br/arquivos/74019>
2. ABNT. (2004). NBR 10007/2004 - Amostragem de resíduos sólidos. Rio de Janeiro, RJ.
3. Abrelpe: Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais. (2020). Panorama Dos Resíduos Sólidos No Brasil 2018/2019. Brasília, DF.
4. Abrelpe: Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais. (2022). Panorama Dos Resíduos Sólidos No Brasil 2020/2021. Brasília, DF.
5. Abren: Associação Brasileira de Recuperação Energética de Resíduos. (2019). Regulação Nacional e Internacional de Waste-to-Energy. WASTE EXPO BRASIL, 12-14 novembro de 2019, São Paulo – SP.
6. Adnan, A., Mahmud, S., Uddin, M. R., Modi, A., Ehsan, M. M., & Salehin, S. (2021). Energy, Exergy, Exergoeconomic, and environmental (4E) analyses of thermal power plants for municipal solid waste to energy application in Bangladesh. *Waste Management*, 134, 136–148. <https://doi.org/10.1016/J.WASMAN.2021.08.006>
7. ASTM - American Society for Testing and Materials. (2007). Standart E1755 - 01.
8. ASTM - American Society for Testing and Materials. (2015). Standart E1756 - 08.
9. Brasil. (2010). Lei Nº 12.305, DE 2 DE AGOSTO DE 2010. Política Nacional de Resíduos Sólidos.
10. Brietzke, D. T. (2016). Avaliação do Processo de Compostagem Considerando a Relação Carbono/Nitrogênio. Lajeado, RS.
11. Canal Energia. (s.d.). Associações lançam Frente Brasil de Recuperação Energética de Resíduos. Recuperado de <https://www.canalenergia.com.br/noticias/53136809/associacoes-lancam-frente-brasil-de-recuperacao-energetica-de-residuos>
12. Canal Energia. (2019). WEG apresenta solução para geração de energia a partir do lixo. Recuperado de <https://www.canalenergia.com.br/noticias/53112117/weg-apresenta-solucao-para-geracao-de-energia-a-partir-do-lixo>
13. David, A., Thangavel, Y. D., & Sankriti, R. (2019). Recover, Recycle And Reuse: An Efficient Way To Reduce The Waste. *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)*, 9(3), 31-42.
14. Ecycle. (s.d.). O que é compostagem e como fazer. Recuperado de <https://www.ecycle.com.br/2368-compostagem.html>
15. Eos Organização E Sistemas. (2019). Como funciona o tratamento de resíduos sólidos no Brasil. Recuperado de <https://www.eosconsultores.com.br/tratamento-de-residuos-solidos-no-brasil/>
16. Fonseca, L. (2017). Estudo Comparativo entre Tecnologia de Queima Direta e de Gaseificação de Resíduos Sólidos Urbanos Brasileiros na Geração de Vapor para Eletricidade em Caldeiras Aquatubulares. Monografia de Especialização, Especialização em Energias Renováveis,

17. Ipea: Instituto de Pesquisa Econômica Aplicada. (2020, 09 de julho). Resíduos sólidos urbanos no Brasil: desafios tecnológicos, políticos e econômicos. Artigo Publicado. Recuperado de <https://www.ipea.gov.br/cts/pt/central-de-conteudo/artigos/artigos/217-residuos-solidos-urbanos-no-brasil-desafios-tecnologicos-politicos-e-economicos>
18. Jones, J. C. (2010). Thermal processing of waste (1st ed.). Recuperado de <https://nsdl.niscpr.res.in/bitstream/123456789/1016/1/thermal-processing-of-waste.pdf>
19. Köhl, R. M. et al. (2015). Tecnologias Para Tratamento Térmico De Resíduos Sólidos: Uma Abordagem Energética. Apresentado no 10º CONGRESSO INTERNACIONAL DE BIOENERGIA, São Paulo – SP.
20. Lino, F. A. M. (2014). Proposta de Aproveitamento do Potencial Energético do Resíduo Sólido Urbano e do Esgoto Doméstico com Minimização dos Impactos Ambientais. Tese de doutorado, Faculdade de Engenharia Mecânica, UNICAMP, Campinas, SP.
21. Lino, F. A. M., & Ismail, K. A. R. (2017). Recycling and thermal of MSW in a developing country. *J Eng IOSRJEN*, 7(7), 30–8. Recuperado de https://www.researchgate.net/publication/318987902_Recycling_and_Thermal_Treatment_of_MSW_in_a_Developing_Country
22. Lino, F. A. M., Ismail, K. A. R., & Ayarzac, J. A. C. (2018). Evaluation of the treatment of municipal solid waste as renewable energy resource in Campinas, Brazil. Campinas, SP.
23. Lino, F. A. M., Ismail, K. A. R., & Ayarzac, J. A. C. (2023). Municipal solid waste treatment in Brazil: A comprehensive review. *Energy Nexus*, 11, 100232. Recuperado de <https://acrobat.adobe.com/link/review?uri=urn%3Aaaid%3Ascds%3AUS%3Adc671871-69cb-3b3a-9137-3d300e95db01>
24. Menezes, R. A., Gerlach, J. L., & Menezes, M. A. (2000). Estágio Atual da Incineração no Brasil. Recuperado de <http://www.resol.com.br/textos/Estado%20Atual%20da%20Incineracao%20no%20Brasil.htm>
25. Morgado, T. C., & Ferreira, O. M. (2017). Incineração de Resíduos Sólidos Urbanos, Aproveitamento na Co-geração de Energia. Estudo para a Região Metropolitana de Goiânia. Universidade Católica de Goiás – Departamento de Engenharia Ambiental, Goiânia, GO.
26. Paulo, B. T., Dalbosco, G. V., & Leites, T. N. (2013). Geração de energia através de resíduos sólidos urbanos. Projeto nível II, Universidade Federal de Santa Catarina, SC.
27. Pereira, T. V., & Seye, O. (2014). Caracterização física térmica de biomassa local. Apresentado no ENEPEX / 5º EPEX – UEMS E 8º ENEPE – UFGD (Encontro de Ensino, Pesquisa e Extensão), Universidade Federal da Grande Dourados, MS.
28. Poli, D. De C. R. et al. (2014). Uma Avaliação das Metodologias para Determinação do Poder Calorífico dos Resíduos Sólidos Urbanos. Artigo publicado na revista Sodebras soluções para o desenvolvimento do país, 9(99), SP.
29. Queiroz, A. J. P. (2014). Análise da Degradação e do Poder Calorífico de Resíduos Sólidos Urbanos. Dissertação de mestrado, Centro de Ciências e Tecnologia, Universidade Federal de Campina Grande – UFCG, PB.

30. Rada, E. C. (2014). Municipal solid waste selective collection and tourism. University of Trento, Italy & Agency for the Effluent Treatments, Italy. Recuperado de <https://www.witpress.com/Secure/elibrary/papers/WM14/WM14016FU1.pdf>
31. Saneamento Básico. (2019). Lixões e aterros sanitários: um desafio permanente na vida dos brasileiros, de 25/10/2019. Recuperado de <https://www.saneamentobasico.com.br/lixoes-aterros-sanitarios-desafio/>
32. Saneamento Básico. (2020). Lixões a céu aberto são tão graves quanto uma pandemia, de 19/05/2020. Recuperado de <https://www.saneamentobasico.com.br/lixoes-ceu-aberto-pandemia/>
33. Semulsp Manaus. (2021). RELATÓRIO ANUAL 2021. Recuperado de <https://semulsp.manaus.am.gov.br/wp-content/uploads/2022/03/RELATORIO-ANUAL-2021.pdf>
34. Weg S.A. (2019). Weg oferece ao mercado solução para geração de energia elétrica com utilização de Resíduos Sólidos Urbanos (RSU). Recuperado de <https://www.weg.net/institucional/BR/pt/news/produtos-e-solucoes/weg-oferece-ao-mercado-solucao-para-geracao-de-energia-eletrica-com-utilizacao-de-residuos-solidos-urbanos-rsu>

The prevalence of neck pain, back pain and low back pain among 3RD year medical students at universities in the metropolitan region of Porto Alegre in times of COVID-19

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ABSTRACT

OBJECTIVE: To verify the prevalence of pain in the cervical, dorsal, and lumbar regions caused by the change to remote classes during the Covid-19 pandemic. **METHODS:** This is an original article based on a cross-sectional study between men and women, over 18 years of age, medical students who are in their third year to assess the incidence of neck pain, back pain and low back pain, through the use of online forms with questions about physical and mental health. **RESULTS:** About 60% of the participants stated that they had adapted their study environment due to remote classes, and another 70% stated that they were attending classes in the office, with their backs poorly supported. In addition, there is evidence of a low number of overweight students who perform and perform daily stretching. **CONCLUSION:** The data were analyzed using tables, descriptive statistics and the statistical test: Non-parametric Mann-Whitney test and Non-parametric Krsukal-Wallis test, and the importance of continuing research was evidenced, given that this research theme is essential for the prevention of possible comorbidities.

Keywords: Cross-sectional study, Cervicalgia, Back Pain, Lumbago, Covid-19.

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INTRODUCTION

Back pain is a colloquial term used to designate pain related to the spine¹. Although most of them refer to low back pain, this study also includes back pain and neck pain². According to the International Association for the Study of Pain (IASP), non-oncological chronic pain (CD) is defined as pain with no apparent biological value that persists beyond the normal tissue healing time, lasting more than 6 months, although other authors have already considered it after a period of three months.³ Discomfort in the lumbar region cannot be understood only in the context of an isolated pain condition, in fact, it has been described in the literature as a deconditioning syndrome, where biopsychosocial factors interact, such as: age, overweight, long hours of sitting, sedentary lifestyle, hyperactivity, stress, lack of stretching, poor posture^{3,10}. The biomechanical model of the spine was not designed to remain in a "sitting position" for long periods, which can cause fatigue, low back pain and cramps.⁴

The model was essential in the identification of the main postural changes caused by spinal overload, enabling learning in a playful and participatory way, since everyone handled and visualized both physiological and pathological vertebral anatomy.⁵

Based on this, in the context of the Coronavirus pandemic, the study scenario of young students has become the home environment, remote educational activities, and these changes have caused behavioral changes, such as increased stress, sleep disorders, and decreased physical activity⁶. With the increase in sedentary lifestyle caused by the isolation of COVID-19, consequently, there may be an increase in pain in the cervical, dorsal and lumbar region. Inactivity can cause lower joint amplitude, limitation of movement, which contributes to exposure to injuries, especially in the spine⁷. In the scenario prior to the Covid-19 pandemic, what was a factor of future concern with the posture of students was the weight of school bags, in a face-to-face modality, which was evidenced in an awareness study in schools about the excess weight carried in backpacks, where through the use of anatomical models of the spine, Students aged 6 to 12 years have been shown to have the direct effects of excess weight carried in backpacks on the musculoskeletal system⁸. In 2020, with the outbreak of the COVID-19 pandemic, Government Organizations recommended numerous preventive measures, such as social isolation⁹.

It is a widespread and relevant problem due to its high incidence, the demand it places on medical care services and the limitations it causes, with consequent damage to patients' quality of life.^{10,11} Whether acute or chronic, pain leads the individual to manifest symptoms such as changes in sleep patterns, appetite, libido, irritability, reduced ability to concentrate, and restrictions in the ability to perform family, professional and social activities¹². Researchers state that the segments of the spine are susceptible to changes throughout life due to the adaptations that life imposes on them¹³. Pain in the spine and adjacent regions corresponds to the vast majority of the reasons for

complaints of orthopedic problems, being one of the structures most affected by sedentary lifestyle and poor posture.¹⁴ Therefore, this study aims to estimate the prevalence of back pain in the population of students in the metropolitan region who are in online classes and to identify whether or not there has been an increase in this complaint among medical students in this year of the Covid pandemic.

METHODS

This is an original article based on a cross-sectional study between men and women, over 18 years of age, medical students who are in their third year to assess the incidence of neck pain, back pain and low back pain, through the use of online forms with questions about physical and mental health. The study was a quantitative study that sought data on neck pain, back pain and low back pain in medical students in the metropolitan region of Porto-Alegre.

RESULTS

The data were analyzed using tables, descriptive statistics and the following statistical test:

Non-parametric Mann-Whitney test

Non-parametric Krsukal-Wallis test

The results were considered significant at a maximum significance level of 5% ($p \leq 0.05$) and the software used for this analysis was Epi Info 7.2.

DISCUSSION

The survey found a larger target audience: most deny working from home, but say they are living with their parents during the pandemic. About 60% of the participants said they had adapted their study environment due to remote classes, and another 70% said they were attending classes in the office, with their backs poorly supported. In addition, there is evidence of a low number of overweight students who perform and perform daily stretching.

Tables 1 and 2 (page 12) show that the position in which they attend classes is the main factor for back pain, as it is also very frequent or sporadic. However, the stress and nervousness factor is frequent among the participants, and they sporadically manage to control such feelings, despite stating about the accumulation of problems, without resolution, most of the time. Table 3 (page 13) shows that there is little or no physical activity by the students, in addition to spending four to nine hours a day sitting. Table 4 (page 13) shows that most of them reported little pain or discomfort and a low percentage of students had pain in the neck region or that prevented them from performing their activities. Table 5 and 6 (page 14) shows that there is no significant difference in pain levels between the age groups. Table 7 (page 14) shows that there is no significant difference in the level of pain

between the places where she attends classes. Table 8 (page 15) shows that there is no significant difference in pain levels between individuals with and without overweight. Table 9 (page 15), through the results of the non-parametric Mann-Whitney test, shows that there is a significant difference in the level of pain between the positions in which the students attend classes only for the question: "During the last week, did you feel anxious" – for this question, a significantly higher degree of pain was observed for individuals who attend classes sitting with poorly supported backs.

Tabela 1. Descrição da amostra investigada

Variável	Categoria	Nº casos	%
Idade	25 ou mais	15	29,4
	Menos 25	36	70,6
Gênero	Feminino	41	80,4
	Masculino	10	19,6
Universidade	FEEVALE	16	31,4
	UFCSPA	5	9,8
	UFRGS	7	13,7
	ULBRA	22	43,1
	UNISINOS	1	2,0
Trabalha em home office	Não	49	96,1
	Sim	2	3,9
Está morando com os pais durante a pandemia?	Não	27	52,9
	Sim	24	47,1
Você teve que adaptar seu local de estudo devido às aulas online?	Não	20	39,2
	Sim	31	60,8
Você assiste a aula onde?	Cama	11	21,6
	Escritório	37	72,5
	sofá	3	5,9
Você assiste a aula em que posição?	Nenhuma das anteriores	1	2,0
	sentado	1	2,0
	sentado com as costas bem apoiadas	11	21,6
	sentado com as costas mal apoiadas	38	74,5
Você tem sobrepeso?	Não	42	82,4
	Sim	9	17,6
Você realiza alongamento diário?	Não	45	88,2
	Sim	6	11,8

Tabela 2. Descrição das variáveis de estudo

Variável	Categoria	Nº casos	%
Selecione a possível causa para sua dor	Doença prévia	3	5,9
	Falta de alongamento	5	9,8
	Local que assisto a aula	2	3,9
	Nenhuma das anteriores	4	7,8
	Nível de stress	15	29,4
	Posição que assisto a aula	18	35,3
	Sedentarismo	4	7,8
Com que frequência você ficou aborrecido por causa de algo que aconteceu inesperadamente?	Às Vezes	19	37,3
	Muito Frequente	19	37,3
	Pouco Frequente	8	15,7
	Quase Nunca	5	9,8
Com que frequência você esteve nervoso ou estressado?	Às Vezes	7	13,7
	Muito Frequente	33	64,7
	Pouco Frequente	9	17,6
	Quase Nunca	2	3,9
Com que frequência você foi capaz de controlar irritações na sua vida?	Às Vezes	32	62,7
	Muito Frequente	9	17,6
	Pouco Frequente	4	7,8
	Quase Nunca	6	11,8
Com que frequência você sentiu que os problemas acumularam tanto que você não conseguiria resolvê-los?	Às Vezes	18	35,3
	Muito Frequente	16	31,4
	Nunca	4	7,8
	Pouco Frequente	4	7,8
	Quase Nunca	9	17,6

Tabela 3. Descrição das variáveis de estudo

Variável	Categoria	Nº casos	%
Em quantos dias de uma semana normal, você caminha por pelo menos 10 minutos contínuos no seu tempo livre?	1 ou 2 dias	18	35,3
	3 ou 4 dias	10	19,6
	5 ou 6 dias	11	21,6
	7 dias	1	2,0
	Nenhum	11	21,6
Em quantos dias de uma semana normal, você faz atividades vigorosas no seu tempo livre por pelo menos 10 minutos, como correr, fazer aeróbicos, nadar rápido, pedalar rápido ou fazer jogging	1 ou 2 dias	18	35,3
	3 ou 4 dias	8	15,7
	5 ou 6 dias	5	9,8
	Nenhum	20	39,2
Em quantos dias de uma semana normal, você faz atividades moderadas no seu tempo livre por pelo menos 10 minutos, como pedalar ou nadar a velocidade regular, jogar bola, volei, basquete, tênis ou musculação	1 ou 2 dias	12	23,5
	3 ou 4 dias	14	27,5
	5 ou 6 dias	5	9,8
	7 dias	1	2,0
	Nenhum	19	37,3
Quanto tempo no total você gasta sentado durante um dia de semana?	De 10 a 12 h/dia	13	25,5
	De 4 a 6 h/dia	17	33,3
	De 7 a 9 h/dia	17	33,3
	Mais que 12 h/dia	4	7,8

Tabela 4. Descrição das variáveis relacionadas à dor

Variável	Categoria	Nº casos	%
Intensidade da dor	A dor é leve nesse momento	13	25,5
	A dor é mais ou menos intensa nesse momento	6	11,8
	A dor é moderada nesse momento	9	17,6
	A dor é muito forte nesse momento	3	5,9
	Sem dor no momento	20	39,2
Sentar	A dor me impede de sentar por mais de 1 hora	5	9,8
	A dor me impede de sentar por mais de 2 hora	15	29,4
	Posso sentar em minha cadeira favorita pelo tempo que quiser	16	31,4
	Posso sentar em qualquer tipo de cadeira pelo tempo que quiser	15	29,4
De pé	A dor me impede de ficar de pé	1	2,0
	A dor me impede de ficar de pé por mais ? hora	6	11,8
	A dor me impede de ficar de pé por mais de 1 h	6	11,8
	Posso ficar de pé pelo tempo que quiser sem dor extra	11	21,6
	Posso ficar de pé pelo tempo que quiser, mas sinto um pouco de dor	27	52,9

Tabela 5. Estatísticas descritivas para as variáveis da escala

Variável	n	Média	DP
1. Durante a última semana, qual foi o nível de dor do seu pescoço:	51	4,24	2,39
2. Durante a última semana, quanto a sua dor no pescoço prejudicou nas suas atividades diárias (estudos, trabalho de casa, tomar banho, colocar roupa, levantar, ler e dirigir)?	41	2,37	2,59
3. Durante a última semana, quanto a sua dor no pescoço prejudicou nas suas atividades recreativas, sociais e familiares?	41	2,07	2,44
4. Durante a última semana, você sentiu-se ansioso (tenso, nervoso, irritado, com dificuldade para se concentrar/relaxar)?	51	7,31	2,79
5. Durante a última semana, você sentiu-se deprimido ("para baixo", triste, pessimista, infeliz)?	51	5,37	3,05
6. Durante a última semana, quanto a sua dor no pescoço piorou (ou poderia ter piorado) com os estudos e trabalho (tanto em casa como fora)?	42	3,93	3,35
7. Durante a última semana, quanto você conseguiu controlar (reduzir) sozinho a sua dor no pescoço?	39	4,74	3,29

Obs.: Alguns casos relatados com "ausência de dor" foram extraídos desta análise
DP – desvio-padrão

Tabela 6. Comparação do nível de dor entre as faixas de idade

Variável	Idade	n	Média	DP	p
1. Durante a última semana, qual foi o nível de dor do seu pescoço:	Menos de 25	36	4,2	2,2	0,983 ^{NS}
	25 ou mais	15	4,3	2,9	
2. Durante a última semana, quanto a sua dor no pescoço prejudicou nas suas atividades diárias	Menos de 25	28	2,0	2,3	0,301 ^{NS}
	25 ou mais	13	3,2	3,1	
3. Durante a última semana, quanto a sua dor no pescoço prejudicou nas suas atividades recreativas, sociais e familiares?	Menos de 25	28	1,6	2,1	0,160 ^{NS}
	25 ou mais	13	3,0	2,9	
4. Durante a última semana, você sentiu-se ansioso	Menos de 25	36	6,8	3,1	0,074 ^{NS}
	25 ou mais	15	8,6	1,4	
5. Durante a última semana, você sentiu-se deprimido	Menos de 25	36	5,1	3,2	0,298 ^{NS}
	25 ou mais	15	6,1	2,5	
6. Durante a última semana, quanto a sua dor no pescoço piorou (ou poderia ter piorado) com os estudos e trabalho (tanto em casa como fora)?	Menos de 25	29	4,2	3,4	0,400 ^{NS}
	25 ou mais	13	3,3	3,2	
7. Durante a última semana, quanto você conseguiu controlar (reduzir) sozinho a sua dor no pescoço?	Menos de 25	27	4,3	3,2	0,238 ^{NS}
	25 ou mais	12	5,7	3,5	

DP – Desvio-padrão
NS – Não-significativo

Tabela 7. Comparação do nível de dor entre as respostas para onde assiste as aulas

Variável	Onde você assiste as aulas	n	Média	DP	p
1. Durante a última semana, qual foi o nível de dor do seu pescoço:	Cama/Sofá	14	4,4	1,7	0,732 ^{NS}
	Escritório	37	4,2	2,6	
2. Durante a última semana, quanto a sua dor no pescoço prejudicou nas suas atividades diárias	Cama/Sofá	10	1,7	1,8	0,493 ^{NS}
	Escritório	31	2,6	2,8	
3. Durante a última semana, quanto a sua dor no pescoço prejudicou nas suas atividades recreativas, sociais e familiares?	Cama/Sofá	10	1,6	1,8	0,660 ^{NS}
	Escritório	31	2,2	2,6	
4. Durante a última semana, você sentiu-se ansioso	Cama/Sofá	14	6,9	3,3	0,881 ^{NS}
	Escritório	37	7,5	2,6	
5. Durante a última semana, você sentiu-se deprimido	Cama/Sofá	14	5,5	3,3	0,702 ^{NS}
	Escritório	37	5,3	3,0	
6. Durante a última semana, quanto a sua dor no pescoço piorou	Cama/Sofá	11	3,1	2,9	0,376 ^{NS}
	Escritório	31	4,2	3,5	
7. Durante a última semana, quanto você conseguiu controlar (reduzir) sozinho a sua dor no pescoço?	Cama/Sofá	10	4,0	3,2	0,437 ^{NS}
	Escritório	29	5,0	3,3	

DP – Desvio-padrão
NS – Não-significativo

Tabela 8. Comparação do nível de dor entre as respostas se possui sobrepeso

Variável	Você tem sobrepeso	n	Média	DP	p
1. Durante a última semana, qual foi o nível de dor do seu pescoço:	Não	42	4,4	2,3	0,255 ^{NS}
	Sim	9	3,4	2,7	
2. Durante a última semana, quanto a sua dor no pescoço prejudicou nas suas atividades diárias	Não	33	2,3	2,5	0,532 ^{NS}
	Sim	8	2,8	2,9	
3. Durante a última semana, quanto a sua dor no pescoço prejudicou nas suas atividades recreativas, sociais e familiares?	Não	33	1,8	2,1	0,196 ^{NS}
	Sim	8	3,4	3,5	
4. Durante a última semana, você sentiu-se ansioso	Não	42	7,1	3,0	0,615 ^{NS}
	Sim	9	8,1	1,6	
5. Durante a última semana, você sentiu-se deprimido ("para baixo", triste, pessimista, infeliz)?	Não	42	5,4	3,1	0,950 ^{NS}
	Sim	9	5,4	3,2	
6. Durante a última semana, quanto a sua dor no pescoço piorou (ou poderia ter piorado) com os estudos e trabalho (tanto em casa como fora)?	Não	34	4,2	3,4	0,291 ^{NS}
	Sim	8	2,6	3,1	
7. Durante a última semana, quanto você conseguiu controlar (reduzir) sozinho a sua dor no pescoço?	Não	32	4,9	3,4	0,593 ^{NS}
	Sim	7	4,1	2,9	

DP – Desvio-padrão

NS – Não-significativo

Tabela 9. Comparação do nível de dor entre as respostas sobre a posição em que assiste a aula

Variável	Assiste a aula em que posição	n	Média	DP	p
1. Durante a última semana, qual foi o nível de dor do seu pescoço:	Sentado com costas bem apoiadas	11	3,6	2,5	0,363 ^{NS}
	Sentado com costas mal apoiadas	38	4,5	2,3	
2. Durante a última semana, quanto a sua dor no pescoço prejudicou nas suas atividades diárias	Sentado com costas bem apoiadas	9	3,1	3,2	0,446 ^{NS}
	Sentado com costas mal apoiadas	31	2,2	2,4	
3. Durante a última semana, quanto a sua dor no pescoço prejudicou nas suas atividades recreativas, sociais e familiares?	Sentado com costas bem apoiadas	9	2,8	3,3	0,616 ^{NS}
	Sentado com costas mal apoiadas	31	1,9	2,2	
4. Durante a última semana, você sentiu-se ansioso	Sentado com costas bem apoiadas	11	6,2	2,8	0,050*
	Sentado com costas mal apoiadas	38	7,7	2,7	
5. Durante a última semana, você sentiu-se deprimido ("para baixo", triste, pessimista, infeliz)?	Sentado com costas bem apoiadas	11	4,5	2,6	0,188 ^{NS}
	Sentado com costas mal apoiadas	38	5,6	3,2	
6. Durante a última semana, quanto a sua dor no pescoço piorou (ou poderia ter piorado) com os estudos e trabalho (tanto em casa como fora)?	Sentado com costas bem apoiadas	9	2,9	3,4	0,180 ^{NS}
	Sentado com costas mal apoiadas	32	4,3	3,3	
7. Durante a última semana, quanto você conseguiu controlar (reduzir) sozinho a sua dor no pescoço?	Sentado com costas bem apoiadas	9	5,0	3,7	0,890 ^{NS}
	Sentado com costas mal apoiadas	29	4,8	3,2	

DP – Desvio-padrão
NS – Não-significativo
* significativo ps0,05

CONCLUSION

In view of these results, the importance of continuing research was evidenced, given that this research theme is essential for the prevention of possible comorbidities.



CONFLICT OF INTEREST

The authors declare no conflict of interest.


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REFERENCES

1. Iguti, A. M., Bastos, T. F., & Barros, M. B. A. (n.d.). Dor nas costas em população adulta: estudo de base populacional em Campinas, São Paulo, Brasil. *Cad. Saúde Pública*, Rio de Janeiro, 31(12), 2546-2558.
2. Guedes, F. G., & Machado, A. P. N. (2008, Jan). Fatores que influenciam no aparecimento das dores na coluna vertebral de acadêmicos de fisioterapia. *Estação Científica Online* (Ed. Esp. Saúde). Juiz de Fora, 5. Recuperado de <https://portaladm.estacio.br>
3. Costa, D., & Palma, A. (n.d.). O efeito do treinamento contra resistência na síndrome da dor lombar. *Rev Port Cien Desp*, 2(V), 224–234.
4. Merskey, H., & Bogduk, N. (1994). *Classification of chronic pain: descriptions of chronic pain syndromes and definitions of pain terms* (2nd ed.). Seattle: IASP Press.
5. Mercúrio, R., Chagas, J. C. M., Oliveira, C. E., et al. (1993). Lombalgia. *J Bras Med*, 64(1), 71-8.
6. Brzęk, A., Dworrak, T., Strauss, M., Sanchis-Gomar, F., Sabbah, I., Dworrak, B., & Leischik, R. (2017). The weight of pupils' schoolbags in early school age and its influence on body posture. *BMC Musculoskelet Disord*, 18(1), 117.
7. Souza, C. E. A., Lopes, C. P., Lima Neto, J. J., & Barbosa, A. V. (2017). Associação da escoliose toracolombar e peso da mochila em estudantes do ensino médio. *Arq Cienc Saude*, 24(4), 25-29.
8. Freitas, A. R. R., Napimoga, M., & Donalisio, M. R. (2020). Análise da gravidade da pandemia de Covid-19. *Epidemiol Serv Saude*, 29(2), e2020119.
9. Bezerra, A. C. V., et al. (2020). Fatores associados ao comportamento da população durante o isolamento social na pandemia de COVID-19. *Cienc Saude Coletiva*, 25(Suppl 1), 2411-2421.
10. Botero, J. P., Farah, B. Q., Correia, M. A., et al. (n.d.). Impacto da permanência em casa e do isolamento social, em função da COVID-19, sobre o nível de atividade física e o comportamento sedentário em adultos brasileiros. *Einstein* (São Paulo), 19, eAE6156.
11. Toscano, J. J. O., & Egypto, E. P. (2001). A influência do sedentarismo na prevalência de lombalgia. *Rev Bras Med Esporte*, 7(4), 132-137.
12. Mesquita, R. (1997). Tradução para o português e validação do questionário genérico de avaliação de qualidade de vida “Medical Outcomes Study 36-Item Short-Form Health Survey (SF-36)” [tese]. São Paulo: Escola Paulista de Medicina, Universidade Federal de São Paulo.
13. Di Bernardi Luft, C., Sanches, S. O., Mazo, G. Z., & Andrade, A. (2007). Versão brasileira da Escala de Estresse Percebido: tradução e validação para idosos. *Rev Saude Publica*, 41(4), 606-615.
14. Benedetti, T. R. B., Antunes, P. C., Rodriguez-Añez, C. R., Mazo, G. Z., & Petroski, E. L. (2007). Reprodutibilidade e validade do Questionário Internacional de Atividade Física (IPAQ) em homens idosos. *Rev Bras Med Esporte*, 13(1), 11-16.
15. Nusbaum, L., Natour, J., Ferraz, M. B., & Goldenberg, J. (2001). Translation, adaptation and validation of the Roland-Morris questionnaire--Brazil Roland-Morris. *Braz J Med Biol Res*, 34(2), 203-210.

Evaluation of the physical-chemical quality of honey without inspection registration sold in municipalities of Itapira and Mogi Guaçu, State of São Paulo

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ABSTRACT

Honey, is The valuable food, but its quality can be compromised by adulteration. Brazilian legislation defines quality parameters for honey, including its chemical composition and physical-chemistry characteristics. The objective of this work is to verify whether commercial honeys are not registered in the municipalities of Itapira and Mogi Guaçu meet these legal standards, with the purpose of evaluating the quality and authenticity of the product. In this study, 10 samples of unlabeled honey were collected from the municipalities of Itapira - SP and Mogi Guaçu -SP. Physicochemistry analysis were carried out covering reducing sugars, moisture, soluble solids, Ash, apparent sucrose, pH, acidity and color, in addition to adulteration tests, Lugol, Lund and Fiehe reactions, with all analysis being carried out in triplicate. The methodologies adopted followed the recommendations of the Adolfo Lutz Institute. The results were submitted I'm statistical analysis with ANOVA/Tukey test, considering a significance level of 5%. The main results revealed that one of the samples contained reducing sugars below the limit for floral honey, suggesting adulteration. For humidity, disappear samples exceeded the acceptable limit, which affects the quality and durability of the honey. The results obtained from soluble solids are in accordance with works found in the literature. At the mineral impurities were found in the ash content analysis. Some honeys showed high levels of apparent sucrose and acidity, raising concerns about adulteration and impact on flavor and quality. There was variation in the acidity content of the samples, but this remained in the typical range for honeys. Furthermore, analysis of colorimetric parameters revealed significant variations in the L*, a* and b* components for all samples. For adulteration tests, in the Lugol reaction, only 40% of the samples presented negative results, suggesting The high level of adulteration by starch or dextrans . Regarding the Lund reaction, only 30% of the samples revealed protein precipitate within the expected range, indicating that 70% of the samples may have been adulterated by the addition of water or another diluent. In the Fiehe reaction, 70% of the samples demonstrated positive results, indicating adulteration due to the addition of sugar syrups or overheating of the honey. Through the results obtained, it was concluded that compliance with legal standards varies considerably between samples.

Keywords: Adulteration, Beekeeping, legislation, Colorimetric parameters.

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INTRODUCTION

According to current legislation in Brazil, honey is considered a food product resulting from the activity of bees melliferas what collect nectar in flowers or secretions in parts living plants, including excretions of plant-sucking insects, which are transformed and combined with specific substances of their own. This process occurs in hives, where the honey It is stored It is matured at over time (BRASIL, 2000).

Honey is made up of two types of sugars, glucose and fructose, along with presence of various mineral salts, such as calcium, sulfur, iron, copper, chlorine, sodium, phosphorus and magnesium. He constitutes one complex mixture what includes vitamins, proteins, enzymes, amino acids, polyphenols It is you products resulting from the reaction in Maillard (FILHO et al., 2012).

The chemical composition of honey, as well as its sensory characteristics, such as color, flavor and aroma, may vary due to several factors, such as climate, species of bee involved and the plant of origin of the nectar. This diversity makes it possible to obtain a wide range of honey types in different regions of the country. Furthermore, other elements what influence so much at quality of honey how much in your parameters physical-chemicals include the appropriate management of the hives, the selection of the location for installing the apiary, the process of harvest, O appropriate transportation It is to the phases in processing of honey (FERREIRA, 2022).

Per account from the growing demand at the Marketplace It is The growing expectation of the consumers for high quality products, it is crucial that the honey available for sale is a product genuine, according to to the regulations current. At the however, O honey he can to be susceptible The tampering what compromise your integrity, such as The inclusion in sugar conventional, corn syrup, glucose, molasses, invert sugar solution and glucose syrup (DANTAS; SANTOS; SANTOS; SILVA; CARVALHO, 2022).

Despite regulations prohibiting the adulteration of honey, which occurs with frequency due to its relatively high price, the ease of incorporating substances adulterants and the need for laboratory analyzes to identify them, it is common to observe the occurrence of fraudulent practices. According to Decree No. 10,468, dated August 18, 2020, which establishes standards for the industrial and sanitary inspection of products of origin animal, consider themselves cheats The action in deprive partial or totally raw material It is products of their original characteristics through replacement by inert substances or foreign substances, as well as the addition of ingredients, additives or technological adjuvants to disguise or hide changes, deficiencies in the quality of raw materials or flaws in the process in production, or with The goal in increase O volume, or Weight of product (FERREIRA, 2022).

Among the circumstances, the legislation in force emphasizes the main parameters of physicochemical composition of honey that must be evaluated, including moisture, sugars reducers,

apparent sucrose, insoluble solids, minerals, ash, acidity, diastasis index and hydroxymethylfurfural (HMF). It also highlights that the detection of fraud and adulteration in honey must be carried out through physical-chemical analyzes stipulated by legislation and the Institute Adolf Lutz (BRAZIL, 2000).

As it is considered of animal origin, honey sold must be registered with the Ministry of Agriculture, Livestock and Supply (MAPA) and have the approval of the Federal Inspection (SIF), responsible for inspecting and ensuring the quality of food products origin animal (ALBUQUERQUE, 2021). O record plays one paper crucial at protection public health, ensuring the quality of honey and promoting ethical business practices It is transparent, ensuring the integrity It is security of the honeys sold.

The present work had the general objective of evaluating the physicochemical characteristics of samples of honey without inspection records sold in the municipalities of Itapira-SP and Mogi Guaçu-SP.

REVIEW IN LITERATURE

HONEY

Among the products resulting from bee activity, honey stands out as the most famous and widely known. Throughout human history, honey has been one of the first foods and also played a significant role as a medicinal resource in many ancient civilizations. Currently, honey is appreciated as a food, recognized so much per your qualities medicinal how put your value nutritional (SILVA, 2006).

According to stipulated at Instruction Normative no. 11/2000 issued for the Ministry from the Agriculture, Livestock It is Supply (MAP), O honey It is categorized with base in your origin, being Divided in two categories main: honey floral It is honey in melate. O honey floral It is collected from flower nectar and can be classified as unifloral or monofloral, depending of the predominance of a single species of flower. This honey variant has properties sensorial, physical-chemical characteristics and distinct microscopic characteristics. For another On the other hand, melate honey is mainly composed of secretions from living parts of plants or excretions of insects that feed on plant sap, which end up accumulating on these plants.

O honey It is one substance composed per several sugars, with predominance of the monosaccharides glucose It is fructose. In addition from that, contains proteins, amino acids, enzymes, acids organic, minerals, pollen It is others substances, including sucrose, maltose, maleitosis It is others oligosaccharides (including dextrans). May also contain small amounts of fungi, algae, yeast It is others particles solid resulting of process in collect of honey (MENDES et al . , 2009).

The honey production process involves collecting nectar from flowers, in the case of honey



floral, or secretions from living parts of plants and excretions from insects that feed on sap in plants, at the case of honey in melate, what they are then stored at vesicle honey of bees. In the hive, the nectar goes through a transformation process that includes two stages, one physics and one chemistry. The physical stage consists of reducing the moisture content, occurring thanks to the mandibular movements of bees, which involve ingestion and regurgitation of the nectar, as well as the flapping of wings, reducing the moisture content to about 17% to 18%. A chemical step involves the addition of specific enzymes, such as invertase, glucose oxidase and diastasis (FERREIRA, 2022).

A invert convert part from the sucrose of nectar collected in glucose It is fructose It is to be continuedacting until the honey ripens. This sucrose hydrolysis reaction produces a solution concentrated sugar content, which contributes to the honey's resistance to fermentation, ensuring its quality. Glucose oxidase generates gluconic acid and hydrogen peroxide from glucose gift at the honey, substances what also help The avoid O growth in microorganisms, especially in the early stages of the process, when the moisture content is still high. Diastase is the enzyme responsible for breaking down starch and can be used as one indicator in overheating of honey, then It is unstable in temperatures high (FERREIRA, 2022).

To the characteristics of honey, as flavor, aroma, color, viscosity It is properties medicinal products, are intrinsically related to the source of nectar and the species of bee that produces it. produced (DAMASCENO, 2012). O honey It is considered one food in high quality nutritional due The presence in vitamins, minerals It is your high value energy, these nutritional characteristics, along with its medicinal properties, have contributed to one growing interest on part of consumers (MACEDO, 2007).

PRODUCTION NATIONAL OF HONEY

A history from the beekeeping at the Brazil started in 1839, at the state of River in January, when Father Antonio Carneiro introduced *Apis mellifera bees* with authorization from Dom Pedro II, per quite of Decree no. 72 in 12 in July in 1839. Posteriorly, immigrants Europeans contributed to the introduction of other bee species, mainly in the South and Southeast. At that time, beekeeping was more of a hobby than a professional activity. It is economic (DAMASCENO, 2012).

In the 1950s, Brazilian beekeeping faced a significant crisis due to pests and diseases that led to the extinction of 80% of hives in the country. Professor Warwick Estevan Kerr, with support from the Ministry of Agriculture, carried out research in Africa to find African queen bees with good productivity characteristics and resistance to illnesses, aiming to improve The beekeeping at the Brazil. At the however, one incident at the apiary experimental in They are Paul resulted at escape in bees queens African for The nature, dueto their aggressive behavior. This led to sensationalist reports and the abandonment of activity per many beekeepers, while others if adapted The techniques in



management for to leadwith to the "bees Africanized " (TREVISOL; BUENO; OLIVEIRA; MACEDO, 2022). Second Damascene (2012), The introduction of bees Africanized he was one point in turn forThe beekeeping Brazilian. After O development in techniques suitable in management at decade in70, The beekeeping if returned an activity strong all over the country.

Honey productivity in Brazil is relatively low compared to others countries. According to the 2017 Agricultural Census, Brazilian beekeepers recorded a average in 19.8 kilos in honey per hive per year. A China leads O ranking worldwide in productionof honey, followed by Türkiye, Iran and Argentina. Brazil occupies tenth position on the list of largest producers, with 51 thousand tons in 2020 (TREVISOL; BUENO; OLIVEIRA; MACEDO, 2022).

According to the Brazilian Association of Bee Studies - ABELHA (2022), in 2021, O Brazil achieved one record at production in honey, with 55.8 thousand tons, representingan increase of 6.4% compared to 2020. The value of production also increased, reaching R\$ 854.4 millions, one addition in 34.8% in relationship The 2020. O price average of honeyrose from R\$ 12.07 for R\$ 15.30 per kilo.

In 2022 data released by IBGE, honey production in Brazil reached 60.97 thousand tons, overcoming you numbers of year previous. O state of River Big of South highlightedas the main producer, contributing 9 thousand tons, generating revenue of R\$ 957,811 thousand. The municipality of Bagé, in this state, led the production, contributing R\$ 8,100 thousand. In Paraná, production totaled R\$ 138,993 thousand with a quantity produced of8.6 tons. O bigger County producer he was Arapoti, contributed with R\$ 16,363 thousand At the Piauí,production reached R\$121,715 thousand with a quantity of 8.3 tons. Saint Raymond Nonato, in this state, he was the municipality with bigger production, generating R\$ 11,198 thousand. In Minas Gerais, production reached R\$89,307 thousand with a quantity of 6 tons. The municipality ofAnt He stood out as O bigger producer, generating R\$ 4,230 thousand. They are Paul occupied The fifthposition, with production valued at R\$73,158 thousand and 4.8 tons. Botucatu was the County more prominent, generating R\$ 9,113 thousand, while Itapira It is Mogi Guaçu contributed with R\$ 147 thousand and R\$ 111 thousand respectively.

LEGISLATION

The physicochemical parameters for honey in Brazil are established by the Ministry from the Agriculture, Livestock It is Supply (MAP) with O purpose in standardize O processing of products of animal origin. This aims to ensure equal conditions and total transparency in the production and marketing of these products. Normative Instruction no. 11, dated 20 of October 2000, approved O Regulation Technician of Identity and Quality of honey. That regulation define The identity, classification, designation, compositionIt is you requirements relative to the characteristics physical-chemical, sensory, conditions in storage, additions, control in contaminants, conditions hygienic,

criteria macroscopic It is microscopic, weights It is measures, labeling, sampling It is methods in analysis to be followed (BRASIL, 2000). This instruction is in accordance with the guidelines of the Ministry of Health, according to The Resolution MERCOSUR/GMC/RES. No. 89/99 (BRAZIL, 1999).

Second The Instruction Normative no. 11, in 20 in October in 2000, to the analytics what must be performed routinely on honey include the quantification of reducing sugars, humidity, apparent sucrose, water-insoluble solids, ash, acidity, diastasis activity and content in hydroxymethylfurfural (HMF). O Regulation Technician in Identity It is Quality of Honey (BRASIL, 2000) strictly prohibits the addition of any sugars or substances that do not do part from the composition original of honey, It is require what all honey intended to the consumption human meets minimum quality requirements. The established physicochemical parameters are described at Table 1.

Table 1: Requirements physical-chemicals of honey second legislation Brazilian

Specifications		
Parameters	Honey Floral	Melato
Color	Variable	
Sugars Reducers (g/100g)	Minimum 65	Minimum 60
Sucrose Apparent (g/100g)	Maximum 6	Maximum 15
Solids Insoluble	Maximum 0.1	
Moisture (g/100g)	Maximum 20	
Ashes (g/100g)	Maximum 0.6	Maximum 1.2
Acidity (mEq/Kg)	Maximum 50	
Activity diastic (scale Gothe)	Minimum 8	
Hydroxymethylfurfural (mg/kg)	Maximum 60	

Source: Adapted in BRAZIL (2000).

Although not included in Brazilian legislation, some guidelines are used to identify adulterations or conservation problems in honey. The standards established for the Lugol, Lund and Fiehe reactions can be consulted in Table 2. These determinations are not specifically included in Normative Instruction no. 11, dated 20 October in 2000, but they are recommended for the Institute Adolfo Lutz as practices auxiliaries at assessment of quality of honey.

Table 2: Standards settled down for the Institute Adolfo Lutz for to the reactions in Lugol, Lund It is Fiehe

Parameters	Limits settled down
Reaction Lugol	Negative
Reaction Lund	maximum 3.0 mL It is minimum 0.6mL.
Reaction Fiehe	Negative

Source: Adapted in IAL (2008).

In addition to the inclusion of unauthorized substances, the legislation also prohibits the honey overheating process, which involves raising the temperature to values superiors The 60°C (BRASIL, 2000). That practice in overheating It is often employee with O purpose in reuse honeys what already demonstrate signals in fermentation initial, reduce to tendency to crystallization or to facilitate the process filling (FERREIRA, 2022).

METHODOLOGY

OBTAINING FROM THE SAMPLE

The bee honey used in this work comes from the municipalities of Itapira- SP (5 samples) It is Mogi Guaçu -SP (5 samples). They were 10 samples collected in warehouses, emporiums, open fairs and markets, in August 2023. They were in the form in liquid honey, devoid of any labeling.

The samples were taken to the Bromatology Laboratory of the Federal Institute of South of Minas Gerais (IFSULDEMINAS) - Inconfidentes campus, where they were duly packaged The temperature environment It is to the shelter in light in your packaging designated, until The conclusion in all to the analytics physicochemical. These analytics they were executed during O month in September of 2023.

ANALYTICS PHYSICAL CHEMISTRY

To the analytics of this work they were carried out at the Laboratory in Bromatology, of Institute Federal southern from Minas General- campus Inconfidentes (IFSULDEMINAS).

They were conducted analytics physical chemistry for The determination in sugars reducers, moisture, solids soluble, ash, sucrose apparent, pH, acidity It is color, in addition of the tests of adulteration, including The reaction in Lugol, reaction in Lund It is The reaction in Fiehe. All to the analytics they were carried out in triplicate, following The methodology recommended for the Institute Adolfo Lutz (IAL, 2008).

Sugars reducers

Reducing sugars were determined according to method A (176/IV) of the Instituto Adolfo Lutz (IAL, 2008). In this technique, the product is hot titrated using solution in Fehling A It is B, at



presence in blue in methylene, no overtaking O period in threeminutes.

Moisture

A determination from the moisture he was carried out in refractometer analog, brand INSTRUTHERM, with scale in 0 The 95 °Brix, getting O index in refraction The 20°C. He was followed the 173/IV method of the Adolfo Lutz Institute (IAL, 2008), obtaining the percentage of humidity according to Table Chataway.

Solids soluble

You solids soluble they were determined in refractometer analog, brand INSTRUTHERM, with scale in 0 to 95 °Brix, getting O index in refraction The 20 °C, second O method 010/IV of Adolfo Lutz Institute (IAL, 2008).

Ashes

Ash determination was carried out by heating the sample, following the method 018/IV of the Adolfo Lutz Institute (2008), where the material was incinerated at 550 °C and cold The temperature environment in one desiccator. To the operations they were repeated until obtaining in constant weight.

Sucrose apparent

The determination of apparent sucrose was carried out by titration. The samples were hydrolyzed It is treated with acid hydrochloric, followed for the neutralization with hydroxide in sodium. The titration of Fehling's solutions A and B, in the presence of methylene blue, was performed quickly, not exceeding three minutes, according to method A (178/IV) established by the Institute Adolfo Lutz (IAL, 2008).

pH

O pH he was determined in meter in pH in bench, brand Alakit, model AT-355, second O Institute Adolfo Lutz. (IAL, 2008) according to O method 017/IV- Determination electrometric of pH.

Acidity

The acidity of the honey solution was determined by titration, after diluting the honey in phenophytalein was added to water, and the titration was carried out with sodium hydroxide solution. sodium, until reaching pH 8.5. The pH measurement was made with a benchtop pH meter from the brand Alakit, model AT-355, following O method 016/IV of Institute Adolfo Lutz (IAL, 2008).

Parameters colorimetric

A analysis in parameters colorimetric he was carried out in samples in 30 mL at the colorimeter Konica Minolta (Model CM-2300). He was used O system CIELab (L*, The* It is B*),at the which L* represents O component in brightness, varying in 0 The 100. The parameters The* It is b* correspond to the two color components, ranging from -100 to 100. The a* componentspans the scale from green to red, while the b* component ranges from blue to yellow .

Reaction in Lugol

Lugol reaction analysis was performed using diluted honey samples. After a process of heating in a water bath, followed by cooling, 0.5 mL was addedfrom the solution in Lugol. A occurrence in one change for shades reddish-brown orblue indicated The presence in dextrans, or starch at sample, according to to the guidelines of InstituteAdolfo Lutz (IAL, 2008) established by method 184/IV.

Reaction in Lund

A reaction in Lund he was determined according to to the guidelines of Institute Adolfo Lutz (IAL,2008), following method 182/IV. In the procedure, the honey samples were diluted and subsequently, 0.5% tannic acid and water were added. After rest, it was observed training or absence of precipitate.

Reaction in Fiehe

A reaction in Fiehe he was determined second to the guidelines of Institute Adolfo Lutz (IAL, 2008), using method 183/IV. In the procedure, the honey samples were diluted in ether. The resulting solution was then transferred to a test tube containing solution hydrochloric in resorcino It is left in rest. O emergence in one coloring red indicatedThe presence in glucose commercial or overheating in honey.

ANALYSIS STATISTIC

The results obtained in the physicochemical and colorimetric analyzes were subjected to analysis in variance (THE NEW) with O test in Tukey The 5% in probability. That procedurestatistical analysis was carried out using the Sensomaker® computer program, developed byPinheiro, Nunes and Viotoris (2013). The results obtained were compared with the legislation in force, specifically Normative Instruction no. 11 of 2000, which establishes the requirements and standards for honey in Brazil (BRAZIL, 2000).

RESULTS AND DISCUSSION

ANALYTICS PHYSICAL CHEMISTRY

Your results of analytics physical chemistry in sugars reducers moisture, solids soluble, ash, sucrose apparent, acidity and pH, are presented in the Table 3.

Table 3: Results of analytics physical chemistry of samples in honeys commercialized us counties in Itapira- SP It is Mogi Guaçu -SP

Sample no.	Sugars reducers (g/100g)	Moisture (%)	Solids soluble (°Brix)	Ashes (%)	Sucrose apparent (g/100g)	Acidity (mEq/kg)	pH
01	75,01 ^c ± 1,18	22,00 ^b ± 0,01	78,00 ^e ± 0,00	0,32 ^b ± 0,20	6,29 ^d ± 0,66	14,86 ^e ± 0,91	3,59 ^b ± 0,08
02	61,23 ^b ± 0,57	22,50 ^a ± 0,02	77,50 ^f ± 0,02	0,23 ^b ± 0,26	15,50 ^b ± 0,34	18,45 ^{d,e} ± 0,07	3,59 ^b ± 0,02
03	73,19 ^{c,d} ± 1,57	22,50 ^a ± 0,02	77,52 ^f ± 0,01	0,45 ^a ± 0,19	1,20 ^c ± 0,56	63,52 ^b ± 6,21	3,77 ^a ± 0,01
04	85,96 ^a ± 0,43	21,00 ^d ± 0,02	79,00 ^c ± 0,04	0,07 ^c ± 0,07	2,82 ^e ± 1,63	27,69 ^d ± 1,26	3,76 ^a ± 0,00
05	75,39 ^c ± 1,43	22,33 ^{a,b} ± 0,28	77,67 ^{e,f} ± 0,28	0,44 ^a ± 0,02	6,61 ^{c,d} ± 2,29	18,84 ^{d,e} ± 1,51	3,66 ^b ± 0,02
06	79,37 ^b ± 1,26	20,00 ^e ± 0,03	80,00 ^b ± 0,04	0,46 ^a ± 0,00	2,59 ^e ± 0,67	93,59 ^a ± 1,23	2,79 ^e ± 0,01
07	68,49 ^{e,f} ± 0,46	20,17 ^e ± 0,27	79,83 ^b ± 0,25	0,04 ^c ± 0,00	10,05 ^c ± 0,94	48,63 ^c ± 8,28	3,04 ^d ± 0,01
08	66,97 ^{f,g} ± 0,68	18,50 ^f ± 0,03	81,50 ^a ± 0,03	0,41 ^a ± 0,05	19,24 ^a ± 0,74	43,59 ^c ± 1,78	3,31 ^c ± 0,01
09	70,59 ^{d,e} ± 0,76	20,00 ^e ± 0,02	80,02 ^b ± 0,01	0,43 ^a ± 0,29	13,69 ^b ± 1,09	69,28 ^b ± 2,39	3,09 ^d ± 0,01
10	64,94 ^g ± 0,73	21,50 ^c ± 0,03	78,51 ^d ± 0,02	0,29 ^b ± 0,18	4,85 ^{d,e} ± 1,50	59,77 ^b ± 2,00	3,80 ^a ± 0,01

*means followed by the same letter, in the same column, do not differ from each other at $p \leq 0.05$ using the Tukey Test. Source: Authors (2023).

Sugars reducers

Upon completing the analysis of reducing sugar levels in honey samples, stands out This one parameter as one indicator fundamental from the composition of that product. Table 3 presents notable variations between the samples, evidenced by the averages followed by distinct letters, indicating statistically significant differences ($p \leq 0.05$), according to observed at the Test in Tukey. A sample what presented O bigger content in reducing sugars was number 04, statistically differing from all other samples analyzed. It can be seen that the sample of No. 02 had the lowest sugar content reducers, statistically differing in all other samples analyzed.

According to the guidelines of current legislation (BRASIL, 2000), the minimum content acceptable for reducing sugars is set at 65% for floral honey. In this study, one can observe at Table 3, what just The sample in no. 02 presented contents below of stipulated limit. However, it is worth noting that legislation allows honey melate possess one content Minimum in 60%. Of that form, although O honey in question exceed the limit stipulated for floral honey, it does not violate the values established for honey melate. The specific categorization of honey, due to the lack of labels in the analyzed samples, remains unknown. All remaining samples comply with current legislation, so much in what if refers to the floral honey how much to honey in melate.

Lopes (2015) analyzed honey from the jatai bee (*Tetragonisca angustula*), collected in the district of Felisberto in the city of Curiúva-PR and identified, when analyzing the rates of sugars

reducers, values maximums reaching 63.43% It is minimums in 54.55%. In significantly, all samples analyzed demonstrated that they did not comply with the standards established by Brazilian legislation.

In one study about The solubility from the glucose in solutions in fructose, similar At the concentrations found in honey, it was observed that glucose became more soluble with O increase from the concentration in fructose. That observation he was explained for the balance between anhydrous glucose and monohydrate glucose (form present in granulated honey). In high levels of fructose, the balance favors the anhydrous form of glucose, which is more soluble in water. The relevance of this balance to granulation was supported by evidence that in solutions saturated with fructose, the transition from glucose monohydrate to glucose form anhydrous occurs below in 30°C. One can infer what honeys with tall contents in fructose It is lows contents in glucose they are any less prone The crystallization, one phenomenon what affects The acceptance of these natural products by consumers (MOREIRA; MARIA, 2001).

According to highlighted per Silva (2006), The presence in sugars at the honey plays one paper crucial at your conservation, one turn what contributes for The creation in one pressure osmotic in the medium, which, in turn, prevents the development of bacteria, mold, yeasts and other unwanted microorganisms. This suggests that honeys that present contents in sugars below of limit Minimum allowed for the legislation they can to create conditions more favorable to the proliferation of these microorganisms, which lights up a signal in alert regarding The quality It is security of these products.

Moisture

To the finish The assessment in analysis in moisture in samples in honeys, he was considerable variability was identified, as can be seen in Table 3. note that samples No. 02 and 03 obtained the highest moisture contents, not statistically differing from sample no. 05. The sample that presented the lowest was no. 08 differing statistically from all other samples analyzed. Among the results obtained, presented in Table 3, only samples No. 06, 07, 08, and 09 they are according to The current legislation, the which establishes a limit maximum of 20%.

The importance of maintaining the moisture content of honey within these parameters legal is directly linked to the quality of the product and its durability. This is due to the fact that, when honey has a high moisture content, there is a greater susceptibility The Law Suit in fermentation. That vulnerability occurs due The possible contamination by microorganisms, which are naturally found both in the area of honey extraction and in the bodies of bees, which play a crucial role in production of this precious liquid (SOUZA, 2016).

Second Mora-Escobedo et al. (2006), The moisture initial of honey also It is one of the factors

influential at your crystallization, then how much smaller The moisture bigger The concentration of monosaccharides (glucose and fructose), resulting in a higher level of saturation and, consequently, greater probability of crystallizing. This crystallization varies depending with several factors, such as the concentration of sugars, the water content in its composition Natural, The origin floral of nectar, O handling during your processing, good as to the conditions of storage (COMFORTI et al., 2006).

The water content in honey is influenced by several factors, ranging from conditions climate at the day from the harvest until O level in maturation of bees responsible for its production. Honey is a hygroscopic product, that is, it has the ability to absorb water of environment. A amount in water gift at the honey it is directly related The occurrence in fermentation unwanted, one turn what how much bigger The amount of water present, the greater its susceptibility to this process. When the moisture content exceeds the limit of 20%, this indicates that the honey has undergone addition of water, has been subjected to inadequate processing or has been harvested before reaching maturity. internship in adequate maturation (MEIRELES, Cçado, 2013).

Solids soluble

Concluding the investigation into the analysis of soluble solids in samples of honeys, notable variations were found between samples, evidenced by the averages followed by distinct letters, indicating statistically significant differences ($p \leq 0.05$), according to introduced at Table 3. One can observe what The sample in no. 08 got the highest content of soluble solids, statistically differing from all other samples analyzed. To the samples in no. 02 It is 03 presented you minors contents in solid solubleno statistically differing from the sample in no. 05.

At the what it says respect to the values medium in solids soluble, It is important observe what The legislation Brazilian no includes This one parameter in its guidelines. How much bigger for the sugar content and the longer the maturation period of the honey, the greater the presence of soluble solids. Therefore, the analysis of this parameter was conducted with the purpose of enrich The gamma of variables for comparing results.

The soluble solids values obtained in the samples analyzed in this work, ranged from 77.50 to 81.50° Brix, as indicated in Table 3. These results are aligned with you found per Barbosa (2013) in your search about honeys marketed in the fairs from the city in Empress, at the state of Maranhão, what presented variations of 77.31 a 81.36° Brix.

In the work carried out by Vieira et al. (2017) , which performed the physical- chemistry of honeys produced in the state of Mato Grosso do Sul, Brazil, for the analysis of soluble solids content (°Brix), the observed values ranged from 75 to 80 °Brix, with value average in 76.05 ± 1.5 °Brix, you values found in this study, they were Upcoming to the obtained by Santos et al. (2010) in honeys produced in the State of Ceará whose indexes found were 73.80 to 80.05 °Brix.

Total soluble solids are not a parameter established in legislation, but its content is directly related to the sweetness of the honey, as it reflects the amount of sugar present. The evaluation of this characteristic is relevant due to the preference of the consumer per honeys with levels lowest of sugar (SILVA et al., 2009).

Ashes

Upon concluding the analysis of the ash content in honey samples, this parameter as a fundamental indicator of the composition of these products. Accordingly with Table 3, as observed in the Tukey Test, the samples that presented you bigger contents in ashes they were to the in no. 03, 05, 06, 08 It is 09, no differing statistically among themselves. It can be observed that samples No. 04 and 07 showed you lower levels medium for the content in ashes, no statistically differing between yes.

According to Brazilian legislation, the maximum permitted limit for ash content in floral honey it is established at 0.60% (BRASIL, 2000). Therefore, based on these data, all the honeys analyzed in this study they are according to the limit stipulated.

The ash content is indicative of the presence of minerals in honey, mainly compounds per abundance in potassium (K), sodium (At), calcium (Here) It is magnesium (Mg), in addition in small quantities in aluminum (Al), iron (Faith), copper (Ass), manganese (Mn) It is zinc (Zn), along with traces of arsenic (Ar), iodine (I) and fluorine (F) (GOIS et al., 2013). As highlighted by Marchini et al. (2004), the ash content represents the minerals present in honey, which can be used as a criterion to evaluate its quality, and it is related to your botanical origin It is geographic.

Anacleto et al. (2009) observed that the percentages of ash varied between 0.21% and 0.60%, with an average of 0.39%, and these values are within the limits established by the Ministry of Agriculture and Supply. Souza (2017) also adds what The determination of content in ashes he can to reveal possible irregularities at the honey, such as contamination caused by lack of decantation or filtration at the end of product extraction process, as well as adulteration, serving as an indication of its quality. Vieira et al. (2017) in their study on physical-chemical characterization of honey produced in the State of Mato Grosso do Sul, reported ash contents that ranged from 0.06% to 0.55%, with an average of $0.25\% \pm 0.17\%$, in accordance with the legislation in force.

Sucrose apparent

According to The Table 3, you results in sucrose apparent in samples in honeys without record commercialized in Itapira It is Mogi Guaçu demonstrated be difference statistic in between you scores medium for This one parameter. A sample what presented O biggersucrose content was no. 08, statistically differing from all other samples analyzed. Note what to the samples in no. 03, 04 It is

06 presented minor contents medium for content in sucrose apparent, no different from the sample in no. 10.

According to current Brazilian legislation (Brazil, 2000), the maximum parameters established for apparent sucrose levels are 6% for floral honey and 15% for molasses honey. It is observed that samples No. 02 and 08 do not comply with the mentioned legal limits, since they exceed the values stipulated for both honey floral how much for O honey in melate. Per other side, to the samples identified by the no. 01,05, 07 and 09 are within acceptable limits for melate honey, however, exceed the tolerated values for floral honey. Finally, it is worth highlighting that the samples with no. 03, 04 It is 06 they were to the unique what if framed us Limits settled down for the honey floral, as recommended by legislation in force.

Sodré et al. (2007) found values for apparent sucrose between 0.16 and 7.63, for honeys analyzed at the state of Ceará. Studies in Rue et al. (2004) about quality in honeys of County in Santana of Cariri, at region from the Chapada of Araripe, described values between 0.84 and 8.19%. The percentages of apparent sucrose in honey samples analyzed ranged from 5.80% to 19.96%. According to Melo et al. (2016), 60% of samples analyzed introduced themselves with values superiors to the what determines The Instruction Normative no. 11 (BRASIL, 2000), regarding his work on honeys sold in region in Uberlândia-MG.

The apparent sucrose content is of critical importance in evaluating the origin It is quality of honey, unraveling if to the bees were fed with sugar at the beginning of flowering or if there was direct adulteration of the honey by adding sucrose, such as highlighted by Silva (2007). This analysis reveals crucial information about the process of production of honey, well like integrity of the final product.

Acidity

Concluding the acidity analysis in the honey samples, it was evident the presence of distinct values, as indicated in the Tukey Test. As can be seen in the Table 3, sample no. 06, had a higher acidity content, statistically differing from all samples others samples analyzed. A sample what presented O smaller content in acidity he was The no. 01, no statistically differing of the samples of no. 02 and 05.

Brazilian legislation establishes a maximum limit of 50 milliequivalents of acidity per kilogram in honey (mEq/kg) (BRAZIL, 2000). In this study, it was found what some samples presented values above this limit. As can be seen in Table 3, specifically, to the samples in no. 03, 06, 09 It is 10 they are in disagreement with The current legislation, demonstrating one discrepancy in relationship to the standards settled down.

Acidity is an extremely important parameter when evaluating honey, as what exercises

influence direct about your flavor It is your capacity in conservation. That occurs because the acidity is significantly affected by processes as fermentation, as pointed per Silva et al., (2008).

A origin from the acidity gift at the honey drift in miscellaneous sources, such as The variation in organic acids from different nectar sources, the action of enzymes, the paper played per bacteria during O process in maturation of honey It is, additionally, the amount of minerals present in the composition of the honey, as discussed by Evangelista et al., (2005). This complex interaction of factors demonstrates as The acidity of honey he can to be one indicative valuable from the your origin It is quality, while also highlights The importance of greeting of the standards settled down for the legislation for ensure integrity of the final product.

In the study conducted by Soares, Aroucha and Góis (2011) , which addressed honeys wild animals in the State of Rio Grande do Norte, high levels of acidity, varying in between 26.73 It is 126.77 mEq/kg. Second to the discoveries in Lopes (2015) ,The variable acidity presented one average in 56.44 meq/kg, with values Minimum It is maximum in 47.41 meq/kg It is 65.00 meq/kg, respectively. Such results suggest what some samples they are in disagreement with you standards settled down for the legislation Brazilian.

pH

The pH values obtained from the 10 honey samples analyzed, presented in Table 3 indicate that samples No. 03, 04 and 10 presented the highest values, not statistically different from each other. It is noted that sample number 06 presented the smaller value, differing statistically in all others analyzed samples.

There is no indication of pH analysis as mandatory in Brazilian legislation for quality control of honey samples, however, proves to be beneficial to assist in indication of fermentation or adulteration of honey (ELLER, 2022). Floral honey has values below 4.0 and melate honey superiors The 4.5.

To the variations in pH found in this work, introduce themselves nearby to the values obtained per Pereira et al. (2015), what, to the analyze O pH in 10 samples in honeys, in the municipality of Maringá, PR, they obtained results of 2.86 to 4.17. Just like, Finco, Moura It is Silva (2010) what found value average in pH in 3.7 in 24 samples in honeys in many different flowery.

Pinto and Lima (2010) who, when evaluating 26 honey samples from the Vale do Steel, MG, got results in pH in between 2.41 The 4.53. Lily et al. (2015) to the analyze 24 samples of wild honey sold in the State of Rio de Janeiro obtained results for pH between 3.80 and 4.90, which are values close to those found by Andrighetto et al. (2009) , with a pH of 3.79 to 4.67, in the city of Santo Augusto, RS, with four samples of honeys.

A variation of the values in pH in honeys no he can to be underestimated, one turn what it suits

as an indication of various conditions that may have a significant impact about the quality and authenticity of honey. Adulteration of honey with syrups or other sugars, for example, can result in a decrease in pH, giving it a greater acidity, as evidenced by Araújo, Silva It is Sousa (2006).

PARAMETERS COLORIMETRIC

Your results of analytics of the parameters colorimetric of samples in honeys they are presented at Table 4.

Table 4: Results of the parameters colorimetric of samples in meais commercialized in the municipalities of Itapira- SP and Mogi guaçú -SP

Sample no.	Luminosity	Component a	Component b
01	50,37 ^a ±1,74	1,24 ^c ±0,15	16,41 ^b ± 0,51
02	45,99 ^{a,b,c} ±1,06	2,36 ^c ±0,29	24,27 ^a ±0,19
03	33,53 ^e ±2,57	10,30 ^a ±1,99	10,39 ^c ±0,77
04	40,59 ^d ±1,03	8,59 ^a ±0,13	24,70 ^a ±0,85
05	43,42 ^{b,c,d} ±0,77	5,54 ^b ±1,01	23,89 ^a ±2,91
06	40,75 ^{c,d} ±0,88	7,50 ^{a,b} ±0,79	23,27 ^a ±1,42
07	43,65 ^{b,c,d} ±1,04	1,19 ^c ±0,06	8,65 ^c ±0,17
08	26,22 ^f ±2,49	2,73 ^c ±0,38	1,22 ^d ±0,40
09	48,07 ^{a,b} ±0,75	0,73 ^c ±0,18	23,42 ^a ±0,18
10	34,16 ^e ±1,20	7,96 ^{a,b} ±0,65	15,47 ^b ± 0,17

*averages followed by the same letter, in the same column, do not differ from each other after $p \leq 0.05$ for the Test Tukey. Source: Authors (2023).

Among you values obtained in each component of system, The Luminosity varied in between 26.22 It is 50.37, as power to be observed at Table 4. To the samples what presented the highest values for this component were numbers 01, 02 and 09, not differing statistically among themselves. It can be seen that sample number 08 obtained the lowest value, differing statistically in all other samples analyzed.

The a* component varied from 0.73 to 10.30, as demonstrated in Table 4. The samples that presented the highest values for this component were samples no. 03 and 04, not statistically different from samples no. 06 and 10. It is noted that samples No. 01, 02, 07, 08 and 09 obtained lower averages, not differing statistically between yes.

For O component B* he was obtained one variation in 1.19 The 24.70 according to presented in Table 4. It can be seen that samples No. 02, 03, 04, 05 and 09 obtained higher values for this component, not statistically different from each other. The samples that presented the lowest averages were numbers 03 and 07, not differing statistically in between yes.

The color of honey may be related to the processing and storage of honey, your composition chemical, to the factors climatic during O flow of nectar It is The temperature at which honey ripens at hive (SOUSA et al., 2020).

For some researchers, the variation in the original color of honey is not considered a significant indicator of its quality, since aging is a factor that can intensify this characteristic (LACERDA et al., 2010). However, Azeredo et al. (1999) conducted a study on the physicochemical characteristics of honeys in São Fidelis, at the state of River in January, It is your results indicated what no there was variation in color, both in absorbance and in visual observation of the samples, throughout analytics carried out at intervals regular over 365 days.

The study carried out by Oroian et al. (2012) included 15 samples of acacia honey, linden and sunflower, classified according to floral origin based on their color. Using the CIELab system, which includes luminosity coordinates (L^*), color axes (a^* and b^*), hue angle (H) and color intensity (C^*). The colorimetric parameters were statistically different between samples, highlighting the usefulness of the CIELab system at classification of honey with base in your origin floral. Analytics colorimetric carried out by Sousa et al. (2020) using the CIELab method indicated that *S. bee honey. Bipunctata* did not present a statistically significant difference in relation to honey produced for the bee *M. Quadrifasciata*.

At the study conducted per Oroian, Ropciuc It is Buculei (2016), dedicated The authentication of different types of Romanian honeys, physicochemical and chemometrics. Five varieties different they were analyzed: acacia, sunflower, linden, honeydew and polyfloral. In the context of colorimetric analysis, it was found that honey acacia had the highest luminosity value (L^*), followed by linden honey, sunflower, polyfloral and honeydew. Acacia and linden honeys proved to be clearer, characterized per values more high in L^* , in comparison with to the too much varieties, while O honey in honeydew revealed itself O more dark, presenting you minors values in L^* . You honeys originating of flowers in sunflower It is linden stood out for the more elevated purity in color, indicating one intensity or saturation significant from the tone, disregarding The influence from the luminosity. In contrast, the honey in acacia revealed itself to be less pure in color, suggesting a less intense tone or saturated. In relationship to the components in color, sunflower It is linden Showed O bigger yellow component (b^*). As for the red components (a^*), sunflower and linden registered values high, while linden exhibited one component green more weak.

TESTS IN TAMPERING

The results of adulteration tests on honey samples are presented in Table 5.

Table 5: Results of adulteration tests on honey samples sold in municipalities of Itapira- SP and Mogi Guaçu -SP

Sample no.	Reaction in Lugol	Reaction in Lund	Reaction in Fiehe
01	Positive	Absent	Positive
02	Negative	Absent	Positive
03	Negative	Present	Negative
04	Negative	Present	Negative
05	Positive	Absent	Positive
06	Positive	Absent	Positive
07	Positive	Absent	Positive
08	Positive	Absent	Positive
09	Positive	Absent	Positive
10	Negative	Present	Negative

Source: Authors (2023).

Reaction in Lugol

A reaction in Lugol is one method qualitative employed to identify the presence of starch or dextrins in honey. After the addition of Lugol's solution, a notable change in color, varying from reddish-brown to blue, or even to red-violet, as described by Périco et al. (2011).

Among the samples analyzed, in relation to the Lugol reaction, as can be seen in Table 5, only sample no. 02, 03, 04, and 10 got a negative result for the Lugol reaction, that is, 60% of the samples analyzed in this study had positive results, showing a high level of adulteration by starch or dextrins in the honey in question.

In one study conducted by Gomes et al. (2017) to assess the quality of honey sold in western Pará, the Lugol test was performed on honey samples coming from bees of the genus *Melipona* and the species *Apis mellifera*. It was observed that honey samples from bees of the genus *Melipona* presented the highest percentage of adulteration. This conclusion can be related to the smaller productivity of these bees, together with a higher price in sale in comparison with *Apis mellifera* honey.

In research conducted by Felix (2019) in the State of Paraíba, the Lugol test was applied in five samples in the honey market. Just one of the samples presented a positive result, indicating a level relatively low in adulteration. In a search carried out by Bera Almeida-Muradian (2007) they analyzed 11 samples acquired at the business of state in Paraíba. All the samples presented a negative result for the Lugol reaction, indicating that the products did not have adulterations with starch or dextrins. The study carried out by Silva et al. (2018) also got a negative result for all samples in honey analyzed, obtained in a fair free from the municipality of Assis Chateaubriand/PR.

Reaction in Lund

Among the samples analyzed, in relation to the Lund reaction, as can be seen in Table 5, only three samples showed protein precipitate within the range expected in 0.6 to 3.0 mL, being these to

the samples in no. 03, 04 It is 10, It is to the too much samples They present an absence of precipitate, and the absence indicates fraud caused by the addition of water or another diluent.

In study accomplished per Santos It is Barbosa (2011) , six samples in honeys purchased in street markets and supermarkets in the metropolitan region of Recife, were subjected to the Lund reaction, five samples showed no precipitate, representing 83.3% in results positive for per addition in water or another diluter. Richter et al. (2011), in their literature, also found samples outside of the standard, having a representation of 10%, two out of 19 samples analyzed from the city from Pelotas/RS. However, Bera and Almeida-Muradian (2007) reported results within the standards expected for pure honey, when carrying out the Lund reaction in 11 samples obtained in commerce of State in They are Paul, with variation in results.

In a survey involving 20 honey samples from the São José do Rio region, Preto/SP, conducted by Garcia-Cruz et al. (1999) , it was observed that 35% of the samples presented results negatives for The reaction in Lund, indicating what those honeys they were considered impure. In counterpart, study accomplished per Aguiar et al. (2016) presented results of rehearsal for O test from Lund, highlighting The presence in albuminoides and, consequently, proving the integrity and purity in all samples in honey analyzed, your search it was founded at realization in analytics physicist-chemicals in honey samples from the stingless bee species, *Trigonaspinipes* and *Tetragonisca angustula* , collected directly from colonies located in the area rural from the municipality of Acrelândia, State of Acre.

Reaction in Fiehe

Among the samples analyzed, in relation to the Fiehe reaction, as can be seen in Table 5, only three samples demonstrated a negative result regarding fraud, these being samples No. 03, 04 and 10, with the remainder having a positive result for Fiehe reaction, that is, 70% of the samples demonstrated adulteration due to the addition of syrups in sugar or overheating honey.

These results are close to those found by Wrobel and Bonfim (2017), which obtained 66.67% of the samples with formation of an intense red color, indicating in the Fiehe reaction indicating positive results for adulterations, the analysis was carried out in nine samples in honeys in points commercials It is in sellers street vendors in various points in the municipality of Castro-PR.

The Fiehe test is recognized for identifying commercial glucose adulterations or overheating in the honey. The practice of subjecting honey to high temperatures during extraction no It is recommended due to the potentials damage associates. A elevation in temperature aims to reduce viscosity, facilitating the filtration stage and preventing crystallization, fermentation and the presence of contaminating microorganisms. However, it is crucial to highlight that excessive heating is extremely harmful, such a process he can result at training in products undesirable, as O 5-

hydroxymethylfurfural(HMF) (TOSI et al., 2002; TURHAN et al., 2007).

HMF is a cyclic aldehyde that is formed by dehydration of fructose in medium acid, the process of which is accelerated by heat (PASSAMANI, 2005), certainly being aof the most common degradation products in honey, indicating its “aging” (SILVA et al., 2008). It is generally practically absent in freshly harvested honeys and its concentration increases over time, being considered an important indicator of quality (SPANNO et al., 2009) . Levels high in HMF indicate changes provoked per storage prolonged in conditions inappropriate, overheating or tampering (NOZAL et al., 2001).

Braga et al., (2009) obtained 56% failure in the Fiehe test in honeys sold in the city of Uberaba/MG. However, Almeida-Muradia and Bera, (2007) obtained 100% negative results for the Fiehe reaction in 11 samplesacquired in commerce in the State of São Paulo, proving that there was no tampering by addition of syrups sugar or overheating of honey.

Comprehensive analysis of physicochemical and colorimetric parameters reveals a panorama complex from the quality of honey, highlighting variations significant in severalaspects. These results highlight the importance of rigorous and to be continued at the sector beekeeping, aiming to guarantee The conformity of the products with to the normative established.

In addition from that, stands out The need in awareness of the producers It is consumers about to the practices suitable in production It is you scratches associates The adulteration, aiming to secure The quality It is The trust at the Marketplace in honey. A search perMore efficient analysis methods may be a promising direction for identifyingearly detection of adulteration, protecting the reputation of Brazilian honey and preserving the trust of the consumer.

CONCLUSION

To the analytics physical chemistry of honey revealed variations significant atconformity with you standards cool in between to the samples. A majority answered to the guidelinesfor sugars reducers, except The sample in no. 02, what it is outside of the Limits for honeyfloral, but within the parameters for melate honey. Samples No. 06, 07, 08 and 09they are inside of limit in moisture allowed, while others indicate risk infermentation. To the samples in ashes they are inside of limit, but The sucrose apparentget up concerns about The authenticity, being to the samples in no. 02 It is 08 standing outsideof the standards for honey in melate It is floral. Exceedances at acidity they can compromise flavorIt is conservation, but to the samples in no. 01, 02, 04, 05, 07 It is 08 they are inside from the legislation,It is variations at the pH suggest possible fermentations or tampering. You solids solublethey are inside from the range common expected. A quality It is authenticity of honey dependof these factors, being crucial to meet to the standards for protect The health of the consumers.



Colorimetric analyzes showed variation in honey color due to factors as O type in bee, processing It is storage. You tests in adulterationrevealed susceptibility in a proportion significant of the samples, with 60% showing adulteration of starch or dextrin in the Lugol reaction (samples no. 02, 03, 04 and 10) and negative results for samples no. 02, 03, 04 and 10 in the Lund, indicating absence of precipitate. For the Fiehe reaction, only three samples had results negatives for adulteration with addition in syrup in sugar oroverheating, being samples no. 03, 04 and 10. After thorough evaluation, it was found that no sample met the established parameters, emphasizing the There is an urgent need for more rigorous standards to guarantee the authenticity and integrity of honey. Guidance for producers to understand and control these variables is essential for guarantee a product authentic ending and in high quality.



REFERENCES

1. Aguiar, L. K., et al. (2016). Parâmetros Físico-Químicos do Mel de Abelhas sem Ferrão do Estado do Acre. *Enciclopédia Biosfera*, 13(23), 908-919.
2. Albuquerque, J. C. G., Elizangela Sobrinho, M., & Lins, T. C. L. (2021). Análise da qualidade do mel de abelha comercializado com e sem inspeção na região de Brasília - DF, Brasil. *Semina: Ciências Biológicas e da Saúde*, 42(1), 71-80.
3. Anacleto, D. A., Souza, B. A., Marchini, L. C., & Moreti, A. C. C. C. (2009). Composição de amostras de mel de abelha Jataí (*Tetragonisca angustula latreille*, 1811). *Ciência e Tecnologia de Alimentos*, 29(3), 535-541.
4. Andrighetto AJ, et al. (2009). Avaliação da qualidade físico-química do mel comercializado em Santo Augusto - RS. In: III Mostra Nacional de Iniciação Científica e Tecnológica Interdisciplinar e I Fórum Nacional de Iniciação Científica no Ensino Médio e Técnico. Resumos... Camboriú: UFSC - Colégio Agrícola de Camboriú.
5. Araújo, D. R., Silva, R. H. D., & Souza, G. S. (2006). Avaliação da qualidade físico-química do mel comercializado na cidade de Crato, CE. *Revista de Biologia e Ciências da Terra*, 6(1), 51-55.
6. Azeredo, M. A. A., et al. (1999). Características físico-químicas dos méis do município de São Fidélis-RJ. *Ciência e Tecnologia de Alimentos*, 19(1), 3-19.
7. Barbosa, J. S. (2013). Avaliação físico-química de méis comercializados nas feiras de Imperatriz-MA. [TCC (Graduação) - Curso de Engenharia de Alimentos, Universidade Federal do Maranhão].
8. Bera, A., & Almeida-Muradian, L. B. (2007). Propriedades físico-químicas de amostras comerciais de mel com própolis do estado de São Paulo. *Ciência e Tecnologia de Alimentos*, 27(1), 49-52.
9. Braga, F. T., Pasqual, M., Castro, E. M. de, Dignart, S. L., Biagiotti, G., & Porto, J. M. P. (2009). Qualidade de luz no cultivo in vitro de *Dendranthema grandiflorum* cv. rage: características morfofisiológicas. *Ciência e Agrotecnologia*, 33(2), 502-508.
10. Brasil. Ministério da Agricultura e Abastecimento. (2000). Instrução Normativa n °11, 20 de Outubro de 2000. Regulamento técnico de Identidade e Qualidade do Mel. *Diário Oficial da União*, Brasília, DF, 23 out. 2000.
11. Conforti, P. A., Lupano, C. E., Malacalza, N. H., Arias, V., & Castells, C. B. (2006). Crystallization of honey at -20°C. *International Journal of Food Properties*, 9(1), 99-107.
12. Damasceno, C. N. R. (2012). Análise físico-química do mel de abelhas comercializado no município de Ariquemes/RO. [Monografia de Especialização, Faculdade de Educação e Meio Ambiente, Ariquemes].
13. Dantas, J. D., Santos, S. C. L., Santos, T. C. L., Silva, A. B. da, & Carvalho, L. X. M. (2022). Análise físico-química do mel de abelhas comercializado no município de Frei Martinho – PB. *Research, Society and Development*, 11(10), 320-326.
14. Eller, K. H. (2022). Fatores que influenciam nas características e qualidade do mel de abelhas *Apis mellifera*. [TCC (Graduação) - Curso de Bacharelado em Agronomia, Instituto Federal de Ciência e Tecnologia do Espírito Santo, Colatina].




15. Evangelista, R. A., Silva, E. M. S., Beserra, E. M. F., & Rodrigues, M. L. (2005). Análise físico-química dos méis das abelhas *Apis mellifera* e *Melipona scutellaris* produzidos em duas regiões no Estado da Paraíba. *Ciência Rural*, 35(5), 1166-1171.
16. Felix, M. D. G. (2019). Análises físico-químicas para determinação da qualidade de méis da Paraíba. [TCC (Graduação) - Curso de Química, Universidade Federal da Paraíba Centro de Ciências Agrárias, Areia].
17. Ferreira, T. S. (2022). Avaliação dos parâmetros de identidade e qualidade de méis comercializados em Belo Horizonte, Minas Gerais. [Dissertação de Mestrado - Escola de Veterinária da Universidade Federal de Minas Gerais, Belo Horizonte].
18. Filho, N. C., Soriano, R. I., & Siena, D. (2012). Avaliação do Mel Comercializado no Mercado Municipal em Campo Grande-Mato Grosso do Sul. *Acta Veterinaria Brasilica*, 6(4), 294-301.
19. Finco, F. D. B. A., Moura, L. L., & Silva, I. G. (2010). Propriedades físicas e químicas do mel de *Apis mellifera* L. *Ciência e Tecnologia de Alimentos*, 30(3), 706-712.
20. Garcia-Cruz, C. H., et al. (1999). Determinação da qualidade do mel. *Revista Alimentação e Nutrição*, (10), 23-35.
21. Gois, G. C., et al. (2013). Composição do mel de *Apis mellifera*: requisitos de qualidade. *Acta Veterinaria Brasilica*, 7(2), 137-147.
22. Gomes, V., et al. (2017). Avaliação da Qualidade do Mel Comercializado no Oeste do Pará, Brasil. *Revista Virtual de Química*, 9(2), 815-826.
23. Instituto Adolfo Lutz (São Paulo). (2008). Métodos físico-químicos para análise de alimentos (4a ed.). São Paulo: Versão Eletrônica.
24. Lacerda, J. J. J., et al. (2010). Influência das características físico-químicas e composição elementar nas cores de méis produzidos por *Apis mellifera* no sudoeste da Bahia utilizando análise multivariada. *Química Nova*, 33(5), 1022-1026.
25. Lopes, A. E. P. (2015). Caracterização Físico-Química do Mel da Abelha Jataí (*Tetragonisca angustula*). [TCC (Graduação) - Tecnologia em Alimentos, Universidade Tecnológica Federal do Paraná, Londrina].
26. Macedo, L. N. (2007). Propriedades Prebióticas e Antimicrobianas de Mel de Abelha. [Dissertação de Mestrado, Universidade Federal Rural do Rio de Janeiro, Seropédica].
27. Marchini, L. C., Sodré, G. S., & Moreti, A. C. C. C. (2004). Mel brasileiro: composição e normas. Ribeirão Preto-SP: A. S. Pinto.
28. Meireles, S., & Cançado, I. A. C. (2013). Mel: Parâmetros de qualidade e suas implicações para a saúde. *FAPAM*, 4(4), 207-219.
29. Melo, C. M. T., Silva, V. S. da, & Queiroz, C. R. A. dos A. (2016). Physicochemical properties of honey marketed in Uberlândia region: physicochemical properties of honey marketed in Uberlândia region. *Ambiência*, 12(2), 739-763.
30. Mendes, C. de G., et al. (2009). AS ANÁLISES DE MEL: REVISÃO. *Caatinga*, 22(2), 07-14.



31. Moreira, R. F. A., & Maria, C. A. B. de. (2001). Glicídios no mel. *Química Nova*, 24(4), 516-525.
32. Nozal, M. J., et al. (2001). High-performance liquid chromatographic determination of methyl anthranilate, hydroxymethylfurfural and related compounds in Honey. *Journal of Chromatography A*, 917(1-2), 95-103.
33. Oroian, M., et al. (2012). Honey Classification Using Colour Measurement. *Food And Environment Safety*, 11(2), 29-32.
34. Oroian, M., Ropciuc, S., & Buculei, A. (2016). Romanian honey authentication based on physico-chemical parameters and chemometrics. *Journal Of Food Measurement And Characterization*, 11(2), 719-725.
35. Passamani, L. (2005). Estudo das características físicas, químicas e microbiológicas de compostos de mel produzidos no estado do Rio de Janeiro. [Dissertação de Mestrado - Universidade Federal Rural do Rio de Janeiro, Instituto de Tecnologia, Rio de Janeiro].
36. Pereira, J. D. M., et al. (2015). Análise físico-química e microbiológica de amostras diferentes de mel comercializadas em Maringá (PR). *Revista Baiana de Saúde Pública*, 39, 356-369.
37. Périco, E., et al. (2011). Avaliação Microbiológica e Físico-química de Méis Comercializados no Município de Toledo, Pr. *Revista Ciências Exatas e Naturais*, 13(3), 365-382.
38. Pinheiro, A. C. M., Nunes, C. A., & Vietoris, V. (2013). SENSOMAKER: A TOOL FOR SENSORIAL CHARACTERIZATION OF FOOD PRODUCTS. *Ciência e Agrotec*, 37(3), 199-201.
39. Pinto, C. C. O. A., & Lima, L. R. P. (2010). Análises físico-químicas de méis consumidos no Vale do Aço/MG. *Farmácia & Ciência*, 1, 27-40.
40. Richter, W., et al. (2011). Avaliação da Qualidade Físico Química do Mel Produzido na Cidade de Pelotas/RS. *Alim. Nutr*, 22(4), 547-553.
41. Santos, D. C., Martins, J. N., & Silva, K. F. N. L. (2010). Aspectos físico-químicos e microbiológicos do mel comercializado na cidade de Tabuleiro do Norte-Ceará. *Revista Verde*, 5(1), 79-85.
42. Santos, E. M. da S., & Barbosa, M. B. C. (2011). Avaliação da qualidade físico-química dos Méis comercializados na Região Metropolitana do Recife. Recuperado de <http://tcc.fps.edu.br:80/jspui/handle/fpsrepo/693>.
43. Silva, R. A. da. (2006). COMPOSIÇÃO E PROPRIEDADES TERAPÊUTICAS DO MEL DE ABELHA. *Alim. Nutr*, 17(1), 113-120.
44. Silva, M. B. L. (2007). Diagnóstico do sistema de produção e qualidade do mel de *Apis mellifera*. [Dissertação de Mestrado em Ciência e Tecnologia de Alimentos - Universidade Federal de Viçosa, Viçosa].
45. Silva, S. J. N., Schuch, P. Z., Vainstein, M. H., & Jablonsk, A. (2008). Determinação do 5-hidroximetilfurfural em méis utilizando cromatografia eletrocínética capilar micelar. *Ciência e Tecnologia de Alimentos*, 28 Supl., 46-50.

46. Silva, M. G. C. da, et al. (2018). Análise das propriedades físico-químicas de amostras de mel comercializado em feiras livres do município de Assis Chateaubriand, PR. *Higiene Alimentar*, 32(278), 68-73.
47. Soares, K. M. P., Aroucha, E. M. M., & Góis, V. A. (2010). Qualidade físico-química de méis silvestres comercializados no município de Apodi, RN. *Acta Veterinaria Brasilica*, 4(1), 55-58.
48. Sodré, G. da S., et al. (2007). Caracterização físicoquímica de amostras de méis *Apis mellifera* L. do Estado do Ceará. *Ciência Rural*, 37(4), 1139-1144.
49. Sousa, F. B. de, et al. (2020). Avaliação da cor do mel de *Melipona Quadrifasciata* e *Scaptotrigona Bipunctata* em Marigá-PR. In: Seminário Paranaense de Meliponicultura, 14. Paraná: Congresse.Me. Disponível em: [\[https://eventos.congresso.me/xivspm/resumos/7066.pdf?version=original\]](https://eventos.congresso.me/xivspm/resumos/7066.pdf?version=original)(<https://eventos.congresso.me/xivspm/resumos/7066.pdf?version=original>).
50. Souza, R. B. (2016). Caracterização físico-química de méis apícolas de Roraima. [Trabalho de Conclusão de Curso - Boa Vista].
51. Souza, L. B. S. (2017). Caracterização Físico-Química e Microbiológica do Mel de Abelhas (*Apis Mellifera*) Produzido no Território Rural de Identidade Parque das Emas. [Dissertação de Mestrado - Instituto Federal de Educação, Ciência e Tecnologia Goiano - Campus Rio Verde Diretoria de Pesquisa d Pós-Graduação Programa de Pós-Graduação em Tecnologia de Alimentos, Goiás].
52. Spano, N., et al. (2009). A Direct RP-HPLC Method for the Determination of Furanic Aldehyde and Acids in Honey. *Talanta*, 78, 310-314.
53. Tosi, E., Ciappini, M., Ré, E., & Lucero, H. (2002). Honey Thermal Treatment Effects on Hydroxymethylfurfural Content. *Food Chemistry*, 77(1), 71-74.
54. Trevisol, G., Bueno, M. P., Oliveira, J. P. L. de, & Macedo, K. G. (2022). Panorama econômico da produção e exportação de mel de abelha produzidos no Brasil. *Revista de Gestão e Secretariado*, 13(3), 352-368.
55. Turhan, I., et al. (2007). Quality of Honeys Influenced by Thermal Treatment. *LWT – Food Science and Technology*, 1(8), 1396-1399.
56. Vieira, G. H. C., Gomes, M. F. F., Moraes, A. N., & Oliveira, A. F. (2017). Caracterização físico-química de méis produzidos no estado de Mato Grosso do Sul, Brasil. *Revista de Agricultura Neotropical*, 4(3), 30-34.
57. Wrobel, L., & Bonfim, S. S. de. (2017). Qualidade físico-química de méis comercializados no município de Castro. [Trabalho de Conclusão de Curso - Universidade Tecnológica Federal do Paraná, Ponta Grossa]. Disponível em: [\[https://riut.utfpr.edu.br/jspui/bitstream/1/16626/2/PG_COALM_2017_2_02.pdf\]](https://riut.utfpr.edu.br/jspui/bitstream/1/16626/2/PG_COALM_2017_2_02.pdf)(https://riut.utfpr.edu.br/jspui/bitstream/1/16626/2/PG_COALM_2017_2_02.pdf). Acesso em: 10 nov. 2023.

Analysis of busbar arrangements in substations: A methodological approach

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ABSTRACT

A substation is the part of a power system, concentrated in a given location, which comprises a set of switching, transformation, compensation and other equipment used to direct the flow of energy and enable its diversification, through alternative routes. According to the 2023 National Energy Balance Report, the final consumption of electrical energy in the country has been growing in recent years, requiring adaptation and expansion of the energy sector, from the generation process, transmission to distribution of electrical energy, emerging the need for investments in the construction of new substations and/or modernization and expansion of existing facilities. Therefore, this study aims to propose a comprehensive methodology for defining the most appropriate busbar arrangement for a given distribution, transmission, and industrial substation project. The methodology is based on qualitative and quantitative criteria, considering elements such as system security, operational flexibility, and availability during maintenance, and thus using a scoring system for each of the criteria taking into account the configuration of the bus arrangement. Additionally, a study of the implementation cost is considered, based on the budget methodology developed by the National Electric Energy Agency (ANEEL). Through these approaches, it is possible to observe that, as the voltage class increases, the system safety and availability requirements also increase, arrangements that more efficiently fulfill these criteria stand out in higher voltage classes, while those that perform poorly in these respects but offer similar operational flexibility excel in lower voltage classes.

Keywords: Substation arrangement, Operational flexibility, System safety, Maintenance availability and Substation cost.

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INTRODUCTION

According to the report of the National Energy Balance (BEN), prepared and published by the Energy Research Company (EPE) [1], whose objective is to present the accounting regarding the supply and consumption of energy in Brazil, it points out that the final consumption of electricity in the country in 2022 grew 2.3%. Thus, according to Monteiro and Miranda [2] the increase in consumption creates the need to adapt and expand the energy sector, from the generation process, transmission to the distribution of electrical energy.

In this context, substations (SEs) become of great relevance, since they are used to direct the flow of energy in a power system, resulting in the need for investments in the construction of new SEs and/or modernization and expansion of existing facilities. [two].

According to Violin; D'Ajuz; Lacorte [3], a substation (SE) is a set of interconnected systems, designed to serve the electrical system in an efficient and economical way. The implementation process is complex and involves several professionals specialized in areas such as civil, electrical, mechanical and communication engineering. The decision to build a new substation arises from studies on the expansion of the electrical system, which identify the need to serve a specific region, city or industrial plant. Crucial aspects are then defined, such as the configuration of the substation bus and the characteristics of the electrical equipment in the switchyard, in accordance with the requirements of the National Electric System Operator (ONS) and ANEEL regulations. The authors also highlight that an ideal substation must offer reliability to the electrical system, which is achieved by the careful choice of its bar configuration and that, in addition, provide facilities for maintenance, expansions and good visibility of its components, aspects guaranteed by a well-designed physical project, they also highlight that the maneuvering yard equipment must be robust enough to withstand the demands of the system, and the command and protection system must operate safely and effectively. Thus, the authors conclude that a well-designed and executed substation plays an essential role in the reliable operation of the system.

The Brazilian Standard NBR 5460 [4] defines that an SE constitutes an essential part of a power system, centralized in a specific location. It mainly encompasses the connection points of transmission and/or distribution lines, accompanied by maneuvering, control and protection devices. This covers not only the electrical aspects, but also the civil structures and necessary assemblies, and may also include other equipment relevant to its operation.

The standard also classifies SEs according to function, form of operation and construction types. The defined function types are:

- a) SE Transformer: It is the one that converts the supply voltage to a different level, higher or lower, being designated, respectively, SE Step-Up Transformer and SE Step-Down Transformer [5].

- Step-down SE: A transformer SE that reduces the voltage level generated by an electrical energy source and distributes the associated power to overhead and underground distribution networks, supplying substations with a lower voltage level [6]. Therefore, in this type of SE, the output voltage is lower than the input voltage.
- Step-up SE: A step-up transformer SE has the function of raising the voltage level generated by an electrical energy source and distributing the associated power to transmission lines with higher voltage than the original [6]. In other words, the output voltage is greater than the input voltage.
- b) SE converter: These SEs are intended to convert alternating current to direct current, or vice versa, in addition to making it possible to change the frequency of alternating current from one value to another [6].
- c) Switchgear IF: Is one that interconnects supply circuits under the same voltage level, enabling their multiplication. It is also adopted to enable the sectioning of circuits, allowing their energization in successive sections of shorter length [5]. These SEs have the main objective of changing the configuration of an electrical system by modifying the interconnections between transmission lines.

It is worth highlighting that, with the advancement of technology and installation methodology, currently, regardless of the construction type of the substation, the way of operation relies on a digital supervisory system. It is not common for operators to be present at the substation, except in cases of maintenance.

Mamede [6] proposes a subclassification into two types of construction for substations in external environments: bare busbars and conventional installation, or construction using compact insulated busbars. The author also highlights the classification of substations according to the means of insulation, which can be by air insulation (AIS - Air insulated substations), total gas insulation SF_6 (GIS - gas insulated substations) or in a hybrid form, which combines substation technology air-insulated with air-insulated substation technology SF_6 .

Monteiro and Miranda [2] define that it is important to take into account several factors when choosing the arrangement of an SE, including simplicity, availability of supply, economy and security, as required by the function and relevance of the SE in the project. The authors also discuss the busbar arrangements most commonly used in substations, covering options such as: simple busbar; main and transfer bus; double busbar with single circuit breaker; ring bus; bus breaker and a half; and double busbar with double circuit breakers. The authors also highlight that in industrial distribution contexts, excluding the input substation, whose configuration depends on the voltage to which it is connected, the arrangements usually used are radial, selective primary, and selective secondary, or combinations of these.

The authors state that substation arrangements can present different levels of complexity, making it important to select the appropriate scheme, given its direct influence on the performance of the substation, where they give the example of simple buses which, in general, are not used in substations of great importance, since this scheme is less flexible, depending on a single main bus, this makes the system more susceptible to frequent shutdowns, as in cases of failures or the need for maintenance at the substation, it is necessary to shut it down completely. However, they highlight that the advantage of this type of arrangement is its low cost. The study conducted in [2] concludes that in most SEs built for transmission, distribution and industrial sectors, air insulation is the standard due to lower initial costs. However, in specific situations, other technologies have proven to be viable options.

Submodule 2.6 of the Network Procedure formulated by the ONS [7], establishes the minimum requirements for SEs, applicable both to transmission facilities that are part or will become part of the basic network, as well as to international interconnections and generation agents. These guidelines are presented below.

Air-insulated SEs must adopt one of the following configurations for the busbar arrangements, depending on their voltage class [7]:

- i) Voltage bus equal to 230 kV: double bus arrangement with single four-key circuit breaker; or
- ii) Bus voltage equal to or greater than 345 kV: double bus arrangement with circuit breaker and a half.

For alternative bus arrangements, including those with isolation technology in SF_6 , the submodule determines that they can be adopted, provided that analyzes of reliability, operational flexibility and availability (scheduled and unscheduled) demonstrate performance equal to or greater than that of the arrangements defined in (i) and (ii) [7,8].

In submodule 2.6 [7], it is also established that, for buses with voltage equal to or greater than 345 kV, it is possible to initially adopt the simple ring bus arrangement, as long as the physical layout of the SE buses follows the guidelines defined in points (i) and (ii). Furthermore, for 230 kV buses, in SEs that operate as simple radial systems, it is permitted to opt for the main bar and transfer arrangement, as long as the physical design of this bus is designed to enable the transition to the arrangement specified in items (i) and (ii).

Therefore, this article aims to offer a holistic view of the relevance of SEs in the electrical system, providing solid support for decision-making in electrical infrastructure projects. A methodological approach for the analysis of busbar arrangements of distribution, transmission and industrial SEs is proposed based on technical and economic criteria.

METHODOLOGY

SEs, as main points of interconnection of transmission, distribution and industrial systems, have a great influence on the reliability of these systems. The choice of arrangements and maneuvering schemes must be made so that component failures do not compromise the safety of the system as a whole. This establishes the need to determine the reliability of each proposed configuration in order to select the most technically suitable arrangement. When choosing the configuration for a new transmission system SE, it is important to clearly define the technical and economic criteria that serve as a basis for comparing the different busbar arrangements considered. In general, basic characteristics to consider include [9]:

- i) System security;
- ii) Operational flexibility;
- iii) Ease of maintenance of components;
- iv) Simplicity of protection and control;
- v) Available space and ease of expansion;
- vi) Cost.

Among these characteristics, only two, system security and cost, have a quantitative element of comparison. The others reflect the experience and operational practice of the different companies. However, to simplify the analysis when choosing a substation bus configuration, four fundamental parameters are considered for the choice. The methodology adopted for the development of this work comes from the work entitled "Circuit Configuration Optimization" carried out by CIGRÉ's Joint Working Group B3/C1/C2.14, in which Lingner and others [10] establish a scoring system, based on the importance of each parameter, being then quantitatively only the cost criterion. Below are the fundamental parameters selected for analysis and evaluation, with their definitions.

SYSTEM SECURITY

This parameter evaluates the ability of the SE configuration to maintain a reliable supply. We examine the impact of equipment on the electrical grid, assuming correct operation of control and protection systems. This involves considering conditions such as circuit breaker tripping in the event of a primary failure and the consequences when the circuit breaker fails to open.

In Table 2.1, numbers 1 to 6 represent different levels of impact or severity. A score of 1 is given when an outcome is seen as the worst, indicating that it had the greatest negative impact, on the other hand, a score of 6 is given when a result is seen as the best, indicating that it had the least or no negative impact. negative impact.

Table 2.1 - Assessment criteria with system security scores

Punctuation	Possible consequences for the network due to a primary failure	Possible consequences for the network due to a primary failure followed by failure of the circuit breaker to open
1	Possible loss of entire substation	Loss of entire substation
two	Loss of one or more feeders, but not the entire substation	Loss of more than one feeder or the entire substation
3	Loss of one or more feeders, but not the entire substation	Loss of more than one feeder, but not the entire substation
4	Loss of a feeder	Loss of a feeder and always an extra feeder, but not the entire substation
5	Loss of none or one feeder	Loss of a feeder and possibly an additional feeder, but not the entire substation
6	Loss of none or one feeder	Loss of a feeder

Source: Adapted from [10].

OPERATIONAL FLEXIBILITY

Refers to the ability of the substation configuration to rearrange feeders or divide the substation into multiple parts as necessary. This involves the substation's ability to perform breakdowns, which can occur in two distinct ways: energized and non-energized.

For energized dismemberment, the reconfiguration of connections is carried out while the substation remains energized, ensuring continuity of energy supply during the process. While the unenergized teardown, specific parts of the substation need to be temporarily shut down to perform the teardown. This capacity is important to meet the possible dynamics of the electrical grid and ensure efficient operation.

Table 2.2 presents the evaluation criteria with the corresponding score for operational flexibility. It is important to highlight that, in addition to the division of the substation, the option to determine which part of the divided substation each circuit will be connected to contributes to a higher score in the configuration. This is especially significant in specific situations where choosing to connect a circuit in a specific part of the substation may be advantageous.

Table 2.2 - Assessment criteria with scores for operational flexibility

Punctuation	Definition
1	Can't split
two	Division not energized (only with disconnecter). No flexibility
3	Energized division (with circuit breaker). No flexibility
4	Energized division (with circuit breaker). Low flexibility
5	Energized division (with circuit breaker). High flexibility, maneuver with disconnecter
6	Energized division (with circuit breaker). Highest flexibility, operation with circuit breaker

Source: Adapted from [10].

AVAILABILITY DURING MAINTENANCE

This parameter checks whether the substation configuration allows the feeders to be kept energized while maintenance activities are carried out on disconnect switches and circuit breakers. During maintenance, the bus disconnecter switch is a critical point as the relevant bus needs to be de-

energized.

The scores, listed in Table 2.3, range from 1 to 7 and have specific meanings. A score of 1 represents the worst consequences on the network, indicating the interruption of the entire substation. On the other hand, a score of 7 indicates the least serious consequences on the network. In this scenario, no network element would be disconnected and the network topology would not be weakened. Therefore, the operation of the substation would not be significantly affected.

INVESTMENT COST

This factor analyzes the total investment required to implement the substation, including the costs associated with command, protection, control and communications equipment. Understanding the complexity involved in preparing budgets for substations and with the objective of establishing the standardization of concepts and values, ANEEL establishes a methodology based on the concept of modulation.

Table 2.3 - Assessment criteria with scores for availability during maintenance of circuit breakers and disconnecting switches

Punctuation	Maintenance of	Consequence
1	Any disconnect switch connected to the bus	Shutdown of the entire substation
two	Bus disconnect switch	Shutdown of the entire substation
3	Disconnect switch connected to the bus or bus disconnect switch	Shutdown of half of the substation
4	Any disconnect switch connected to the bus	Disconnection of a bus and corresponding circuit. Remaining circuits in operation.
5	Any disconnect switch connected to the bus	Disconnection of a bus and corresponding circuit. Remaining circuits in dual-bus operation
6	Any disconnect switch connected to the bus	Shutdown of a bus and all circuits in operation on the same bus
		Open Ring
	Circuit breaker	Substation breakdown or loss of configuration
7	Any disconnect switch connected to the bus	Loss of substation setup or split, but all circuits in operation
	Circuit breaker	Shutdown of a bus. All remaining circuits in operation
		All circuits remain in operation

Source: Adapted from [10].

The approach consists of detailing and quantifying the modules based on the materials, equipment and services necessary to carry out the project. Annex I of Order No. 3,246 of November 16, 2022, from ANEEL [11], presents this methodology. The modulation concept used in the ANEEL Reference Price Bank involves the subdivision of the substation into smaller units, each representing distinct sectors in terms of function, operation and physical structure. Therefore, a substation is composed of a variety of modules that are essential for its operation, including those related to line

inputs, equipment connections and infrastructure [12,13].

Modular units, regardless of voltage class and type of arrangement, are subdivided into three types: Infrastructure Module, Maneuver Module and Equipment Module. The definition of these units and the parameters used in preparing budgets is based on the minimum requirements established in the Network Procedures [7].

The ANEEL resolution also establishes fundamental criteria for the classification of substations, which is of great importance for preparing budgets and planning electrical installations. This categorization is based on two main factors, voltage level and physical arrangement, as shown in Table 2.4.

Therefore, the substation bus arrangements are divided into two blocks for more accurate analysis and comparison.

The first block is composed of the Single Bus (BS), Main and Transfer Bus (BPT) and Double Bus with Five Switches (BD5) arrangements, classified with voltage levels of 69 kV and 138 kV. While in the second block there are the physical arrangements in the configuration of Ring Bus (AN), Double Bus with Circuit Breaker and a Half (DJM) and Double Bus with Double Circuit Breaker (BDDD), which are analyzed and compared at voltage levels of 440 kV and 500 kV.

Table 2.4 - SEs arrangements according to voltage level

Voltage (kV)	B.S.	BPT	BD5	AN	DJM	BDDD
13.8	X	X				
69	X	X	X			
138	X	X	X			
230		X	X			
345				X	X	
440				X	X	X
500				X	X	X
750					X	X

Source: Adapted from Annex I of Order No. 3,246 of November 16, 2022 from ANEE [11].

It is important to highlight that defining an evaluation criterion based on an important characteristic, such as operational issues or maintenance procedures, facilitates the choice of the bus arrangement of an SE in the most appropriate way.

This adopted methodology, focused on network performance, allows comparison between configurations, regardless of the technology used. However, the choice of technology should not be ignored, as it can influence the type of configuration or even result in new arrangements [10].

COMPARATIVE ANALYSIS OF THE MAIN SUBSTATION MANEUVERING SCHEMES

Each array received specific scores for system security criteria, which reflect its ability to handle

normal and faulty conditions. The score assigned was shown in Table 3.1.

Table 3.1 - Score of bar arrangements for the system Safety criterion

	B.S.	BPT	BD5	AN	DJM	BDDD
Punctuation						
1	1	1				
two			two			
3						
4				4		
5					5	
6						6

Source: Adapted from [10].

When evaluating the safety of the service, it is important to note that, when analyzing the configurations in terms of functionality and possible consequences, it is clear that double busbar systems do not guarantee the total prevention of loss of SE in situations of additional circuit breaker failure. Furthermore, as a higher level of system security is sought, there is an increase in the amount of equipment required for SE. This increase in complexity and number of devices consequently results in higher implementation costs to ensure more robust security of the electrical system.

Availability assessment during maintenance analyzes how the network is affected when circuit breakers and disconnect switches in the SE are out of operation. During maintenance, the bus disconnect switch is a critical point as the relevant bus needs to be de-energized. Multi-busbar configurations improve availability during bus-disconnect switch maintenance, but this comes with additional cost and space footprint.

For the availability criterion during maintenance, the scores assigned are as shown in Table 3.2.

The high score of the BDDD arrangement in availability during maintenance is attributed to the specific characteristic of this arrangement, its redundancy of circuit breakers, which guarantees the continuous availability of the system.

Other arrangements with high scores are BD5, AN and DJM. The BD5, due to the large number of disconnecting switches, allows for different configurations, reorganizing itself during the maintenance period. On the other hand, AN and DJM configurations, as well as BDDD, also provide a certain level of redundancy, resulting in a good score.

BPT offers the ability to transfer load to a backup bus during maintenance, thus maintaining service continuity, however no circuit breaker is available to protect the circuits and the process for replacing the tie breaker is difficult and can lead to errors of operation. This transfer capacity together with the difficulty of operation contributes to a lower score in the criterion.

Finally, the BS configuration scores lower due to its limited maneuverability and redundancy. During maintenance, there may be a need to completely stop service rather than transferring load to a backup bus.

Table 3.2 - Score of bar arrangements for the Availability criterion during maintenance

	B.S.	BPT	BD5	AN	DJM	BDDD
Punctuation						
1	1					
two						
3		3				
4						
5						
6			6	6	6	
7						7

Source: Adapted from [10].

To assess operational flexibility, Table 3.3 presents the score for this criterion according to the bar arrangements studied.

Table 3.3 - Score of bar arrangements for the criterion of Operational Flexibility

	B.S.	BPT	BD5	AN	DJM	BDDD
Punctuation						
1	1					
two						
3		3				
4			4	4	4	
5						
6						6

Source: Adapted from [10].

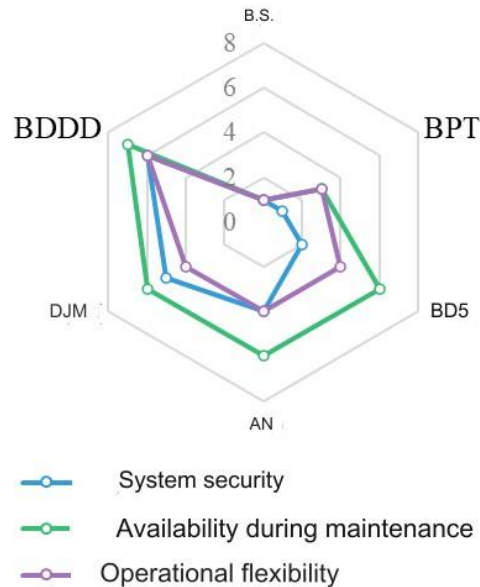
Again, the highest score is given to the double busbar arrangement with double circuit breaker, for the same reason as the previous criteria, this is due to its ability to provide circuit breaker redundancy, ensuring the presence of two independent interrupting devices. This feature increases operational reliability, allowing faults in circuit breakers to be isolated without affecting the entire substation. Therefore, this configuration has the capacity for selective isolation and adaptation to different operating conditions.

In Figure 3.1, it is possible to visualize all bus arrangements accompanied by the evaluation criteria. A trend can be observed when seeking greater security in the system, less interruption and greater flexibility. The BDDD, AN and DJM arrangements stand out as the best options, being recommended for busbars with voltages equal to or greater than 345 kV, which are substations that are of great importance.

Therefore, for the Simple Busbar arrangement, it is suggested to install it at voltages equal to or lower than 138 kV. This recommendation is aimed at substations where the temporary loss of the substation, whether due to failure or maintenance, does not cause significant impacts in its absence. It is advisable that facilities of this type adopt a maintenance and operation plan, aiming to minimize the period of unavailability in emergency situations.

In the voltage class equal to or less than 230 kV, BD5 arrangements, or the variation, the Double Four-Switch Busbar (BD4), are recommended.

Figure 3.1 - Scoring of evaluation criteria for bus arrangements



Source: Prepared by the author.

For cost analysis, Figure 3.2 shows the costs of implementing the switchyard for voltages of 69 kV and 138 kV of SEs arrangements with BS, BPT and BD5. It is observed that the increase in implementation cost when going from the primary voltage of 69 kV to 138 kV is around 74% for all arrangements, therefore, the analysis for one input voltage level is valid for the other.

To build the BS array at 69 kV, approximately R\$ 25,779,743.09 are required; for BPT, the cost is R\$29,997,407.23; while for the arrangement in BD5, the value is R\$ 31,960,215.74. The difference between BS and BPT is R\$4,217,664.14 in the project, and between BS and BD5 is R\$6,180,472.65. This difference is mainly related to the cost of the bus interconnection circuit breaker that the BPT and BD5 arrangements have, as well as the presence of a greater number of disconnecting switches compared to the BS.

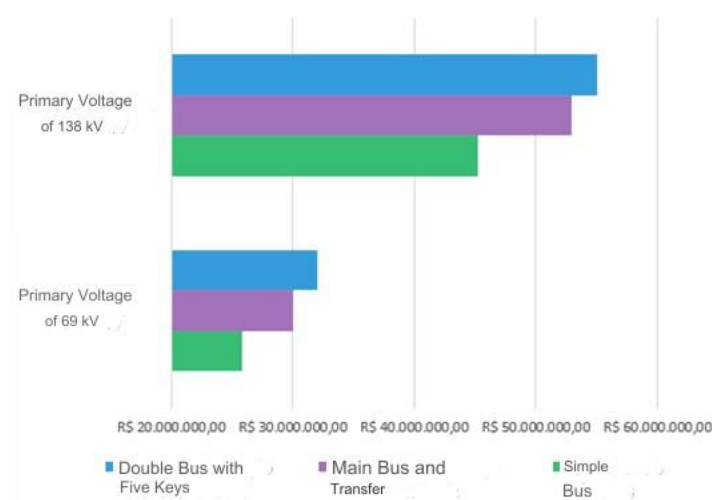
The difference between BPT and BD5 is R\$ 1,962,808.51. It is also worth mentioning that the BPT and BD5 arrangements occupy an area of approximately 13,200 m² for 69 kV and 21,000 m² for 138 kV, while the single bar occupies an area of 12,320 m² for 69 kV and 19,200 m² for 138 kV. This factor is important to be considered in the SE project.

The analysis for choosing the best arrangement for the 69 kV or 138 kV yard of a SE depends on the designer and the criterion that is most important to the SE. Furthermore, it is important to consider whether there are future expansion plans for the SE. It is observed that the cost difference between BPT

and BD5 is relatively small compared to the difference between each of these configurations and the BS arrangement. Therefore, when choosing between BPT and BD5, it is recommended to be based on the advantages that each arrangement will provide and the specific priorities of the project, as BD5 performed better in the evaluation criteria compared to BPT. As a result, these arrangements offer greater operational flexibility and reliability to the power system compared to the BS arrangement.

Considering the described advantages of the BPT and BD5 arrangements in relation to the BS arrangement, the additional amounts of R\$4,217,664.14 and R\$6,180,472.65 in the project can be justified by the benefits that are provided to the system over the years, being able to serve the load more efficiently and safely.

Figure 3.2 - Implementation Costs at 69 kV and 138 kV for BS, BPT and BD5



Source: Prepared by the author.

For the analysis of ring bus (AN), double bus with breaker and a half (DJM) and double bus with double breaker (BDDD) arrangements, Figure 3.3 presents the implementation costs for voltages of 440 kV and 500 kV. Observing the same point of the previously analyzed bus set, the increase in implementation cost when going from the primary voltage of 440 kV to 500 kV is around 25% for all arrangements, therefore, as in the block previously evaluated, the analysis for one input voltage level is valid for the other.

The AN arrangement has an implementation cost of R\$81,588,905.35 for 440 kV and R\$100,439,135.80 for 500 kV. For the BDDD arrangement, the investment is R\$ 102,180,023.82 for 440 kV and, for 500 kV, it is R\$ 127,592,057.40. Finally, the DJM arrangement costs R\$82,936,572.89 and R\$101,759,787.74 at 440 kV and 500 kV, respectively.

It appears that AN has the lowest investment in cost, with a difference in relation to BDDD of R\$ 20,591,118.47 and between DJM of R\$ 1,347,667.54, for the input voltage of 440 kV. However, for AN, installing more than five circuits is not recommended. However, it is possible and usual to initially design

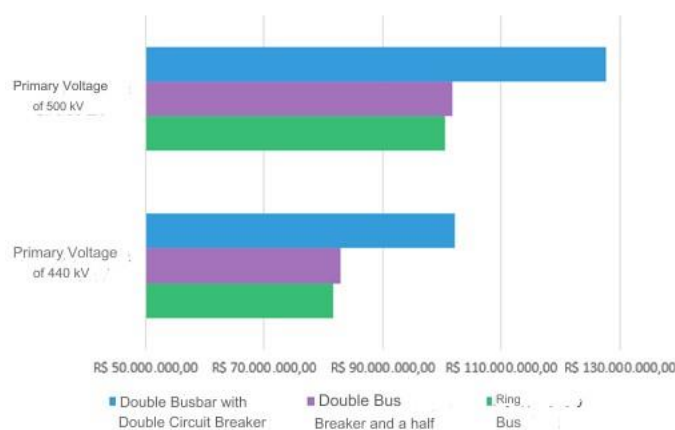
an AN and when more than five circuits are needed, transform it into a DJM.

Comparing the AN arrangement with BDDD and DJM, it can be seen that for the operational flexibility criterion, BDDD has a better score, while for the system security criterion, AN has a lower score compared to both BDDD and the DJM. Thus, for cases in which it is possible to opt for DJM or AN, the installation of the breaker and a half bus can be advantageous, as the cost difference is significantly low, and can offset in the long term the performance benefits of the breaker and a half bus arrangement. quite.

When comparing the costs of implementing BDDD and DJM, a difference of R\$ 19,243,450.93 is observed. Considering the advantages analyzed as shown in Figure 3.1, BDDD has a better score in the system safety criteria, availability during maintenance and operational flexibility than the DJM arrangement. Therefore, because this cost difference is significant, it is recommended to evaluate how important these advantages are for the SE project.

Therefore, if we only consider the implementation cost, the AN arrangement becomes better, however, it is important in the initial phase of the project to consider which path is more advantageous in the long term and which criteria are indispensable, especially if the substation has a plan of future expansion.

Figure 3.3 - Implementation Costs at 440 kV and 500 kV for AN, DJM and BDDD

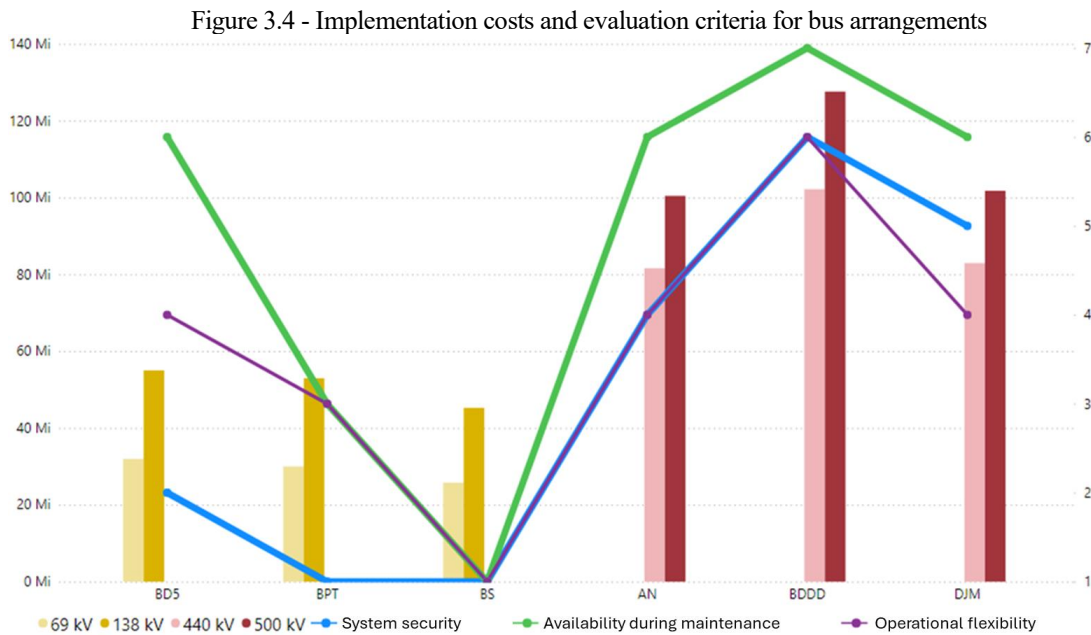


Source: Prepared by the author.

After an in-depth analysis of each criterion and the evaluation of the bus arrangements, it becomes evident that each configuration presents its distinct characteristics in relation to safety standards, operational flexibility, maintenance availability and costs associated with implementation. It is highlighted that the BDDD, AN and DJM arrangements have emerged as options that offer greater security, availability and operational flexibility.

On the other hand, the BS arrangement has lower initial costs and proved to be more limited in terms of security and operational flexibility. Its application is recommended in less complex SEs, where

service interruption during scheduled maintenance is acceptable. Figure 3.4 presents the qualitative analysis and implementation costs for the studied arrangements.



Source: Prepared by the author.

This is a graph that displays the costs for the primary voltages of 69 kV, 138 kV, 440 kV and 500 kV, along with the score of the qualitative criteria associated with each bus arrangement.

Concluding, then, that the choice of the ideal bus arrangement must be guided by the specific needs of each ES. Therefore, it is recommended to classify the substation into one of the categories such as transformation SE, maneuver SE or generation SE, and thus assign different weights to the methodology criteria based on these categories. This links the selection of busbar arrangement to the specific function of the substation in the power system. In a high-capacity generation substation, the System Safety criterion must be more considered, as it is necessary to guarantee supply for as long as possible, while in a maneuvering substation, Operational Flexibility may have greater importance.

Table 2.4, which summarizes the substation arrangements according to voltage level, justifies the bar configuration criteria established by the ONS. It highlights that, as the voltage class increases, system safety and availability requirements also increase, arrangements that more efficiently meet these criteria stand out in higher voltage classes.

CONCLUSION

This study aimed to present criteria to guide the evaluation and comparison of ES configurations, through an appropriate quantifiable process to meet the specific needs of each ES, adopting the most efficient bus configuration for the type of installation. The work defined and

described the classic and most used bus arrangements for SEs, which were then used to apply the methodology.

The methodological approach of this work was based on the evaluation of three fundamental factors that influence the SE configuration: service security, analyzing the SE configuration in terms of availability of supply to the network; availability during maintenance, examining the ability of the SE configuration to keep circuits energized during maintenance of disconnect switches and circuit breakers; and operational flexibility, analyzing the capacity of the SE arrangement to allow the reorganization of circuits or the SE to be divided into two or more parts.

The three qualitative analysis criteria were assigned a scoring system to compare them in relation to each of the bus configurations. Thus, an objective classification matrix was generated, considering all classifications and scores of the different configurations that are used in different applications. This matrix can be used as an aid in a decision process, during the selection or optimization of a SE bus configuration. It is important to highlight that the matrix should only be used as a guideline and not in a dogmatic way.

Furthermore, an implementation cost assessment was carried out, adopting the methodology for implementation costs used by ANEEL in its budget simulator for SEs and transmission lines. This methodology is based on SE modulation.

In addition to the four criteria discussed in this work, it is necessary to recognize that there are specific technical implications related to the project and needs of each planned SE. The choice of installation technology, such as compact, conventional, gas-insulated SF_6 or hybrid modules, and the consideration of the area available for installation are examples of aspects not detailed in this study, but which play a vital role in the specific project and must be considered by the designer.

Therefore, the main contribution of this work is to provide engineers with an additional tool in choosing the most appropriate bus scheme for an SE. By applying the methodology, it was possible to verify that each configuration presents its characteristics in relation to security standards, operational flexibility, maintenance availability and costs associated with implementation. Noting that as voltage increases, system security and availability requirements also increase. More efficient configurations in these criteria stand out in higher voltage classes.

REFERENCES

1. Empresa de Pesquisa Energética. (2023). ****Balanço energético nacional 2023: Ano base 2022**** (pp. 5-65). Rio de Janeiro.
2. Monteiro, P. R. D., & Miranda, J. M. (2021). Arranjo de subestação: Um estudo de revisão bibliográfica. **Research, Society and Development**, 10(14), 12. Disponível em: <<https://rsdjournal.org/index.php/rsd/article/download/21805/19592/264679>>. Acesso em: 15 abr. 2023.
3. Violin, A., D'Ajuz, A., & Lacorte, M. (2013). ****Equipamentos de alta tensão – Prospecção e hierarquização de inovações tecnológicas: Subestações de alta tensão****. Brasília: Teixeira.
4. Associação Brasileira de Normas Técnicas (ABNT). (1992). ****Norma Brasileira NBR 5460:1992 - Sistemas elétricos de potência**** (pp. 1-63). Rio de Janeiro.
5. Monteiro, P. R. D. ****Introdução à subestação e seus principais equipamentos****. Seven Editora.
6. Mamede, J. (2021). ****Subestações de alta tensão****. Rio de Janeiro: LTC.
7. Operador Nacional do Sistema Elétrico. (2022). ****Procedimentos de rede - Submódulo 2.6 - Requisitos mínimos para subestações e seus equipamentos**** (pp. 1-25). Rio de Janeiro.
8. Operador Nacional do Sistema Elétrico. ****Procedimentos de rede****. Rio de Janeiro. Disponível em: <<http://www.ons.org.br:80/p%C3%A1ginas/sobre-o-ons/procedimentos-de-rede/vigentes>>. Acesso em: 6 nov. 2023.
9. Corssen, C. L. (1979). ****Avaliação de índices de confiabilidade em subestações**** (Dissertação de Mestrado, Universidade Federal de Santa Catarina, Centro Tecnológico). Santa Catarina. Disponível em: <<http://repositorio.ufsc.br/xmlui/handle/123456789/74887>>. Acesso em: 30 out. 2023.
10. Lingner, G., Esteban, A. S., Twomwy, C., Mortensen, E., Colombo, E., Olovson, H.-E., Abdalla, H., Sogaard, K., Curro, L., & Koenig, P. (2014). Circuit configuration optimization. **CIGRÉ – Technical Brochures, Comitê Internacional: CIGRÉ Editora** (n. 585). Disponível em: <<https://www.e-cigre.org/publications/detail/585-circuit-configuration-optimization.html>>. Acesso em: 31 out. 2023.
11. Agência Nacional de Energia Elétrica (ANEEL). (2022). ****Despacho ANEEL N° 3.246 de 16 de novembro de 2022**** (pp. 1-82). Rio de Janeiro.
12. Eletrobrás S/A e Agência Nacional de Energia Elétrica (ANEEL). (2005). ****Diretrizes para elaboração de orçamento de subestações****. São Paulo.
13. Agência Nacional de Energia Elétrica (ANEEL). ****Orçamento banco de preço****. Rio de Janeiro. Disponível em: <<https://bprsimulador.aneel.gov.br/#>>. Acesso em: 1 nov. 2023.

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