Handbook T-XXII
CIERMMI Women in Science
Engineering Sciences and Applications

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ECORFAN CIERMMI Women in Science

Volume XXII

The Handbook will offer volumes of selected contributions from researchers who contribute to the scientific dissemination activity of the Colegio de Ingenieros en Energías Renovables de Querétaro A.C. in their areas of research in Engineering and Innovation. In addition to having a total evaluation, in the hands of the directors of the Colegio de Ingenieros en Energías Renovables de Querétaro A.C., the quality and timeliness of its chapters, each individual contribution was refereed to international standards (RESEARCH GATE, MENDELEY, GOOGLE SCHOLAR and REDIB), the Handbook thus proposes to the academic community, recent reports on new developments in the most interesting and promising areas of research in the Science and Technology.

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Prologue

This book contains information that has been compiled by research professors who are committed to the sustainability of the planet committed to the sustainability of the planet, join their efforts in science to share it as in the case of this book and then share it as in the case of this book. It is a compilation of the effort to understand, to then apply and share in their students the concepts of energy and share in their students the concepts of energies, and to instill in them that commitment of empathy. In different topics you can see the effort to think about the application and hope that their achievements become a reality achievements become a reality.

It is a range of thinkers who have made their best effort and translate it in such a way that their students and the general public who are passionate about the subject can see the variety of opportunities opportunities, translated into pedagogy, in the production of biofuels, in the design of inks that are totally environmentally friendly environmentally friendly inks, in the application of highly sophisticated designs such as SEPIC but also in the designs such as SEPIC, but now already landed in a nanosatellite application, or from the perspective of a prototype from the point of view of a prototype developed to measure environmental conditions in glass to support to support renewable energies and, for example, the creation of bee-friendly packaging bees also in the possible application in learning for sentiment analysis in data and perspectives data and perspectives, and to conclude we will have the curricular evaluation from the critical critical view, in support of the feeling of commitment to the reality we are living and the feeling of where we are going feeling of where we are going, if we do not unite our efforts.

This book is the sum of efforts that are translated in the different chapters, which drive the growth of science in current topics and reflect the great work of the the growth of science in current topics and that reflect the great work behind them behind them. The CIERMI congress is a window where it is possible to talk about science and development science and development, it is an opportunity to create and share.

I invite you to read these incredible works to recognize the great work of their creators, their dedication and commitment translated into a the dedication and commitment translated into an article that is exposed in this book.

I want to congratulate the authors for their work given, and the congress for creating this space of science.

CASTILLO-MARTÍNEZ, Luz Carmen
Universidad Tecnológica de San Juan del Río

Content

Chapter 1 Pedagogical activity to teach the concepts of renewable energy to Mexican engineering students

Capítulo 1 Actividad pedagógica para enseñar los conceptos de energías renovables a estudiantes mexicanos de ingeniería

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Abstract

This paper describes a dynamic activity to teach the concepts of renewable energy and evaluates its effects on engineering students in Mexico. The dynamic activity is based on variations of percentages of energy consumption proposed by a teacher and the participants using bean seeds. A total of 92 students of Renewable Energy Engineering from three different periods involved the study. The participants were divided into groups, and presented a report where they demonstrated their level of understanding. Using the One-Way ANNOVA test determined differences between their proposals and the teacher ones and interpreted the level of participants' knowledge acquired. A survey was also implemented to examine the effects of understanding the topic and detect discrepancies between directed questions and their proposals. The results showed that the dynamic activity helps participants with their difficulties in understanding the topic. It was found satisfactory outcomes when the dynamic activity is applied face to face.

Proposal, ANNOVA test, Energy sustainability, Energy consumption

Resumen

Este artículo describe una actividad dinámica para enseñar los conceptos de energía renovable y evalúa sus efectos en estudiantes de ingeniería en México. La actividad dinámica se basa en variaciones de porcentajes de consumo de energía propuestos por un docente y los participantes utilizando semillas de frijol. Un total de 92 estudiantes de Ingeniería en Energías Renovables de tres períodos diferentes participaron en el estudio. Los participantes fueron divididos en grupos, presentaron un informe donde demostraron su nivel de comprensión. Mediante ANNOVA One-Way se determinaron diferencias entre sus propuestas y las del docente, y se interpretó el nivel de conocimiento adquirido por los participantes. También se implementó una encuesta para examinar los efectos de la comprensión del tema y detectar discrepancias entre las preguntas dirigidas y sus propuestas. Los resultados mostraron que la actividad dinámica ayuda a los participantes con sus dificultades en la comprensión del tema. Se encontraron resultados satisfactorios cuando la actividad dinámica se aplica cara a cara.

Propuestas, Prueba ANOVA, Sostenibilidad energética, Consumo de energía

1. Introduction

Conservation of sources energy is one of today's most critical issues of the world (Dunlop, 2019). Regarding the rapid reduction in supplying non-renewable resources, nations are improving policies and strategies that promote a mixture of renewable and non-renewable energy resources (Sharvini,2018). However, the current energy model is still characterized by constant growth in global energy consumption based on fossil fuels (IEA,2020). In the case of Mexico, with the discoveries of important oil fields, the Mexican energy system has been evolving towards a pattern of energy production and consumption based on hydrocarbons. Currently, the total demand for primary energy in Mexico reflects the dependence on fossil resources with 89%, 2% on nuclear energy, and 9% on renewable energy sources, mainly hydroelectricity (4%) (SENER, 2018).

Mexico faces a deterioration in its natural resources mainly due to the expansion of agricultural, livestock, forestry and fishing productive activities, which have been developed to obtain a greater economic return without considering the damage caused to the environment, the social and economic impacts (Islas, 2010). One of the areas for the promotion and diffusion of energy resources is the education systems (Jennings, 2009, Kandpal et al., 2014), especially vocational-technical education (Kacan, 2015). Under this context, the Government of Mexico and the United Nations System (UNS) signed the United Nations Cooperation Framework for the Sustainable Development of the United Mexican States for the period 2020-2025 (UNESCO, 2022), searching to promote education as the basis for generating a more viable society and promoting the integration of sustainable development in the school education system at all levels (OMS, 2013).

To fulfil this international commitment, Mexico has taken on the task of developing the Environmental Education Strategy for Sustainability (Gonzalez, 2000), in an effort to organize and promote the activity in the field of environmental education in the country.

In this sense, Higher Education Institutions consider that environmental education should be a common transversal axis to the higher education curriculum so that students obtain knowledge, become aware of their environment and acquire values that promote favourable behaviour towards the environment (Gerritsen et al. 2006, Jennings, 2009, Kandpal et al., 2014).

The teaching system on environmental education in Mexico has directed its attention to the design of plans and programmes. However, they have put aside teaching-learning in the classroom. Authors like Juarez et al. (Juarez et al., 2006) reported that when environmental programmes are tried to implement in the classroom, professors and educators are not suitably qualified for developing techniques or strategies that increment students' interest and acquirement of knowledge in this topic. Reyes et al. (Reyes et al., 2019) identified that there is a lack of collaborative work to deal with problems on sustainability in the classroom. Sosa et al. (Sosa et al., 2010) pointed out environmental education has deficiencies to educate Mexican students, some of them are that the majority of schools do not have renewable energy laboratories, the programmes lack practices or activities for achieving a deep understanding of the topic and the spaces, infrastructure and support are insufficient to teach and promote the environmental topics.

In recent years, prior works have examined strategies for improving learning processes of renewable and non-renewable energy resources. This is because it is known current teaching methods are not always sufficiently motivating and practical; thus, students reduce their interest and acquirement of knowledge in this topic (Alawin et al. 2016, Friman, 2017). Under this context, Massa et al. (Massa et al., 2011) proposed to teach solar energy via problem-based learning, where the students solve homework problems, lectures and engage in structured-type laboratory activities. Taking into account such an approach, problems were designed to engage secondary and post-secondary students in authentic real-world problem-solving focused on a broad range of contemporary issues of sustainability; including solar and wind energy, clean water, energy-efficient lighting, sustainable agriculture, and "green chemistry" in personal care products. In (Lund et al., 2001), authors developed "picture book" laboratory sessions for isolated students who cannot attend on campus. These enable them to learn techniques of data analysis and experimental design. Torres et al. (Torres et al., 2014) introduced a video-sharing educational tool applied to teaching in renewable energy subjects that consists of a web channel of an online platform, which integrates multimedia materials that show the techniques and technology used to produce electricity or thermal energy from renewable resources. This learning tool was applied and used as a support in two ambits, face-to-face and non-face-to-face education, in two different educational levels: undergraduate and postgraduate education. The results showed that the students improved their understanding of the theoretical concepts.

Supported by the above, this paper describes and evaluates the effects of a dynamic activity to teach the concepts of renewable energy to engineering students in Mexico, which is based on teaching-learning techniques with dynamic activities and games (Jennings, 2009). Through this dynamic activity, students gain an increment of understanding of the effect of energy consumption, the differences between renewable and non-renewable resources and the need to implement new strategies on energy use in the future. This research considers a report and a survey. In the report, the participants demonstrate qualitatively and quantitatively the level of understanding with graphical proposals, and the teacher examines the effects of this activity. With the survey applied to each student, the teacher detects discrepancies between directed questions and the proposals made as a team. Using One-Way ANOVA test we determine differences between the proposals of teachers and participants and interpreted the level of participants' knowledge acquired for the three different periods.

2. Research Method

2.1 Participants

The regarded sample consisted of bachelor students from Instituto Tecnológico de la Laguna in Coahuila, Mexico. A total of 92 students in 1st semester of the Renewable Energy Engineering degree and a teacher helped by two master's students were involved in this study. The participants were part of the Introduction of Renewable Energy course corresponding to the years 2020, 2021 and 2022. They were divided randomly into 18 groups, as shown in Table 2.1. The teacher and the two master's students were assigned to explain the rule of the activity and the master's students in order to control their performance.

Table 2.1 Courses and number of participants

Period	Descripción	Number of participants
September 2020	6	32
October 2021	6	32
April 2022	6	28
Total	18	92

Source: Self Elaboration

2.2. Materials

For this dynamic activity, each participant needed a paper bag, which contained 100 beans; 90 of these were black, and the other ten were white. A number of extra beans were available for variants on the proposed approach. Figure 1.1 shows as an example, the table that each participant carrying out the activity.

Figure 1.1 Table of renewable and non-renewable resources per decade


SEP
SECRETARÍA DE EDUCACIÓN PÚBLICA
TECNOLÓGICO NACIONAL DE MÉXICO
INSTITUTO TECNOLÓGICO DE LA LAGUNA

Activity
Renewable and Non-renewable resources

Stage:_____

Number of Decades	**Number of Non-Renewable resources (Black beans)**	**Number of Renewable resources (White beans)**	**_____% decrement/incremented in the energy consumption**	
			Equation	No. Seeds
1				
2				
3				
4				
5				

Source: Self Elaboration

2.3. Instrumentation, data collection and analysis

One of the instruments used in this study was based on a report made by the participants after executing the activity described in Section 3. The such report contained quantitative and qualitative data using graphics of energy used over time and a discussion of their results obtained from the three simulated stages.

Statgraphics Centurion XVIII software was used in the data analysis (Rojewski et al., 2012, Keselman et al., 1998, Rutherford, 2011), and One-way ANNOVA was employed to detect differences between the proposals in the three different stages and evaluate the effects of understanding the topic on engineering students. For this study, the dependent and independent variables were the number of total decades of each proposal and the periods, respectively. Subsequently, a post hoc test (least significant difference [LSD]) was used as a comparative measurement between the periods. The analysis of the proposals had reliability of α=0.05, which indicates good internal consistency.

Another instrument consisted of the application of a survey with ten items to each student, which contains statements that reflected the student's perception of the rhythm of energy consumption and the impact on the use of renewable and non-renewable energy.

3. Description of proposed strategy

Initially, participants of each period were divided into different teams. Each team had one bag with 100 beans. Each bag represented the energy consumption over time (100%), and the black and white beans represented 90% and 10% of non-renewable and renewable resources, respectively. This is based on current fossil fuel consumption reaching 90% in Mexico (Banco Mundial, 2023).

Based on (Robin, 2022), the narrative of this dynamic activity was as follows: participants from each team took turns to take out the specific number of beans (according to the variant in each stage) from the bag in a blind way to avoid choosing the colour. Each extract represents the rate of energy consumption in a decade. The number and colour of beans extracted are related to the simulated conditions: increments or decrements of total energy consumption and changes in the use of energy. These conditions are described in three stages:

a) Stage I: There are no changes in current energy consumption per decade; therefore, total energy consumption will be 100%. In order to represent this percentage, each participant removes ten beans from the bag without selecting them. Then the team takes note of each colour (Figure 1.1), and only returns the renewable beans to the bag. The participants continue until renewable beans are depleted and have to take the non-renewable beans in the last round. The team must plot the number of black and white beans as a function of the number of rounds. And afterwards, they will determine how many decades of total energy are used at the current rate.

b) Stage II: Two proposals as hypothetical situations were raised by the teacher under the same conditions.

1. An increment of 6% of total energy consumption per decade. Each participant now will extract a rate of 0.6 more beans per turn. For example:

– For 1st decade, ten beans are extracted from the bag due to it is the initial condition.
– For 2nd decade, 10.6 beans are extracted from the bag, which represents an increment of 6%. It is equivalent to 11 beans.
– For 3rd decade, considering the result obtained in the 2nd decade, 6% of total energy consumption is added. Therefore, 11.236 beans are extracted from the bag, which is equivalent to 11 beans.
– And so on.

The equation that represents this case is given by:

$$x = (10)(1.06)^{n-1} \quad (1)$$

where x is the number of extracted beans by round and n is the number of rounds.

2. A decrement of 2% of the total energy consumption per decade. For this case, each participant will extract a rate of 0.2 fewer beans per turn.

– For 1st decade, ten beans are extracted from the bag because that is the initial condition.
– For 2nd decade, 0.98 beans are extracted from the bag, which represents an increment of 2%. It is equivalent to ten beans.
– For 3rd decade, considering the result obtained in the 2nd decade, 2% of total energy consumption is reduced. Therefore, 9.604 beans are extracted from the bag, which is equivalent to ten.
– And so on.

The equation that represents this case is given by:

$$x = (10)(1.02)^{n-1} \quad (2)$$

where x is the number of extracted beans by round and n is the number of rounds.

c) Stage III: The participants propose two activities with different percentages based on the experience obtained in the first and second stages and the process is repeated. However, these proposals also may contain increase or decrease the consumption of renewable or non-renewable energy. For example, if a participant proposes a 5% increase in the consumption of renewable energy, 100% of the consumption is maintained, and only the amount corresponding to the proposed percentage of white beans will be added to the bag, keeping the amount of:

$$x_w = (10)(1.05)^{n-1} \tag{3}$$

where n is the number of rounds and x_w is the total amount of white beans that must remain in the bag until they are extracted in the last rounds. Furthermore, if a participant proposes a decrease in consumption of non-renewable energy, then from the black beans extracted in each round, the proposed percentage amount per decade will be returned to the bag.

Finally, the participants from each team had to choose which of its proposals in Stage III could prolong more duration of non-renewable energy and discuss real forms of consumption to reach its purpose and obtain a result more sustainable.

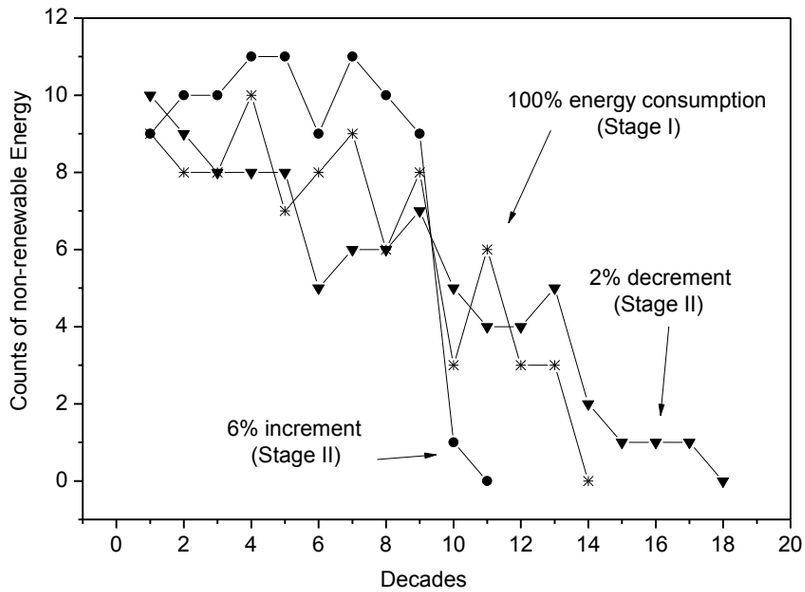
4. Survey results

4.1 Report results

As an example of the activity to be carried out in the participants' reports, Graph 4.1 shows the comparison of the graphs corresponding to stages I and II of the activity.

In Graph 4.1, it can be observed that the total duration of non-renewable energy was 14 rounds in stage I, which corresponds to the total energy consumption without increment or decrement; i.e., there are no changes in the energy current consumption per decade (100%). Such a result indicates that this current consumption rate of 90% and 10% of non-renewable and renewable energy, respectively, would last for 14 decades. In stage II, where there is an increment of 6% of energy demand, the duration of non-renewable energy was 11 decades, showing how this increment could limit non-renewable energy in 3 decades. In the case of a decrease in energy demand by 2%, the average reached values up to 18 decades, indicating that this strategy could be a solution possible to have a sustainable consumption of energy. The participants could deduce that an increment in energy consumption reduces the decades of use of renewable energy. On the other hand, a decrement in energy consumption increments the decades and the use of renewable energy.

Graph 4.1 Graphs of stages I and II of the activity



Source: Self Elaboration

Based on the reports' generated information, Table 4.1 contains the results of participants' proposals from Stage III, separated into three periods. It was found that most of the proposals made by students are based on extending total energy by decades changing energy consumption or using renewable energy, thus more than 14 decades of total energy duration were obtained. This result showed that participants deduced the effect of increasing and decreasing energy consumption on the increase or decrease of decades. In other words, an increment in energy consumption reduces the decades and use of renewable energy and vice-versa.

Table 4.1 Report results of participants' proposals from Stage III

Period	Teams	Proposal	Decades	Long-term sustainable	Teacher Conclusion
September 2020	1	-Increase the use of renewable energy by 10% per decade	17	Yes	They understand energy issues and sustainable needs.
		-A decrease in 5% demand energy	27	Yes	
	2	-Increase the use of renewable energy by 20% per decade	20	Yes*	They understand energy issues and sustainable needs.
		-Increase the use of renewable energy by 8% per decade	16	Yes	They understand energy issues and sustainable needs.
	3	-A decrease in 5% demand energy	25	Yes	They do not understand the problem beyond that non-renewable energy is depleted, they do not address measures to prevent it.
		-An increase in 5% demand energy	10	No	
	4	-Increase the use of renewable energy by 8% per decade	17	Yes	They understand energy issues and sustainable needs.
		-Increase the use of renewable energy by 5% per decade	19	Yes	
	5	-An increase in 8% demand energy	15	No	They understand the need for renewable energy, but don't sustainable needs.
		-Increase the use of renewable energy by 12% per decade	19	Yes*	
	6	-Increase the use of renewable energy by 30% per decade	25	Yes*	They understand energy issues and sustainable needs.
		-A decrease in 2% demand energy	17	Yes	
October 2021	1	-An increase in 15% demand energy	13	No	They understand the need for renewable energy, but don't sustainable needs. The conclusion does not show anything relevant, raise the need for renewable energy but point out that it must be fast and not something that increases with time.
		-Increase the use of renewable energy by 20% per decade	20	Yes*	
	2	-Increase the use of renewable energy by 20% per decade	18	Yes*	They understand the need for renewable energy, but don't sustainable needs. They conclude the problem and sustainable need, although it is out of proportion.
		-An increase in 12% demand energy	10	No	
	3	-Increase the use of renewable energy by 30 % per decade	23	Yes*	They partially understand the problem and propose sustainable measures.
		-A decrease in 20% demand energy	25	Yes	
	4	-Increase the use of renewable energy by 25% per decade	24	Yes*	There is an understanding of the problem, but with unrealistic proposals, although with a sustainable theme.
		-A decrease in 25% demand energy	21	Yes	
	5	-A decrease in 20% demand energy	23	Yes	The problem is not understood and has no consistency.
		-A decrease in 8% demand energy	22	Yes	
	6	-An increase in 6% demand energy	18	No	They understand the need for renewable energy, but don't sustainable needs. They understand the problem and sustainable needs
		-Increase the use of renewable energy by 10% per decade	19	Yes	

*Not real proposal

Source: Self Elaboration

Table 4.1 Report results of participants' proposals from Stage III (continuation)

Period	Teams	Proposal	Decades	Long-term sustainable	Teacher Conclusion
April 2022	1	-An increase in 5% demand energy	12	No	They do not understand the problem of the need for renewable energy, but understand sustainable strategies.
		-A decrease in 10% demand energy	16	Yes	
	2	-An increase in 4% demand energy	14	No	They partially understand the problem and propose sustainable measures.
		-An increase in 60% demand energy	8	No*	
	3	-An exponential increase in demand energy	6	Yes	They don't understand the rules. They seem to understand the dynamics and the problems, they point out the factors for sustainability and the factors that make it worse.
		-Increase the use of renewable energy by 1% per decade	15	No	
	4	-An increase in 8% demand energy	9	No	The problem and sustainable actions are understood, but not enough results are proposed
		-An increase in 2% demand energy	11	No	
	5	-Increase the use of renewable energy by 10% per decade	16	Yes	They understand the problem of the need for renewable energy, but do not understand sustainable strategies. The problem and the actions are understood, but not the dynamics and the proposals are not real.
		-An increase in 30% demand energy	14	No	
	6	-Increase the use of renewable energy by 20% per decade	17	Yes*	The problem and the actions are understood, but not the dynamics and the proposals are not real.
		-A decrease in 2% demand energy	15	Yes	

*Not real proposal

Source: Self Elaboration

According to the proposals presented by each team, participants based on two points: 1) the importance of using renewable energies and 2) the rational use of total energy consumption. In this context, the teacher's conclusions showed that not all students clearly understood the concepts, or they confused them. In this point, the activity could be reinforced by completing a questionnaire with the basic concepts and providing more examples.

4.2 Survey results

In order to understand the effectiveness of the activity described above, participants were surveyed with respect to the three different periods after performing the activity. Table 4.2 shows the survey questionnaire as affirmative responses.

Results of the survey showed that this dynamic activity seems to have a positive effect on the understanding of the concept of renewable energy. To both first questions, it was obtained percentages from 96.7% onward. With respect to the third and fourth questions, participants of the 2020 period showed the lowest percentage in creating awareness of the exhaustion of non-renewable sources and in the concept of energy sustainability after completing the activity. According to teacher observations, these participants did not show as much interest in the activity as in other periods.

About the fifth question, the study found that a participant of the three periods could understand the problem of the eventual exhaustion of fossil fuels with this activity. This result showed that the participants acquired a high level of consciousness in this topic. However, in the question of how changes in energy consumption affect the use of renewable and non-renewable resources, it was obtained a low percentage in the 2021 period with a 76.7%, followed by 2020 period (86.7%), and 2022 period (96.7%). It reveals that the participants failed in understanding fully the role of energy resources on energy consumption.

Table 4.2 Statistical description of the questionnaire

Item/Period	September 2020	October 2021	April 2022
	Percentage (%)		
1. Did you help this activity to understand the concept of renewable and non-renewable energy?	96.7	96.7	100
2. Did you think that create awareness of the depletion of non-renewable sources after doing the activity?	96.7	96.7	96.7
3. Did you increase awareness of the depletion of non-renewable sources after doing the activity?	86.7	90	90
4. Did you understand the concept of energy sustainability after doing the activity?	66.7	86.7	86.7
5. Did you understand the problems of eventual exhaustion of fossil fuels after doing the activity?	96.7	90	93.3
6. Did you understand how changes in energy consumption affect the use of renewable and non-renewable resources?	86.7	76.7	96.7
7. Did you understand the importance of optimizing the energetic resources after doing the activity?	86.7	86.7	90
8. Did you visualize the need to develop technology for using renewable resources after doing the activity?	100	93.3	96.7
9. Of the results obtained from activity, what type of strategy do you that could be more favourable nowadays?			
10. To reduce current energy consumption	46.7	63.3	50
11. To increase consumption of renewable energy	26.7	13.3	16.7
12. To reduce consumption of non-renewable energy	26.7	23.3	33.3
13. Do you think the proposal described in your activity report could be implemented in real life?	83.3	90	96.7

Source: Self Elaboration

Regarding the seventh and eighth questions, results were obtained with respect to the need to conserve current energy sources and develop new renewable resources. It was observed a direct impact on raising awareness of participants in the topic. From the three periods, the responses of participants were over 76%. Based on the participants' opinions on the ninth question; the most favourable type of strategy today, inconsistencies were found between participants' reports and the questionnaire. Firstly, most participants think that the best option is to reduce current energy consumption, 46.7% (2020 period), 63.3% (2021 period) and 50% (2022 period). While in the proposals of the activity, 33% (2020 period), 25% (2021 period) and 16.6% (2022 period) proposed strategies to reduce current energy consumption. When comparing these percentages with the proposals, their answer only is consistent in the 2020 period.

Secondly, the following option as the most favourable type of strategy today is to reduce consumption of non-renewable energy, 26.7% (2020 period), 23.3% (2021 period) and 33.3% (2022 period). In the proposals of the activity, no proposal was made regarding this response in the three periods. Finally, the third option as the most favourable type of strategy today is to increase the consumption of renewable energy, 26.7% (2020 period), 13.3% (2021 period) and 16.7% (2022 period). In the proposals of the activity, 50% (2020 period), 75% (2021 period) and 33% (2022 period) proposed that the best solution favourable is an increase in renewable energy. It indicated that the activity reinforces this point and clarifies the doubts of the participants on this topic.

According to the participants' opinions on the tenth question, more than 83% think that their proposals could be implemented in real life. It indicates that this activity may help to generate new proposals in the use of energy supply and their prolongation over the years. The interest of the participants in knowing the role of energy demand may be increased during their professional careers.

4.3 Statistic analysis

To evaluate the effect differences between the proposals in the three different stages and evaluate the effects of understanding the topic on engineering students, One-way ANNOVA test was performed using the results of Table 4.1 and the total of decades obtained as a result of the activity carried out by participants for each stage in the three different periods with a 95% confidence interval (α=0.05). One-way ANNOVA results are shown in Tables 4.3, 4.4 and 4.5.

Table 4.3 shows results for stage I (initial proposal), where the current energy consumption is 90% of non-renewable energy and 10% of renewable energy. In stage I, the null hypothesis is that all participants obtained the same knowledge for this stage of the activity carried out. As shown in Table 4.3, the p-value = 0.5803 obtained was higher than the p-value of 0.05 (α = 0.05). This means that there is no statistically significant difference between the proposals presented in all periods, and therefore, the assumption of homogeneity in the knowledge obtained by the participants in stage I was not violated. Thus, participants obtained same knowledge for this stage in the three periods.

Table 4.3 One-way ANNOVA analysis on the learning of participants stage I (n=18)

Source	SS	df	MS	F-value	P-value
Periods*	0.777778	2	0.388889	0.56*	0.5803
Error	10.3333	15	0.688889	-	-
Total	11.1111	17	-	-	-
* p > 0.05, a Stage I teacher proposal in 3 different periods.					

Source: Self Elaboration

Table 4.4 shows One-Way ANNOVA test for stage II (teacher proposal). There, one proposal was an increase of 6% of total energy consumption per decade and the other was decreased by 2%. In this case, the null hypothesis is that participants of the three different periods noted the effect of change in energy consumption in the number of decades, i.e., an increment in energy consumption reduces decades and limits the use of non-renewable energy and vice-versa. Table 4.4 shows a p-value = 0.9397, which is higher than the p-value = 0.05; that is an allowable error (α= 0.05) (Rojewski et al., 2012). This means that there is no statistically significant difference in the three different periods of stage II, indicating that most participants observed the relationship between increasing and decreasing energy consumption, duration in decades, and use of renewable energy, as shown in Graph 4.1.

Table 4.4 One-way ANNOVA analysis on the learning of participants stage II (n=18)

Source	SS	df	MS	F-value	P-value
Periods*	2.33333	2	1.16667	0.06*	0.9397
Error	280.167	15	18.6778	-	-
Total	282.5	17	-	-	-
* p > 0.05, a Stage II teacher proposal in 3 different periods.					

Source: Self Elaboration

Table 4.5 shows One-Way ANNOVA test results for stage III, where the proposals made were of all participants. In this case, the null hypothesis was based on the fact of participants could define their own proposals about energy consumption by decade regarding the knowledge acquired from previous stages; p-value = 0.0006 obtained in Table 4.5 was lower than 0.05, indicating that there is a significant difference between the results of proposals. It points out that not all the participants were able to elaborate their proposals about energy consumption by decade, even though they observed a relationship established in stage II.

Table 4.5 One-way ANNOVA analysis on the learning of participants stage III (n=36)

Source	SS	df	MS	F-value	P-value	LSD*
Periods*	349.389	2	174.694	9.44*	0.0006	P1 = P2 P1 ≠ P3 P2 ≠ P3
Error	610.917	33	18.5126	-	-	
Total	960.306	35	-	-	-	
* p > 0.05, a Stage II teacher proposal in 3 different periods, wrong adjustment for multiple comparisons: Least Significant Difference						

Source: Self Elaboration

One-way ANNOVA test results for this stage indicate there were differences between the participants' knowledge without knowing the specific periods where they differ, therefore a One-Way ANNOVA post hoc test was performed. Results using LSD analysis showed that there was not a significant difference between both periods 2020 and 2021.

However, there is a significant difference in LSD with respect to the period 2022. Based on the results of Table 4.1, it was observed that basic concepts or communication between team members were not clear enough. Most of the proposals in the period 2022 do the energy have a duration lower than the proposal with respect to current consumption, which is not concordant with the aim of the activity.

It was also found that 50% of the proposals on the type of strategy more favourable nowadays during the 2022 period was based on an increase in the demand for energy. These differ from the objectives of the activity. In other words, participants misunderstood the concepts of energy consumption, because there was a change in the execution of activity in the year 2022. It passed from face-to-face to virtual mode to understand the difficulties in the teaching learning process.

5. Conclusions

A validation of the effects of a dynamic activity to teach the concepts of renewable energy to engineering students in Mexico was described and evaluated. This research used a One-Way ANNOVA test determined differences between the proposals of teachers and participants and interpreted the level of participants' knowledge acquired, and a survey to examine the effects of understanding the topic and detect discrepancies between directed questions and their proposals. Evidence from previous research supports the following conclusions:

1. This study has shown that the dynamic activity has a positive impact on students' understanding of the concepts of renewable energy.

2. The application of this dynamic activity allows the teacher to evaluate the level of knowledge of the students, as well as their difficulties in understanding concepts related to renewable energy.

3. The effectiveness of this dynamic activity is evident in participants, especially when participants interact face to face.

4. The communication face to face between team members is a key factor for learning achievement and the reduction of misconceptions in the participants.

5. The dynamic activity in virtual mode impacts negatively the performance of participants and increases the confusion of concepts of the renewable energy topic.

6. It was observed that the dynamic activity offers a better panorama of energy substantively.

7. It was found that students created awareness in the topic of renewable energy, mainly in the current rate of energy consumption.

8. It is suggested the teacher's feedback or the application of a test to correct any deficiencies or misunderstandings in the topic.

6. Credit author statement

Laura Andrea, Pérez: Methodology, Software, Writing - Review & Editing, Lizbeth Salgado: Investigation, Writing - Original Draft, Carlos Álvarez: Conceptualization, Methodology, Writing - Review & Editing, Supervision

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Chapter 2 Thermal evaluation of multi-glazed windows under *Aw* Köppen climate classification: An analysis by mean of global energy balances

Capítulo 2 Evaluación térmica de ventanas de vidrios múltiples bajo el clima *Aw* de la clasificación de Köppen: Un análisis por balances globales de energía

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Abstract

Nowadays, researchers have proposed the use of multi-glazed window as a strategy to improve the thermal comfort in buildings. Therefore, in this study the effect on the thermal performance of three glazed configurations: single (SW), double (DW), and triple (TW) windows under *Aw* Köppen climate classification was evaluated. The thermal analysis was carried out starting with the modeling of the window conjugate heat transfer by mean the global energy balance method. In this work, the window thermal performance for the warmest and coldest days of the year are presented first, in order to show the temperature and heat flux trends. Based on these results it was observed that the TW decreased the window energy gains by 36.7 % and losses by 8 %. Subsequently, an annual thermal evaluation of the TW is presented in order to show the advantages and disadvantages of positioning the window in different orientations and its potential on energy saving. The highest energy savings were obtained for the north orientation (2.2 $kW \cdot h \cdot m^{-2}$), followed by west (3.6 $kWhm^{-2}$), south (3.9 $kWhm^{-2}$) and east (4.0 $kWhm^{-2}$). On the north orientation, the solar radiation values are low (<400 W/m^2), so the window energy gains are 50% lower than the other orientations, therefore multi-glazed windows are unnecessary.

Thermal evaluation, Numerical study, Heat transfer, Multi-glazed, Thermal comfort

Resumen

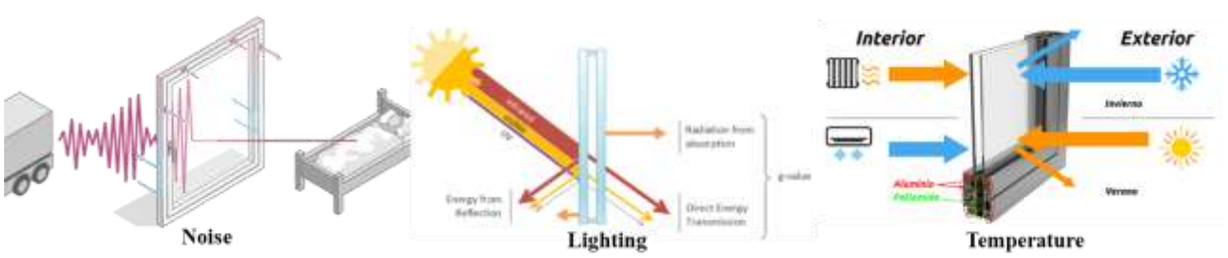
Actualmente, los investigadores proponen utilizar vidrios múltiples como una estrategia para mejorar el confort térmico. En este estudio se evaluó el efecto de tres configuraciones de acristalamiento: simple (SW), doble (DW) y triple (TW) en el desempeño térmico de una ventana bajo el clima *Aw* de la clasificación Köppen. El análisis se llevó a cabo a partir del modelado de la transferencia de calor por el método de balances globales de energía. Primero se muestran las tendencias de la temperatura y flujo de calor en el día más cálido y frío del año. Con base en los resultados, la TW redujo la pérdida y ganancia de energía 36.7 % y 8 %, respectivamente. Después, se presentó la evaluación térmica anual de la TW para mostrar el potencial de ahorro de energía en diferentes orientaciones. El mayor ahorro de energía se obtuvo en la orientación norte (2.2 $kW \cdot h \cdot m^{-2}$), seguida del oeste (3.6 $kWhm^{-2}$), sur (3.9 $kWhm^{-2}$), y este (4.0 $kWhm^{-2}$). En la orientación norte, los niveles de radiación son bajos (<400 W/m^2), debido a esto la ganancia de energía de la ventana es 50 % menor que en las otras orientación, por lo tanto, el uso de vidrios múltiples es innecesario.

Evaluación térmica, estudio numérico, transferencia de calor, vidrios múltiples, confort térmico

1. Introduction

Currently, researchers are looking for strategies to save energy, especially in buildings, where people perform their activities 90 % of the day. Energy saving means reducing the building energy needs through the use of efficient systems with a positive cost-benefit balance, in other words, energy saving should not affect people comfort during the development of their activities. Building comfort is established based on three main parameters: noise, lighting quality, and temperature, Figure 1. In order to improve the building comfort, efficient lighting systems, acoustically and thermally insulated systems are required. In addition, improvements in thermal insulation are expected to reduce CO_2 emissions and electricity consumption in the building sector.

Figure 1 Factors that determine the comfort level in buildings



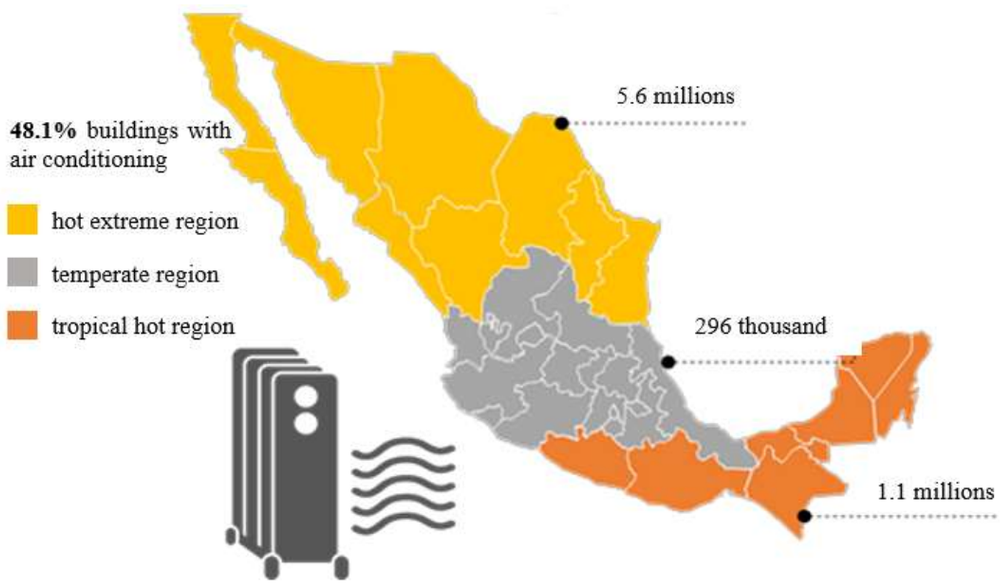
Source: Own Elaboration

In Mexico, the demand for housing is increasing, as well as the ambient temperature due to climate change, therefore, it is necessary to develop thermal insulation strategies and devices that alone improve thermal comfort and avoid the use of ventilation devices, which increase the electricity consumption and environmental pollution, especially in the north and the coasts of the country, where ventilation and air conditioning systems are recurrent (see Figure 2).

In order to reduce the time of use of ventilation devices and improve the building thermal insulation several investigations have been carried out focused on the study of the building envelope elements such as the roof, walls, and windows, and the relationship with the design variables (location, position, and orientation) in order to develop strategies to save energy. According to Bienvenido-Huertas et al.[1], it is necessary to optimize the thermal performance of glaze facades in order to control solar gains and reduce energy demand in buildings.

For the building's envelope, windows are only aesthetic elements, whose function is to allow us to look outside and receive natural light, which improves the people physical and mental health [Vitro[2]]. However, from the thermal approach, the low thermal insulation and the high transmittance value of single glazed increase the window heat transfer rate, and consequently the indoor building temperature. Therefore, conventional windows must be redesigned taking into account the location, climate, and façade orientation in order to improve the windows thermal efficiency and the building thermal comfort. Around the world, researchers have proposed the use of multi-glazed window as a strategy to improve the thermal comfort in buildings.

Figure 2 Climate map by regions, use of air conditioning



Source: INEGI, 2018

Several investigations have focused on analyzing multi-glazed design parameters such as glazing panes number [Arıcı et al., 2015[3]], encapsulated fluids like air [Gonzalez-Julian et al., 2018[4]] and noble gases [Heydari et al., 2020[5]], phase change materials [Yang et al., 2023[6]], and supplied water [Yamaç and Koca, 2023[7]]. On the other hand, authors such as Huang et al., 2023[8], applied the new concept of window with air supply, and changed the structure of the conventional window to improve the thermal performance. However, changing the window structure is insufficient.

In addition, it is also necessary to take into account the parameters that relate the window to the façade such as the window size [Djamel and Noureddine, 2017[9]], position [Kahsay et al., 2020[10]], and orientation [Kaasaleinen et al., 2020[11]]. In this sense, Amaral et al., 2016[12] considered the number of glazing panes (1-3), size, position, and shadow effect that would improve the window thermal performance in terms of comfort and energy savings; in all cases, single and double glazed had a similar thermal behavior; however, triple glazed provided promising results.

Later, Arici et al., 2020[13] analyzed the effect of the number of panes and the air layer thickness on the overall heat transfer coefficient, U-value; the risk of increasing the U-value in sloped windows can be reduced by using more panes and an optimal air layer thickness. Recently, Rodríguez-Aké et al., 2022[14] reported the first work focused on the thermal performance of a triple-glazed window (TW) under warm climate conditions of Mexico and evaluated the energy saving potential and CO_2 emission compared to single and double glazed windows. Based on the numerical results, the heat flux, energy demand and CO_2 emissions can be reduced by 40 % when triple-glazed is used instead of single-glazed window.

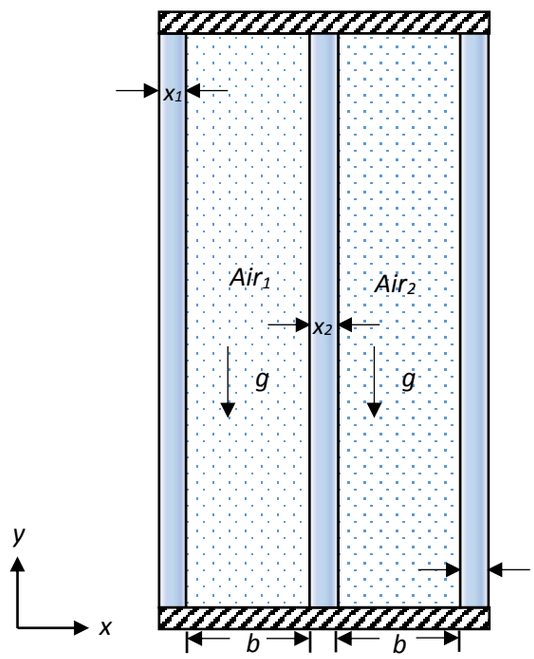
In this study, the potential for energy saving and CO_2 emissions reduction by implementing multi-glazed windows under *Aw* Köppen climate classification is presented. The thermal analysis is carried out based on the numerical modeling of the window heat transfer by mean of the global energy balances method. The temperature and heat flux trends are presented in order to show the window heat transfer rate for the four main orientations. Subsequently, the triple glazed annual thermal performance is presented in order to describe the window orientation advantages and disadvantages.

2. Physical and mathematical model

The physical model, the coordinate system, and the nomenclature used in the numerical solution of multi-glazed windows are shown in Figure 3; the triple glazed window was considered as a representative system. Three semitransparent walls form the TW configuration with a height of Hy=0.80 m and a thickness of $x_{glazing}$=0.006 m; an air-gap b=0.02 m separates each glazing from another. The horizontal walls, top and bottom, are adiabatic.

According to Figure 4, glazing 1 is in contact with the internal temperature, T_{in}=25 °C, while glazing 3 is subjected to external conditions of temperature (T_{out}), wind speed (V_{wind}), and solar radiation (G_{solar}). The heat transfer mechanisms involved in TW are shown in Figure 4a: conduction through semi-transparent walls, natural convection in the encapsulated air, and surface radiation between the vertical walls in both cavities. Conjugate heat transfer comes into play across the boundaries that make up the TW. The normal component of solar radiation strikes the surface of glazing 3; it is reflected, absorbed, and transmitted through the glazing in different proportions, as shown in Figure 4b.

Figure 3 Physical model of a multi-glazed window: TW configuration



Source: Own Elaboration

The energy absorbed by the semitransparent walls increases the window temperature, so do the radiative and convective heat transfer rate. The value of the heat transfer coefficient by convection between the interior environment and glazing 1 is considered constant, h_{in}=8.3 W/m^2 [ASHRAE Book, 2001[15]]. To determine the value of the convective coefficient between the external environment and the glazing 3 Eq. (1) was used [Zhang et al., 2019[16]]; the external convective coefficient depends on the wind speed.

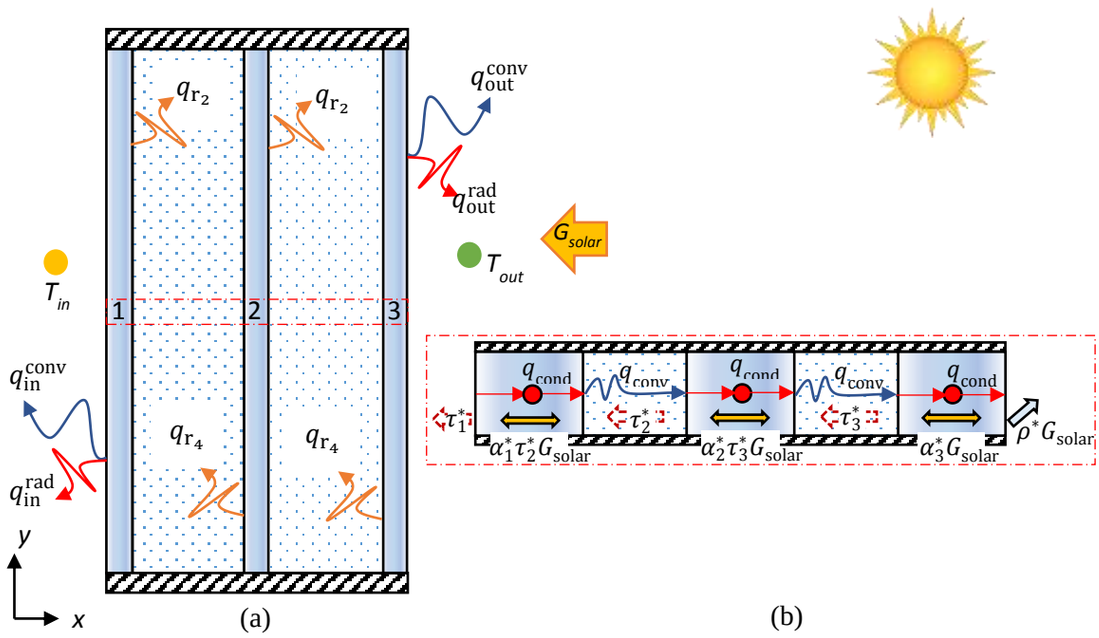
$$h_{out}^{conv} = 2.8 + 3V_{wind} \tag{1}$$

The emissivity of all glazings is assumed to be constant ε=0.85, and their surfaces are considered opaque, gray, and diffuse to long wave radiation. The thermophysical properties of the glazings were taken from [4], and the optical properties were calculated through the WINDOW[17] software.

Considerations for the mathematical model

- Two-dimensional heat transfer in transient state is considered.
- Due to the dimensions of the window and the difference in temperature that can occur between the glazings, the flow regime is laminar.
- Encapsulated air in DW and TW configurations is considered a Newtonian and incompressible fluid.
- Due to the low moisture content, the air is considered dry; therefore, it is a non-radiatively participating medium.
- The thermophysical and optical properties of glazings are constant.
- On the surface radiative exchange model, the surfaces are considered opaque, diffuse and isothermal.

Figure 4 Conjugate heat transfer in triple-glazed window



Source: Own Elaboration

In this study, according to Figure 5 the heat flux direction the heat flux direction was assumed from left to right. In order to consider the two-dimensional effect on heat transfer, the three window configurations were divided into multiple sections sections all along the height, as shown in Figure 5a. An energy balance was performed for each section at a point in the center of the glazings. Figure 5b shows the model of thermal resistances with which the heat transfer by conduction (R_{cond}), convection (R_{conv}), and radiation (R_{rad}) in the TW is represented. The value of the conductive thermal resistances for the glazings $\left(R_{glass}^{cond}\right)$ is presented in Eq. (2). As for the encapsulated air, for the encapsulated air, the thermal resistance by convection is represented by Eq. (3).

$$R_{glass}^{cond} = \frac{Hx_{glass}}{2\lambda_{glass}} \tag{2}$$

$$R_{air}^{conv} = \frac{1}{h_{air}^{conv}} \tag{3}$$

Eq. (4) was used to determine the convective heat transfer coefficient for the encapsulated air. This equation relates the Nusselt number (Nu), the air thermal conductivity (λ_{air}), and the characteristic length, L_C; the characteristic height is computed in each section and depends on the position where the energy balance is carried out.

$$h_{air}^{conv} = Nu\frac{\lambda_{air}}{L_C} \tag{4}$$

On the other hand, to determine the Nusselt number, the correlations of Eqs. (5) and (6) were obtained following the methodology reported by Xamán et al., 2005[18].

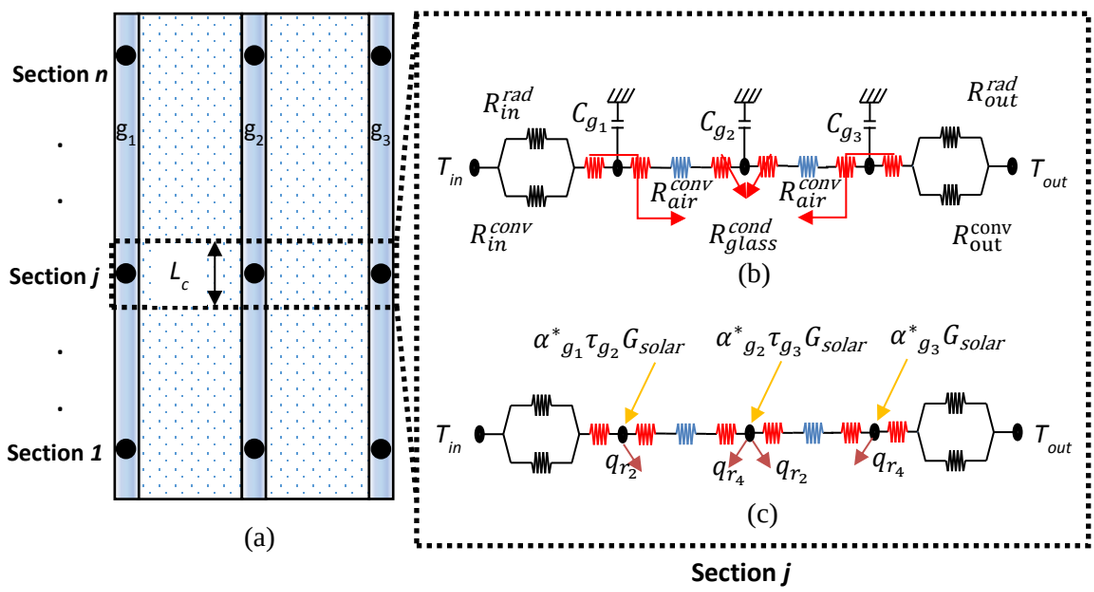
$$A = 40 \quad \begin{cases} Nu = 6.4411 \times 10^{-16} Ra^2 + 1.9150 \times 10^{-9} Ra + 40 & (5) \\ Ra \leq 6.4 \times 10^7 \\ Nu = 2.8765 \times 10^{-1} Ra^{2.6832^{-1}} & (6) \\ 6.4 \times 10^7 < Ra \leq 6.4 \times 10^{10} \end{cases}$$

The thermal resistances by convection and radiation inside (R_{in}^{conv} and R_{in}^{rad}) and outside (R_{out}^{conv} and R_{out}^{rad}) of the window include the heat transfer coefficients by convection (h^{conv}) and radiation (h^{rad}). Figure 5b shows the thermal conductances C_{g_1}, C_{g_2} and C_{g_3}, which are used to represent the time dependency effect; These include the density (ρ_g), the specific heat (Cp_g), the thickness of each glazing (Hx_g), and the temperature variation over time; the conductances are determined by Eq. (7).

$$C_g = \rho_g Cp_g Hx_g \frac{\partial T_g}{\partial t} \tag{7}$$

Figure 5c shows the heat fluxes resulting from the radiative exchange between surfaces (q_r) and the energy absorbed by the incidence of solar radiation ($\alpha^* G_{solar}$). The radiative heat fluxes, q_{r_2}, and q_{r_4} were calculated by the radiosity-irradiation method (RIM). The Hottel Crossed String method was used to determine the view factors.

Figure 5. Thermal resistances and energy balance in a triple-glazed window



Source: Own Elaboration

An energy balance was performed on the glazings to determine the temperature (see Figure 3a). The point where the energy balance was carried out is called a node. At this point, the energy stored ($q_{storage}$) and exchanged ($q_{in_t} - q_{out}$) in the system is established, as presented in Eq. (8).

$$q_{storage} = q_{in} - q_{out} \tag{8}$$

The energy balances for the configurations of one (SW), two (DW), and three (TW) glazings are presented in equations 9, 10-11, and 12-14, respectively. The total thermal resistances $R_{SPW-g}^{in/out}$, $R_{DPW-g}^{in/out}$ y $R_{DPW-g}^{in/out}$ are defined in Annexes.

SW (9)

$$Cp_{g_1} Hx_{g_1} \frac{\partial T_{g_1}}{\partial t} = \left[\alpha_{g_1}^* G_{solar} + R_{SPW-g_1}^{in}\left(T_{in} - T_{g_1}\right)\right] - \left[R_{SPW-g_1}^{out}\left(T_{g_1} - T_{out}\right)\right] \tag{10}$$

DW – inner glazing (1)

$$\rho_{g_1} Cp_{g_1} Hx_{g_1} \frac{\partial T_{g_1}}{\partial t} = \left[\alpha_{g_1}^* \tau_{g_2} G_{solar} + R_{DPW-g_1}^{int}\left(T_{in} - T_{g_1}\right)\right] - \left[R_{DPW-g_1}^{out}\left(T_{g_1} - T_{g_2}\right) + q_{r_2}\right] \tag{11}$$

DW – outer glazing (2)

$$\rho_{g_2} Cp_{g_2} Hx_{g_2} \frac{\partial T_{g_2}}{\partial t} = \left[\alpha_{g_2}^* G_{solar} + R_{DPW-g_2}^{in}\left(T_{g_1} - T_{g_2}\right)\right] - \left[R_{DPW-g_2}^{out}\left(T_{g_2} - T_{out}\right) + q_{r_4}\right] \tag{12}$$

TW – inner glazing (1)

$$\rho_{g_1} Cp_{g_1} Hx_{g_1} \frac{\partial T_{g_1}}{\partial t} = \left[\alpha_{g_1}^* \tau_{g_2} G_{solar} + R_{TPW-g_1}^{in}\left(T_{in} - T_{g_1}\right)\right] - \left[R_{TPW-g_1}^{out}\left(T_{g_1} - T_{g_2}\right) + q_{r_2}\right] \tag{13}$$

TW – middle glazing (2)

$$\rho_{g_2} Cp_{g_2} Hx_{g_2} \frac{\partial T_{g_2}}{\partial t} = \left[\alpha_{g_2}^* \tau_{g_3} G_{solar} + R_{TPW-g_2}^{in}\left(T_{g_1} - T_{g_2}\right)\right] - \left[R_{TPW-g_2}^{out}\left(T_{g_2} - T_{g_3}\right) + q_{r_2} + q_{r_4}\right] \tag{14}$$

TW – outer glazing (3)

$$\rho_{g_3} Cp_{g_3} Hx_{g_3} \frac{\partial T_{g_3}}{\partial t} = \left[\alpha_{g_3}^* G_{solar} + R_{TPW-g_3}^{in}\left(T_{g_2} - T_{g_3}\right)\right] - \left[R_{TPW-g_3}^{out}\left(T_{g_3} - T_{out}\right) + q_{r_4}\right]$$

3. Numerical solution methodology

In this section, the implemented numerical solution process implemented to determine the temperature in the glazing through equations 9-14 is presented.

The numerical solution flowchart is presented in Figure 6. The numerical code was developed in FORTRAN; an implicit scheme was used to discretize the transient term. As a first step, the dimensions of the system and the modeling time must be entered; from these parameters, the nodes are generated (step 1), and the climatic variables are calculated (step 2), respectively.

Next, the thermophysical properties of air and the convective heat transfer coefficients are calculated (step 3). In step 4, the Jacobi method is applied to solve the equations, and the temperature is obtained. Steps 3 and 4 are repeated until *j=Ny*, according to the number of sections established for the solution. Once this process is complete, a convergence criterion of $1.0E10^{-10}$ must be satisfied. If this criterion is true, the results of each time step are stored and the process starts again from step 2 for the next time step, $t = t + \Delta t$.

Table 1 Results of time step selection

Δt	$T_{g_1}^{average}$ (°C)	Error (%)	q_{in} (W/m^2)	Error (%)
1	31.07	--	82.37	--
3	31.07	0.01	82.35	0.03
5	31.07	0.01	82.32	0.03
10	31.07	0.02	82.25	0.08
15	31.06	0.02	82.18	0.08

Source: Own Elaboration

A time mesh independence study was performed to determine the appropriate time step for modeling, Δt= 1, 3, 5, 10 y 15 s; the number of sections was set at 40. The results of the average temperature and the heat flux to the interior (by convection and radiation) for the TW are shown in Table 1; these results correspond to the hour with the highest solar radiation (952 W/m^2) during the warmest day in Mérida, Yucatán. The difference between the results with different time steps was less than 1 %, so an intermediate time step of 5 s was chosen.

4. Results

The numerical modeling of the three glazing configuration: single (SW), double (DW), and triple (TW) were carried out for the four main orientations, north, south, east and west, under the warm weather conditions of Mérida, Yucatán. The modeling was carried out for the warmest day (in July) and the coldest day (in January) of 2018; the days were chosen based on the outside temperature. The weather data (outside temperature, wind speed and solar radiation) were provided by the National Water Commission (CONAGUA by the acronym in Spanish- MEXICO).

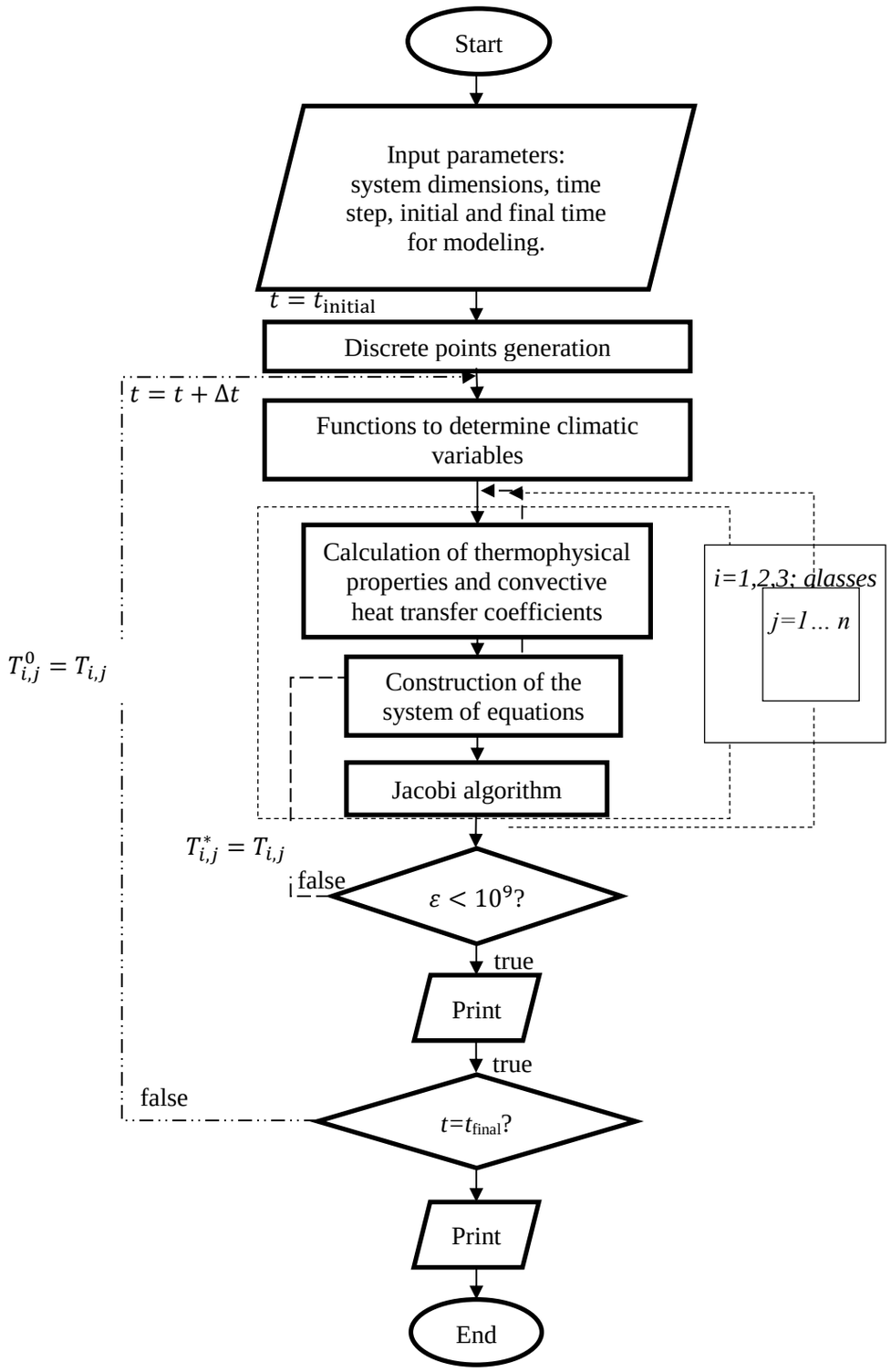
Table 2 Weather data for the warmest and coldest days

Day	Highest temperature (°C)	Lowest temperature (°C)	Solar radiation (W/m^2)			
			North	South	East	West
Warmest	40.8	26.1	366.4	197.6	952.2	595.5
Coldest	22.6	15.1	190.7	270.8	190.4	270.3

Source: National Water Commission (CONAGUA) and National Meteorological Service in Mexico

According to the Köppen climate classification, Mérida has an *Aw* climate, warm tropical with dry winters and humid summers. The highest and lowest values of the outside temperature and the highest value of solar radiation for the orientations described above, for the warmest and coldest days of the year are presented in Table 2. For the coldest day, the values of solar radiation on the north and east surfaces are similar between both, so are the values of solar radiation on the south and west oriented surface. Therefore, the thermal evaluation for the coldest day was carried out only for the north and south orientations.

Figure 6 Flowchart of numerical solution methodology



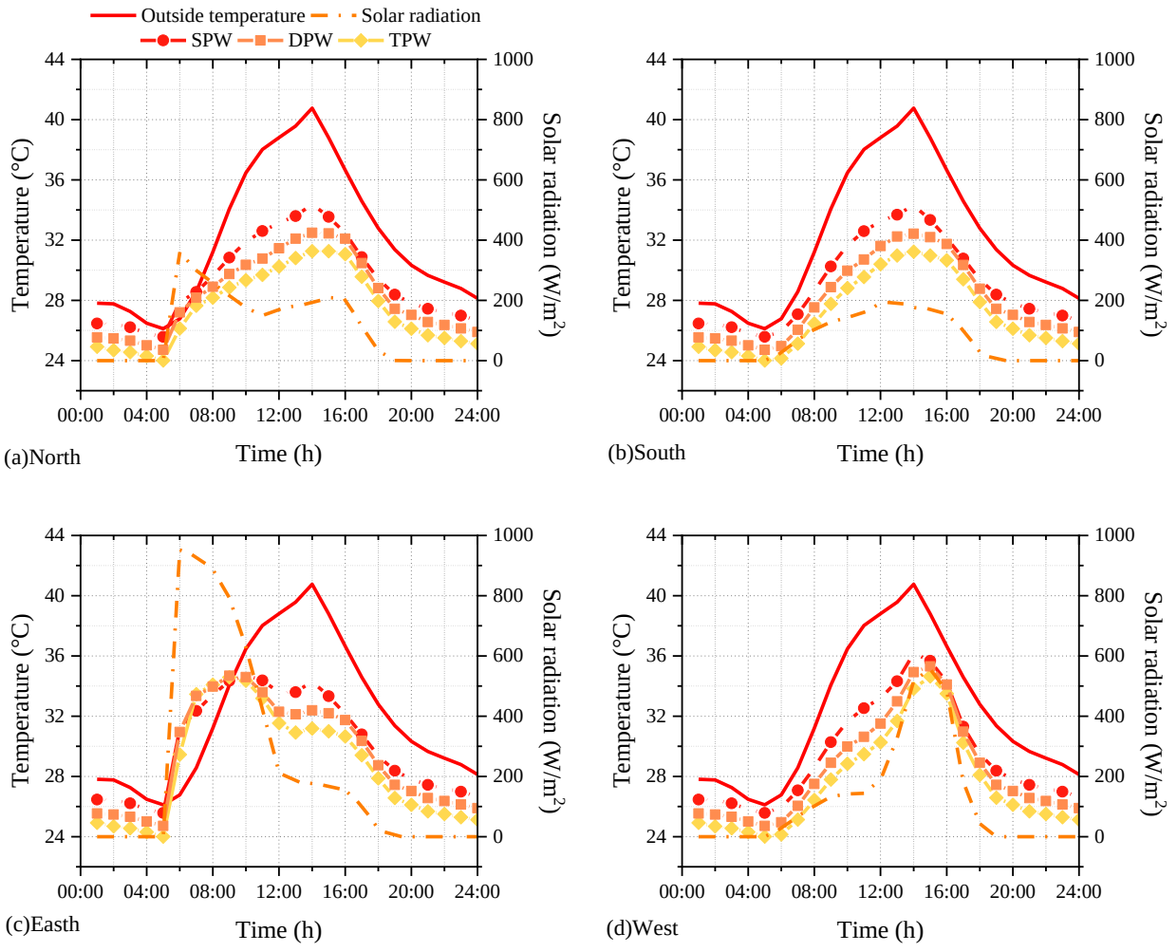
Source: Own Elaboration

4.1 Effect of the panes number on the window thermal performance

For the warmest day, Graphic 1 shows that the average internal surface temperature of glazing 1 ($T_{s,in}^{ave}$) of the triple-glazed (TW) configuration remains below the outside temperature, as well as the temperature of the single (SW) and double (DW) glazed configurations throughout the day. However, the increase in solar radiation from 06:00 h to 08:00 h, causes and increment of $T_{s,in}^{ave}$ on the north oriented surface, where the $T_{s,in}^{ave}$ of the SW and DW configurations exceed the outside temperature by 1 °C during that period.

On the other hand, on the south orientation the most noticeable differences among the configurations occur from 10:00 h to 16:00 h, with a continuous interval of high values of solar radiation and outside temperature; during this period the $T_{s,in}^{ave}$ of the TW configurations remains between 6 °C to 9.5 °C below the outside temperature and 1 °C to 3.5 °C below the $T_{s,in}^{ave}$ of the SW configuration. At 14:00 h in the north and south orientation, the highest temperature of the TW is 31.3 °C, while the highest temperature recorded by the SW and DW configurations is 34.4 °C and 32.5 °C, respectively.

Graphic 1 Average internal surface temperature trend on the warmest day



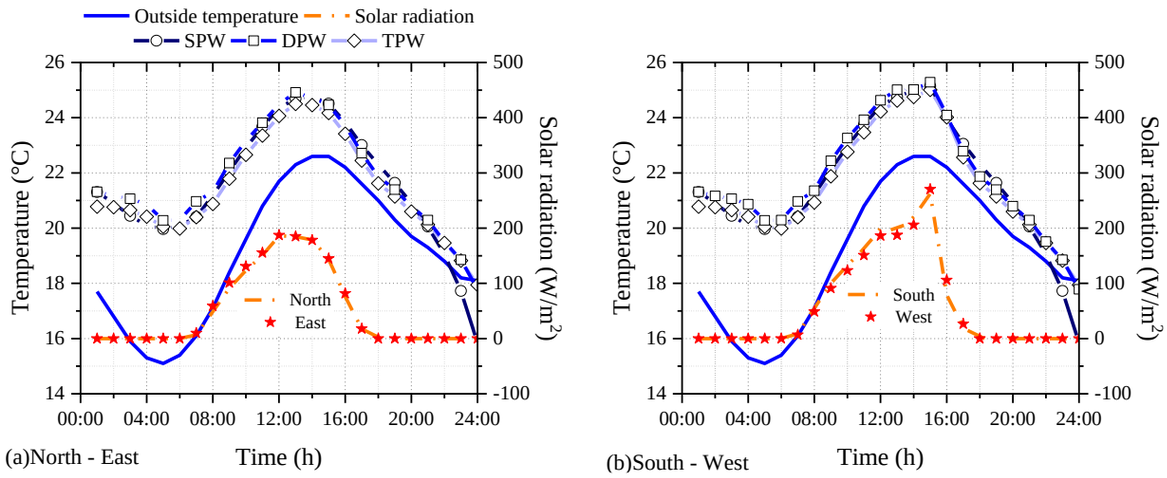
Source: Own Elaboration

On the east and west orientations, Graphic 1c and 1d show that there is an increase of the $T_{s,in}^{ave}$ during the period in which highest peaks of solar radiation occur on both orientations. On the east orientation (Graphic 1c) it is shown that the $T_{s,in}^{ave}$ for the three configurations reaches the highest values from 06:00 h to 12:00 h due to solar radiation with a slight decrease right after 12:00 h in order to raise again, now caused by the increase on the outside temperature and solar radiation values close to 200 W/m^2. However, from 12:00 h to 16:00 h the temperature increases in multiple glazed windows and presents a similar trend to the $T_{s,in}^{ave}$ of the north and south orientations, during this period. On the other hand, the highest temperature values in the three configurations are presented on the west orientation: 36.2 °C, 34.9 °C and 33.8 °C for SW, DW and TW, respectively, at 14:00 h, when solar radiation and the outdoor temperature register the highest values, 595.5 W/m^2 and 40.8 °C, respectively. In this orientation, the temperature in the three window configurations remains 2 °C above the highest temperature recorded in the other orientations at 14:00 h.

For the coldest day, Graphic 2 shows that the difference for $T_{s,in}^{ave}$ among configurations for all orientations is approximately 0.03 °C. On the other hand, the $T_{s,in}^{ave}$ of the DW and TW configurations stayed above the outside temperature all along the day, unlike the $T_{s,in}^{ave}$ of the SW configuration which falls 2 °C below the outside temperature by the end of the day, and 1 °C below the $T_{s,in}^{ave}$ of the DW and TW configurations. The lowest outdoor temperature value occurred at 05:00 h, the $T_{s,in}^{ave}$ of the SW and TW remained 4.9 °C above the outdoor temperature, while the DW configuration was also 5.2 °C above.

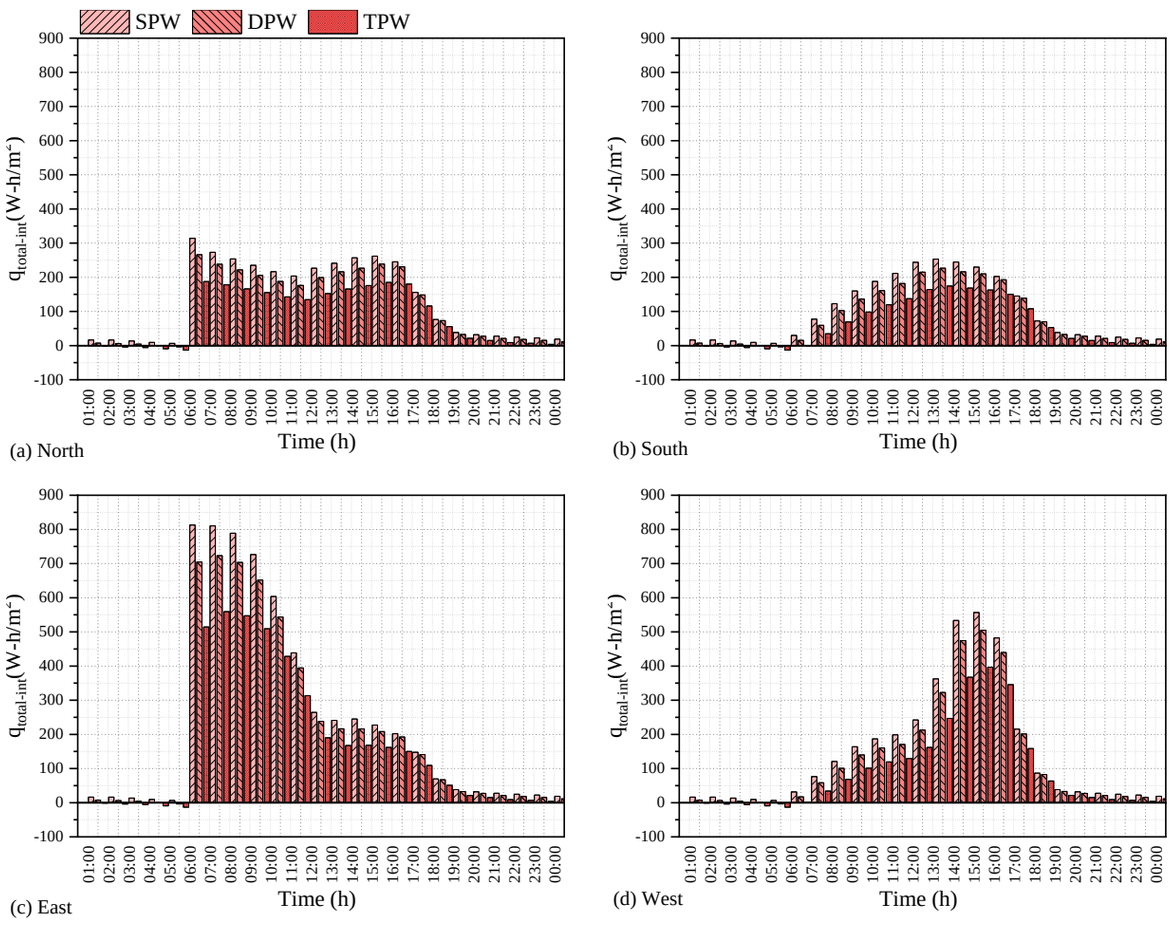
The total heat flux, $q_{total\text{-}in}$, was determined to quantify the heat transfer through the window; the total heat flux is the product of the contributions by convection, radiation and the heat flux transmitted due to the incidence of solar radiation. When $T_{s,in}^{average} > T_{in}$, $q_{total\text{-}in}$ the value is positive, and it indicates that the window gains energy from the outside environment and transports it towards the inside. On the other hand, if the $q_{total\text{-}in}$ values are negative, it is an indication that energy is transferred from the interior environment towards the outside through the window, because $T_{s,in}^{average} < T_{in}$. Consequently, the window releases energy (loses energy) to the outside environment.

Graphic 2 Average internal surface temperature trend on the coldest day



Source: Own Elaboration

Graphic 3. Heat flux trend on the warmest day



Source: Own Elaboration

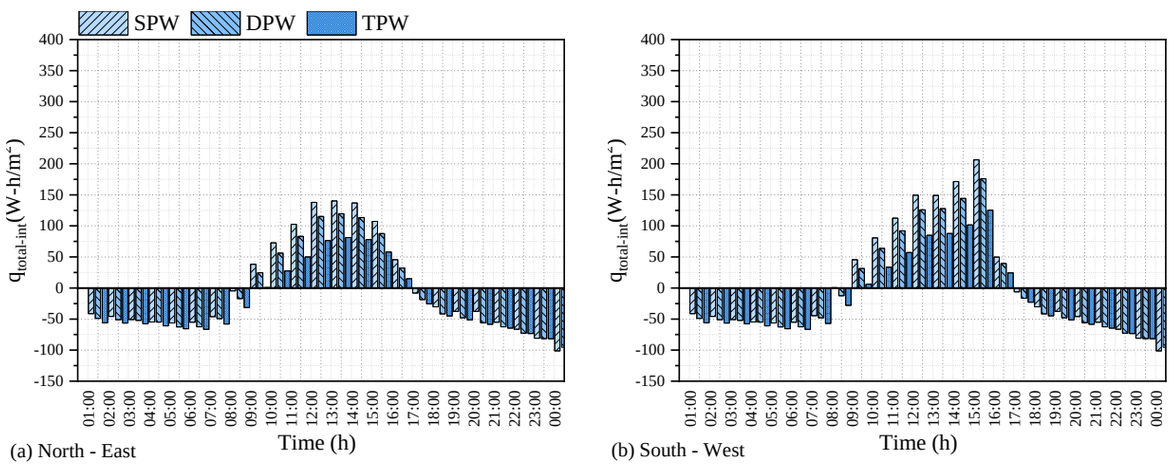
For the warmest day, Graphic 3 shows that the single glazing (SW) and double glazing (DW) configurations reach the highest values of $q_{total\text{-}in}$ for all orientations, even at times in absence of solar radiation. The east orientation $q_{total\text{-}in}$ registers the highest values of $q_{total\text{-}in}$ at 06:00 h, with 812.8 W/m^2, 704.5 W/m^2, and 514.4 W/m^2 for SW, DW and TW, respectively. At this time, solar radiation reaches the highest value (952.2 W/m^2), causing an increase in the transmitted heat flux, which represents the greatest contribution of $q_{total\text{-}in}$.

For the north orientation, the TW reaches the highest value (187.4 W/m^2) also at 06:00 h, while for the south and west orientations it occurs at 14:00 h with values of: 162.9 W/m^2 and 396.7 W/m^2, respectively. In the east orientation, the one with the highest values of solar radiation (specifically at 06:00 h), with respect to the single glazing configuration, the TW reduces energy gains up to 36.7%, while the DW reduces them by 13.3 %. Throughout the day the heat flux values are positive, this is because the outside temperature is higher than the 25 °C inside temperature, so the window continually gains energy, these gains increase as solar radiation does.

For the coldest day, Graphic 4 shows that the heat flux through the window presents positive and negative values, that is, the window gains and loses energy throughout the day, unlike the warmest day, in which the window gains energy all day long (except for the hours 00:00 h to 05:00 h). On the coldest day, from 09:00 h to 16:00 h, the values of $q_{total\text{-}in}$ are positive, during this period the highest values of $q_{total\text{-}in}$ that correspond to the TW are: 81.3 W/m^2 and 125.4 W/m^2 on the north and south surfaces, respectively.

On the other hand, in absence of solar radiation, the variables that define the thermal behavior of the window are the outside temperature and the wind speed. These variables do not depend on the orientation; therefore, similar energy losses occur in the four orientations: -101.4 W/m^2, -95.4 W/m^2,and -93.3 W/m^2 for SW, DW and TW, respectively. Regarding the SW configuration, the TW reduces the energy losses through the window by 8 %, while the DW reduces them by 5.9 %.

Graphic 4 Heat flux, three glazed types, all orientation on the coldest day



Source: Own Elaboration

Table 3 presents the results of the numerical integration of $q_{total\text{-}in}$ per hour during the warmest and coldest day of the year for the three configurations and the four orientations, this integration represents the thermal energy load of the window. For the warmest day, the lowest energy gain of all the configurations is registered on the south orientation, while the highest is presented on the east orientation; this is largely due to the solar radiation that hits on both orientations. However, on all orientations, the TW configuration presents the lowest energy gains: 2.08 kWhm^{-2}, 1.53 kWhm^{-2}, 3.96 kWhm^{-2}, and 2.28 kWhm^{-2} on the north, south, east and west orientations, respectively. The TW configuration reduces the energy gain to the building by 35.9 % y 13.6 % with respect to the SW and DW configurations, respectively.

Table 3 Average heat flux, three glazed types, all orientations

Orientation	$\int_{time_{initial}}^{time_{final}} \lvert q_{total\text{-}in}(t) \rvert \, dt$, (kWhm^{-2})					
	Warmest day				Coldest day	
	SW	DW	TW		SW	DW	TW
North	3.17	2.77	2.08		1.48	1.44	1.26
South	2.39	2.06	1.53		1.67	1.60	1.39
East	5.79	5.14	3.96		1.51	1.45	1.27
West	3.47	3.02	2.28		1.64	1.57	1.36

Source: Own Elaboration

On the other hand, for the coldest day the values of solar radiation are similar, due to this the energy gain in all orientations is similar. However, there is a significant difference between configurations. The north orientation, followed by the east, present the lowest energy gain, while the south orientation registers the highest: 1.67 kWhm^{-2}, 1.60 kWhm^{-2}, and 1.39 kWhm^{-2} for SW, DW and TW, respectively. For the south orientation, the TW configuration reduces the energy gain by 16.9 % with respect to SW, while the DW reduces it by 4.3 %.

4.2 Annual Thermal Evaluation - Triple Glazed Window (TW)

The results obtained for the warmest and coldest day of the year showed that multiple glazings, specifically the triple glazing (TW) configuration. However, evaluating only two days of the year provides little revealing data to support that the triple glazing configuration has favorable results throughout the year. Due to this, the thermal analysis of the window with the TW configuration was carried out during the warmest and coldest day of each month of an entire year. For the annual evaluation, the window is also considered in different orientations.

Table 4 The lowest and highest values of outside temperature per month

Month	Warmest day		Coldest day	
	T_{out}^{max} (°C)	T_{out}^{min} (°C)	T_{out}^{max} (°C)	T_{out}^{min} (°C)
January	33.4	21.7	22.6	15.1
February	36.9	22.0	32.0	16.9
March	39.8	23.4	35.5	18.2
April	40.8	23.4	29.3	17.7
May	39.4	25.2	37.4	22.3
June	38.9	24.4	33.8	23.3
July	40.8	26.1	35.7	23.8
August	37.4	25.5	38	25.5
September	36.9	23.8	36.2	22.0
October	36.6	22.9	35.0	20.3
November	35.3	22.8	29.0	15.7
December	35.8	21.7	28.4	11.2

Source: Own Elaboration

Since the outside temperature does not depend on the orientation, the highest and lowest values are the same for all four orientations, these are presented in Table 3 for the warmest and coldest days of the year. The highest temperature all along the year occurs in two months: April and July, with a value of 40.8 °C. However, on the warmest day in April the lowest temperature is 23.4 °C, approximately 3 °C below the lowest temperature recorded on the warmest day in July (26.1 °C). On the other hand, on the coldest days, the lowest temperature value occurs in December (11.2 °C). However, unlike January, the temperature interval is wider and reaches up to 28.4 °C, while in January the outside temperature only reaches 22.6 °C.

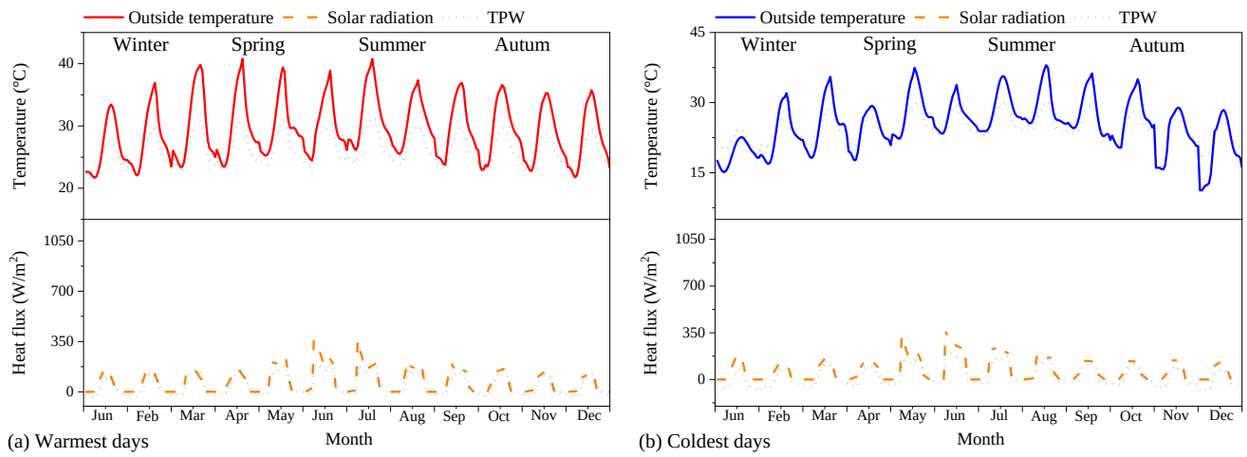
The solar radiation values depend on orientation; the lowest values occur on the north orientation, during autumn and winter. On the other hand, the south orientation has a longer exposure time to direct solar radiation of approximately 12 continuous hours and the values of solar radiation during autumn and winter are similar to those presented for the east and west orientations. However, these orientations only receive direct solar radiation for 6 hours, on the first and last hours of the sun.

Graphics 5-8 show the results of temperature and total heat flux of the window with the TW configuration with respect to the outside temperature and solar radiation that were recorded on the warmest and coldest days of the year (24 days) in different orientations.

The north orientation only receives direct solar radiation in spring and summer, due to this an increase in solar radiation values is recorded during these seasons, specifically in the period from May to July (see Graphic 5). The highest value of solar radiation occurs in July (360.8 W/m^2) for the warmest days and in June (376.8 W/m^2) for the coldest days. In autumn and winter, radiation values are very low, and the highest values barely reach 136.6 W/m^2 and 132.3 W/m^2 in December for the warmest days and in February for the coldest days, respectively.

On the warmest days (Graphic 5a) the interval of the highest $T_{s,in}^{ave}$ is 28.2 °C to 31.4 °C, the highest value was recorded in May, when the outside temperature reached 39.4 °C and solar radiation was 232.8 W/m^2. On the other hand, the highest total heat flux ($q_{total\text{-}in}$) is in the interval of 112 W/m^2 to 195.4 W/m^2. The increase in solar radiation from May to July favors an increase in $T_{s,in}^{ave}$ and in $q_{total\text{-}in}$, since the highest values of both variables are recorded in these months. Except for these months, the highest $q_{\text{total-int}}$ through the window does not exceed 150 W/m^2. For the coldest days (Graphic 5b), the highest outside temperature and the highest $T_{s,int}^{ave}$ were recorded in August: 38 °C and 30.3 °C, respectively. For the coldest day in August, the highest solar radiation is 192.7 W/m^2, while the $q_{total\text{-}in}$ is 157.9 W/m^2. For the coldest days, the interval of the highest $T_{s,in}^{ave}$ is 24.5 °C to 30.3 °C, while that of the highest $q_{total\text{-}in}$ is 69 W/m^2 to 201.5 W/m^2. The highest value of $q_{total\text{-}in}$ coincides with the day in which the highest solar radiation occurs, which for these days is in June.

Graphic 5 Triple-glazed annual thermal performance (a) the warmest period and (b) the coldest period, north orientation



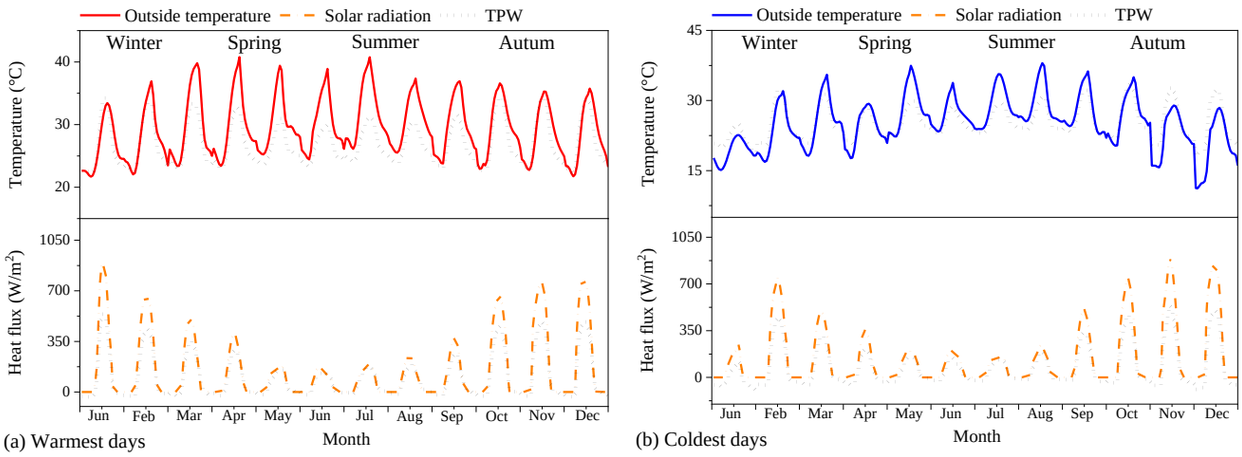
Source: Own Elaboration

Unlike the north orientation, direct solar radiation affects the south orientation all year round, especially during autumn and winter (see Graphic 6), due to this an increase in solar radiation values is generated from September to February. On the warmest days, the highest values of solar radiation are between 174.2 W/m^2 to 893.1 W/m^2, while on the coldest days these values are between 159.2 W/m^2 to 915 W/m^2. The lowest values of solar radiation are recorded in spring and summer: in June for the warmest days and in July for the coldest days.

For the warmest days, Graphic 6a shows that the highest values of $T_{s,in}^{ave}$ and $q_{total\text{-}in}$ are strongly affected by the behavior of solar radiation, the outside temperature is neglected. In January, the highest value of $T_{s,in}^{ave}$ is 34.3 °C, approximately 1 °C above the outside temperature recorded in that month. The increase in $T_{s,in}^{ave}$ and solar radiation lead to an increase in the total heat flux, due to this the highest $q_{total\text{-}in}$ interval on the warmest days is: 138.5 W/m^2 to 539.2 W/ m^2. With respect to the highest total heat flux recorded on the north orientation, the highest $q_{total\text{-}in}$ on the south is above 343.8 W/m^2. For the coldest days, Graphic 6b shows that the solar radiation also leads to an increase in the window temperature, especially in February, November and December when the $T_{s,in}^{ave}$ exceeds the outside temperature by up to 3.9 °C.

The highest $T_{s,in}^{ave}$ values fall between 25 °C to 33.4 °C, while the highest $q_{total\text{-}in}$ values fall between 125.4 W/m^2 to 540.5 W/m^2. Because in January the difference between the interior temperature and $T_{s,in}^{ave}$ is minimal, there is no heat transfer by convection and radiation, so the main contribution of $q_{total\text{-}in}$ is radiation solar energy that falls on the window in different orientations.

Graphic 6 Triple-glazed annual thermal performance (a) the warmest period and (b) the coldest period, south orientation



Source: Own Elaboration

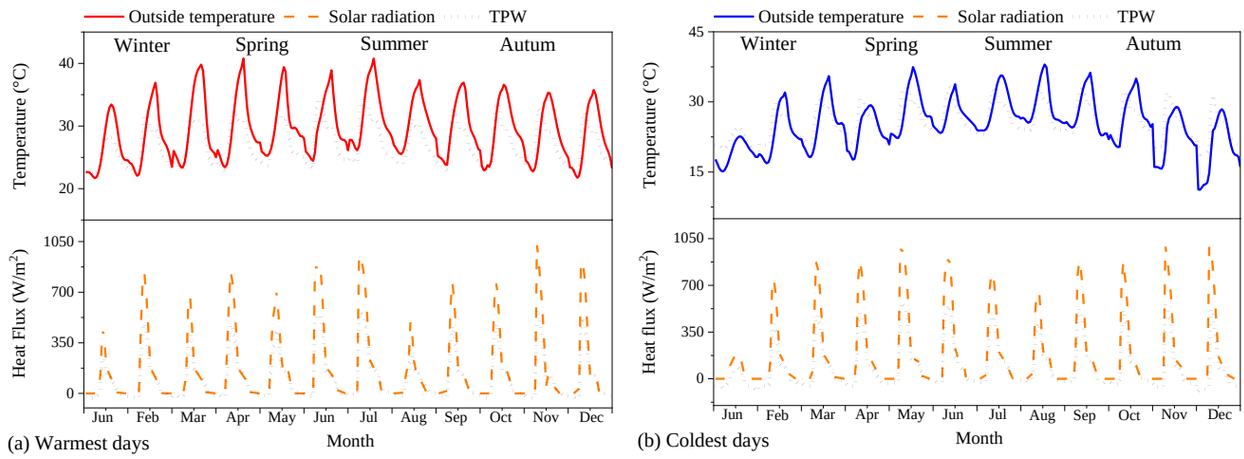
On the warmest and coldest days, the lowest energy gains (positive heat flux) through the window were recorded from May to August, months in which solar radiation is less than 200 W/m^2, despite the fact that in these months, the highest outdoor temperature values between 37.4 °C to 40.8 °C on the warmest days and 36.7 °C to 38 °C on the coldest days.

The sun trajectory begins in the east orientation, from approximately 06:00 h to 12:00 h, time when the highest values of solar radiation are recorded, even more so in spring and autumn, seasons in which the sun does not tilt to the north or south. On the warmest days the highest solar radiation is between 455.4 W/m^2 to 1034.8 W/m^2, while on the coldest days is between 187.2 W/m^2 to 1008.7 W/m^2, on both days the lowest values occur in January and the highest in November. As shown in Graphic 7, the increase in solar radiation during the first hours of the day causes an increase in $T_{s,in}^{ave}$ before the outside temperature reaches the highest value on the warmest and the coldest days.

On the warmest days (Graphic 7a), the highest $T_{s,in}^{ave}$ value is between 28.3 °C to 34.6 °C, while the highest $q_{total\text{-}in}$ value is between 246.3 W/m^2 to 580.1 W/m^2. The highest $T_{s,in}^{ave}$ is recorded in July and is 6 °C below the highest outside temperature. While the $q_{total\text{-}in}$ occurs in November when solar radiation reaches 1034.8 W/m^2. On the coldest days (Graphic 7b), from November to January the $T_{s,in}^{ave}$ exceeds the outside temperature by up to 3 °C, while in the other months it remains up to 5 °C below. Although in November and December, the outside temperature barely reaches 28.9 °C, the solar radiation exceeds 950 W/m^2, so the window absorbs energy and increase the temperature, which is why the $T_{s,in}^{ave}$ reaches up to 32 °C . On the other hand, the highest $q_{total\text{-}in}$ is between 81.6 W/m^2 to 573.5 W/m^2, the highest value occurs in May due to the combination of high values of solar radiation (996 W/m^2) and the outside temperature (37.4 °C).

Unlike the north and south orientations, for the east orientation the results between months are not far from each other since the solar radiation in this orientation does not present a significant variation with the change of seasons.

Graphic 7 Triple-glazed annual thermal performance (a) the warmest period and (b) the coldest period, east orientation

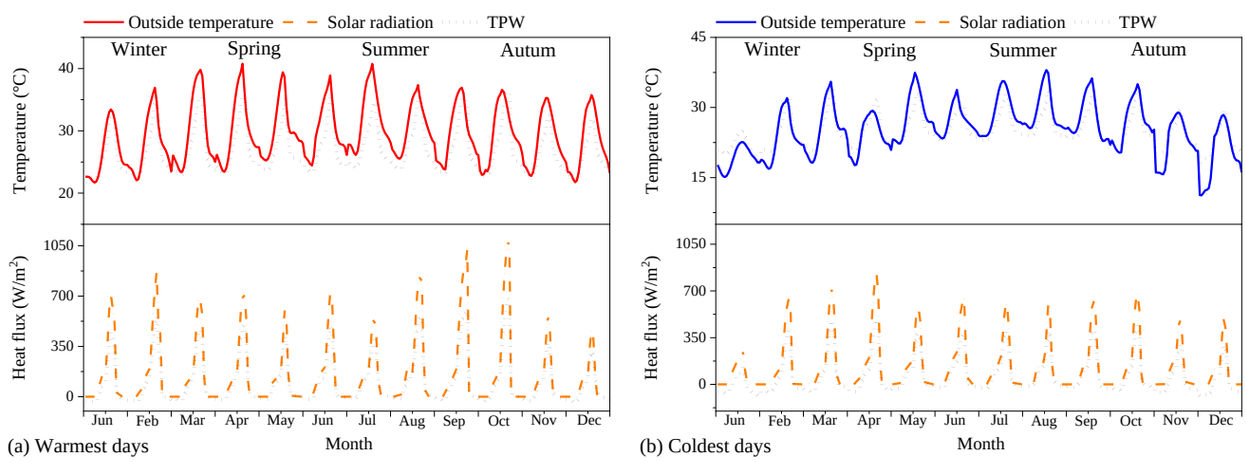


Source: Own Elaboration

For the west orientation, Graphic 8 shows that the solar radiation values rise after noon and until sunset, which occurs at approximately 18:00 h. On the warmest days, the interval of the highest solar radiation value is between 459.7 W/m^2 to 1098.9 W/m^2, while on the coldest it is 270.3 W/m^2 to 832 W/m^2. On the warmest days, the highest value is recorded in October and the lowest in December, while on the coldest days the highest is in April and the lowest in January. For this orientation, the highest value of solar radiation and outside temperature coincide in the hour, this causes the $T_{s,in}^{ave}$ and the highest outside temperature also to coincide. However, when this does not happen, a gap between both reference lines can be observed, as it occurs on the warmest day in October (see Graphic 8a).

On the warmest days, the interval of the highest $T_{s,in}^{ave}$ is 32 °C to 36.5 °C, while the interval of the highest $q_{total\text{-}in}$ is 314.2 W/m^2 to 679.1 W/m^2. The highest values of both variables are recorded in October, because on this day the solar radiation reaches 1099 W/m^2. On the other hand, on the coldest days the highest $T_{s,int}^{ave}$ is recorded in March when the outside temperature is 35.5 °C and solar radiation is 735.2 W/m^2. However, the highest $q_{total\text{-}in}$ occurs in April, although the outside temperature is 6 °C lower than in March, due to the fact that solar radiation is 832 W/m^2. These days the highest $T_{s,in}^{ave}$ interval is between 24.9 °C to 34.3 °C, while the highest $q_{total\text{-}in}$ interval is 128.2 W/m^2 to 487.6 W/m^2.

Graphic 8 Triple-glazed annual thermal performance (a) the warmest period and (b) the coldest period, west orientation



Source: Own Elaboration

In the absence of solar radiation, the effect of the window orientation is negligible, because the variables that define the thermal behavior of the window are: outside temperature and wind speed. In general, during the early morning the outside temperature remains below the inside temperature of 25 °C, this causes the surface temperature of the window to remain very close to the inside temperature and the heat flux is negative. Table 5 shows the lowest values of $T_{s,in}^{ave}$ and $q_{total\text{-}in}$; on the warmest days the interval of the lowest $T_{s,in}^{ave}$ is 22.3 °C to 24 °C, while on the coldest days it is 17.9 °C to 23.7 °C. In winter, specifically in December, the lowest $T_{s,in}^{ave}$ remains up to 6 °C above the lowest outside temperature recorded in that month. Regarding $q_{total\text{-}in}$, for both days the lowest values recorded in January are: -35.8 W/m^2 and -93.33 W/m^2 for the warmest and coldest days, respectively. The heat flux is negative, because the energy is transferred from the interior environment to the window, since the interior temperature is greater than $T_{s,in}^{ave}$.

Table 5 The lowest temperature and heat flux values per month, triple-glazed window

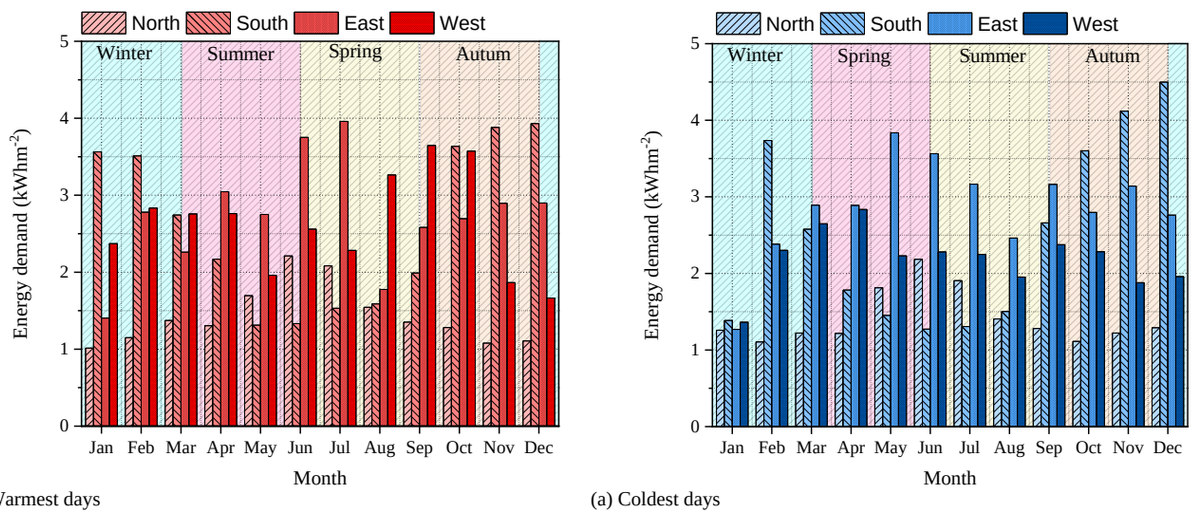
Month	Warmest days		Coldest days	
	$T_{s,in}^{ave}$ (°C)	$q_{total\text{-}in}$ (W/m^2)	$T_{s,in}^{ave}$ (°C)	$q_{total\text{-}in}$ (W/m^2)
January	22.3	-35.8	17.9	-93.3
February	22.5	-34.0	20.6	-59.0
March	23.0	-26.7	20.8	-55.6
April	23.0	-26.4	20.8	-56.0
May	23.6	-18.2	22.5	-33.3
June	23.3	-23.1	23.0	-27.1
July	24.0	-13.3	23.0	-26.0
August	23.8	-16.6	23.7	-16.9
September	22.9	-26.3	22.6	-31.9
October	22.7	-30.4	21.8	-42.7
November	22.7	-30.5	20.3	-63.0
December	22.3	-35.4	18.0	-91.7

Source: Own Elaboration

4.3 Energy demand and CO_2 emissions of Triple-glazed window

Graphic 9 shows the energy gains towards the building due to the use of the TW configuration in different orientations on the warmest and coldest days of the year. On the warmest days the energy gain interval on the north orientation is 1.01 kWhm^{-2} to 2.21 kWhm^{-2}, on the south it is 1.31 kWhm^{-2} to 3.93 kWhm^{-2}, on the east 1.40 kWhm^{-2} to 3.96 kWhm^{-2} and on the west 1.66 kWhm^{-2} to 3.65 kWh^{-2}. While on the coldest days the intervals are: 1.11 kWhm^{-2} to 2.18 kWhm^{-2} on the north, 1.27 kWhm^{-2} to 4.50 kWhm^{-2} on the south, 1.27 kWhm^{-2} to 3.84 kWhm^{-2} on the east, and 1.36 kWhm^{-2} to 2.83 kWhm^{-2} on the west.

Graphic 9 Annual energy demand of triple-glazed window



(a) Warmest days

(a) Coldest days

Source: Own Elaboration

The greatest energy gain occurs in the months in which solar radiation registers the highest values on each orientation. For example, on the warmest days (Graphic 9a) the solar radiation on the south orientation reaches the highest values in autumn and winter; from October to February, the energy gain was in the interval 3.51 $kWhm^{-2}$ to 3.88 $kWhm^{-2}$, providing this period the highest values out of all the orientations. On the north orientation, the greatest energy gain occurs from May to July in the interval of 1.70 $kWhm^{-2}$ to 2.21 $kWhm^{-2}$, however, these values remain below the results on the east and west orientations. On the east orientation, the greatest energy gain was obtained from April to July with values ranging from 2.75 $kWhm^{-2}$ to 3.96 $kWhm^{-2}$. While on the west orientation, the greatest energy gain occurred in August (3.26 $kWhm^{-2}$) and September (3.57 $kWhm^{-2}$).

On the warmest days, the east orientation shows the greatest energy gain, followed by the west, south, and north orientations. On the other hand, on the coldest days, the increase in solar radiation on the south orientation in February and from October to December causes an increase in energy gain (see Graphic 9b), even when the outside temperature decreases in these months. During this period, the energy gain on the south orientation is greater than the other orientations; in December, the highest recorded value of energy gain is: 4.50 $kWhm^{-2}$. On the other hand, the north orientation, for the warmest days, registers the lowest energy gain, except in the period from May to July (1.81 $kWhm^{-2}$ to 2.18 $kWhm^{-2}$). From March to September on the east orientation, the energy gains are in the interval of 2.46 to 3.84 $kWhm^{-2}$. On the coldest days, the energy gain in the west orientation is not greater than within other orientations: 1.36 $kWhm^{-2}$ to 2.83 $kWhm^{-2}$; the highest value occurs in April and the lowest in January.

Table 6 shows the annual atmospheric CO_2 emissions due to the heat flux through the window with the triple-glazed window. The conversion of energy into CO_2 emissions was based on the 2021 electricity emission factor of 0.423 tCO_2e/MWh that was established by the Ministry of the Environment and Natural Resources of Mexico to calculate the indirect emission of greenhouse gases from the consumption of electricity.

Table 6 CO_2 emissions per year, triple-glazed window in all orientations

	Orientation			
	North	**South**	**East**	**West**
CO_2 emissions ($kgCO_2em^{-2}$)	217.08	387.56	425.90	367.36

Source: Own Elaboration

Annexes

Nomenclature

A	aspect ratio
b	air layer thickness, (m)
C_P	specific heat, (J kg K^{-1})
G	solar radiation, (W m^{-2})
H_y	height of the window, (m)
H_x	glazing thickness, (m)
L_C	characteristic length, (m)
Nu	Nusselt number
q	heat flux, (W/m^2)
Ra	Rayleigh number
T	temperature, (°C)
t	time, (s)
V_{air}	wind speed, (m/s)
x, y	cartesian coordinates

greek

α^*	absortance
Δt	step time, (s)
ε	emittance
λ	thermal conductivity, (W m^{-1} K^{-1})
ρ	density, (kg m^{-3})
ρ^*	reflectance
σ	Stefan – Boltzman's constant, (5.67×10^{-8} W m^{-2} K^{-4})
τ^*	transmittance

subscripts

cond	conductive
conv	convective
out	outside
g	glazing
in	interior
rad	radiative
s, in	internal surface

abbreviations

SW	single glazing window
DW	double glazing window
TW	triple glazing window

The total thermal resistances $R_{SPW-g}^{in/out}$, $R_{DPW-g}^{in/out}$ y $R_{DPW-g}^{in/out}$ are defined as:

$$R_{SPW-g_1}^{in} = R_{DPW-g_1}^{in} = R_{TPW-g_1}^{in} = \left(\frac{1}{h_{in}^{conv} + h_{in}^{rad}} + \frac{Hx_g}{2\lambda_g}\right)^{-1} \tag{17}$$

$$R_{SPW-g_1}^{out} = R_{DPW-g_2}^{out} = R_{TPW-g_3}^{out} = \left(\frac{Hx_g}{2\lambda_g} + \frac{1}{h_{out}^{conv} + h_{out}^{rad}}\right)^{-1} \tag{18}$$

$$R_{DPW-g_1}^{out} = R_{DPW-g_2}^{in} = R_{TPW-g_1}^{out} = R_{TPW-g_2}^{in} = \left(\frac{Hx_g}{2\lambda_g} + \frac{1}{h_{air_1}^{conv}} + \frac{Hx_g}{2\lambda_g}\right)^{-1} \tag{19}$$

$$R_{TPW-g_2}^{out} = R_{TPW-g_3}^{in} = \left(\frac{Hx_g}{2\lambda_g} + \frac{1}{h_{air_2}^{conv}} + \frac{Hx_g}{2\lambda_g}\right)^{-1} \tag{20}$$

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Conclusions

In this work, the effect of multi-glazed on a window thermal performance under *Aw* Köppen climate classification was analyzed. Based on the numerical modeling of the conjugate heat transfer, on a two-dimensional window in transient state, the following is concluded:

– On the warmest day of the year, the surface temperature of the TW configuration remained 3.5 and 9.5 °C below the temperature of the SW configuration and the outside temperature, respectively. The DW configuration reduces the window temperature by 8.3 °C from outside temperature. On the other hand, on the coldest day, the TW remained up to 4.9 °C above the lowest outside temperature value.

– In terms of energy gain/loss, on the warmest day the DW and TW configurations reduced energy gains by 13.3 % and 36.7 %, respectively with respect to the SW configuration .Whereas on the coldest day they reduced losses by 6 % and 8 %.

– The TW configuration had the best thermal performance for all orientations, since on the warmest day it reduced the total heat flux by up to 35.9 %.

– From the annual thermal evaluation of the TW configuration, on the warmest days the west orientation presents the highest values of temperature (32 °C – 36.5 °C) and heat flux (314.2 W/m^2 – 679.1 W/m^2) since the increase of solar radiation on this orientation coincides with the time when the outside temperature reaches the highest values.

– On the south, east and west orientations the energy gains did not exceed 1.2 kWhm^{-2} every month and reached up to 4.5 kWhm^{-2}, specifically on the south orientation in winter, due to this, the use of multiple glazings is recommended.

– The highest value of solar radiation on the north orientation is 58.8 %, 63.5 %, and 65.7 % lower than on the south, east and west, respectively; In addition, the north orientation has a limited time of exposure to direct solar radiation during the year, due to this the use of multi-glazed such as DW or TW may not be feasible on this orientation.

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Chapter 3 Prototype of ergonomic container of polyethylene LD-PE/PEAD for packaging honey from native bees

Capítulo 3 Prototipo de envase ergonómico de polietileno LD-PE/PEAD para envasar miel de abejas nativas

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Abstract

In the present work, the container prototype for melipona bee honey is shown, characterized by being operational and complying with the characteristics of interactivity, progressive improvement, flexibility for changes and functionality. In the experience of Garcerant (2019) the containers are physical means that preserve the organoleptic characteristics of the products, specifically the exposed model is oriented to contain a sweet liquid (honey), which is extracted from the meliponarios of the Sierra Norte of the State of Puebla and comes from native bees (Tetragonista Angustula), the need for the creation of this packaging arises due to the high packaging costs currently absorbed by regional bee growers, who, when observing high packaging costs, choose to sell honey to intermediaries in larger containers (19 liters) at low costs, significantly reducing their own profits from honey, which is harvested in two seasonal periods (april/august), what is described above brings with it the design of the container which is manufactured with high (Cap)/low (Body) density polyethylene (LD -PE/ PEAD), designed to contain a volume of 500 ml and preserve honey at a temperature ranging from 5°C to 25°C (Room temperature), being resistant to impacts and the introduction of external agents. The design of the container validates ergonomic aspects of use: 1) The opening-closing (flip flop lid), 2) Take-carry (Body shape), this prototype was made in the SketChup software, later it was printed in 3D and validated by technical viscosity tests, finally, the unit cost of the container was calculated, which amounts to a monetary value of $11.09, being 44.85% competitive in the commercial market and low cost for meliponiculturists.

Container, Polyethylene, SketChup, Ergonomics, Honey

Resumen

En el presente trabajo, se muestra el prototipo de envase para miel de abeja melipona, caracterizado por ser operacional y cumplir con las características de interactividad, mejora progresiva, flexibilidad para cambios y funcionalidad. En experiencia de Garcerant (2019) los envases son medios físicos que preservan las características organolépticas de los productos, específicamente el modelo expuesto está orientado a contener un líquido dulzoso (miel), mismo que se extrae de los meliponarios de la Sierra Norte del Estado de Puebla y proviene de las abejas nativas (Tetragonista Angustula), la necesidad para la creación de este envase surge debido a los altos costos de envasado que actualmente absorben los meliponicultores regionales, los cuales al observar costos altos de envasado, optan por vender la miel a intermediarios en contenedores de mayor tamaño (19 litros) a bajos costos, disminuyendo notablemente las ganancias propias por la miel, misma que se cosecha en dos periodos estacionales (abril/agosto), lo descrito anteriormente trae consigo el diseño del envase el cual está fabricado con polietileno de alta (Tapa)/baja (Cuerpo) densidad (LD-PE/PEAD), diseñado para contener un volumen de 500 ml y conservar la miel a una temperatura que va desde 5 °C y 25 °C (Temperatura ambiente), siendo resistente a impactos y a la introducción de agentes externos. El diseño del envase válida, aspectos ergonómicos de uso: 1) La apertura-cerrado (Tapa flip flop), 2) Tomar-transportar (Forma del cuerpo), este prototipo se realizó en el software SketChup, posteriormente se imprimió en 3D y se validó por pruebas técnicas de viscosidad, para finalizar se calculó el costo unitario del envase el cual asciende a un valor monetario de $11.09, siendo competitivo en un 44.85% en el mercado comercial y de bajo costo para los meliponicultores.

Envase, Polietileno, SketChup, Ergonomía, Miel

1. Introduction

In México and the world, the consumption of honey is a habit that has become very relevant in recent years. In Mexican homes, it is more common every day to have this important sweetener on our tables, which is composed of different properties that contribute notably to the nutritional diet of human beings, at this point of consumption it is important to take into account the needs of the people (Producers) who harvest this vital nectar, which are relevant to preserve current production levels, which supply our consumption needs.

These producers in the northern area of the State of Puebla are recognized as meliponiculturists, who individually or collectively make up meliponarios, which are physical establishments equipped to conserve, preserve and promote the reproduction of the melipona bee of the genus Tetragonista Angustula .

It is worth mentioning that this important productive activity in the region and area of influence serves approximately a total of 200 meliponarians present in different communities that make up the geographical area. Like any production process, it is notorious that there are problems which bring with them the following two effects: The increase in costs, and the loss of production, for two problems a common source of origin has been detected, which is born from the sale of honey to intermediaries, this in response to the fact that the honey grower does not have the means to package the product and tends to market it directly with intermediaries.

The intermediary is a natural person who adopts the role of buyer, offering meliponiculturists low prices for honey. This physical entity carries out the packaging process and direct marketing with the client, placing additional costs that exceed 50% of the original price. of the natural sweetener, this action triggers the problems mentioned above that harm the original producer (meliponiculturist).

As we can see, meliponiculturists do not carry out the direct sales process with the client, because they currently do not have the appropriate means to package honey. Taking this observation into account, in this work a prototype of an ergonomic LD-PE polyethylene container is made. / PEAD to package honey from native bees, this physical medium was manufactured through the following Phases: Phase 1) Exploratory study, Phase 2) Phase 2: Package design in specialized software (Ergonomics), Phase 3) Label design, Phase 4) Validation of packaging prototype, each of these stages contribute substantially to the creation of the standardized prototype, which was evaluated through a comparison with the costs of existing containers, and represents a significant saving of 44.85% (Automated production) being beneficial for the acquisition of meliponiculturists, also the material from which it is manufactured allows the conservation of the organoleptic properties of the honey, being resistant to impacts and preventing the entry of external organisms, however taking into consideration the different aspects for the ergonomic handling, the following functionalities are met: a) Take, transport, store, open and close, through the design and manufacture of the body of the container with a curvature shape and the implementation of a flip flop model lid. It is worth mentioning. To validate the usability of the prototype, viscosity tests were carried out confirming the conservation of the honey inside the container at room temperature, as well as simulated refrigeration processes.

2. Objetives

2.1 General objective

Design and build a physical prototype of ergonomic packaging, to package the honey obtained from meliponaria, with materials that preserve the organoleptic characteristics of honey and represent competitive sales costs, seeking to supply the growing demand for direct packaging means in the region and area of influence, as well as the reduction of intermediaries in the honey sale processes.

2.2 Specific objectives

a) Determine the optimal dimensions of the container to generate a capacity of 500 milliliters.
b) Identify the appropriate materials for the manufacture of the prototype.
c) Assessment of ergonomic aspects to consider during design.
d) Design prototype in SketChup design software**.**
e) Packaging cost projection.
f) Printing of physical prototype of ergonomic packaging.
g) Ergonomic packaging functionality validation.

3. Justification

Honey is an adjuvant to human health thanks to its chemical composition, since it is rich in vitamins and minerals, carbohydrates, amino acids and water. A study recently carried out by Tesla magazine states that, thanks to the presence of hydrogen peroxide, flavonoids, phenolic acids and glucose oxidase, honey is a powerful antibacterial element. In addition to having anticancer and antioxidant properties, its positive effect has been demonstrated in conditions related to the respiratory and digestive systems, among others (Campo and Hincapié 2023). Official records by the Agro-Food and Fisheries Information System (SIAP) exposed that in the year 2022 the production of honey in the state of Puebla was 2 thousand 449 tons of honey.

This being the eighth producer nationwide, and having as main producers the municipalities of Cuetzalan del Progreso, Atlixco, Acatzingo, Chalchicomula de Sesma, Izúcar de Matamoros, Puebla, Tlacotepec de Benito Juárez, Pantepec, Huauchinango and Pahuatlan (Gobierno de México, 2023). Specifically, the municipality of Huauchinango Puebla has approximately 200 melipona bee hives.

Due to the above and considering the 200 meliponarios in the Huauchinango region, projecting an annual production of 480,000 ml, which require a container for their commercialization, which protects their chemical and physical properties, is manageable, attractive to the client, ergonomic, of accessible materials, a container prototype was created that satisfies the aforementioned needs, taking into account that the meliponiculturists of the region and area of influence require this standardized container that identifies the northern zone of the State of Puebla, so that each meliponario have the possibility of bottling their own honey, and obtain higher profits by selling directly with the client, reducing the sales control that exists up to now by intermediaries, who acquire honey at low costs, carry out the process of packaging and sell with additional costs that add up to approximately 50% with respect to the cost paid to meliponiculturists.

Due to what has been described above, it is imperative to use a container that preserves the organoleptic characteristics of honey and maintains an affordable price for meliponiculturists. It is important to mention that there are currently containers oriented to be honey containers, but currently they handle costs that They range from $12.9 to $27.275., being costs that significantly increase the cost of sale and decrease profits, so by manufacturing a container with a lower cost ($11.09) the benefit will be profitable, thus also allowing meliponiculturists to carry out Individually, the packaging process ensured the preservation of 100% of the organoleptic characteristics of honey.

4. Theoretical Framework

To understand the objective of this research, the theoretical foundations that support the formulation, design and manufacturing of the packaging prototype are described:

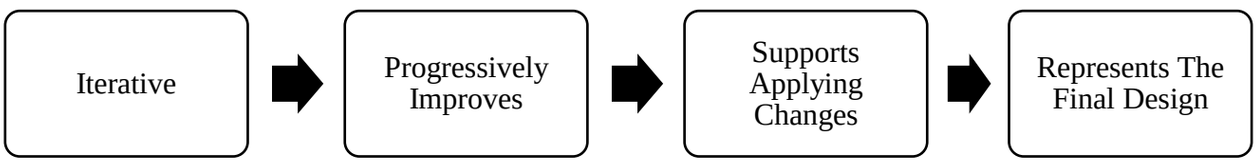
4.1. Prototype

A prototype in the experience of Luque (2019), is a physical medium that allows observing the interaction of quantitative and qualitative variables for the formulation of a physical product. Through the generation of the prototype, the different factors are combined to know in a real way the resources that will be used for the presentation of the physical good, in general, a prototype exposes the reality of the product with a manufacturing level that goes from an artisanal process to semi-automated processing.

4.2. Types of prototypes

Specifically, Soto, Bones and Santos (2021) consider the existence of 5 types of prototypes, which are: Low fidelity, high fidelity, exploratory, experimental and operational, the type of prototype developed in this work being the type operational which contains the following characteristics (Figure 1 Characteristics of the operational prototype):

Figure 1 Characteristics of the operational prototype



Source of Consultation: Soto, Bones and Santos (2021)

4.3. Technical requirements (resources) for the manufacture of prototypes

It is important to mention that for the realization of the prototype exposed in this work the following resources were used:

a) Human resources: These means are directly related to the interaction of the personnel, which carries out administrative and operational functions, actions that directly contribute to the physical formation of the product, for this reason the human factor turns out to be the means required for the transformation. raw material and inputs, being essential to have skills and competencies that substantially add to the operational process (Guerrero, 2017).
b) Material resources: They are considered as the physical means (raw material, inputs), which allow the manufacture of the product, these resources are essential to supply the production lines and are requested according to material requirements plans proposed by the designer and the manufacturer production area.
c) Financial resources: They are commonly known as economic capital from public or private sources, which is intended for the acquisition of material resources and payment for the service of human resources, this type of resource is directly monitored by senior management. and it is assigned through accounting items to cover the expenses of each of the areas, as well as its use and allocation is audited to ensure proper functioning (Santos, 2008).

4.4. Packaging prototype

Once the type of prototype has been determined (Operational prototype), the manufacturing approach is then denoted, which is oriented to the design of a container. Garcerant (2019) indicates that packaging is the means to preserve the organoleptic characteristics of products, mentioning that the design of a container must always be at the forefront, taking into account that packaging is as old as humanity itself. because humans use them to contain and preserve food for longer periods of time.

4.5. Materials for the manufacture of packaging

Specifically, a container designed and manufactured with the correct materials will bring with it quality products, the type of material from which it is made being relevant, the plastic materials used for the preparation, the properties and its main applications are (Table 1 Properties and applications of materials plastics):

Table 1 Properties and applications of materials plastics

Material	Properties	Applications in the packaging manufacturing sector
Low Density Polyethylene (LD-PE)	1. Resistance to impacts and sudden movements. 2. Acceptable stability to high temperature exposures. 3. Standard hermeticity to entry/exit of water vapor. 4. It exposes light to light brown color. 5. Resistance to the introduction of chemical substances.	Special containers for prepared meals.
High Density Polyethylene (PEAD)	1. Resistance to temperature variations. 2. Excellent rigidity and impact resistance. 3. Hermetic for the entry of steam and water. 4. Sensitivity to the introduction of acids and alkalis. 5. Transparent hue.	Containers for: – Food products. – Technical articles.
Polyester	1. Resistance to extreme temperatures and tears. 2. Hermetic to the entry of gas, aromas and water vapor. 3. Transparent hue.	Vacuum packaging for: – Fresh meat. – Prepared to fry. – Stews.
Polyvinyl Chloride (Rigid PVC)	1. Hermetic to the entry of gas, aromas and water vapor. 2. Resistance to mechanical actions. 3. Resistance to the entry of oils and fats. 4. Transparent with possibility of color change. 5. Metallizable.	Containers for: – Food products. – Frozen products.
Polyvinyl Chloride (PVDC)	1. Excellence in transparency. 2. Sealable. 3. Sterilizable. 4. Boiling resistance.	Containers for: – Food products.

Source of Consultation: Benavides, Sigcha and Milton (2013)

According to the properties of the plastic materials for the manufacture of containers, it was decided to make the prototype using high (Cover)/low (Body) density Polyethylene (LD-PE/ PEAD), because they have the ideal characteristics for the preservation and conservation of honey, emphasizing the property of resistance to temperature variations, taking into account that honey is a viscous liquid that solidifies at low temperatures, and there are minimum temperatures in the State of Puebla ranging from 5 °C to 15 °C. In the same way, it is extremely beneficial that the material is highly resistant to impacts, and shows tightness for the entry of external agents.

4.6. Software design

The exposed work was designed in a 3D modeling program, this program is called SketChup, specifically the program manages a friendly and easy-to-use interface for the user, allowing a faithful design of the product, because the tools it contains They model all kinds of volumes.

SketChup was born in 2000 and is characterized by providing exceptional results to design. Currently, this program is a benchmark in the world of 3D modeling. Being free, it includes a gallery of objects and images that optimize the designer's work hours (Catalan, 2017).). Within the complements of this software we find the following two functions:

1. Pluggins: Variety of tools or subprograms that include preloaded drawings such as Roofs, pieces of different materials, parts of the human body, etc.

2. Renders: Includes modeling through geometry that exposes photorealistic representations, also in this function it integrates tools to create layouts.

The exposed benefits of the SketChup program bring with it that the prototype of ergonomic high and low density polyethylene container LD-PE (Body of the container)/PEAD (Lid of the container) to package honey from native bees, is designed in this software evidencing the following advantages: a) Ease of interpretation of the design tools (smooth and flexible learning curve), b) Graphic and visual design tools (Simple and intuitive), c) Infinite resources available (Tutorials, courses and free training), d) Availability of the largest library of 3D models (Textures), e) Precision in the introduction of measures and dimensions for the design of the products, f) Generation of models to print on 3D printers (Sheets, lay Out to build and print).

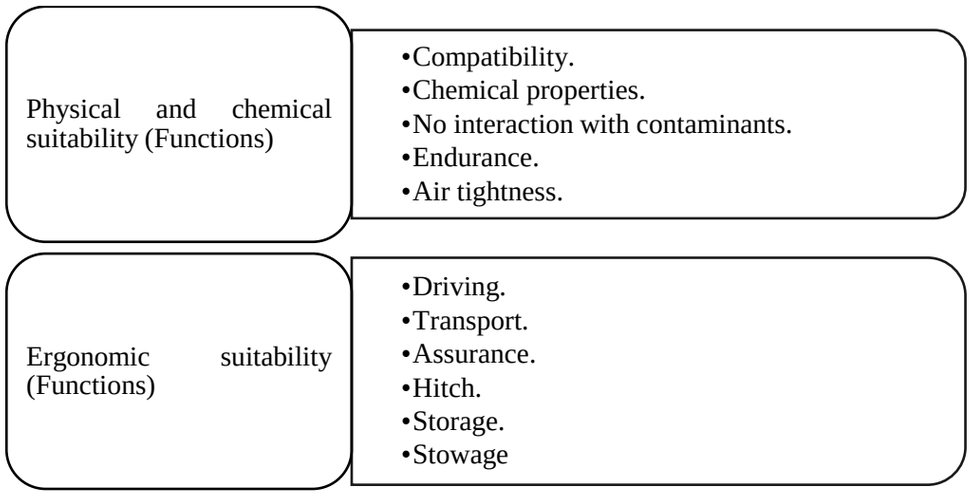
4.7. 3D Printing

3D printing allows transforming digital designs into tangible products, through the generation of layer prints, the most common 3D printing methods are: Casting, laser, and injection (Jorquera, 2016), for the present work the printing model was used by injection by the type of filament selected for manufacturing (High and low density polyethylene LD-PE / PEAD). This type of technology allows users or designers to become product creators within the field of engineering, industry and education.

4.8. Ergonomics in packaging design

Ergonomics is defined by the Spanish Ergonomics Association as the set of scientific and technical knowledge that is applied so that work, systems, products and the environment adapt to the physical and mental capacities and limitations of the end user, to originate adequate adaptations ergonomics is introduced from the design of products, machinery, tools, devices. Taking into account the importance of the ergonomic introduction in the design of the products, the design of the container was carried out, according to the experience of Benavides, Sigcha and Milton (2013), the design of the container must take into account the relationship between the user and the product, with the main objective of adapting the container to reduce fatigue and errors when using it, as well as ensuring the closing process and product transport. It is important to mention that the goal of ergonomics applied between the container and the consumer must strictly comply with the following adaptations (Functions) (Figure 2 Ergonomic adaptations (Functions) of the container):

Figure 2 Ergonomic Adaptations (Functions) of the container



Source of Consultation: Benavides, Sigcha and Milton (2013)

4.9 Containers for honey products

These containers have as main focus to preserve the healthy and natural attributes of honey, through models adaptable to ergonomic designs that are useful and do not represent high manufacturing costs, the containers for this type of product are identified by the following 6 variables (Table 2 Measurement variables of packaging for honey products):

Table 2 Measurement variables of packaging for honey products

Variable number	Description	Measurement factors	
Variable 1	Functions	Basic	– Contain – Protect – Keep
		Communications	– Inform – Communicate – Persuade
Variable 2	Application	– Multiple – Collective	
Variable 3	Consistency	– Flexible packaging – Semi-rigid packaging – Rigid packaging	
Variable 4	Materials	– Paper/cardboard (20%) – Glass (30%) – Plastic and its variants (50%)	
Variable 5	Shape	– Abstract – Organic – Basic	
Variable 6	Color	– Transparent – Hue – Brightness range – Saturation or intensity range	

Source of Consultation: Quisiguiña (2022)

4.10 Production of honey from native bees

Currently in Huauchinango Puebla the Tetragonista Angustula melipona bee has been identified as a native bee (Figure 3 Tetragonista Angustula melipona bee from the Sierra Norte region of the State of Puebla), this is a medium-sized Negrillo honey fly that inhabits the meliponaria Located in the northern region of the State of Puebla and area of influence, this native bee produces a total of 800 milliliters of honey quarterly, which is a sweet, non-fermented substance with a complex physical composition because it depends on directly from the feeding of this type of bee (Otero, Meneses and Águila, 2017), according to the report presented on May 20, 2021 by the Government of México.

The State of Puebla is the eighth national producer of honey, The main producers being the municipalities of Cuetzalan del Progreso, Atlixco, Acatzingo, Chalchicomula de Sesma, Izúcar de Matamoros, Puebla, Tlacotepec de Benito Juárez, Pantepec, Huauchinango and Pahuatlán, (Gobierno de México, 2023). As we can see, native bees contribute a large amount to the generation of honey and by-products, which is why the generation of means to package this valuable product is relevant, seeking to preserve the organoleptic characteristics and the innocuousness of this sweet mixture.

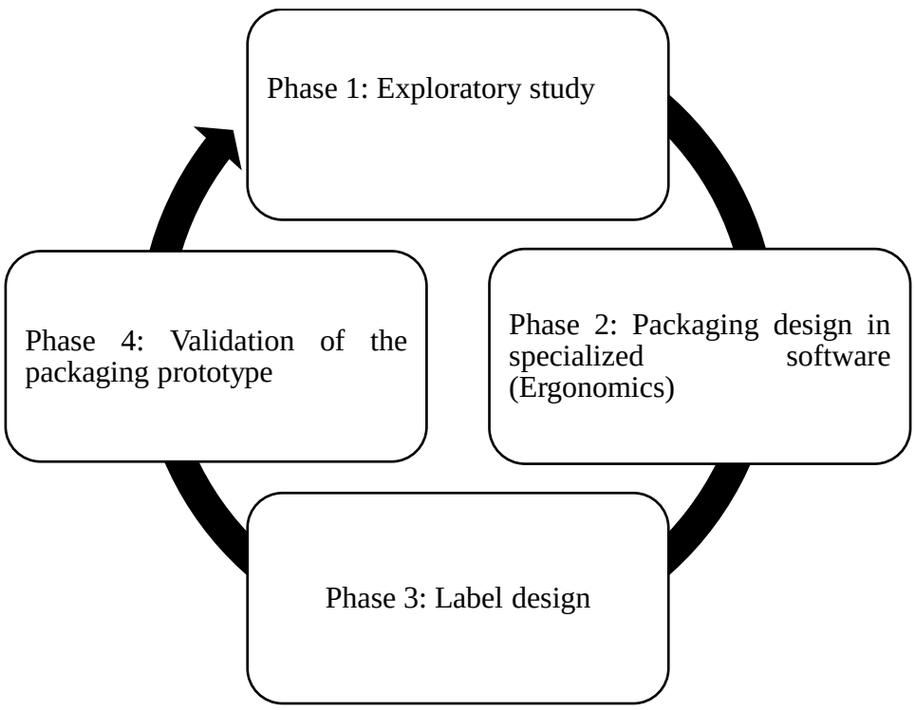
Figure 3 Tetragonista Angustula melipona bee from the Sierra Norte region of the State of Puebla

Source of Consultation: Own Elaboration

5. Methodology to develop

The methodological description that allowed the design and manufacture of the Prototype of ergonomic container of polyethylene LD-PE/ PEAD to package honey from native bees, was developed from the following 5 phases (Figure 4 Phases of the methodological process corresponding to the investigation).

Figure 4 Phases of the methodological process corresponding to the investigation



Source of Consultation: Own Elaboration

5.1 Phase 1: Exploratory study

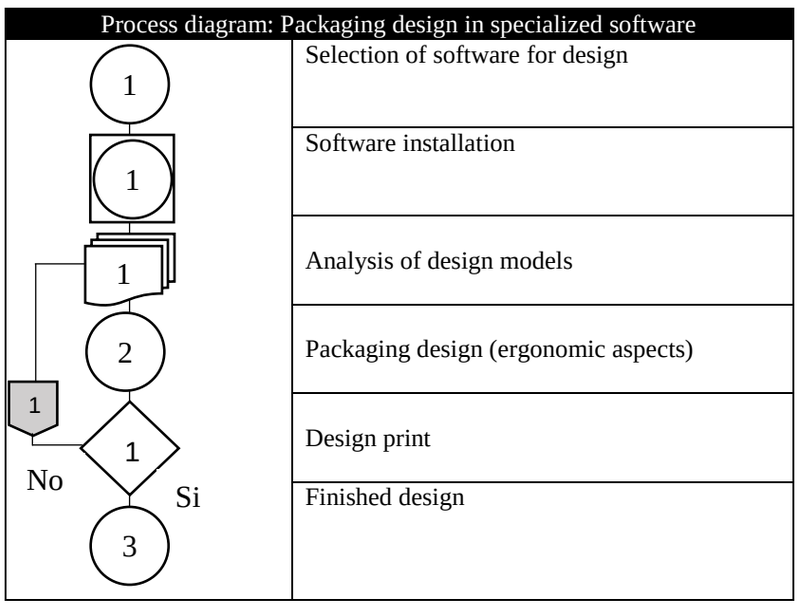
Several authors have made proposals for the manufacture of honey containers, seeking that the packaging processes notably preserve the characteristics of honey, such is the case of the cooperative "Abriendo caminos", which in 2015 requested support to create a center of honey packaging seeking to unify the organic characteristics involved in the production process, as a result of this research a machine was generated that represented a high investment cost of both material and care (2 operators per shift) (Proserpi and Milani , 2015) . , in this same line of research in the project called "Economic and financial market analysis to install a honey collection and packaging center in Delicias, Chihuahua, México", the prevailing need to generate a suitable packaging environment for honey, which is currently collected in approximately 14,115 hives with a total of 443.3 tons of sweet liquid, considering that the packaging is carried out by intermediaries, a feasible proposal was generated through the creation of a bottle center which processes weekly 200 liters of honey (Soto, Magana , Kiessling , Licon, Hernández and Villarreal, 2010). This solution is feasible and consistent with the present project, in response to the solution from the generation of a physical environment that works as container for honey, taking into account that producers need to reduce costs and preserve to a great extent the organoleptic characteristics of honey. In accordance with the previously reviewed and exposed literature, it was decided to use the plastic container as the main raw material, with the aim of avoiding a break in the transportation of the product and the estimation of the prices is more viable, taking into account that the PET containers they are non-toxic and preserve the content without any type of addition or alteration to its structure, the production of this material requires less energy consumption, which also reduces polluting gases, on the other hand, it is also 100% recyclable, making it an environmentally friendly plastic.

The container will be a plastic bottle, specifically high and low density polyethylene LD-PE/ PEAD will be used, to optimally preserve the properties of melipona honey. Now, taking care of the ergonomic aspects for the opening and closing of the container, a flip top lid model is used. This flip top system contains an internal crown that allows greater movement and safe preservation of the product, providing greater comfort to the user and avoiding the generation of honey waste. To finish the exploratory study, it is concluded that the sweet product will be packaged and will have a 100% natural liquid presentation, which will be offered in a single presentation and size, with a content of 500 ml, considering that the packaging will be in cardboard boxes because they expose greater ease of transportation, technically each box will have a quantity of 24 containers of honey and the secondary packaging is made up of pallets, non-stick film and strapping.

5.2. Phase 2: Packaging design in specialized software

Within this phase, the following activities were carried out (Figure 5 Process diagram: Packaging design in specialized software).

Figure 5 Process diagram: Packaging design in specialized software



Source of Consultation: Own Elaboration

5.2.1. Selection of design software

An analysis of the advantages and disadvantages of commercial design programs is carried out, this analysis allows determining that the ideal software is SketchUp, because it is a graphic design and modeling program in three dimensions (3D) based on faces. Rosado and Guerrero (2022) indicate that this software package is used for modeling environments for urban planning, architecture, civil engineering, industrial design, scenic design, GIS, video games or movies, it is also convenient to mention that it manifests the following advantages : 1) Attractive interface that creates interest and facilitates the designer's work, 2) Develops a playful and motivating character in the designer through the integration of technological resources, 3) Intuitive interface because it has a reduced number of commands compared to other design programs, but it provides all the essential tools to build models of exceptional quality (Hernández, 2014).

5.2.2. Software installation

Once the software is selected, the package is installed on the hardware with the following technical requirements: a) 1 GHz processor, b) 4 GB of RAM, c) 500 MB of free disk space, d) 3D graphics card with 512 MB of memory and hardware acceleration capacity, compatible with OpenGL 3.1. Taking these characteristics into account for the proper functioning of the design process.

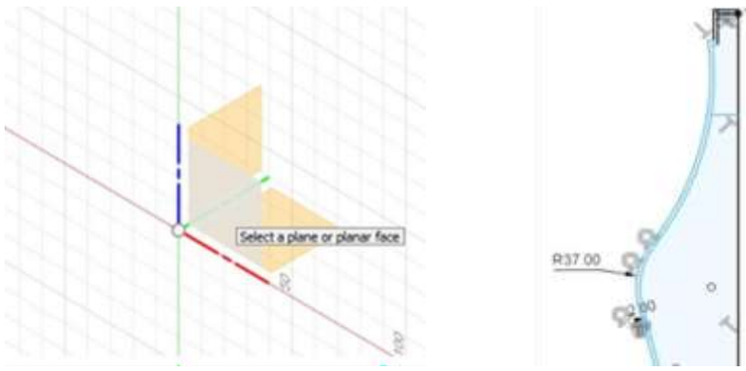
5.2.3. Analysis of design models

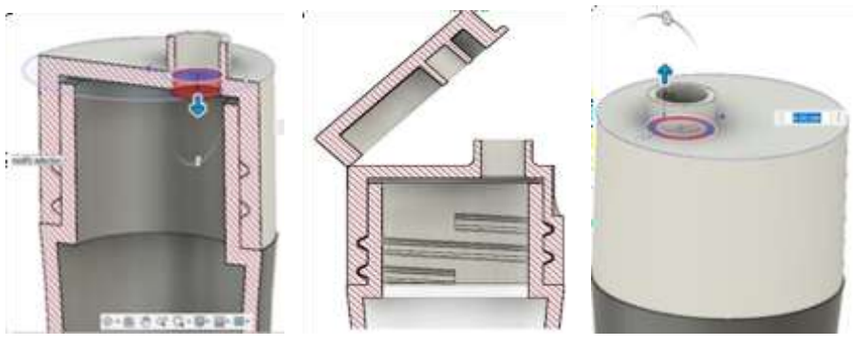
Different models of existing containers were analyzed, taking into account that the proposed container must contribute to: a) Good ergonomic handling, b) total closure of the container, c) lower cost of sale than the existing cost of other similar products, d) preservation and preservation of the organoleptic characteristics of honey.

5.2.4. Container design

The container design was carried out through the following steps (Table 3 Container design procedure):

Table 3 Container design procedure

Description	Visual representation
Plane generation (Create Sketch) and design using lines and vectors of the base shape of the model.	
360° revolution of the model profiling and application of materials to differentiate packaging components	

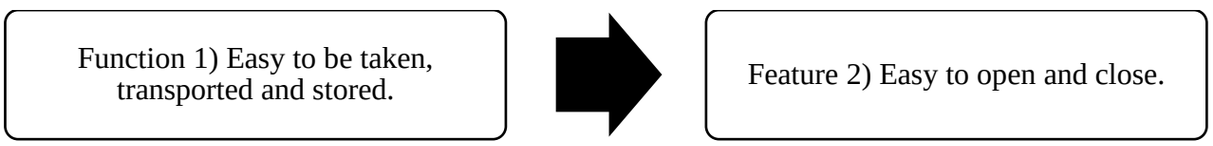
Packaging nozzle nut design	
Flip flop system design	

Source of Consultation: Own Preparation

5.2.4.1. Ergonomic aspects

The contextualization aimed at ergonomics for the design of the container was based on the fulfillment of the following two functions (Figure 6 Ergonomic aspects of the container):

Figure 6 Ergonomic aspects of the container

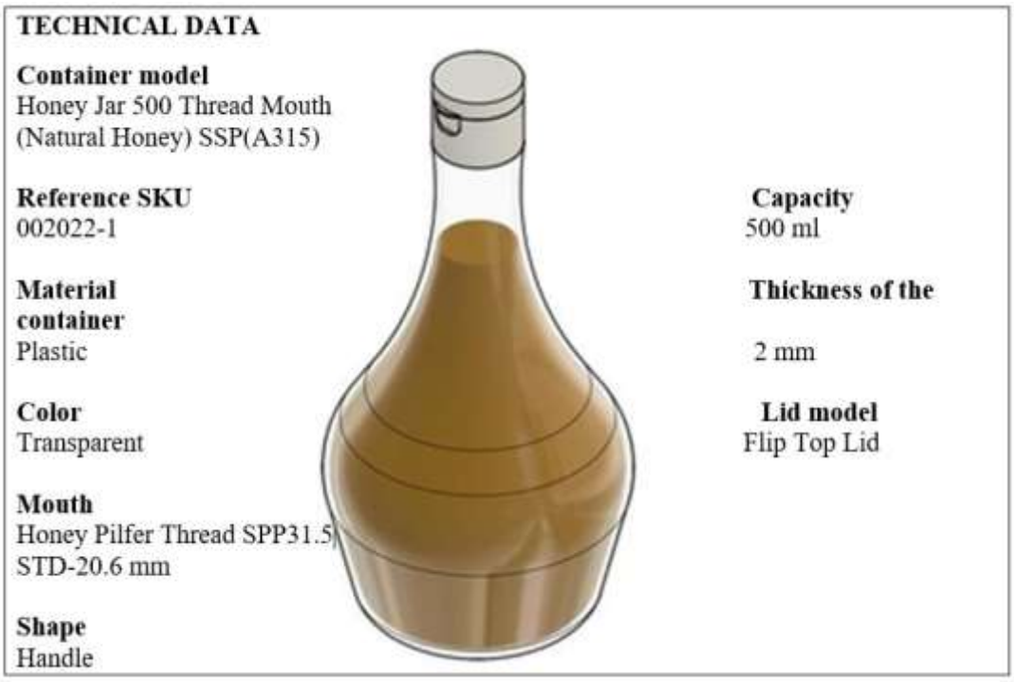


Source of Consultation: Own Elaboration

5.2.4.1.1. Function 1) Ease of being taken, transported and stored

The designed container is made up of different parts, within which the wavy profiling of the container body stands out, which is made of low-density polyethylene (LD-PE), this profiling has as its main objective compliance with the following ergonomic aspect: That the user takes the container in a safe way with the use of the whole hand (Sufficient space (9 cm) to take with the use of the 5 fingers, secure and close a fist) and transport it preserving the content of the honey, keeping Taking into account a maximum grip diameter of 10 cm between the first and third phalanxes, these characteristics are displayed below (Figure 7 Technical data of the container to be taken, transported and stored).

Figure 7 Technical data of the container to be taken, transported and stored



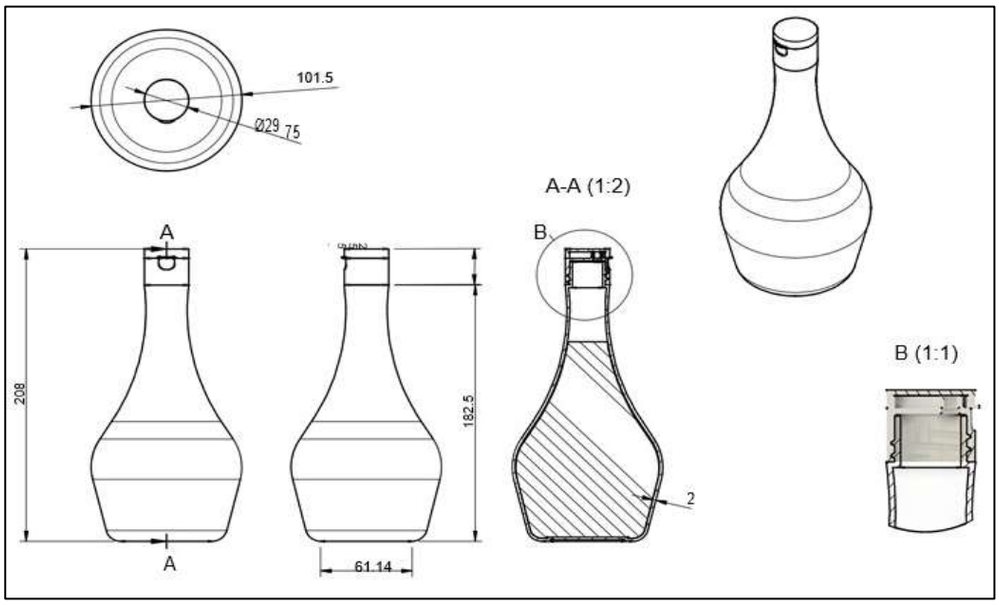
Source of Consultation: Own Elaboration

5.2.4.1.2. Function 2) Ease of opening and closing

Once the importance of the lid of the container had been analyzed, it was designed using the flip-flop model made from high-density polyethylene (PEAD), taking into account the following ergonomic principles (Figure 8 Technical data of the container to open and close):

– Principle 1) Determine the type of grip: According to the activity carried out, the ergonomic grip is known as: Hook (Hook): It is a type of power grip that refers to the shape that the fingers acquire when executing it. They can intervene from the index to the little finger, with a flexed position around the object, placing the hand in the shape of a hook (hence the name of the grip). The MCP joint is extended and the IFP and IDP have a certain flexion (Cepriá, 2016).
– Principle 2) Force of the grip type: To comply with the clamping pressure, the following forces are assigned for the ring finger 4 N, and for the index finger 7 N.

Figure 8 Technical data of the container to open and close



Source of Consultation: Own Elaboration

5.2.5. Design printing

The prototype was printed using 3D printing technology taking into account the properties of high/low density polyethylene, which are: a) Transparency, b) Steam and water tightness, c) Resistance to cold, d) Good rigidity and impact resistance, e) Low sensitivity to alkalis and acids. However, with respect to the technical characteristics of the printing process, the validation of the following variables was taken into account: Layer thickness, porosity, contour and screen angle, these variables are described below (Table 4 Design print characteristics):

Table 4 Design print characteristics

Characteristic	Description
Layer thickness	Thickness of each layer of filament that is deposited in the nozzle of the 3D printer, transversally.
Porosity	It is established according to the vacuum volume of 500 ml, with respect to the total volume of the printed prototype, the minimum porosity between each filament is 50% (Body) and the maximum porosity is 67% (Lid), with respect to the filament caliber.
Outline	It counts the number of filaments that the 3D printer deposits on the outside of the geometric construction of the prototype. For this prototype, 3 contours are used. Contour 1 and 2 belong to the body of the container and close in the center of the prototype, contour 3. refers to the cover.
Raster angle	An angle of 90° was used for the extruder to deposit the filaments in each of the printing layers.

Source of Consultation: Own Elaboration

5.3. Phase 3: Label design

Within the commercial field , in the experience of Estrada, Cantú , Torres and Barajas (2020), labeling is a determining process for product packaging, since its main objective is that consumers have access to general product information, for For this reason, the product label was designed under the idea of communicating the identity of the brand directly related to the packaged honey product (Figure 9 Packaging label).

Figure 9 Packaging label

Source of Consultation: Own Elaboration

5.4. Phase 4: Validation of the container prototype

Validation tests: 3 tests were carried out to validate the usability of the manufactured container (Figure 10 Validation tests).

Figure 10 Validation tests

Source of Consultation: Own Elaboration

Taking into account that melipona bee honey establishes an interval of 18.1% to 24% water (Fonte, Díaz, Machado, Blanco, Demedio and García, 2013), validation tests were carried out for the following variables: Y= Viscosity (Poises), X_1= Temperature °C, X_2= Fall time, the quantitative results of these variables are shown below (Table 5 Quantitative results of validation tests):

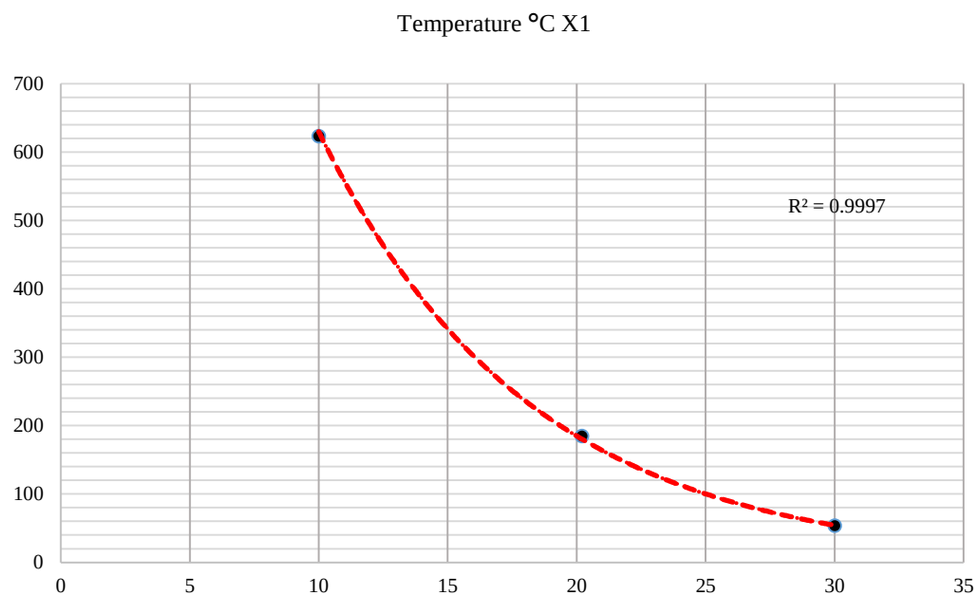
Table 5 Quantitative results of validation tests

Viscosity (Poises) Y	Viscosity (Pascal/second) (Pa *s)	Temperature °C X_1	Time Seconds X_2
622.9	62.29	10	00:15.28
184.5	18.45	20.2	00:07.35
53.66	5.366	30	00:03.83

Source of Consultation: Own Elaboration

Subsequently, the correlation analysis is carried out, in the first instance the existing correlation between the variables of Y= Viscosity (Poises), X_1= Temperature °C is studied, the results obtained are shown below (Graph 1 Correlation analysis Y= Viscosity (Poises), X_1= Temperature °C):

Graph 1 Correlation analysis Y= Viscosity (Poises), X_1 = Temperature °C



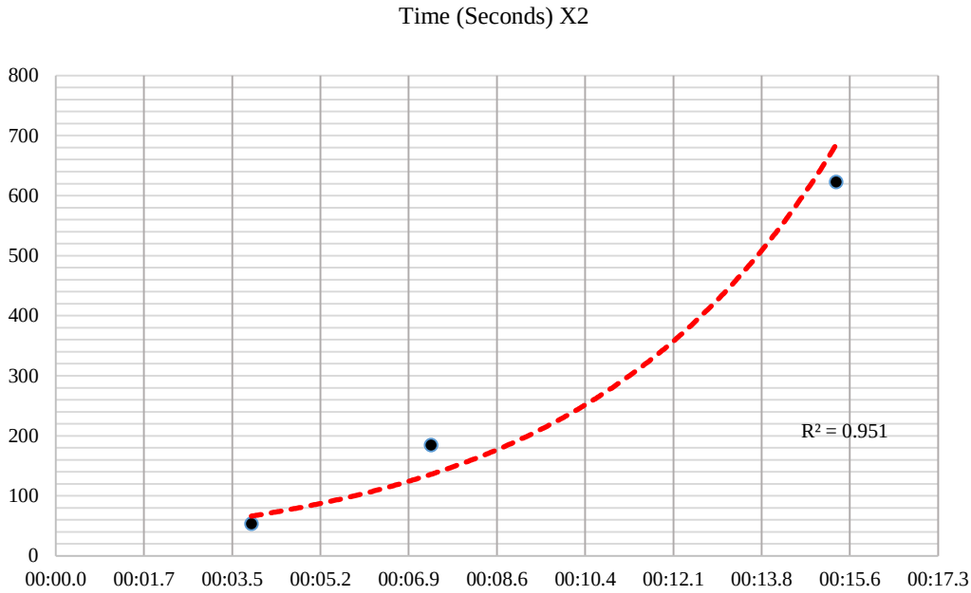
Source of Consultation: Own Elaboration

The interpretation of the first correlation analysis allows confirming the non-Newtonian behavior of the pseudoplastic type that honey has, which is based on the following principle: "Honeys exhibit crystallization over time" (Ramos, Jordán, Pablo, Espinoza and Añaños, 2014).

This behavior is notorious because the correlational study indicates that the lower the temperature °C, the lower the viscosity value (Poises) of the honey contained in the designed container, it is important to mention that these tests validate a strong positive correlation with $R^2 = 0.9997$, indicating that the container maintains the viscosity characteristics according to the temperature variable and to the principles of food chemistry established for honey (Badui, 2006).

Subsequently, the second correlation analysis is carried out between Y= Viscosity (Poises), X_2= Fall time, evidencing the result that is presented below (Graph 2 Correlation analysis Y= Viscosity (Poises), X_2= Fall time):

Graph 2 Correlation analysis Y= Viscosity (Poises), X_2= Fall time



Source of Consultation: Own Elaboration

The interpretation of the second correlation analysis indicates that the lower the falling time (Seconds), the lower the viscosity value (Poises) of the honey contained in the designed container, it is important to mention that these tests validate a strong positive correlation with a $R^2 = 0.951$, indicating that the container maintains the viscosity characteristics according to the time variable.

6. Results

The results are evident below:

6.1. Result 2

6.1.1. Physical prototype

The design of the container prototype was elaborated in the SketchUp program for the 500 ml honey product, it is mentioned that the lid was manufactured using the Flip Top model with a high-density polyethylene (PEAD) liner, the body of the container was It was manufactured from low-density polyethylene (LD-PE), the label was made in the Photoshop program, the final model was printed using 3D technology (Figure 11 Physical container prototype).

Figure 11 Physical container prototype

Source of Consultation: Own Elaboration

Taking into account the need to generate a physical environment to package the honey produced in the meliponarios, a validated ergonomic container prototype was created, which will be used by meliponiculturists in the region, avoiding additional costs resulting from intermediaries, which until Currently, their main activity is the purchase of honey at low prices from meliponiculturists (in 19-liter drums) and later they package it in smaller units, registering payments for the acquisition of honey that are low for meliponiculturists, for which this container prototype will make it possible to carry out the packaging directly by the meliponiculturists and obtain greater profits for the honey from the native bees of the region.

6.2. Result 2

6.2.1. Costing (Automated process projection)

The manufacturing process of the packaging model requires the initial economic intervention of the following factors (Table 6 Costing (Automated process projection)):

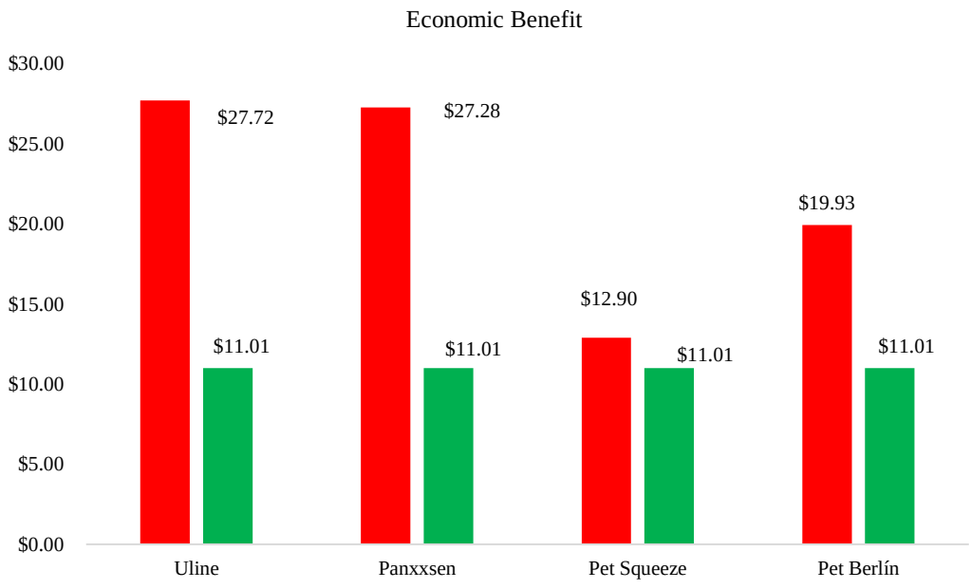
Table 6 Costing (Automated process projection)

Investment cost in machinery and equipment (20 thousand hours of use)	
Injection/printing machine **Automated process.	$160,200.14/ $8.01 per print/jetting hour
Unit value per day/lot	$64.08
Product manufacturing cost (It is raised per batch of 200 containers x working day (8 hours))	
Low density polyethylene LD-PE	$1062.47
Matt PEAD high density polyethylene for flip flop cover	$467.19
Label (Front/back)	$0.20 front, $0.20 back = $0.40 per unit/$80 per lot
Unit value per lot/day	$1609.66
Fixed Costs (Monthly)	
Repairs and maintenance	$1,200.00 monthly/$300 weekly/$50 daily
Office supplies	$4,00.00 monthly/$1000 weekly/$166.6 daily
Supplies	$1,000.00 monthly/$250 weekly/$41.66
Salaries	$270.00 per working day
Unit value per day	$528.26
Total value per batch of 200 pieces	$2202
Unit value per package	$11.01

Source of Consultation: Own Elaboration

Taking into account the above information, a cost per container of $11.09 is deducted, it is important to mention that an automated process must be considered to reach the goal of 200 containers per working day**,** the cost turns out to be a competitive advantage compared to the costs of products similar, this advantage is shown below (Figure 12 Cost comparison with existing packaging brands):

Figure 12 Cost comparison with existing packaging brands



Commercial brand	Cost	Container Cost	Profit Margin
Uline	$27.72	$11.01	60.28%
Panxxsen	$27,275	$11.01	59.6%
Pet Squeeze	$12.9	$11.01	14.65%
Pet Berlin	$19.93	$11.01	44.75%
Average			44.85%

Source of Consultation: Unline.mx. (2023), Mercado Libre (2023)

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9. Conclusions

The development of this work shows a feasible solution that arises from the prevailing need to support meliponiculturists in the Northern Zone of the State of Puebla, since through previous analysis it has been detected that they do not have the financial means to acquire packaging containers. high cost, which is why they proceed to market honey wholesale to people who are known as intermediaries, causing economic losses due to the low costs resulting from these negotiations, in the Sierra Norte of the State of Puebla this productive activity provides economic resources to a approximately 200 families, the same ones that currently own meliponarios, for which a community project was sought through the application of Industrial Engineering (Design, ergonomic analysis, costing, validation tests, etc.) to improve conditions economics of honey producers in this geographical area.

Taking this assignment into account, the design and manufacture of a container prototype was carried out with easily accessible materials and designed in specialized SketChup software. This design is of the operational type, which is why it adapts to the capacity needs of each meliponary. In the first instance, a model with a capacity of 500 ml is presented, but it can be molded to future capacities suggested by producers. This designed model takes into account ergonomic aspects to preserve the organoleptic properties of the sweetener, significantly improving through these aspects the functions of taking, transporting, storing, opening and closing.

As is evident, one of the factors that causes the sale to intermediaries is focused on the high costs of the current containers, for which, contemplating this requirement, the costing of the automated process is carried out taking into account all the elements that intervene, the costing The resulting cost is $11.09 per unit, this cost for meliponiculturists is accessible and opens up a wide portfolio of possibilities for their acquisition, causing them to be in charge of carrying out the packaging process, and later sell directly to producers. customers, bringing with it the reduction of extra costs and greater customer acquisition. However, within the possibilities for improvement, the development of good packaging practices is highly recommended, making use of methodologies/work instructions that document the packaging process, seeking to preserve the safety characteristics of honey.

Finally, the high effectiveness of this work is concluded by linking a community need with Industrial Engineering tools to create a community project that directly benefits the economic sector of regional meliponiculture.

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Chapter 4 Machine learning for sentiment analysis in social networks data: Advances and perspectives

Capítulo 4 Aprendizaje automático para el análisis de sentimiento en datos de redes sociales: Avances y perspectivas

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Abstract

Sentiment analysis is a field of study within artificial intelligence aimed at comprehending opinions and emotions expressed in natural language, such as texts published on social networks. Social networks are understood as online technologies, tools, and applications that allow users to generate content, share and exchange information, and create interpersonal and communal relationships through the Internet. The data generated from these sources are highly intricate to analyze, hence the relevance of computational tools. Multiple approaches exist that tackle sentiment analysis through artificial intelligence, specifically through machine learning. In this chapter, a literature review and state-of-the-art analysis were conducted regarding sentiment analysis on social network data, with the objective of identifying technologies that exhibit superior performance in this task; the available methodologies are cited to facilitate the selection of an appropriate method, and the advantages and disadvantages of all reviewed methodologies are enumerated. The guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology were applied and finally, the systematization of knowledge was carried out on 21 articles.

Sentiment analysis, Artificial intelligence, Machine learning, Data from social networks, Text processing

Resumen

El análisis de sentimientos es un área de estudio de la inteligencia artificial para comprender opiniones y emociones expresadas en lenguaje natural, como textos publicados en redes sociales. Las redes sociales se entienden como tecnologías, herramientas y aplicaciones en línea que permiten a los usuarios, a través de Internet, generar contenidos, compartir, intercambiar información, crear relaciones interpersonales y comunitarias. Estos datos generados son muy complejos de analizar, por lo que es pertinente el uso de herramientas computacionales. Existen varios enfoques que abordan el análisis de sentimientos a través de la inteligencia artificial y específicamente el aprendizaje automático. En este capítulo se desarrolló una revisión de la literatura y estado del arte sobre análisis de sentimiento en datos de redes sociales, con el fin de identificar tecnologías con el mejor desempeño en el desarrollo de esta tarea; se citan las metodologías disponibles, para facilitar la selección del método apropiado y se enuncian las ventajas y desventajas de todas las metodologías revisadas. Se aplicaron los lineamientos de la metodología Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) y finalmente se realizó la sistematización del conocimiento sobre 21 artículos elegidos.

Análisis de sentimientos, Inteligencia artificial, Aprendizaje automático, Datos de redes sociales, Procesamiento de texto

1. Introduction

Sentiment analysis (SA) refers to the application of Natural Language Processing (NLP), computational linguistics and text analytics to identify and extract subjective information in source materials, like opinions from the text and classify the polarity of subjects into positive, negative, or neutral to determine the public group perception. NLP is a field of Computer science, Artificial intelligence (AI) and Linguistics concerned with the interactions between computers and human natural languages. Extracting useful knowledge from naturally written texts, allows NLP to resolve the distance between humanity and machine. The goal of SA is to extract and analyze knowledge from personal data or reviews and feedback provided from different sources of data on the internet (Batrinca & Treleaven, 2015), (Xue et al., 2023), (Yadav, 2023).

SA is divided into three different levels which are sentence level, document level and feature level. The purpose is to classify the opinion either from sentence, document or features into positive and negative sentiment or even neutral. Therefore, the methods are divided into lexicon-based, machine learning-based, hybrid methods and, more recently, deep learning-based approaches. Machine learning-based approach utilized algorithms to extract and detect sentiment from a data, while lexicon-based approach works by counting the positive and negative words that relate to the data and uses a glossary of sentiment terms including enhancement and negation to measure the polarity of each phrase.

However, this method depends on the extraction of knowledge from a statement with an opinion polarization. The deep learning-based approach has two phases, the term embedding in the text corpus is learned in the first phase and the second phase focuses on the use of word embedding to create interpretations of sentences of semantic composition using different deep learning techniques (Drus & Khalid, 2019), (Sharma et al., 2019), (AlBadani et al., 2022), (Xue et al., 2023).

SA is improved, considerably, by the application of Machine Learning (ML), with supervised learning and unsupervised learning methods; where a computer program is assigned to perform some tasks and it is said that the machine has learnt from its experience if its measurable performance in these tasks improves as it gains more and more experience in executing these tasks. So, the machine makes decisions and does predictions / forecasting based on data. The supervised learning approach is used when there is labeled data available for training the model and the unsupervised learning method is used when the reliability of labeled data is difficult (Sharma et al., 2019), (Ray, 2019), (Yadav, 2023).

At present, social media data is the largest, richest and most dynamic evidence base of human behavior, bringing new opportunities to understand individuals, groups and society. The use of social networks generates massive data characterized computationally by big size, noise, and dynamism; now most frequently named as big social data. These characteristics make it very complex to analyze, resulting in the pertinent use of computational means to it (Batrinca & Treleaven, 2015) (Xue et al., 2023).

The purpose of SA on data extracted from social networks is to recognize potential drift in society as it concerns the attitudes, observations, and the expectations of the populace (Batrinca & Treleaven, 2015). SA with ML techniques on social network data is increasingly used by organizations to understand the opinion and emotions of users expressed on social networks and to understand where the organization is headed and when the institution needs to change strategies to be more efficient and effective (Carvalho & Plastino, 2021), (Shofiya & Abidi, 2021). Its application ranges from monitoring a brand's reputation to monitoring public opinion on political or social issues; to the identification of patterns and trends in user opinions, which can be useful for decision-making (Ansari & Khan, 2021), (Chandrasekaran et al., 2021), (Shekhawat et al., 2021), (Xue et al., 2023), (Yadav, 2023).

The objective of this study is to analyze the empirical and practical evidence available and provide a better understanding of the application of ML for SA expressed in social networks, by examining related literature published between 2018 and 2022; to determine the scientificity, validity of its use and social impact in other contexts, which will allow determining the state of the art based on the behavior of said phenomenon. This study does not intend to define concepts or substantiate the theoretical aspects of the approaches, models or algorithms summarized in the reviewed research. This manuscript is intended for researchers in computer science and information technology, who are assumed to be familiar with the terms discussed here.

The main contributions are the literature review, in order to identify technologies with the best performance to the SA in data from social networks; the available methodologies are cited to facilitate the selection of the appropriate method for a specific sentiment analysis task, giving advantages and disadvantages of all reviewed methodologies. The text is organized as follows: Section 2 describes the methodology, Section 3 details about the different approaches for sentiment analysis, Section 4 summarizes the challenges related to sentiment analysis, and finally in Section 5 the conclusions are given.

2. Methodology

This study was reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement and aimed to conduct a meta-analysis for assessing a systematic review of published scientific literature on ML for SA expressed in social networks, between 2013 and 2022, focusing attention on the last five years of the mentioned period (Page, 2021). The initial search for published research on the subject was carried out in December 2022, in Google Scholar Web Page, with the purpose of determining the use of the terms and their combination. The terms used initially were 'sentiment analysis' and 'social media' and later, it was extended with a combination, using the boolean operators AND and OR as appropriate, of the terms 'opinion mining', 'social network', 'artificial intelligence'. These searches offered a global vision of the breadth of the subject.

In March 2023, the search was bounded to publications from the last five years, from 2018 to 2022 inclusive; and the results found in databases such as the IEEE, Scopus, ScienceDirect and Web of Science were added, with the purpose of covering the largest number of articles that should have been included. The combination of terms that yielded the best results was the following: ((sentiment analysis OR opinion mining) AND (social media OR social network)) AND (artificial intelligence OR machine learning). Finally, 678 results were obtained in this search.

The searches in SciSpace and Elicit were also considered. Both sites use AI algorithms for facilitated searching and generate a general and specific summary of the most relevant components and contributions of the resulting articles and research, as well as essential data of each of them. According to the website itself, Elicit is a research assistant using language models like GPT-3 to automate parts of researchers' workflows (Ought, 2023).

If you ask a question, Elicit will show relevant papers and summaries of key information about those papers in an easy-to-use table, whereas SciSpace is the easiest way to find, understand, and learn any research paper (SciSpace, 2023). In general, these applications improve the selection of the articles for the review and the management of references. For every paper, it gets simple explanations and answers using AI and discovers a network of connected and relevant papers (Kung, 2023).

Through Elicit and SciSpace, 125 results were obtained and limited in dates. Considering the non-veracity or authenticity of these tools by the scientific community, the results were only considered for the triangulation of the information and the initial readings of the abstracts to support the defined inclusion and exclusion criteria. The integration of AI in these sites is considered a contribution in the development of the systematic review, undoubtedly beneficial for the scientific community. During the entire review process, the total number of articles processed was 803, based on the defined inclusion and exclusion criteria.

The inclusion criteria defined for the selection of articles include: AI techniques and mainly ML used to predict sentiment behavior in text-type data; published between 2018 and 2022, including empirical researches and not reviews, books or manuals, reports, methodologies or tools for sentiment analysis with data obtained from social networks.

Among the exclusion criteria are: duplicated works; papers in which ML and AI are not used, publications without open access; studies limited to proposals; conceptual reviews and theoretical foundations papers without strategies and methodologies or activities for sentiment analysis; works in which data are not obtained from social networks; papers focused on industrial, manufacturing, or production of tangible goods sectors; research that does not draw conclusions on the behavior of the sentiment analysis.

According to these criteria, initially, 407 articles were considered adequate. Subsequently we eliminated 158 duplicates; 185 by reading the title and 53 for not being able to access the full text of the publication. The remaining articles were studied, and from the reading, 33 articles were discarded for being limited proposals, conceptual reviews and theoretical foundations; 119 for not applying data obtained from social networks; and 29 for not using ML for data processing.

In a more detailed, but fragmentary or partial reading, 63 were discarded for not specifying the methodology to be used; 111 for being studies focused on industrial, manufacturing, or production of tangible goods sectors; and 31 because they are only texts that justify the need for analysis and do not yield conclusions on the behavior of feelings or the accuracy of the methods used.

Nineteen articles satisfied the inclusion criteria, indicating the use of ML, as a technique for processing feelings expressed in social networks. Taking into account these nineteen articles we carry out the detailed reading necessary for the development of the systematic review. After reading the selected 19 articles in depth, based on their references, 2 new articles were included, considering them important for the review; therefore, in total, the systematization of knowledge was carried out on 21 articles.

3. Results

The final articles, chosen for the review, were separated for review and summary, considering the objectives pursued by the authors, which allowed a better understanding of the results. Three of the investigations presented a study of topics related to sentiment analysis and the algorithms, methods and approaches used. Two of them conceptually addressed the fundamentals, provided a global vision of the sentimental analysis task and compared the results shown by different authors in terms of techniques and methods of sentiments according to the specified contexts and data. The periods studied by these authors range from 2013 to 2020, inclusive.

Consequently, most of the investigations of the articles studied were relevant and interesting. The results presented in these studies serve as a basis to strengthen the theoretical and practical knowledge related to the subject. The main conclusions drawn from the investigations, reflected in the articles studied, are summarized in Table 1.

In Sharma et al.'s study (2020), the authors discussed the methods for sentiment classification and gave a comparison of algorithms experimented by different researchers on different datasets along with performance measures. As a result of the research, the authors concluded that the "term presence" is more important than the "term frequency" in SA; adjective, adverb, and verbs can be considered as features and irrelevant words can be removed from the corpus so that vocab size can be reduced (Mejova & Srinivasan, 2011). In addition, the authors indicated that most researchers performed SA using English language; but they found some researchers used non-English languages for solving SA problems providing compatible results as well (Che et al., 2015; Sharma et al., 2015; Sumit et al., 2018, as cited in Sharma et al., 2020).

Meanwhile, the perspective of Babu and Kanaga (2022), is also interesting. They addresses the impact of feature and detail extraction on the techniques used in the classification stage of SA; and the handling of emoticons and emojis in the text, referring to the fact that NLTK Tokenizer should be used to tokenize data from social networks into individual words where all emoticons and emojis are saved without deleting them (Li et al., 2023). These authors studied thirteen articles, in which ML techniques are utilized for the analysis of sentiments in data obtained from social networks. Among the techniques applied on Facebook datasets: Support Vector Machine (SVM), Naive Bayes (NB), K- Nearest Neighbors (KNN), and Random Forest (RF). In that case, the method with the best performance was RF with an accuracy of 84.6%. On Twitter datasets, ten studies in the main article applied SVM, five applied NB, four applied RF and four applied Multimodal NB. The highest results, on that datasets, were for applying SVM with 93.1% accuracy and Multimodal NB with 92.2% accuracy.

Previous results are reaffirmed in the investigation of Drus and Khalid (2019), in which it is pointed, that the most used method in ML application for SA, is the SVM and NB model. They explained that NB is successful when applied on well-formed text corpus, while SVM gives a good performance for low shape dataset. Moreover, it is explicit in their review that most of the study adapted SentiWordnet and Term Frequency-Inverse Document Frequency (TF-IDF) methods, when conducting sentiment analysis (Agarwal et al., 2015), (Rahman et al., 2022). Nonetheless, they affirm that, ML method performs poorly on Facebook with people posting in random length and lots of spelling mistakes and it requires a huge amount of training samples to adapt the method as the amount of dataset will influence the size and quality of the output.

The remaining reviewed articles were selected, after meeting the inclusion criteria, for presenting diverse and notable methodologies among the results published in the reviewed period. The performance value of the studied ML methods for SA on different dataset is summarized in Table 2. The reported results make evident that the authors agree that sentiments can be extracted, processed and classified, using a wide variety of algorithms and they recognize that the lexicon-based approach, standard machine-based approach, and deep learning-based approach are the three main approaches in SA. In most of the publications summarized in Table 2, a comparison is made between algorithms, methods and models to be applied for SA; highlighting, in this sense, the application of Artificial Neural Networks (ANN) (Batrinca & Treleaven, 2015); Recurrent Neural Network (RNN) (Goel et al., 2018), (Khan & Malviya, 2020); Single-layered Long-Short Term Memory (LSTM) (Moshkin et al., 2019), (Chintalapudi et al., 2021), (Mujahid et al., 2021), (Velampalli et al., 2022); and Neural Network (NN) (Mostafa et al., 2021), (Khasanova & Pasechnik, 2021), (Velampalli et al., 2022).

Table 1 Summary of the conclusions and observations of the reviewed systematization studies

Cite	Reviewed articles	Cited Methods	Conclusions/Contributions
(Drus & Khalid, 2019)	77 articles was screening and 24 selected for review. Period study: 2014 - 2019.	SVM, NB, TF-IDF (Das & Chakraborty, 2018), SentiWordnet (Agarwal et al., 2015)	– The obtained results demonstrated the usefulness of either Lexicon based method, Machine learning method or a mix of both methods when implementing sentiment analysis. – Most of the study adapted Sentiwordnet and TF-IDF method when conducting sentiment analysis.
(Sharma et al., 2020)	36 cited and 13 are summarized. Period study: 2013 - 2018.	Term presence versus term frequency, N-gram features, parts of speech tagging (Mejova & Srinivasan, 2011). Bayesian networks (Al-Smadi et al., 2019), SVM (Zainuddin & Selamat, 2014), ANN, Decision tree (DT) (Kotenko et al., 2015), Rule based classifier (Xia et al, 2016).	– High accuracy of classification depends upon the quality of selected features and classification algorithm used. – SVM and NB are used by the researchers as a reference model for comparing their proposed work. – Lexicon-based approach is used by the researchers to solve sentiment analysis problems as it is scalable and computationally efficient.
(Babu & Kanaga, 2022)	101 collected, 13 of applications in social networks are summarized. Period study: 2016 - 2020.	SVM, NB, RF, KNN, Convolutional Neural Network (CNN), Bidirectional LSTM (Bi-LSTM)	– Emoticons examples presented in a table form. – Summary of application articles that evaluate ML and Deep learning techniques on social networks data, where the accuracy obtained and the dataset used are highlighted. – RF and SVM achieved the best performance on Facebook and Twitter dataset with 84.6% and 93.1%, respectively.

Source: Own Elaboration

Table 2 Results of reviewed articles that apply and evaluate ML techniques for sentiment analysis

Cite	Methodology	Models/Algorithms	Dataset source	Dataset size (registers)	Best performance	Accuracy	Measure performance parameters
(Khasanova & Pasechnik, 2021)	Training a neural network to classify the text	NN and Bag of Words (BoW)	VKontakte	400000	NN	80 %	confusion matrix
(Chintalapudi et al., 2021)	A fine-tuned 12-layer Bidirectional Encoder Representations from Transformers (BERT) model	Logistic regression (LR), SVM, Single-layered LSTM, BERT and AdamW optimizer.	Twitter	3090	BERT	89 %	accuracy
(AlBadani et al., 2022)	ULMFiT combined with SVM and applied it on different sentiment analysis datasets	SVM, LSTM, ULMFit–SVM model	Twitter Yelp IMDb	28595 14485 65000	ULMFit–SVM model	99.78%	accuracy, training time, testing time
(Başarslan & Kayaalp, 2020)	Comparison of the SVM, ANN and NB algorithms with the TF-IDF and Prediction-based text representation (W2V) methods	NB, SVM, ANN, TF-IDF, W2V	IMDB Twitter	1000 4500	ANN with W2V method	96 % and 86 % on IMDB and Twitter datasets respectively	accuracy, precision, sensitivity and F - score
(Alatabi & Abbas, 2020)	A sentiment analysis system built on Bayesian Rough Decision Tree (BRDT) algorithm	BRDT, DT	Facebook Movie reviews	4000 2000	BRDT	99.62 % on Facebook dataset, 96.15 % on Movie reviews dataset	accuracy, precision, recall, F1 score
(Mostafa et al., 2021)	Comparison between different selected machine learning algorithms for classification	NB, SVM, KNN Classifier, LR, NN.	Twitter	448013	NN	81.33% (subject to dataset size)	accuracy, costs per iterations, memory usage, training time
(Carvalho & Harris, 2020)	The accuracy off-the-shelf technologies and the bag-of-words approach is studied	Sentiment analysis services provided by four major cloud platforms (IBM Cloud, Amazon Web	Twitter Facebook	14640 3240	IBM NLU (Twitter dataset), Amazon Comprehend	85.4 % (IBM NLU), 76.3 % (Amazon Comprehend)	accuracy

Cite	Methodology	Models/Algorithms	Dataset source	Dataset size (registers)	Best performance	Accuracy	Measure performance parameters
		Services, Microsoft Azure, and Google Cloud)			(Facebook dataset)		
(Khan & Malviya, 2020)	A new approach and classification method	Rough Set Theory, PSO, NB, Hadoop based deep RNN (Başarslan & Kayaalp, 2023) method	Twitter	no se determina en el documento	Hadoop based deep RNN method	93.02 %	accuracy
(Moshkin et al., 2019)	Assessing of the sentiment analysis of social network texts through an original ontological method	Ontological method based on SentiWordNet, NB classifier, LR, SVM, LSTM network	VKontakte	420	NB	78 %	accuracy
(Karthika et al., 2019)	RF and simulated by using SPYDER	RF, SVM	Twitter	448013	RF	97 %	accuracy
(Goel et al., 2018)	Methodology for automatic multilingual processing	NB, RNN	Twitter	no se determina en el documento	RNN	96.15 %	accuracy, confusion matrix
(Velampalli et al., 2022)	Universal Sentence Embedding and S-BERT to embed sentences to sentence vectors.	NN, LSTM NN, S-BERT	Twitter	2253	S-BERT with Standart NN, Universal Sentence Encoder with LSTM NN	98 %	precision, recall, F - score and accuracy
(Cyril et al., 2021)	Automated learning with CA-SVM based sentiment analysis model	TGS-K means clustering, Semantic sentiment score (SSS), Gazetteer and symbolic sentiment support (GSSS), Topical sentiment score (TSS), CA-SVM based model	Twitter	1,000,000,000	CA-SVM based model	92.48 %	recall, accuracy
(Mujahid et al., 2021)	Analysis of the sentiments of people about e-learning.	TF-IDF and BoW, TextBlob, VADER, and SentiWordNet, CNN (Başarslan & Kayaalp, 2023), LSTM, CNN-LSTM, Bi-LSTM, Synthetic Minority Oversampling Technique (SMOTE) and Topic modeling with Latent Semantic Analysis (LSA).	Twitter	17155	DT, RF, SVM with TF-IDF, with SMOTE	95 %	accuracy, precision, recall, F1 score, confusion matrix and K-Fold Cross-Validation
(Rustam et al., 2021)	Feature extraction technique based on BoW and TF-IDF and a new methodology	RF, XGBoost classifier, SVM, Extra trees classifier (ETC), and DT, TF-IDF, BoW	Twitter	7528	ETC with concatenate BoW and TF-IDF	93 %	precision, recall, F - score, accuracy, confusion matrix
(Salmony & Faridi, 2021)	Negation scope identification methods to find negated tokens and investigate how these tokens can raise SA classifiers' accuracy. Presents a methodology workflow process that they used to conduct Twitter Sentiment Analysis.	NB, SVM, LR with BoW and TF-IDF vector representation technique	Twitter	1,600,000	LR with TF-IDF embedding negated token	81 %	accuracy
(Alharbi & El-kenawy, 2021)	A hybrid approach, named GWOPS, that combines Grey Wolf Optimizer (GWO) and Particle Swarm Optimization (PSO) algorithms, for training NN classifiers.	GWO, PSO and Genetic algorithm (GA) with NN.	Twitter	2000	GWOPS with NN	93,85 %	standard error of mean, standard deviation mean
(Hassan et al., 2021)	A compressive annotation guideline for manual coding of tweets.	SVM, LR, NB	Twitter	6388	SVM with uni-gram	85 %	accuracy, precision, recall, F1 score and ROC curve

Source: Own Elaboration

The compared supervised learning algorithms are SVM (Karthika et al., 2019), (Moshkin et al., 2019), (Başarslan & Kayaalp, 2020), (Chintalapudi et al., 2021), (Mostafa et al., 2021), (AlBadani et al., 2022), (Rahman et al., 2022); Clustering-based Adaptive SVM (CA-SVM) (Cyril et al., 2021); LR (Moshkin et al., 2019), (Chintalapudi et al., 2021); (Mostafa et al., 2021); BRDT (Alatabi & Abbas, 2020); DT (Alatabi & Abbas, 2020); NB (Başarslan & Kayaalp, 2020), (Goel et al., 2018), (Khan & Malviya, 2020), (Moshkin et al., 2019), (Mostafa et al., 2021), (Rahman et al., 2022); KNN (Mostafa et al., 2021) and RF (Karthika et al., 2019); combined in some cases with the natural language processing techniques like BoW (Carvalho & Harris, 2020), (AlBadani et al., 2022), (Rahman et al., 2022); TF-IDF (Rustam et al., 2021), (Salmony & Faridi, 2021), (Rahman et al., 2022); Word2Vec (Başarslan & Kayaalp, 2020), (Rahman et al., 2022), (Başarslan & Kayaalp, 2023); and PSO (Başarslan & Kayaalp, 2020).

Inside the approaches to sentiment analysis, the authors characterized and applied the Semi-Supervised Ultra-Lightweight Multi-lingual Fine-Tuning (SIS-ULMFiT) (AlBadani et al., 2022), Rough set theory (Khan & Malviya, 2020), Ontological method based on SentiWordNet (Moshkin et al., 2019). In general, in all approaches to the subject reviewed, it is recognized that operations like text preprocessing have a big impact on the accuracy of the system as this process facilitates dealing with words and the deletion of unwanted words. Also, feature selection is a significant process because it reduces the number of features by selecting the most useful set of features, decreasing the number of features means less training time.

The importance of data preprocessing operations is evidenced in the publications of Carvalho and Harris (2020) y Chintalapudi et al. (2021). The comparing of the off-the-shelf technologies around the sentiment analysis services provided by four major cloud platforms, like IBM cloud, Amazon web services, Microsoft Azure, and Google cloud, against the BoW approach; makes evident that the pre-trained models available on the aforementioned platforms are more accurate than the BoW approach. The difference between IBM NLU, the most accurate technology, and the BoW approach is more than 30 percentage points (Carvalho & Harris, 2020).

However, there is no single technology that is consistently more accurate than the others across different sentiments. For example, Amazon comprehend is highly accurate when classifying neutral and positive posts, but drastically less accurate when handling negative posts. The main features and pricing scheme of sentiment analysis services provided by major cloud platforms is a good contribution to the review of Carvalho and Harris (2020).

Likewise, the effect of types of text representation on the performance of sentiment analysis is investigated by Khan and Malviya (2020). They demonstrated the performance of SVM, ANN and NB algorithms with the traditional TF-IDF and W2V methods in two different datasets. The results of the experiments with TF-IDF on Twitter and IMDB datasets, showed that the ANN algorithm had the best performance with an accuracy of 89% and 86% respectively, while the results applying W2V on the same datasets, also showed the best performance in the ANN algorithm with an accuracy of 87% and 90% respectively. The NB gave the worst performance among others in both datasets and the applied experiments.

Assessing the sentiment of social network texts within a software System for Opinion Mining is developed through the research of Moshkin et al. (2019); the research proposes an original ontological method that takes into account the features of the text data presentation in social networks and develops an architectural scheme of the software. The best result was with the use of the NB classifier with a 78% of accuracy. The developed method based on the dictionary obtained from SentiWordNet showed an efficiency of 77%.

On the other hand, the ULMFiT-SVM model, proposed by AlBadani et al. (2022), introduces an effective deep learning architecture that combines the universal language model fine-tuning with a SVM. The extensive results on three real-world datasets (Twitter, Yelp, IMDb) demonstrate that the model increases detection efficiency and accuracy, being between 95.78% and 99.78%. Therefore, in the study, the sentiment analysis was restricted to document level and they did not consider the sentiment at the aspect level.

However, in (Cyril et al., 2021) the authors propose an Automated learning CA-SVM based sentiment analysis model, which has produced efficient results than other feature selection and classifiers such as ANN and k-means; their proposal achieved an accuracy of 92.48%. In spite of, when contrasting the previous results associated with the proposed models, better performance results are obtained compared to models that have already been pre-trained.

In the case of the novel deep-learning model called BERT, the accuracy of 89% is achieved. Despite this result, it is still superior to other models like LR, SVM, and LSTM, in the context of its application in the investigation of Chintalapudi et al. (2021). When contrasting the previous results associated with the proposed models, the performance is higher compared to models that have already been pre-trained.

Another interesting approach is the one developed by Khan and Malviya (2020), who proposes to allocate a review of real-valued input twitter data using deep RNN with Hadoop framework to distribute data for feature extraction process. The comparative performance between Hadoop based deep RNN method and the Rough set theory, PSO and NB methods showed that the proposed method is more accurate with the value of 93.02%.

In another hand, a singular application of sentiment analysis was reviewed about measuring the performance of Tweets that contain emojis. The investigation of Velampalli et al. (2022), aims to generate embeddings using Universal Sentence Encoder and SBERT sentence embedding models, to improve the classification accuracy using standard fully connected NN, and LSTM-NN models. Training the models using a distributed training approach instead of a traditional single-threaded model is implemented for better scalability. The text classification accuracy was almost the same for the NN and LSTM-NN models, around 98%. But, on the contrary, when the validation set was built using emojis that were not present in the training set, the accuracy drastically reduced to 70% (Li et al., 2023).

In the same way, the general comparison between algorithms applied on data from the social network for SA, the performance of the NN classifier algorithm, obtained in the investigation of Mostafa et al. (2021), stood out, were achieved the highest accuracy of 81.33%, followed by SVM, with 79%. The rest of techniques achieve an accuracy of less than 77%. However, the authors consider that the results are limited by the size of the selected dataset, so the work can be done on an even bigger data set to obtain better accuracy.

A better performance was obtained by using RF, with accuracy of 97%, among other algorithms like SVM, with the accuracy of 92%. The application of the RF algorithm also includes unbalanced data into the process and limits overfitting without increasing the error rate (Alatabi & Abbas, 2020). Meanwhile, in Karthika et al. (2019), went further into the construction of a special system and gave it the ability to classify each input as positive sentiment or negative sentiment employing a recently developed BRDT. The performance of the BRDT in two datasets (Facebook and movie reviews) was about 99.625% of accuracy.

Several architectures and methodologies are proposed by the authors cited in Table 2, being consistent with the approaches found in the literature for sentiment analysis applying ML techniques with data obtained from social networks. The use of Twitter is coincidental as the most used social network for obtaining data for sentiment analysis, due to the easy access, being Facebook, less consulted without intuitable or stated reason. But, most of the research work mainly focuses on tweets in only one language. A solution, in the form of a methodology, to multilingual sentiment analysis problems by implementing algorithms, was proposed by Goel et al. (2018) and it was complemented by comparing precision factors to find the best solution for this type of analysis.

The Google Translator API is used to translate the text into a common language, such as English, and then a sentiment analysis model is applied to the translated text to obtain a sentiment score. It has been cleared from the observations that, RNN classifier is significantly ahead of the other classifier in the task of predicting the feelings with almost an accuracy of 96%.

Keeping in view the adequacy and efficacy of machine learning models, the research of Mujahid et al. (2021), adopts TextBlob, Valence Aware Dictionary for Sentiment Reasoning (VADER) and SentiWordNet to analyze the polarity and subjectivity score of tweets text. Two feature extraction techniques, TF-IDF and BoW have been used to effectively build and evaluate the models. All the models have been evaluated in terms of various important performance metrics such as accuracy, precision, recall, and F1 score.

Performance comparison is carried out for results of TextBlob, VADER, and SentiWordNet, as well as classification results of machine learning models and deep learning models such as CNN, LSTM, CNN-LSTM, and Bi-LSTM. Results indicate that using the data balancing with SMOTE enhances the classification accuracy. DT, SVM, and RF perform very well and achieve an accuracy of 0.95 using Bow and SMOTE, while SVM achieves 0.95 accuracy using TF-IDF with SMOTE. VADER and SentiWordNet techniques are also used for performance comparison with TextBlob, and results indicate that TextBlob shows superior results for data annotation in comparison to VADER and SentiWordNet (Mujahid et al., 2021).

Finally, Rustam et al. point out another way to extract information and conform a dataset for sentiment analysis, by the use of identifiers provided by the IEEE dataport. The text of each tweet is extracted via IDs by an internal crawler using the Tweepy library (2021).

4. Challenges in the reviewed literature

Despite the large amount of research found regarding the application of SA with ML techniques in data obtained from social networks, challenges that the scientific community must face are still revealed. Optimizing hyperparameters is a critical problem in the development and design of an effective learning model for network sentiment detection. Problem that AlBadani et al. (2022) suggests solving, using a k-fold cross-validation strategy, which allows, according to these authors, to increase the overall performance of the single SVM to find the optimal RBF kernel parameters and to fine-tune the approach hyperparameters.

Another of the challenges faced during the sentiment analysis of Twitter data is the creation of noise while labeling the data and the major challenge lies in building technology that identifies and compiles the overall sentiment. To solve this, according to Khan and Malviya (2020), "a dedicated and integrated platform based on Twitter-based content is needed for extracting the obtainable information in public from huge text streams to synthesize and analyze the feedback of the customers" (p. 2).

Other aspects to take into account in the application of AS with ML techniques are those point out in the research of Cyril et al. (2021), where issues related to the effect of clustering in sentiment analysis are addressed, to classify a tweet under available class. of sentiment; the semantic sentiment score, to consider the semantic terms in tweets; the topical sentiment score, to measure the sentiment score according to the topical score; and the gazetteer and symbolic sentiment support (GSS), to represent the support of tweet towards any sentiment class according to the gazetteer and symbolic features present in the tweet.

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8. Conclusions

Various sentiment analysis methods with their performance parameters and methodologies for SA, have been explored in the present review and the reviewed literature shows that ML is a powerful tool to extract and process data from social networks and perform SA on a given topic. The approaches, methods and methodologies reviewed, provide a solution with a satisfactory degree of effectiveness in all cases, where high accuracy of classification depends upon the quality of selected features and classification algorithm used. The methodology to multilingual sentiment analysis provided by Goel et al. (2018), it's a reference for future experiments.

SVM and NB are recurrently used by the researchers as a reference model for comparing their proposed work. These two algorithms provide high accuracy with feature selection techniques. But, instead of relying on one method, studies have proven that combining both methods has better efficiency. Thus, in order to improve the outcome, it is recommended to combine both methods, lexicon and machine learning method, as it will complement each other, and the result is improved compared to using one approach only.

Based on the reviewed paper, twitter is the top social media platform used to collect information on user opinion. 85% of the reviewed papers, on this and the research reviewed in the cited studies, use twitter to collect information for sentiment analysis. In the same way, Facebook has the largest social media users in the world. But it is not very popular for sentiment analysis as the data is messy, it is not structured well, and people often use short forms and a lot of spelling errors. This makes the data harder to analyze.

The accuracy of the applied classification algorithms differs as a result of the size of the dataset, the topic being addressed, the complexity of the cultural and idiomatic lexicon, and the ML models with which the algorithm is combined. To the best of our knowledge and according our review, the ULMFiT model combined with SVM applied in the work of AlBadani et al. (2022), the BRDT developed by Alatabi and Abbas (2020) and the S-BERT with standard NN and the Universal sentence encoder with LSTM-NN explained by Cyril et al. (2021); are the algorithms that, according to the review carried out, have a better performance with an effectiveness between 98% and 99.8%.

For future recommendation, further investigation is needed to develop a universal model of sentiment analysis that can be applied to a different type of data, exploring other potential social networking sites to obtain users' opinion and expanding the context of sentiment analysis application.

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Chapter 5 Theoretical reflections on curricular evaluation from a critical perspective

Capítulo 5 Reflexiones teóricas sobre la evaluación curricular desde una mirada crítica

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Abstract

It present the analysis and reflection on evaluation processes in higher education programs, postgraduate-doctoral level, sharpens the position regarding how research is constituted and formalized in and from the educational fact and curricular action within the training of professionals of education in the state of Chihuahua, promoting the improvement of the curriculum not only in initial training but for academic improvement whit a critical vision that guides evaluation in, from and with the design of postgraduate programs aimed at new researchers as generators of knowledge in the curriculum field. Theme object of analysis from the last century and the present. The work consists of an empirical analysis based on the content analysis methodology focused on research training and academic performance during the last year of the Doctorate in Education, based on the review, critical argumentation to enhance prospects for improvement for the next generation or generations.

Evaluation, Processes, Doctorate

Resumen

Presenta el análisis y la reflexión sobre procesos de evaluación en programas de educación superior, nivel de posgrado-doctorado, agudiza posicionarse respecto a cómo se constituye y formaliza la investigación en y desde el hecho educativo y acción curricular al interior de la formación de profesionales de la educación en el estado de Chihuahua, promoviéndose la mejora del currículo no sólo en la formación inicial sino para la superación académica con visión crítica orientadora de evaluación en, desde y con el diseño de programas de posgrado dirigido a nuevos investigadores como generadores de conocimiento en el campo del currículo. Tema objeto de análisis desde el siglo pasado y el presente. El trabajo consiste en un análisis empírico basado en la metodología de análisis de contenido centrado en formación investigativa y desempeño académico durante el último año de Doctorado en Educación, a partir de la revisión, la argumentación crítica para potenciar perspectivas de mejora para la próxima generación o generaciones.

Evaluación, Procesos, Doctorado

Introduction

The research evidences in a theoretical-practical and argumentative way the evaluation of the curriculum on: training and action to investigate processes that refer to and provide bases for questioning, analyzing and reflecting on challenges, difficulties, setbacks and vicissitudes to consolidate the conceptual structure that trains the researcher. This work is carried out by the 90th Academic Body of the Universidad Pedagogica Nacional (UPN) of Curriculum and Educational Innovation to assess the Doctorate in Education program and submit it to possible academic reorientation.

To activate research based on epistemological support, implies consolidating the gnoseological, ontological and teleological, to focus the investigative act on reality towards the search and creation of knowledge, through logical-reflexive and coherent explanation, which implies critically reasoned activities. So then, how to promote the link between the newcomer researcher and the researcher who generates knowledge in training institutions for this scientific activity, by contributing to the generation and application of new knowledge?

The product of this research is aimed at clarifying those difficulties and/or potentialities that students face when proposing, developing and explaining the research project with the support and tutorial accompaniment that later becomes the knowledge product to be socialized as a thesis.

The evidence produced in this object of inquiry provides details on the theoretical-methodological process for research training given its systematic complexity. The evidence reports concretize the references of experiences arisen and provided by each student during their transit and journey in the training of the Doctorate in Education program during the last year of curricular training.

The exercise is based on the argumentation of each individual case, the work of each student understood as an object of research that orientates, constitutes, organizes, validates, disposes, and builds based on the criticality of plans and programs generated and developed by the Universidad Pedagogica Nacional del Estado de Chihuahua, in the different units that offer said program. The logic exposed in previous paragraphs makes explicit the theoretical and reasoning support throughout the methodological evolution to obtain an academic degree in the doctoral program. Also, elucidates the necessary improvements for the student's academic reorientation.

Development

Theoretical foundations

The epistemological position registered in the doctorate program, contributes to the review, analysis, critique and assessment of both, the processes and products that the newcomer researcher has been producing as a student in training for the investigation of phenomena, situations, themes and problems of attention, solution and/or educational resolution. This is the vision of the emancipation of knowledge and science from the critical-social point of view.

Based on this epistemic position, the researcher in training decides on the gnoseological approaches and tools to explain the object to be investigated, which it is critical-dialectical when rescuing the vision of the other, the otherness for the constitution of the self and the individual that is mediated by the curriculum.

This evolution that sustains the act of theorizing and inquiring, binded in a parallel way, perceives reality as a concretion of totality, exposed through a holistic worldview at the same time that enables to generate knowledge through an essential path of scientific research.

Melchor's position (2003) before the knowledge and recognition of epistemology, allows having a reason based on the construction and building of knowledge where knowing the theory, its categories, the concepts involved, the elaborate scaffolding and its frameworks, facilitates the newcomer researcher to position oneself for the appropriation of the real. Reality is not only the mental representations that the person elaborates, but also the awareness of reflection on the concrete in mutant and dialectical time and space.

Every investigative act undertaken by the program under review, originates from the interest and motivation of the doctoral student. Due to the above, it is a priority to speed up knowing and recognizing which are the lines of generation and application of knowledge (LGAC) that are investigated and in which scientific activity is produced by the academics responsible for the program to train new researchers. The purpose is not to promote false expectations, fallacies and unreal imagination that disable the research apprentice.

Methodology

From the theoretical assumption of Díaz (2018), the implementation of content analysis is potentiated as a method for the review, analysis and reflection of the empirical evidence provided by the participating students with their information, all of them are students who are in the last semester of the Doctorate in Education program, located between the fifth and sixth semester of their academic training.

The students show qualities and patterns from their academic training prior to this program, as well as the professional profile from the educational level where they work, finding teachers of basic, secondary and higher education, therefore, their cultural wealth is multifaceted.

Among their training profile, supposed truths are coined from the peculiarity of their professional training characteristics that differentiate them and that emerge in the course of the in-depth interview carried out with each one. Each student decides to participate voluntarily and openly to provide information about their life experiences to train as researchers in the field of education.

This research approach is reported as a theoretical and methodological support for the analysis of the situational and contextual reality from the coherent explanation of the discourse expressed and experienced by each of the seven students. What is relevant and central to this methodology is that reality emerges from the text expressed by the participant, which is latent in each empirical contribution, since it is part of their life and professional training for both empirical and analytical inquiry.

To complement the methodological space, a focus group is implemented in which eight other students participate, to complement the phenomenon of investigating the reality that was being investigated, by assessing each of them their level of progress with reference to the curricular structure, the established contents, the sequence, progress and development achieved at the end of each semester, as well as the accompaniment in tutorials for the completion of the titling process. Here, the performance, endorsement and recognition of the curricular processes and products, in the course of the investigation, is experienced.

It is essential and important to rescue the narrative sense provided by the students in, during and closing the shared stories to demonstrate an expeditious analysis when narrating what has already been narrated, what happened within the context and from the context as a source and richness for their own formation in the field of the constitution of a real object to be investigated and specified in a knowledge product.

The participants are eight men, all of them work in higher education and seven women, one of them works in basic education, one in upper secondary education and the rest in higher education, who participate with interest to provide explicit information as evidence that allows substantial improvement of the current program and thereby, activating the titling process and professional training and that of subsequent generations. His age fluctuates between 43 and 55 years old.

Results

The construction of the results is presented in three categories whose analysis facilitates reflection based on the arguments expressed by the participants, in addition to the conceptual support that promotes the constitution and evaluation of the evidence, based on: The epistemological formation infrastructure of the process *of investigation; Investigative action in light of the construction of theoretical-practical tools; The capitalization of the time and the effort allocated to the training processes within the tutorial.*

The epistemological formation infrastructure of the research process

Training for research obliges to seek a building and/or constitution of basic education or secondary education and higher education professionals committed to the educational act, with a solid comprehensive training to model, plan and develop scientific and social knowledge, questioning, How is the scientific nature of knowledge generated and promoted? It is necessary an explanatory and conceptual action with theoretical flow as valid before scientific knowledge.

The constitutive role of theory cannot be ignored as the articulating axis in the formation of research, in the same way, the construction of categories and concepts in addition to the possible scaffolding that enables the logical and coherent explanation of the doing of science. The students report having these epistemological precisions about the generation of knowledge. Then, consolidating that clear epistemological and conceptual formation on knowledge makes it possible to discriminate between what happens, between what is thought and felt in reality itself and reality in the other or for the other.

The doctoral program that is being evaluated exemplifies the research training process, observing and identifying two versions to generate scientific activity, one as a methodological option based on an ontological and epistemological orientation under an implicit assumption, as indicated by De Miguel (2000), since from each methodological version there is a theoretical substratum that clearly emerges as a basis. On the other hand, when it is recognized paradigmatically that there is no paradigm that is superior to another, as the simple fact of conceiving reality in a different way, makes the way of investigating be located or positioned differently.

The program that is being evaluated exemplifies, in the research training process, two versions of generating scientific action; one as a methodological option based on an ontological and epistemological orientation in an implicit assumption, as indicated by De Miguel (2000), that based on each methodological version, there is a theoretical substratum that clearly emerges.

It is relevant in the work and space to promote research when it is recognized that paradigmatically there is no paradigm as superior to another, simply the fact of conceiving reality in a different way makes the way of investigating be located or positioned differently. No paradigm is more important than another, only the way in which science is carried out and knowledge is constructed or generated matters.

According to Verdú (2020), it has been argued that both the support of philosophy and methodology are essential in the training of every person who has learned to appropriate reality. Hence, the epistemological review during the first phase of the doctoral program favors the act of discerning, reasoning, reflecting as a philosophical act of the relationship with knowledge.

In this sense, Verdú (2020), states that a doctoral training must be consolidated based on the interference of scientific training in the matter of doing science, therefore, the generation between the new and the investigated is essential for the coexistence between the accepted and demanded.

The empowerment of investigative action guides towards a search for education that incubates the modification of reality. Hence the motto of UPN and UPNECH *Educar para transformar*. This explanatory logic demands a dialectical position, in which the differences between paradigms must be shared and allow delineating versions and/or promoting inter-games, alliances, orientations with different ontological and gnoseological positions of various theories for the transdisciplinary proposal that enables training to any investigator.

In the interviews, it appears that every student tends or is oriented to review the lines that require the implementation of a certain paradigm and the corresponding methods to outline the investigative work, they assure that a segregation or omission causes a detachment of the epistemological endorsement to be developed and complemented to provide meaning and originality to the process of investigation and construction of the object that is being known, or, to discover reality as a whole and, above all, to concretize that construction of knowledge, not only learning the construction of its investigation.

Both in the in-depth interviews and in the focus group, the students report that in-depth research training on the epistemological foundation guides the professionalization of researchers who prioritize their research activity based on complementarity and on the object of research the student decides to investigate.

Verdú (2020), refers to joint activity, such as the use of trust and teamwork for collaboration within the work teams session after session, among the students of each research object, since the team regroups and solves or guides in the resolution of doubts, raises concerns and generates possible solutions.

De la Cruz & Abreú (2017), declare the high level of demand experienced by doctoral students who are subjected to a high degree of ambivalence for and due to their training at the top of the educational pyramid to which they now belong, as well, each one manifests a differentiated degree of uncertainty due to the projects that are demanded of it.

The investigative action in light of the construction of tools for the capture of information

90 percent of the interviewees suppose that they have chosen a conceptual support referring to their research object since the very moment of inquiring, posing the question or questions that generate research or, at the moment of structuring the accurate approaches in the design of their protocol for the gather of information, without leaving aside the elements that forge the explanatory logic as a theoretical support of what is generated in the investigation.

Knowledge and learning are not the same, they are not synonymous, to the doctoral students, therefore, it is necessary to appropriate the research object and make it the object of their knowledge since every researcher is the one who needs the paradigm with which he performs and generates his object of knowledge. 100 percent of the students endorse that the link between the Academic Bodies and the knowledge production of new researchers provides tools for research training.

For the participants in the research, the act and effect of appropriating and feeling their research is no other feeling than appropriating reality through the construction of the object that is being known, therefore, each student demands a related formative action with skills and tools that combine the work of their tutor with him or her as an apprentice to investigate, or between pairs of newcomers researchers. The learning that is elaborated with the ideas of others and from the ideas of others generates a range of positions and decision-making where the integrality of thought is respected and critical thinking attached to analysis, reflection, argumentation is encouraged and the staging of what has been acquired.

The relevant in the generation of tools to process information, favors among students the implied use of the theoretical-conceptual and methodological domain that permeates the tutelary action of their thesis directors, therefore, an absence in this training results in an investigative fallacy.

The students in the focus group specify and ponder that the permanent and pressing activity for the training of students in and for research is established with the communication between the disciplinary knowledge of various computer programs for the process of analysis and systematization of the information that coins the construction of scaffolding, concepts and categories which are constructors of scientific knowledge.

The students in the focus group clarify that they are not used to self-training, self-learning; On the contrary, they find themselves hoping that whoever supposedly possesses knowledge will communicate it, in such a way that they generally wait for instructions to see and do as they are entrusted and assure what they are going to do, without promoting self-knowledge.

Capitalize the time and effort in the training processes within the tutoring

More than 75% of the students participating both in the in-depth interviews and in the focus group argue that the possibilities to increase investigative work require the constitution of academic networks in order to promote processes of inquiry and generation of knowledge for individual, personal and professional growth as students. This goal can be achieved by promoting work teams with national and international expert researchers, a condition that increases tools and access to national and international research, through groups and networks that favor the integration of formal work teams for the benefit of each student as a researcher.

Covarrubias (1995), expresses that every subject is constituted as a person through the multiple referents that permeate their consciousness from the planes of social and cultural reality. The human being is built from what lives in its context, becoming the sum and more than the sum of phenomena, because the person never stops changing, always remains in constant transformation, is an endless being forming and reforming in a day to day basis; so then, its process of building the object of knowledge is also in real and constant modification.

De la Cruz & Abreú (2017), point out that the training of any doctorate that seeks to generate a researcher profile for its students must rescue the research work as a generator of ambivalence and uncertainty during the preparation of the research project in which it is carried out whenever it is constituted in the space to direct and promote research autonomously.

For more than 85 percent of the students, this is the most weighty challenge, since they are not interested in generating discomfort and discontent by leaving their comfort zone and remaining in crisis and uncertainty that promotes inquiry and criticism.

Melchor (2003), De la Cruz (2017) reaffirm that the newcomer researcher requires competencies, skills and abilities, but above all, knowledge of an epistemological, ontological and paradigmatic nature that constitutes science and scientific knowledge. As for them, almost 100 percent of the participants reaffirm this position, but do not see it translated into their work to obtain the academic degree.

Financing

The researchers received no funding sources

Conclusions

This evaluative action obeyed the evaluation criteria, therefore, this research product is linked to the act of exercising the claim to improve the doctoral program in education focused on the curricular position, acting within the research practice that is shaping the doctoral candidate based on the progress of his research project, enabling the insertion of epistemological scaffolding that enriches the graduate profile of the Doctor in Education, through the implementation of complementary methodological processes with necessary agreements for its streamlining, likewise, to be able to restructure and provide feedback for the activation of tools of all kinds for the capture of information that focuses the role of the tutoring exercise. It is urgent to expand the accompaniment processes to expand the feedback in search of enrichment and professional improvement in research processes and products, which come together in a desired terminal efficiency. Since there is not a high degree rate, it is barely close to 30 percent.

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Chapter 6 Artisanal production of ink, recycling the waste applied in the softening process of Amate paper

Capítulo 6 Elaboración artesanal de tinta, reciclando los desechos aplicados en el proceso de ablandamiento del papel Amate

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Abstract

The elaboration of amate paper is a totally handmade process that is carried out in the indigenous communities that inhabit the Sierra Norte of the State of Puebla, within the production process a liquid desire (ink) is obtained, which is discarded in the sewers. and drains contributing to the contamination of rivers and soils of the Otomi indigenous community of San Pablito Pahuatlan. The present work seeks to take advantage of this residue by producing an ink that will be used in the first instance as: a) Input in pens, b) Input in ink injectors for printers, c) Screen printing: Preparation of party cards, thus ending the contamination of stagnant and fluvial rivers, in addition to storing the ink for the decorative painting of amate paper, benefiting the community by not generating excessive expenses in obtaining the same ink, and the environment by not disposing of the residue and providing it with second use. In this way, it seeks to train trained and qualified human capital with the capacity to innovate, adapt and develop new craft methodologies that allow the solution of existing problems in the indigenous community that is dedicated to producing amate paper.

Ink, Amate Paper, Indigenous Community

Resumen

La elaboración del papel amate es un proceso totalmente artesanal que se lleva a cabo en las comunidades indígenas que habitan la Sierra Norte del Estado de Puebla, dentro del proceso de producción se obtiene un desecho líquido (tinta), el cual es desechado en las cloacas y desagües contribuyendo a la contaminación de ríos y suelos de la comunidad indígena otomí de San Pablito Pahuatlan. El presente trabajo busca aprovechar este residuo produciendo una tinta que será utilizada en primera instancia como: a) Insumo en bolígrafos, b) Insumo en inyectores de tinta para impresoras, c) Serigrafía: Elaboración de tarjetas de fiesta., reduciendo así notablemente la contaminación de ríos y estancamientos fluviales, además de almacenar la tinta para la pintura decorativa de papel amate, beneficiando a la comunidad al no generar gastos innecesarios en la obtención de la misma tinta, y al medio ambiente al no desechar el residuo y brindarle un segundo uso. De esta manera, busca formar capital humano capacitado y calificado con capacidad de innovar, adaptar y desarrollar nuevas metodologías artesanales que permitan la solución de problemas existentes en la comunidad indígena que se dedica a producir papel amate.

Tinta, Papel Amate, Comunidad Indígena.

1. Introduction

The jonote tree grows in many places in Mexico and other countries. Jonote (Trema micrantha) has straight trunks and a broad crown with sufficient foliage to provide good shade for coffee plants. Its leaves are elongated, small and soft, its flowers are white, small and come out in groups. The fruits are very abundant, they appear as very small drupes that turn red when ripe and the birds like them as food. In the Sierra Norte de Puebla, the bark of these trees is used to make a very popular craft: Amate paper produced by ÑaÑhu-Otomi artisans from the town of San Pablito belonging to the municipality of Pahuatlán. In this activity of obtaining jonote bark, residents of towns belonging to the municipalities of Pahuatlán, Tlacuilotepec and Tlaxco, among others, participate.

The amate paper process is 100% handmade, its production process begins when the bark of the jonote tree is selected, it is boiled, rinsed, dried, worked and decorated with natural dyes. The production of amate paper, obtained from the bark of white and red jonotes, contaminates the environment of the San Pablito de Pahuatlán community, whose main economic activity is focused on the sale of this craft. And it is that, according to the study "Sustainability of the amate paper system in San Pablito, Pahuatlán, Puebla", published this year by Colpos Campus Montecillo, the manufacturing process does not meet some environmental protection requirements.

Amate paper is a type of paper of pre-Hispanic origin from Mesoamerica, it is made in an artisanal way, crushing the bark of the jonote, which is cooked in water with ash, lime and jonote bark, once this bark has been softened on liquid is discarded and dumped into the rivers of the community, causing them to dry up in addition to the loss of marine species found in these rivers, due to the chemical compounds that are being used in the softening process, this being a problem serious in the future for this community and its surroundings.

Faced with this problem, they have considered obtaining an ink that will be used in three main products: a) pens for the educational/school/professional area, b) Printers for the educational/school/professional area, c) Serigraphy (Invitations etc.), reducing the contamination of the rivers, the generation of the ink occurs through the development of two phases which are: Phase 1) Decrease in density by increasing temperature, Phase 2) Decrease in density using filtration, once it is The two mentioned phases were carried out, we proceed to select the phase that yields a density similar to that of commercial inks, for which the corresponding calculations are made to determine the density indices of each of the phases, to finish tests are carried out of writing that validate the quality of the ink made from the waste resulting from the process of making amate paper in the community of San Pablito Pahuatlan.

2. Objectives

2.1. General objective

Prepare an organic ink from the waste obtained from the processing of amate paper, to reduce the levels of contamination of rivers and fluvial stagnations in indigenous communities that speak the Otomi dialect, through an artisanal production process, to provide the community with productive systems that contribute to environmental improvement and the generation of new modalities of economic subsistence for the communal inhabitants.

2.2. Specific objectives

a) Learn about the amate paper production process.

b) Determine the existence of waste from the production of amate paper.

c) Ink production process.

d) ink validation

3. Justification

In Mexico and the world, in recent years, transformation processes have caused a growing generation of waste. Which, due to the lack of control and recycling places, are dumped in common areas, causing the contamination of soils, rivers and common spaces, where human beings cohabit. This problem represents a source of improvement, where various public organizations and Municipal, state, national and international private companies seek to propose and apply effective solutions to reduce the effect of this waste and generate awareness among the individuals who are participants. Taking into account the growing need to generate effective solutions, this work is carried out, which focuses on the elaboration of an ink, using the waste that results from the softening of amate paper, considered an artisan process that is carried out in the community. of San Pablito Pahuatlán.

San Pablito Pahuatlan is an Otomi community located in the Sierra Norte of the State of Puebla, with coordinates of longitude (dec): -98.161944 and Latitude (dec): 20.302222, this town is located at a median altitude of 1180 meters above sea level. sea. The main economic activity of this indigenous community is the manufacture of amate paper, in the experience of Fuentes (2019) the production of amate paper dates back to the 300s AD. C by the Mayans, in the Yucatan Peninsula and later in the years 1100 and 1300 the Aztecs used it for the placement of offerings to the deities of the culture, now in the Otomi culture the artisanal production was initially destined according to of the following two activities: 1) Making ritual objects, 2) Representing divinities through figures. Specifically, in this community the production of amate paper is valued from two perspectives, these are:

1. Market value as a craft product.

2. Sacred value

According to these two evaluations, the production of amate paper in this community is the main economic activity, originating high levels of production that bring with it higher rates of waste, taking into account that the production of amate paper uses a large amount of water, approximately 5 liters per kilo of jonote bark. This liquid waste, which contains chemicals and particles of organic material, is being dumped into rivers, causing a significant source of pollution.

As the community of San Pablito Pahuatlan is notorious, it does not profitably take advantage of the generation of waste resulting from the manufacture of amate paper, for which in the present work a viable solution is proposed through the production of quality ink from this waste, with the sustainability objective of reducing the amount of polluted water that is discharged into stormwater bodies, supporting the preservation of water quality and protecting aquatic ecosystems. In addition to contributing to a circular economy in the town, with the creation of a new product that results from the sustainable use of the waste generated, and the implementation of an artisan production process at low costs and easy to understand.

4. Theoretical framework

In order to understand the objective of this research, the theoretical foundations that support the artisan elaboration of organic ink using the waste applied in the softening process of Amate paper are described:

4.1. Community of San Pablito Pahuatlan

Considered an indigenous community because 99.70% belong to this cultural regime, while 86.50% speak the Otomi dialect (PueblosAmerica.com, 2023), for this reason it is named by the inhabitants as "Nvite", whose meaning in this same dialect is "At the foot of the hill", this community maintains a deep synergy between pre-Hispanic beliefs and Catholic worship, among the main activities that contribute to economic development are agriculture and the transformation of the bark of the jonote tree on amate paper (Díaz, 1988).

Regarding agriculture, the production of crops such as: sugar cane, peanuts, corn and coffee is observed, but the main activity is the production of amate paper, which is extracted from the jonote tree through an artisanal process inherited from the first inhabitants of the area up to the present.

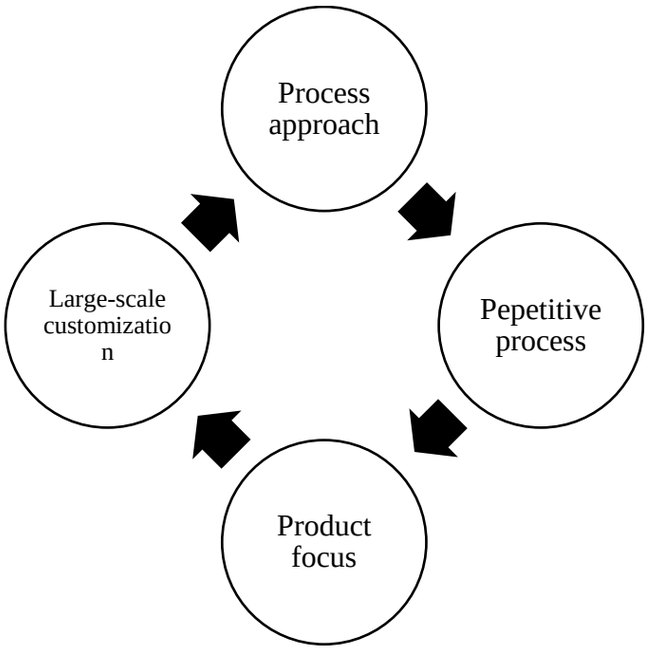
4.2. Artisan processes

A production system based on artisanal processes, according to the experience of Bustos (2009) consists of a methodology oriented towards obtaining products/services through manual techniques, with a minimum intervention of machines or tools, this type of process uses materials local raw materials and the production processes are transmitted from generation to generation, the characteristics that identify this process are: a) The artisan/producer intervenes in all stages of the process, b) Techniques based on ancestral knowledge are used, c) The processes imply longer production time, d) Lower amounts of investment are required for the generation of the product, 3) Sophisticated technology is not used, f) Manufacturing takes place in the producer's house or in small workshops.

4.2.1. Types or approaches of craft processes

Heizer and Render (2001) indicate that, according to the continuity of the process, these are classified into (Figure 1 Approaches to artisanal processes):

Figure 1 Approaches to artisanal processes



Source of Consultation: Own Elaboration

Bustos (2009), considers the general characteristics of the approaches according to the following description:

1. Process approach: This type of approach is identified as a production process that manufactures products in small quantities, but with different varieties. It is carried out mainly in workshops and its main characteristic is flexibility; it tends to be an intermittent methodology.

2. Repetitive process: This process is oriented to mass production, the characteristic that identifies it is the manufacture of large volumes of standardized products through a clear division of operations and little flexibility to change.

3. Product approach: This modality is known as a continuous process, dedicated to producing a large quantity of physical goods, but of a controlled variety.

4. Large-scale customization: Approach characterized by presenting high flexibility to new production processes, responsible for producing a wide variety of products, and in larger volumes.

According to the characteristics of the approaches, it can be deduced that the process applied for the elaboration of the ink is the process approach.

4.3. Matte paper (Processing)

To obtain the raw material, the artisans take the bark of the jonote tree, to process it, the following steps are carried out:

a) Boiling process: The bark of the jonote tree is placed in a container with water, lime is deposited on it, and it is boiled.

b) Cooling process: The bark of the jonote tree is allowed to cool at room temperature in a time interval of 12-48 hours.

c) Resting process: Once the bark of the tree has cooled, it is left to rest for a period of 2-3 days.

d) Compaction process: The crust is spread out on a clean surface, placed in thin layers (5-8 mm), and proceeded to flatten with the use of rocks of different sizes (volcanic rocks), this compaction process allows the formation of plates of different dimensions (according to the craft that was manufactured) (Fuentes and Jiménez, 2019).

e) Compaction process: The crust is spread out on a clean surface, placed in thin layers (5-8 mm), and proceeded to flatten with the use of rocks of different sizes (volcanic rocks), this compaction process allows the formation of plates of different dimensions (according to the craft that was manufactured) (Fuentes and Jiménez, 2019).

f) Drying process: The previously formed plates are placed under the sun, so that they dry completely, distributed sequentially.

g) Separation process: Each one of the layers is detached, in thin layers and sent to the transformation process, which follows different treatment methodologies, according to the craft that will be manufactured.

The manufacture of amate paper is considered an artistic technique from Mesoamerican cultures, it is a resource that symbolically represents the spirituality of indigenous communities (Pérez, 2021), and for the municipality of San Pablito Pahuatlan it is the cultural heritage that is inherited from generation to generation and represents a source of employment to support the families that produce it.

4.3.1 jonote tree

As previously mentioned, the main material for amate paper is the jonote tree (Trema micrantha) (Figure 2. Jonote tree), which is considered a tree for artisanal and medicinal use, used as weaving fiber, identified by growing in mostly within coffee plantations, this tree is characterized by:

a) It has a height of 12-14 meters.
b) The foliage shows a dark brown hue.
c) The foliage is composed of alternate ovate leaves up to 16 cm long and 14 cm wide, pointed with regular teeth.
d) Large inflorescence, measuring up to 15 cm long and 14 cm wide.
e) Circular dry fruit 5 mm long and 4 mm wide, and seeds with branched hairs on their surface.

Figure 2 Jonote tree

Source of Consultation: Own Elaboration

4.4. Waste

López (2003), indicates that the production of amate paper brings with it the generation of waste, due to the disposal of wastewater and the use of different inputs that are applied to reduce the resistance of the paper, it is convenient to mention that the diversity of The waste comes from the different amate paper production processes, such is the case of the boiling process, where the waste resulting from the cooking of the fibers has effects on the quality of the soil. These wastes, mostly made up of large amounts of fibers, firewood, ashes, water and dyes, are thrown freely into pluvial stagnations, causing a high rate of environmental impact.

4.4.1. Components of the main waste

The waste that is generated by the production of amate paper is the result of the conjunction of the following elements:

1. Caustic soda: This polluting element, made up of sodium hydroxide, is incorporated into the process to soften the bark of the jonote tree, in less time, seeking to reduce plate preparation times.

2. Chlorine: This chemical element is incorporated into the bleaching process, to obtain layers with greater bleaching, to be used in crafts for export.

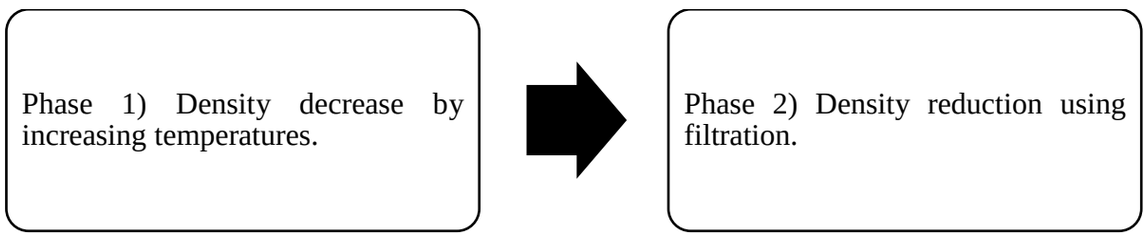
3. Lime: Calcium oxide is placed in the boiling preparation to soften the bark of the jonote tree, it is suggested by artisans that lime works as a softener, speeding up the softening process.

4. Dyes: Chemical elements that are used as a means of decoration for artistic design, are part of the final process, to provide aesthetics and a good presentation to the manufactured crafts.

5. Methodology to develop

The present work is developed through the intervention of the following two phases (Figure 3 Phases of intervention), these phases were carried out to select the phase that contributes significantly to the generation of the ink, which must comply with the density indices that identify commercial inks.

Figure 3 Phases of intervention



Source of Consultation: Own Elaboration

Phase 1) Density decrease by temperature increase

Bearing in mind that density is known as the relationship between the weight of a substance and the volume it occupies, we proceed to decrease the weight of the sample by increasing the temperature (Figure 4 Density decrease by temperature increase), considering the assumption that the density will decrease.

Figure 4 Density decrease by temperature increase

Source of Consultation: Own Elaboration

The aforementioned experiment is carried out for three replicates which are described below (Table 1 Replicate 1, Table 2 Replicate 2, Table 3 Replicate 3):

Table 1 Replicate 1

Operation	Activity description
1	Measure 100 milliliters of waste from the softening of the amate paper in a test tube, this measurement is called test 1.
2	Place test 1 in direct exposure to fire, with a maximum temperature range of 80° Celsius.
3	Weigh the material resulting from test 1.

Source of Consultation: Own Elaboration

Table 2 Replicate 2

Operation	Description of activity
1	Measure 100 milliliters of waste from the softening of the amate paper in a test tube, this measurement is called test 2.
2	Place test 1 in direct exposure to fire, with a maximum temperature range of 100° Celsius.
3	Weigh the material resulting from test 2.

Source of Consultation: Own Elaboration

Table 3 Replicate 3

Operation	Activity Description
1	Measure 100 milliliters of waste from the softening of the amate paper in a test tube, this measurement is called test 3.
2	Place test 1 in direct exposure to fire, with a maximum temperature range of 200° Celsius.
3	Weigh the material resulting from test 3.

Source of Consultation: Own Elaboration

When carrying out the previous replicas, we noticed that the loss of material is considerable, recording the following values for each replica (Table 4 Record of material decrease in replicas Phase 1):

Table 4 Record of material decrease in replicas Phase 1

Replica	Temperature (ºC)	Volume (ml)	% Decreasing	Weight (g)	% Decreasing
0	Room temperature	100	------	523	------
1	80	90	10%	451	13.76%
2	100	85	15%	446	14.72%
3	200	70	30%	420	19.63%
Average					

Source of Consultation: Own Elaboration

As is notorious, this method causes a minimum decrease in volume of 10% (Replica 1) and weight of 13.76% (Replica 1) with respect to the initial sample, for which the next phase is carried out, seeking to preserve a greater quantity of ink with the ideal characteristics for its usability.

Phase 2) Density reduction using filtration

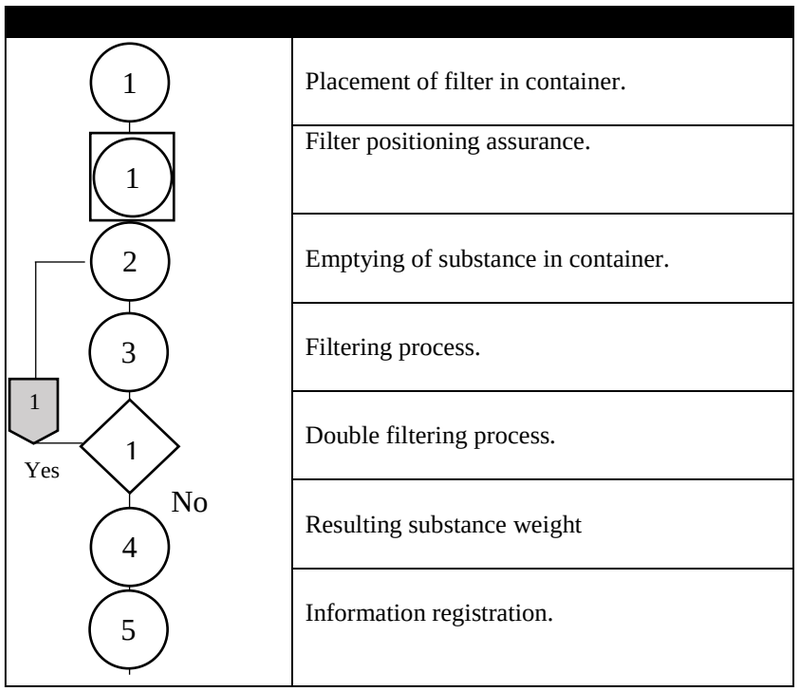
Filtration is a process that is responsible for separating the solid particles present in a liquid through a porous material called filter paper. This process (Figure 5 Density reduction using filtration) allowed within the present work to obtain ink free of impurities or external agents that contaminate the safety of the product.

Figure 5 Density reduction using filtration

Source of Consultation: Own Elaboration

Taking into account the aforementioned, a sequence of 3 replicas was carried out through the following operational process (Figure 6 Process diagram for carrying out phase 2 replicas):

Figure 6 Process diagram for carrying out phase 2 replicas



Source of Consultation: Own Elaboration

The general observations of each replicate are explained below:

Replication 1) For this first replica, the type of filter used is the one commercially known as Superabsorbent Polymer (SAP), which is used for its excellent capacity to retain moisture, the filtering process is carried out correctly following the indicated operational sequence. , but at the end of the weighing process, the loss of liquid substance was observed by 40% (Table 5 Record of decremental material from replicas Phase 2).

Replication 2) For this second replica, filter paper was used, observing a high degree of effectiveness when carrying out the filtering process only once, at the end of the weighing process (Figure 7 Phase 2 weighing process) a loss of material was recorded of 6 %.

Figure 7 Phase 2 weighing process

Source of Consultation: Own Elaboration

Replication 3) This third replica was carried out by means of a double filtration, obtaining a 12% decrease in the liquid substance (Table 5 Record of decremental material from replicas Phase 2).

Table 5 Record of decremental material from replicas Phase 2

Filtration	Volume (ml)	% Decreasing	Weight (g)	% Decreasing
0	**100**	------	**523**	------
1	60	40%	300	42.63%
2	94	6%	456	12.87%
3	88	12%	354	32.31%
Average		19.33%	Average	29.27%

Source of Consultation: Own Elaboration

The results obtained indicate a minimum volume decrease of 6% for replicate 2, while the minimum decrease in weight is 12.87% for replicate 2.

6. Results

The quantitative results observed for each of the samples are subjected to mathematical calculations to determine the density index, using the formula Density=mass/volume, for Phase 1 the results are shown below (Table 6 Results of Phase 1) Decrease in density by increasing temperature):

Result 1

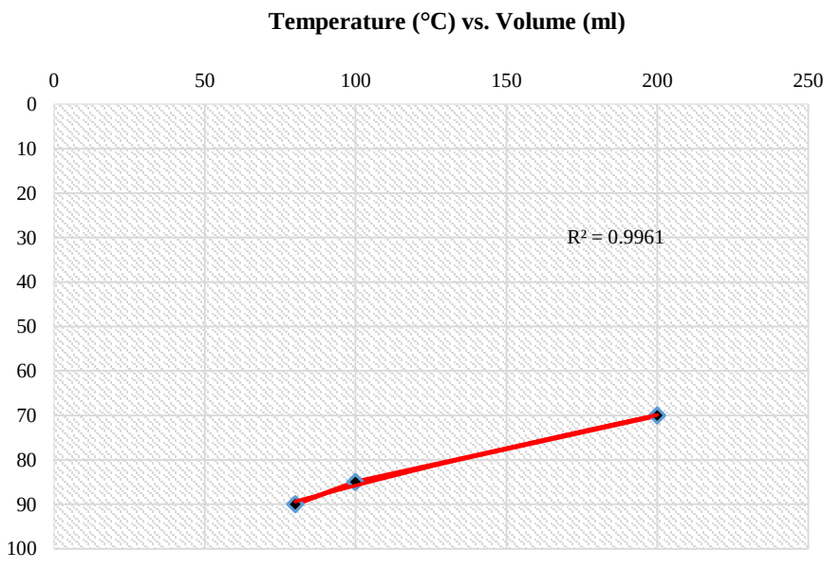
Table 6 Results of Phase 1) Decrease in density by increasing temperature

Replica	Temperature (º C)	Volume (ml)	Weight (g)	calculations d=mass/volume	Density (g/ml)	% Increase
1	80	90	451	451/90	5.01g/ml	0%
2	100	85	446	446/85	5.24g/ml	4.59%
3	200	70	420	420/70	6.0g/ ml	14.50%

Source of Consultation: Own Elaboration

Once the density has been calculated, a statistical analysis is carried out to verify which of the three replicas for this phase is the one that would contribute to a greater generation of ink with optimal density characteristics, which meet the writing requirements of the main consumers. In the first instance, the existing correlation between the supplied temperature (80°, 100°, 200°) with the resulting volume is analyzed (Graph 1 Correlation Temperature (°C) vs. Volume (ml)).

Graph 1 Correlation Temperature (°C) vs. Volume (ml)

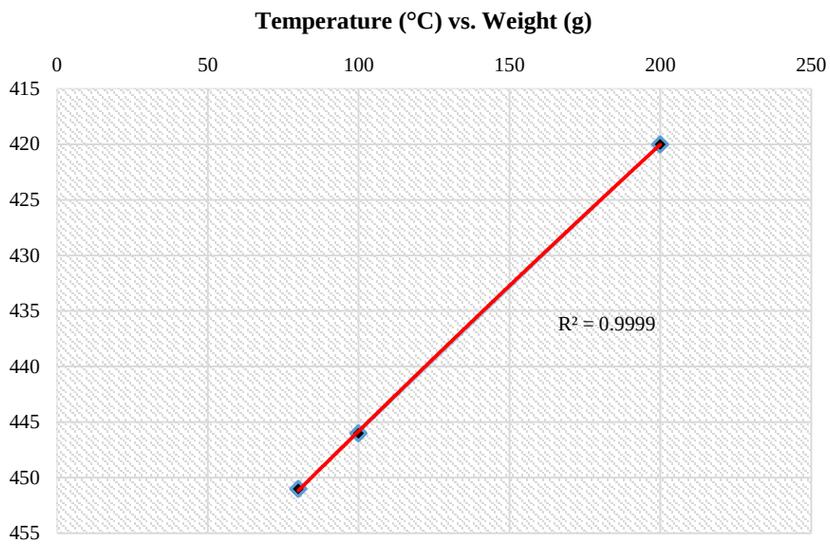


Source of Consultation: Own Elaboration

The existing correlation between the temperature and the volume indicates that the higher the temperature, the lower the resulting ink volume will be, with an R ^{2} of 0.9961, confirming that this type of experiment generates considerable losses for the final product.

Continuing with the analysis, we proceed to carry out the study that evaluates the action of temperature with the total weight (g) recorded at the end of the experiment (Graph 2 Correlation Temperature (°C) vs. Weight (g)).

Graph 2 Correlation Temperature (°C) vs. Weight (g)

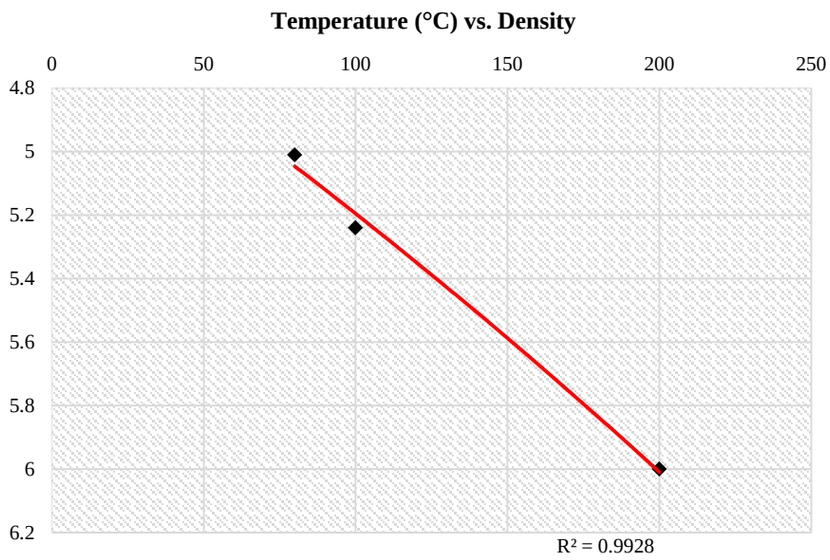


Source of Consultation: Own Elaboration

The existing correlation between the temperature and the weight (g) indicates that the higher the temperature, the lower the total weight of the resulting ink will be, with an R 2 of 0.9999, $^{\text{confirming}}$ that this type of experiment generates considerable losses for the final product.

To finish this correlational analysis, the action of the heat input to the samples with respect to the resulting density is studied (Graph 3 Correlation Temperature (°C) vs. Density).

Graph 3 Correlation Temperature (°C) vs. Density



Source of Consultation: Own Elaboration

As we can see, the correlation indicates that the higher the temperature, the greater the density shown by the ink. However, in general and taking into account the statistical analysis carried out, it is concluded for this phase that:

1. The process of supplying heat causes volume loss of the ink.
2. The process of supplying heat brings with it quantifiable losses in the weight of the ink.
3. The process of supplying heat brings about a gradual rate of increase in the density factor, causing the ink to become less fluid.

Result 2

The results of Phase 2) Density reduction using filtration, shown below (Table 7 Results of Phase 2) Density reduction using filtration:

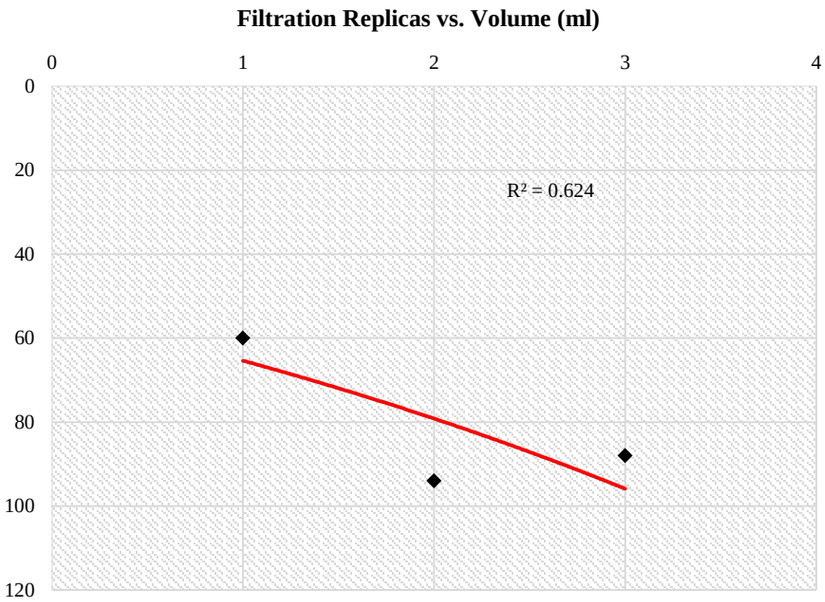
Table 7 Results of Phase 2) Density reduction using filtration

Filtration	Volume (ml)	Weight (g)	Calculations Density=mass/volume	Density (g/ml)
1	60	300	300/60	5.0g/ml
2	94	456	456/94	4.85g/ml
3	88	354	354/93	3.80g/ml

Source of Consultation: Own Elaboration

Once the density has been calculated using the filtration method, a statistical analysis is carried out to verify which of the three replicates for this phase is the one that would contribute to a greater generation of ink with optimal density characteristics, which meet the writing requirements of primary consumers. In the first instance, the existing correlation between the filtration replicas with the resulting volume is analyzed (Graph 4 Filtration Replicas vs. Volume (ml)).

Graph 4 Filtration Replicas vs. Volume (ml)

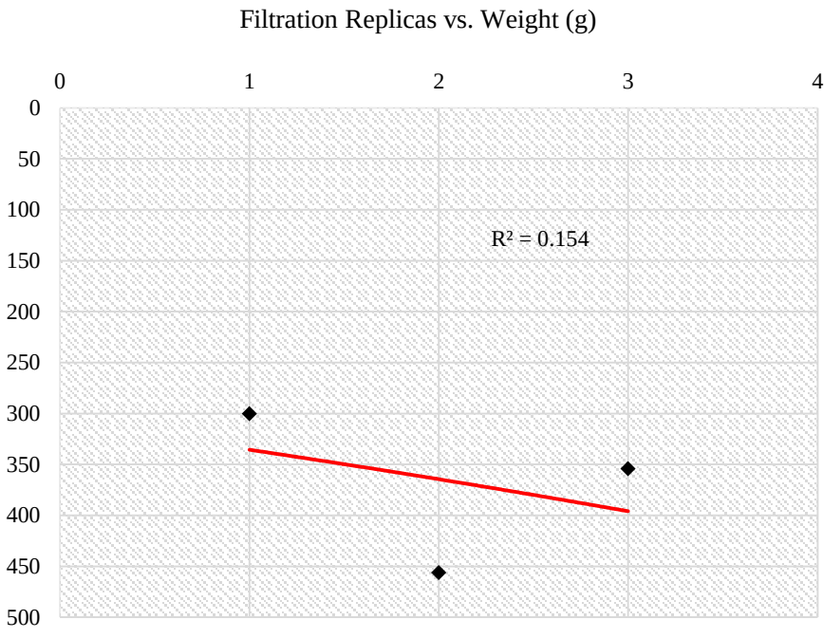


Source of Consultation: Own Elaboration

The existing correlation between the s replicates and the volume indicates that they are independent samples, confirming that each of the replicates used a similar method, but different filters, this is confirmed with $R^2 = 0.624$, for this reason the volume is affected independently. for each replica

Continuing with the analysis, we proceed to carry out the study that evaluates the action of each replica with the total weight (g) recorded at the end of the experiment (Graph 5 Filtration Replicas vs. Weight (g)).

Graph 5 Filtration Replicas vs. Weight (g)

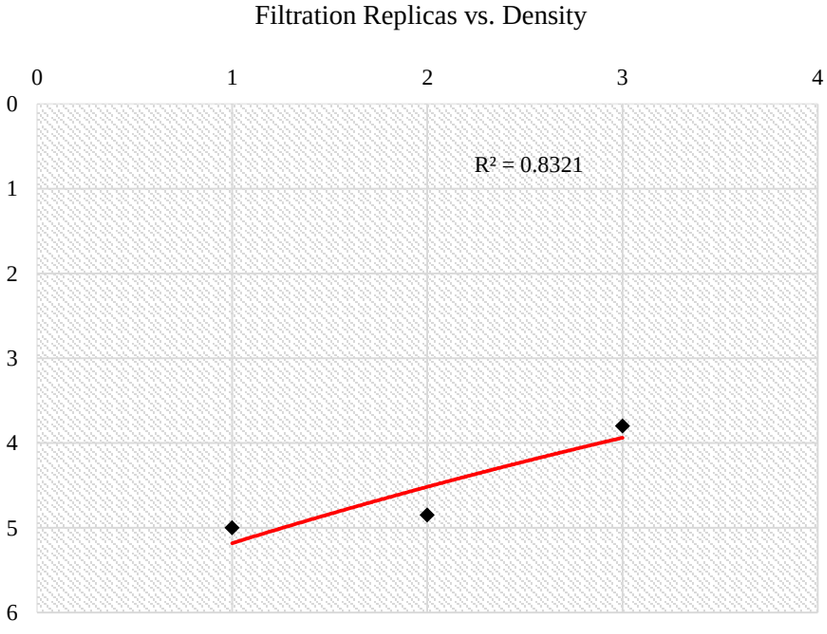


Source of Consultation: Own Elaboration

The existing correlation between the replicates and the weight indicates that they are independent samples, confirming that each of the replicates used a similar method, but different filters, this is confirmed with R 2 = 0.154, for this reason the weight is affected independently for each replica.

To finish this correlational analysis, the action of the filtering process on the samples is studied with respect to the resulting density (Graph 6 Filtration Replicas vs. Density).

Graph 6 Filtration Replicas vs. Density)



Source of Consultation: Own Elaboration

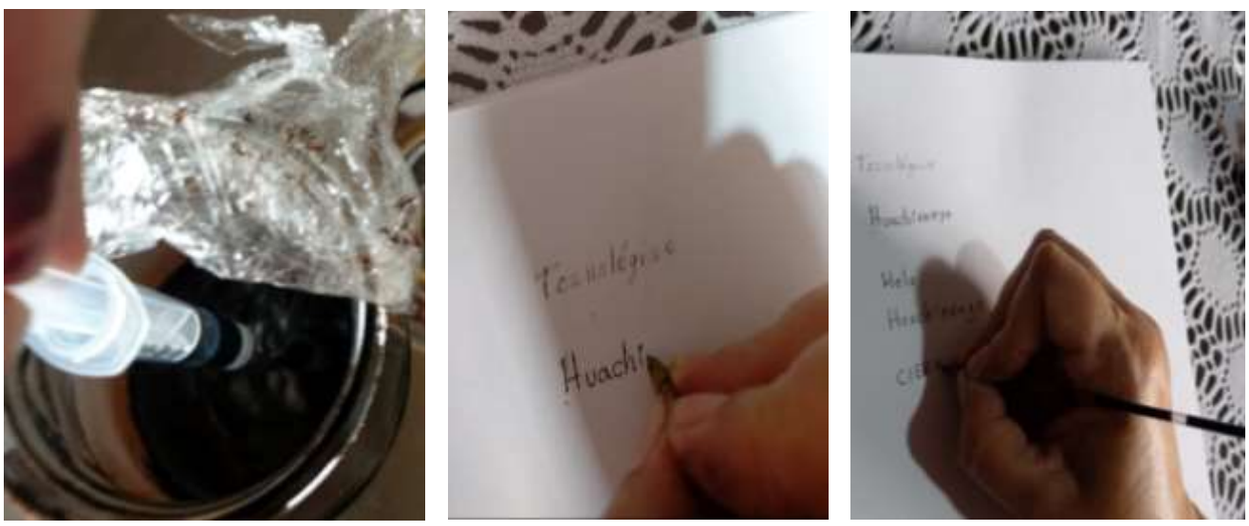
As we can see, the correlation indicates that the filtering process is independent for each replica, this in response to the fact that different filter materials were used, so the third test also underwent a double filtering process, for which the operating method is the same, evidencing an $R^2 = 0.8321$, but the means and decisions were made independently. The conclusion of the results obtained for this phase infers that with the process carried out a gradual decrease in the density index between each replica is reached, bringing with it ink with greater fluidity, in the same way it is notorious that there is less weight loss (12.87%). , volume (6%) (Table 5 Record of decremental material from replicas Phase 2).

Result 3 Obtaining ink

As stated in this paper, the use of ink is oriented to three main products: a) pens for the educational/school/professional area, b) Printers for the educational/school/professional area, c) Screen printing (Invitations etc.), for which we proceed to select the ink that will be useful, specifically the density for this type of products in dark tones (black) is established in an interval that goes from 1.40-2.80 (Grupohdflexo, 2023), therefore which ink that most closely matches this density value is the one obtained by the filtering process with replica model 3, which shows a density index of 3.80, this replica is characterized by having a double filter, considering this action, the possibility of performing 1 to 2 more filters to obtain the indicated index should be assessed.

Once the appropriate replica has been detected, the usability tests are carried out, which consisted of filling a pen, adding 2 milliliters of the selected ink, later writing was captured on a sheet of paper, obtaining positive results (optimal visibility of the characters written with the ink produced), as well as a good fluidity of the liquid inside the polypropylene tube (Ink replacement) was also observed (Figure 8 Ink use tests).

Figure 8 Ink use tests



Source of Consultation: Own Elaboration

5. Acknowledgments

We thank the Instituto Tecnológico Superior and the Division of Mechatronic Engineering, Electrical Engineering, Industrial Engineering and the community of San Pablito for their support in the development of the work presented.

6. Financing

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7. Conclusions

With the generation of this work, we direct our efforts to support the community of San Pablito located in the State of Puebla, which is characterized by developing the artisan productive activity oriented to the treatment of amate paper for the elaboration of handicrafts, considering during this process the detachment of organic waste that is thrown into the river flows, causing severe water pollution, for which the valuable utility of this waste has been detected for the creation of an ink, which is used in the educational, school and professional, either by the communal inhabitants or by external agents, taking into account this entrepreneurial idea, the generation of the ink was carried out, through two methodologies, the first artisan methodology is based on providing heat (Different temperatures) to the waste, in order to reduce the water content and promote an adequate density index, it is important to consider that this process was carried out through 3 replicates, whose results were submitted to a statistical analysis, indicating that by supplying heat, the following average losses: Volume 18.33%, weight 16.03%, in the same way a minimum density of 5.01 is obtained.

With respect to the second methodology, a filtering process is applied, making use of different materials such as filters, it should be noted that this method exposed an independent correlation with the following average losses: Volume 19.33%, weight 29.27%, in the same way a minimum density of 3.80 is obtained, as we can see in this second process the weight loss is greater, this in response to the fact that It is subjected to a second filtering, but it is also convenient to mention that this second filtering more assertively eliminates impurities and generates optimal fluidity of the ink. Prior to this analysis, it is concluded that the artisanal system that provides the greatest benefits is the filtration, with the replica 2 or replica 3 model, taking into account the level of density to be achieved (According to the product for which the ink is oriented).

Finally, it is concluded that an artisanal methodology has been created for the use of waste that currently causes pollution of rivers and fluvial slopes, this methodology is easily accessible and generates a sustainable product (Ink) that will bring with it: a) New sources of employment , for the producers of the exposed ink, b) Improvement and sanitation of rivers, and a continuous contribution of the community to the sustainable development of its inhabitants.

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Chapter 7 Determination of the correlation factor to achieve inference with greater certainty in the creation of 3D printed prototypes

Capítulo 7 Determinación del factor de correlación para lograr inferir con mayor certeza en la creación de prototipos impresos en 3D

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Abstract

3D printing strengthens the manufacturing and design area, since, given the possibility of making product models and prototypes with this technology, it saves on their production and on tests to improve them. The objective of this research is to find the correlation that exists between the models made with 3D Printing and their current materials and the prototype in question. Using a correlation study and physical stress tests, it was possible to obtain a correlation factor that when multiplied by the stress calculated by the SolidWorks Software, a more accurate value is obtained when the prototypes are manufactured.

Correlation Study, Tension Test, 3D Printing Models

Resumen

La impresión 3D fortalece el área de manufactura y diseño, ya que, dada la posibilidad de realizar modelos y prototipos de productos con esta tecnología, se ahorra en su producción y en pruebas para mejorarlos. El objetivo de esta investigación es encontrar la correlación que existe entre los modelos realizados con Impresión 3D y sus materiales actuales y el prototipo en cuestión. Mediante un estudio de correlación y pruebas físicas de tensión, se pudo obtener un factor de correlación que al multiplicarlo por la tensión calculada por el Software SolidWorks, se obtiene un valor más exacto al momento de fabricar los prototipos.

Estudio de correlación, Prueba de tensión, Modelos de impresión 3D

1. Introduction

With the invention of the 3D printer a world of possibilities opened up in the area of manufacturing and design, because even though design software can predict certain static, dynamic and kinematic behaviors, these have a margin of error and it is always better to evaluate in real conditions of both assembly and mechanical testing.

The application of 3D printing for polymers is one of the most widely used at present, but the performance of the elements printed with 3D printers manufactured as prototypes have resulted in very high margins of error with respect to the real state of the process or final product. It should be taken into account that there is no software with structural or functional studies of the 3D printing process, in addition to this, the 3D printing process is to some extent somewhat handmade, since the order, pattern and other printing parameters will depend on the element to be printed and the person who performs the operation.

When building prototypes with 3D printing, there is the problem that there is no test factor to be able to make prototypes that can predict the real behavior (or as close as possible to this). This research is done to decrease the cost of design errors and/or unexpected prototype behavior. This is beneficial for companies, because they will have more accurate data regarding mechanical stresses, which has a direct impact on costs, since it is not necessary to wait to manufacture a model or product, to know if it resists as planned and thus reduce future modifications to them.

1.1 Hypothesis

In the experiment the variable to be measured will be the tensile stress of specimens printed in 3D printer (solid) against the results calculated by spreadsheet and SolidWorks.

X_1= Calculated by spreadsheet and SolidWorks.
X_2=Probes manufactured with 3D printing.
σ= Tensile stress.

Once the variables have been identified it can be identified that:

The null hypothesis defines that, H_0= Both X_1 and X_2 resist the same tensile stress, in other words, there are no changes between the Solidworks simulation and the tensile test on the printed specimens.

$\sigma_{x1} = \sigma_{x2}$

The alternative hypothesis states, H_1=The tensile stress in X_1 is different from that in X_2, with this data a correlation factor can be created.

$\sigma_{x1} \neq \sigma_{x2}$

1.2 Contextual Background

With the advance of technology, inkjet printers were created in 1976, but it was not until 1984 when they began to transform to material printers. This implies a great leap in the manufacturing process because before there were only design softwares, where data is obtained based on statistics of physical tests but limited. With 3D printers it is possible to perform pilot runs and tests before obtaining the molds (exclusively of parts molded with polymers). This adds a new method to perform such process, the problem is that the current software does not have statistics of tests made with 3D printers. Cantrell, J. (2015).

2. Development of the study

2.1 Specimen design

For the specimen design, the DIN 50125 standard is taken as a reference, which is responsible for specifying the geometries and dimensions for mechanical tensile test specimens, these dimensions meet the specifications of the DIN EN 10002-1 standard, which is a standard intended for the creation of mechanical tests. DIN 50125:2004 defines eight types of specimens identified as A, B, C, D, E, F, G and H with the following characteristics:

- Type A. A specimen, of circular section and with smooth and cylindrical ends to be clamped in wedge grips.
- Type B. Test tube, circular section, with threaded ends.
- Type C. Probe, circular section, with shoulder ends.
- Type D. Probe, circular section, with tapered ends.
- Type E. Test piece, flat bar with ends for clamping in wedge grips.
- Type F. Tensile specimens.
- Type G. Tensile specimens.
- Type H. Test piece, flat bar with ends for clamping in wedge grips.

The standard also defines that these specimens must be marked (identification for the test), so that after the test they are identifiable if possible at both ends of the specimens. Based on the theory described above, specimen type E was defined for the method of fastening described in this specimen. In this type of specimen, 12 types of specimens with dimensions according to figure 1 are proposed.

Figure 1 Dimensions of type E tensile specimens.

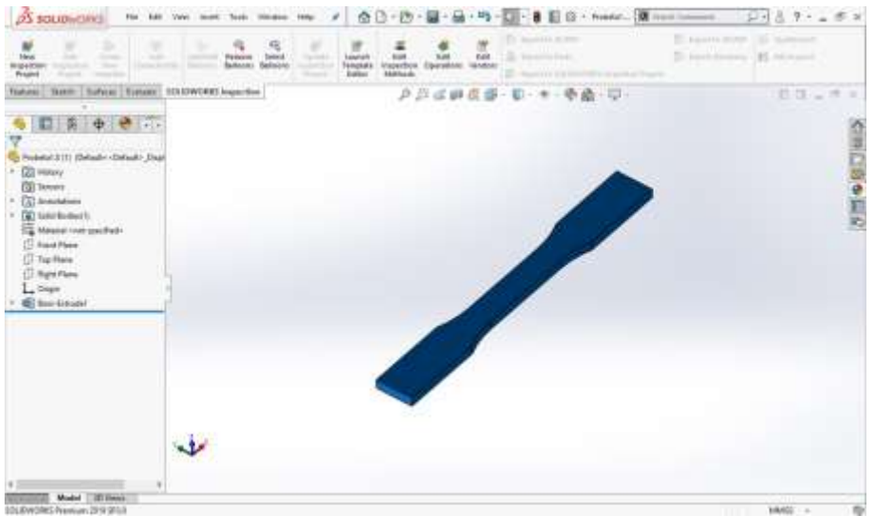
Dimensions in millimetres

a_o	b_o	L_o	R min.	r min.	h min.	L_c min.	L_t min.
3	8	30	12	12	26	38	104
4	10	35	15	12	30	45	120
5	10	40	15	12	30	51	126
5	16	50	22	15	40	64	162
6	20	60	27	15	50	77	197
7	22	70	29	20	55	89	222
8	25	80	33	20	60	102	246
10	25	90	33	20	60	114	258
10	30	100	40	25	70	126	296
12	26	100	34	25	65	127	285
15	30	120	40	25	70	152	322
18	30	130	40	25	70	165	335

Source: DIN 50125:2004

From the options corresponding to the type E specimen, the 3 mm thick specimen is selected, with the help of SolidWorks design software a mathematical model of the selected specimen was made, Figure 2.

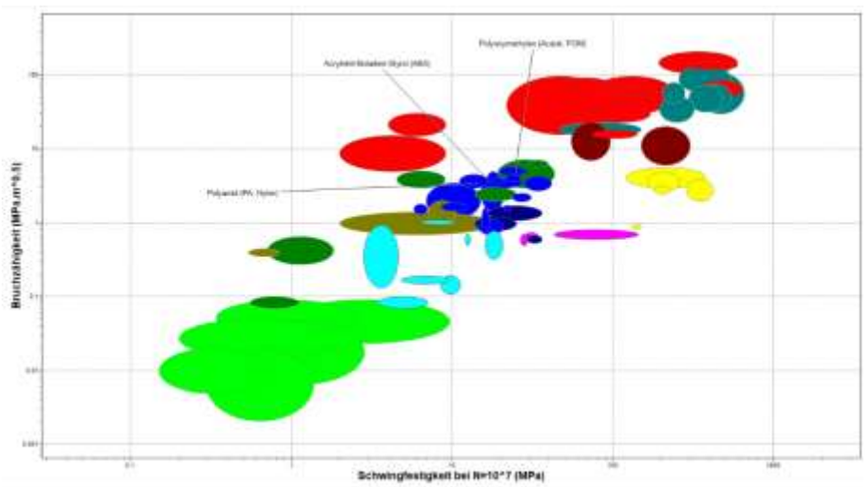
Figure 2 Mathematical model of the specimen in SolidWorks



2.2 Material selection

Within the 3D printing world there are many materials such as nylon, PVA, HIPS, ABS, PLA, Flexible, PETG and POM (polycetal). Of all these materials 3 have been selected, POM, ABS and PA Nylon, these were evaluated with the help of CES Edupack 2019 software which is a tool that allows comparing, with logarithmic scale graphs, the properties of the materials, the graphs of stress at break were obtained in Figure 3, elasticity in Figure 4 and traction in Figure 5.

Figure 3 Logarithmic graph of stress at break - cycles, Edupack Software



Source: Own Elaboration

Figure 4 Logarithmic graph of elasticity-cycles, Edupack Software

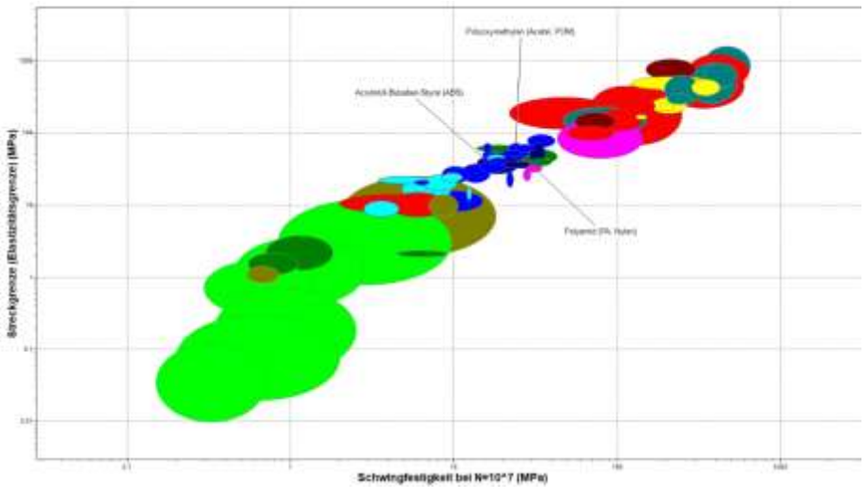


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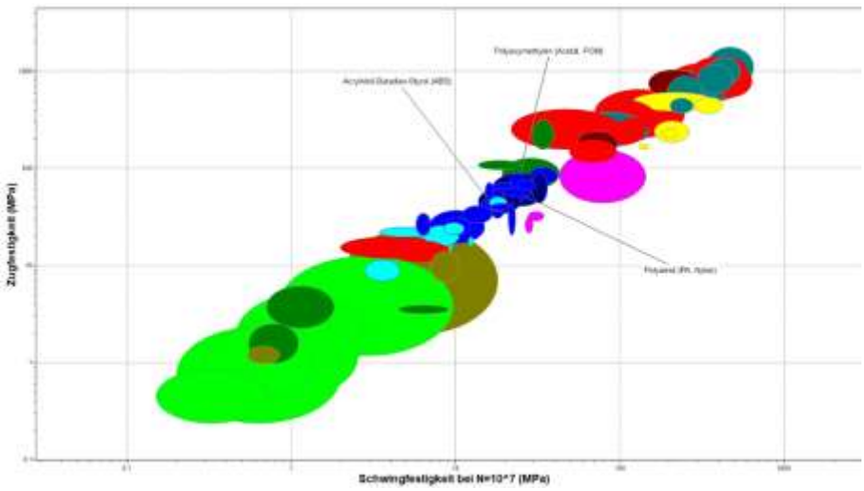
Figure 5 Logarithmic graph of stress-cycles, Edupack Software



Source: Own Elaboration

2.3 Printing of the specimen.

The printing of the specimens was performed with an Artillery Sidewinder-X_1 Figure 2 3D printer, it has an aluminum extrusion frame and filament sensor and power failure recovery, 300 x 300 x 400 cm.

The specifications for printing defined by the filament manufacturer are as follows:

– 1.75mm diameter with ±0.03mm variation.
– Hot bed necessarily between 90 and 110 degrees Celsius.
– Printing temperature between 230 and 250 degrees Celsius.

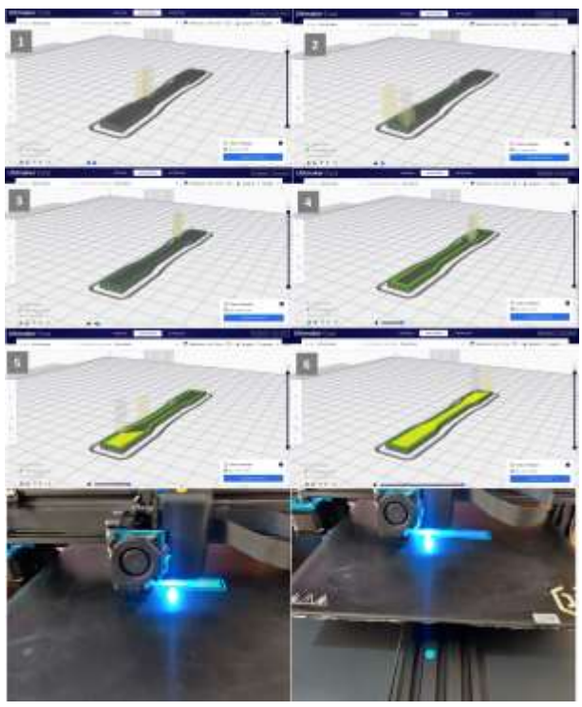
Based on the parameters delivered by the supplier, the specimen geometry and on the theory reviewed, the printing parameters defined in Table 1 have been defined, and with the printing flow shown in Figure 6. C, K. L. (2016).

Table 1 Printing parameters

Parameter	Specification	Unit of measurement
Bracket cantilever angle	45	grados
Support pattern	triángulos	
Support density	5	%
Support Z-distance	0.22	mm
Angle of support branches in the tree	45	grados
Distance of support branches in the tree	1	mm
Diameter of the support branches in the tree	2	mm
Diameter angle of the support on the tree	5	mm
Support placement	Everywhere	location
Printing temperature	240	C
Printing plate temperature	100	C
Printing speed	50	mm/s
Wall speed	25	mm/s
Outside wall speed	20	mm/s
Inner wall speed	25	mm/s

Source: Own Elaboration

Figure 6 Printing flow



Source: Own Elaboration

2.3 Simulation of the mathematical model of the specimen

With the help of SolidWorks design software, a tensile test simulation was performed on the three millimeter specimen E, with the results described in the, table 2, model information, table 3, material properties, table 4, fastening and applied load, table 5, mesh information, table 6, mesh information in detail and table 7, results of the study. Delfanian, B. R. (2016). Cody, S. (2019).

Table 2 Model information, SolidWorks

Model name: Probe E-3		
		
Solid body		
Item evaluated	Evaluated as	Properties
	Solid body	Mass: 0.00324637 kg Volume: 3.18271e-06 m^3 Density: 1.020 kg/m^3 Weight: 0.0318144 N

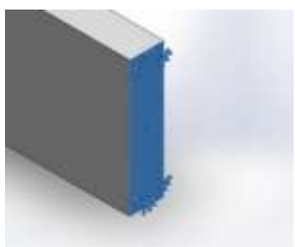
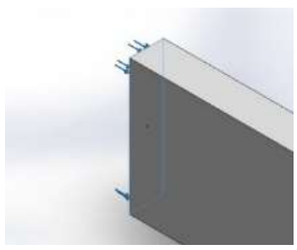
Source: Own Elaboration

Table 3 Material properties, SolidWorks

Reference model	Properties
	Name: ABS. Type of model: Linear isotropic elastic. Tensile stress: 3e+07 N/m^2

Source: Own Elaboration

Table 4 Fastening and applied load, SolidWorks

Fixing name	Fixing image	Fixing details
Fixing		Entities: 1 side. Type: Fixed geometry.
Cargo name	Image of the load	**Cargo details**
Force		Entities: 1 side. Type: Apply normal force. Value: 5,000 N

Source: Own Elaboration

Table 5 Mesh information, SolidWorks

Type of mesh:	Solid mesh
Meshing used:	Standard mesh
Jacobin stitches:	4 stitches
Element size:	1.47158 mm
Tolerance:	0.0735788 mm
Mesh plot quality:	High

Source: Own Elaboration

Table 6 Mesh detail information, SolidWorks

Total, of nodes	12052
Total, of elements	7007
Maximum aspect ratio	3.8612
% of elements with aspect < 3	99.9
% of elements with aspect > 10	0
% distortion of elements (Jacobin)	0

Source: Own Elaboration

Table 7 Results of the study, SolidWorks

Name	Type	Min	Max
Traction	VON: Von Mises Tracción	3.920e+07 N/m^2 Node: 77	2.297e+08 N/ m^2 Node: 488

Source: Own Elaboration

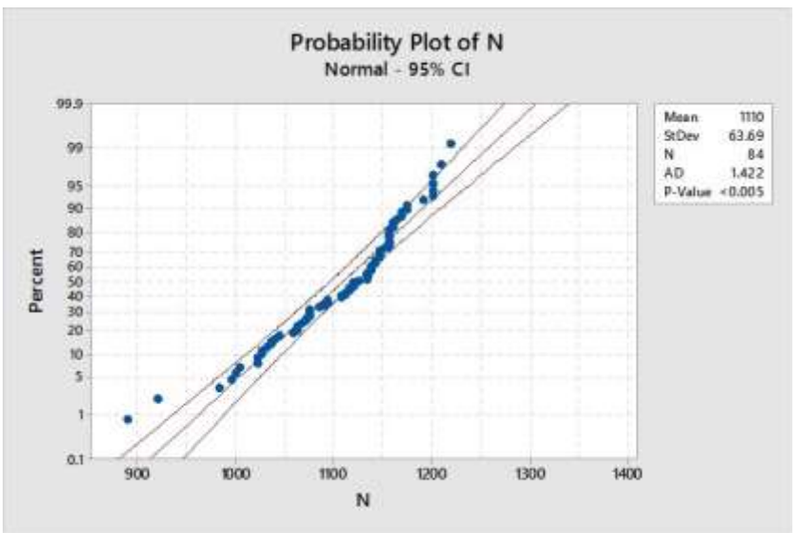
3. Results

3.1 Normality test of the data.

In order to infer in the results of the study, the distribution of the data must be normal, therefore a linearity analysis was performed with the help of Minitab 17 software, in which the data corresponding to the forces necessary to achieve the rupture in the specimens evaluated were used.

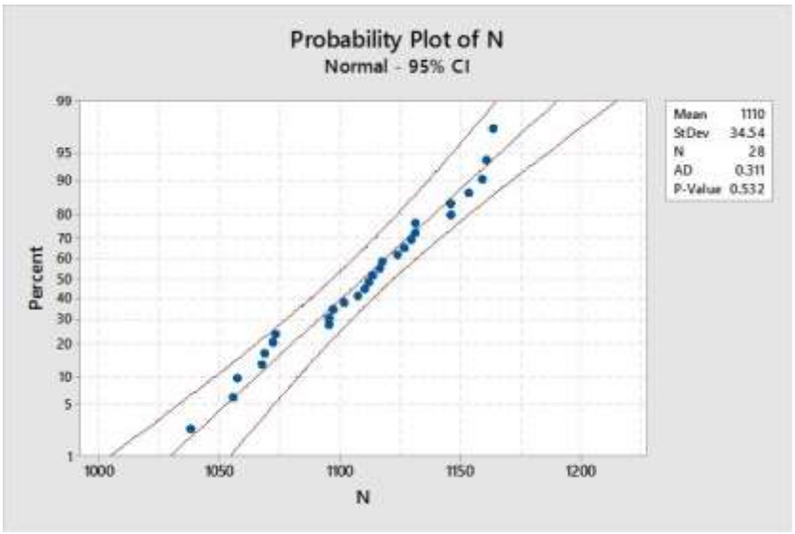
After the linearity test, Figure 6, the P value shows a result of <0.005, for the distribution of the values to be normal it needs to have a P value > at a significance level of 0.05 and as in this case it is lower the data does not follow a normal distribution.

Figure 6 Linearity study 1



To be able to infer in these data it is important to normalize them, which is achieved by creating subgroups, of the 84 samples to which the tensile test was performed were divided into subgroups of 3 pieces to achieve that the data are normal, Figure 7, in this way to infer in these data. In this second linearity test a P value of 0.532 is shown. Being greater than 0.05, it confirms that the values are normal and in this way it can be inferred in these.

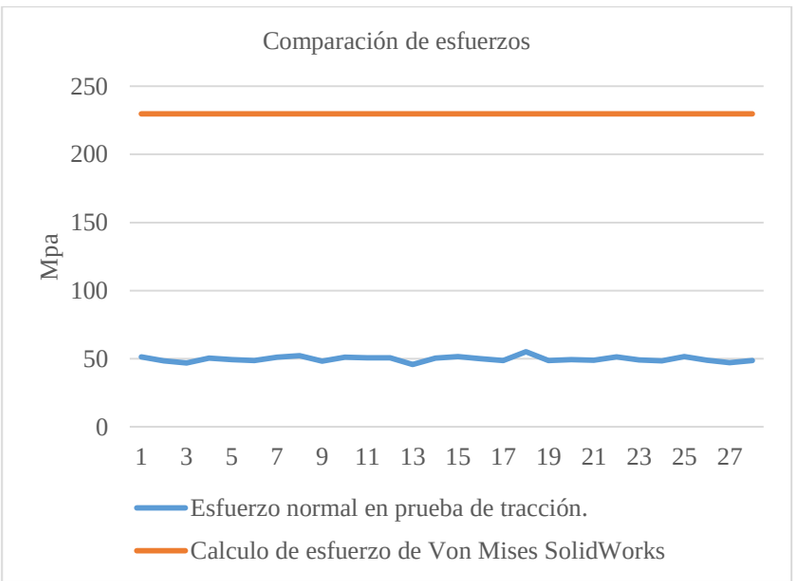
Figure 7 Linearity test 2



3.2 Comparison of calculations against test results

The following graph 1 shows the results of the tests against the stress calculated by the Von Mises method in SoldWorks.

Graph 1 Results of tensile test against Von Mises in SolidWorks.



4. Conclusions and recommendations

The study has a large number of variables, such as 3D printing method, specimen dimensions and material specifications, since the filament suppliers do not show the mechanical properties of their products, only the recommended parameters to use them and some properties by attributes.

The results found in the specimens after the test show a clear effect of the manufacturing method, i.e. the adhesion between filaments is much lower than the adhesion by casting since in the latter the molecules can join internally and accommodate their structures in the case of ABS in an amorphous form while, although the filaments are still amorphous, in 3D printing the union is only external.

Therefore, the null hypothesis is discarded and the alternative hypothesis is approved, which establishes that the tensile stress in X_1 would be different from that of X_2, with this data a correlation factor can be created.

$\sigma_{x1} < \sigma_{x2}$

And the values of these two stresses are substituted.

$\sigma_{x1} = 50\ Mpa < \sigma_{x2} = 229\ Mpa$

Then it would be possible to define a correlation factor, assuming that the normal stress supported by the specimens only reached 21.83% of the one recommended by the software, therefore the following correlation could be established.

"If the tensile stress calculated by the SolidWorks software is multiplied by a factor of 0.2183, this would be a value closer to the actual value when creating the prototypes."

This is just one advance in this field that has great opportunity for improvement, the next step should be to mold the parts and perform the tensile tests to find a factor that could be used in the design software and thus be able to predict behaviors in prototype parts.

It would also help to increase the sample size to reduce uncertainty and to define a printing pattern that distributes the applied stresses in an equitable way if possible, since in the prototypes these printing patterns will probably be modified and all the results will be affected by this factor.

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Chapter 8 Obtaining Biodiesel from waste cooking oil using MOF-Zn-II as a heterogeneous acid catalyst

Capítulo 8 Obtención de biodiésel a partir de aceite usado de cocina utilizando el MOF-Zn-II como catalizador ácido heterogéneo

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Abstract

The metal-organic structure [{Zn(O_2CCH_3)$_2$}(m-bpe)]$_n$, MOF-Zn-II, was evaluated as a heterogeneous acid catalyst in the production of biodiesel by simultaneous esterification and transesterification of waste cooking oil from a hamburger restaurant. At reaction conditions of 140 °C, 7.5 h, molar ratio MeOH:Oil 24:1 and 1 % w/w catalyst, the yield of methyl esters reaches 94.31 %. The values of the parameters of the obtained biodiesel, such as acid number, viscosity, and density, were among those established in the ASTM D6751 and ASTM D1298 standards. In addition, MOF-Zn-II is a material that can be recovered and reused during three reaction cycles without significantly decreasing the performance of methyl esters. Consequently, MOF-Zn-II can be used as a catalyst in the production process of biodiesel from waste cooking oil, since the obtained biodiesel not only meets the specifications required to be sell, but is also obtained from waste raw materials, besides contributing to sustainability and the protection of the environment.

Metal-Organic Framework, Heterogeneous catalyst, Waste cooking oil, Esterification

Resumen

La estructura metal-orgánica [{Zn(O_2CCH_3)$_2$}(m-bpe)]$_n$, MOF-Zn-II, fue evaluada como catalizador ácido heterogéneo en la producción de biodiesel mediante la esterificación y transesterificación simultánea de aceite usado de cocina, proveniente de un restaurante de hamburguesas. Se encontró que, a condiciones de reacción de 140 °C, 7.5 h, relación molar MeOH:Aceite (24:1) y 1 % p/p de catalizador, el rendimiento de los ésteres metílicos alcanza el 94.31 %. Los valores de los parámetros del biodiesel obtenido, como índice de acidez, viscosidad y densidad se encontraron entre los establecidos en los estándares ASTM D6751 y ASTM D1298. Además, el MOF-Zn-II es un material que puede recuperarse y reutilizarse durante tres ciclos de reacción sin que disminuya de forma significativa el rendimiento de los ésteres metílicos. Por lo tanto, el MOF-Zn-II puede ser usado como catalizador en el proceso de producción de biodiesel a partir de aceite usado de cocina, dado que el biodiesel obtenido no solo cumple las especificaciones requeridas en el mercado para comercializarlo, sino también se obtiene de materias primas de desecho, contribuyendo a la sustentabilidad y al cuidado del medio ambiente.

Estructura Metal-Orgánica, Catalizador heterogéneo, Aceite usado de cocina, Esterificación

1. Introduction

Edible vegetable oils are used for cooking and most of them are disposed of in landfills, drains or soil, creating different environmental problems (Monika et al., 2023). These are heated to temperatures between 160 and 190 °C for relatively long times, which causes them to undergo physical and chemical changes, such as an increase in viscosity and specific heat, changes in surface tension and color, as well as a decrease in the smoke point, i.e., the point at which the oil decomposes and loses its nutritional properties, generating an unpleasant odor and taste. Similarly, due to the high temperatures, the oil undergoes thermal oxidation, generating the formation of free radicals, causing damage at the cellular and molecular level, which makes it dangerous for human consumption (Lam et al., 2010). According to Profeco (2019), each Mexican consumes approximately 10 L of oil per year, with soybean oil being the most used (31%) and then canola oil (18%). In addition, it is in homes where the largest amount of vegetable oil is consumed (more than 80 %), the rest comes from food preparation establishments, such as restaurants and bars. If this oil is poured into drains or sewers, it can clog them and generate problems of bad odor, waterlogging and flooding, among others (Mandolesi De Araújo et al., 2013).

On the other hand, the high consumption of fossil fuels brings with it pollution problems, such as the emission of greenhouse gases, acid rain and global warming, which leads to the search for alternative fuels from renewable sources, such as biodiesel, which has gained great interest as a substitute for petroleum diesel due to the similarity between their properties. Therefore, an alternative for the production of third-generation biodiesel is used cooking oil, because it would overcome the problems faced by the raw materials of previous generations that influence the food chain, availability, flexibility with environmental parameters and economic viability. Coupled with this, the burden of waste management and water pollution would be decreased (Singh et al., 2020).

Homogeneous and heterogeneous catalysts are used in the transesterification process for biodiesel production. The traditional method uses basic homogeneous catalysts, mainly sodium hydroxide (NaOH) and potassium hydroxide (KOH), and requires high quality raw materials (free fatty acid content < 3 %), such as edible vegetable oils, the use of which can generate competition with the food sector. Likewise, although homogeneous alkaline catalysis allows the use of low-quality raw materials (free fatty acid content > 3 %), such as used cooking oil, this would require pretreatment (esterification) to reduce the percentage of free fatty acids, thus avoiding undesired secondary reactions (saponification).

A solution to this problem would be the use of acid heterogeneous catalysts, with which it is possible to carry out the esterification and transesterification of the oil simultaneously, allowing the use of low quality raw materials. In addition, this type of catalysts can be easily separated from the reaction mixture, which allows their reuse and lowers production costs. An example of heterogeneous catalysts are metal organic frameworks (MOF), whose physicochemical properties (high surface area, pore size, high thermal stability, etc.) allow their use as catalysts.

Therefore, the capacity of MOF-Zn-II as a heterogeneous acid catalyst in the production of biodiesel from used cooking oil was evaluated. First, the used cooking oil was characterized to know its viability in obtaining biodiesel (acidity index, saponification index, kinematic viscosity, density, water content, free grade acids and molecular weight); and the effect of parameters such as temperature, amount of catalyst, methanol/oil ratio and reaction time in the production of biodiesel was evaluated: oil ratio and reaction time in the synthesis of biodiesel; the reuse of the catalyst in the simultaneous esterification and transesterification of used cooking oil; and finally, the physicochemical properties of the biodiesel obtained were determined.

2. Description of the method

2.1 Materials

Used cooking oil, originally canola oil, was provided by a hamburger restaurant. Prior to use, it was filtered and dried at 100 °C on a hot plate. The anhydrous reagent grade methanol, 99.8 %, was purchased from TECSIQUIM, S.A. de C.V. Zinc acetate and 4,4'-bipyridylethylene were from Sigma-Aldrich. For the autogenous pressure system, a Sigma-Aldrich glass ace pressure tube was used.

2.2. Obtaining the MOF-Zn-II catalyst

4,4'-bipyridylethylene (0.182 g, 1 mmol) in DMF (2 mL) was added to $Zn(O_2CCH_3)_2$-$2H_2O$ (0.220 g, 1 mmol) in DMF (4 mL), the white precipitate obtained was immediately separated by filtration and redissolved in hot water. The clear solution was filtered and allowed to evaporate slowly in order to crystallize the material, obtaining yellow crystals, which were separated and washed with ether and left to dry in the oven at 105 °C for 1 h (0.140 g, 36 %). Subsequently, the crystals were crushed to obtain a crystalline powder which was analyzed by infrared spectroscopy to corroborate its obtaining (Toh et al., 2005).

2.3 Obtaining biodiesel

In order to obtain biodiesel from used cooking oil with MOF-Zn-II as catalyst, different reaction conditions were evaluated, varying the temperature, the molar ratio MeOH:oil, amount of catalyst and reaction times, in order to obtain the best conditions that would generate the best yields (Table 1). The optimal conditions previously found in the research group for the production of biodiesel from canola oil using MOF-Zn-II were taken as starting conditions, which were T = 150 °C; molar ratio MeOH:Oil, 12:1; amount of catalyst (% w/w) = 0.68 and reaction time = 4.5 h (Arceo-Ruiz, 2016).

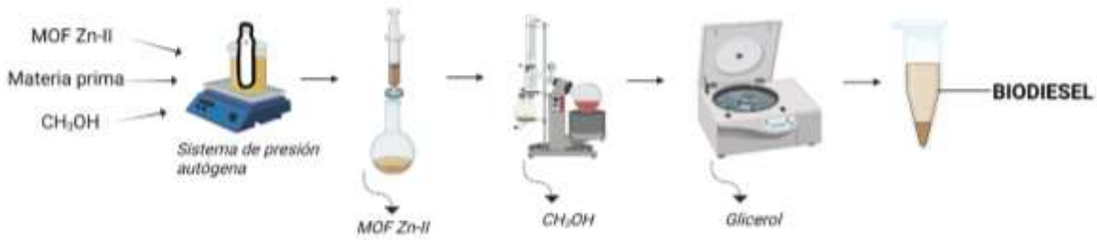
Table 1 Reaction conditions for the experiments conducted for the production of biodiesel with MOF

Variable parameter	No. Exp.	T (°C)	Molar ratio (MeOH:Oil)	Amount of catalyst (% w/w)	Reaction time (h)
Temperature	1	130			
	2	140	12:1	0.68	4.5
	3	150			
Molar ratio	4		12:1		
	5	140	24:1	0.68	4.5
	6		36.1		
	7		48.1		
Amount of catalyst	8			0.5	
	9	140	24:1	0.68	4.5
	10			1	
	11			1.2	
Reaction time	12				3
	13				4.5
	14	140	24:1	1	6
	15				7.5
	16				9

Source: Own Elaboration

For the transesterification reaction, a tube with an airtight lid fitted with a magnetic stirrer was used in duplicate, where 5 mL of the used cooking oil was placed and different amounts of anhydrous methanol and MOF-Zn-II were added, Table 1. To separate the biodiesel from the reaction mixture, first the catalyst was recovered by filtering the mixture obtained with a 20 µm Millipore membrane. Subsequently, with the aid of a rotary evaporator, methanol was separated from the reaction mixture (50 °C at 150 rpm). The product obtained was centrifuged at 12,500 rpm for 8 minutes, with the biodiesel at the top and the glycerol at the bottom. The general scheme of the methodology for obtaining biodiesel is shown in Figure 1.

Figure 1 Scheme of the methodology for obtaining biodiesel



Source of consultation: Own elaboration. Created with BioRender.com

2.4 Catalyst recovery

The catalyst recovered by membrane filtration of the reaction mixture was washed with hexane (10 mL) to remove traces of oil and biodiesel. Then, it was dried in the oven at 105 °C for 24 h.

2.5 Characterization of the biodiesel

2.5.1 Thin Layer Chromatography (TLC)

The reaction product was qualitatively analyzed by thin layer chromatography using silica gel plates. This procedure was carried out in order to determine if there was any conversion in the raw material (oil) to proceed with the quantitative analysis. For this purpose, a mixture of hexane, ethyl acetate and acetic acid in a 90:10:1 ratio was used as mobile phase; and a 50 % v/v solution of sulfuric acid with water was used as developer (Shah et al., 2004).

2.5.2 ^{1}H Nuclear Magnetic Resonance (^{1}H NMR)

One way to express the yield of biodiesel is as the percentage of fatty acid methyl esters, % MS, (Yang et al., 2016). So the yield was expressed as the percentage of methyl esters obtained from the triglycerides present in the oil, equation (1).

Triglycerides + $MeOH \rightleftharpoons$ methyl esters + glycerol

$$\% EM = \frac{\text{methyl esters } (mol)}{\text{triglycerides } (mol)} \quad (1)$$

The quantification of the methyl esters was performed using a Varian/Agilent 600 MHz spectrometer and $CDCl_3$ as solvent. The percentage was calculated using a ratio between the integration of the signal corresponding to the protons of triglycerides, I_{TG} (4.07-4.35 ppm) and methyl esters, I_{ME} (3.67 ppm); following equation (2) (Alegría et al., 2014).

$$X\ (\%) = \frac{4\ x\ I_{ME}}{4\ x\ I_{ME} + 9\ x\ I_{TG}}\ x\ 100 \quad (2)$$

Where the factor 4 refers to the four hydrogen atoms present in the two C-H bonds of the methylene groups in the triglycerides and the factor 9 comes from the hydrogen atoms in the three C-H bonds in each of the three methoxy groups, resulting from the transesterification of each triglyceride molecule.

2.5.3 Gas chromatography (GC)

The determination and quantification of methyl esters was performed using an Agilent gas chromatograph with mass detector, equipped with an SP-2560 column of 100 m length, 250 μm thickness and an internal diameter of 0.2 μm. Nitrogen was used as carrier gas, at a constant flow rate of 1 mL/min. Injections of the reaction products were 0.2 μL of sample. The oven temperature was set at an initial 150 °C, increasing 5 °C/min to 180 °C and remaining at this temperature for 10 min. Subsequently, the temperature was increased 5 °C/min until 240 °C was reached. The total time of the sample analysis was 38.2 min.

3. Results

3.1 Characterization of the raw material

The residual cooking oil used as raw material for the simultaneous esterification and transesterification reactions was characterized to determine its properties and quality (Table 2). It presented a percentage of free fatty acids (FFA) of 3.82 %. Alkaline catalysis requires an oil with a fatty acid percentage lower than 3 % (Sharma & Singh, 2009), so it is deduced that acid catalysis is the most viable method to carry out the transesterification of the oil.

Table 2 Characterization and composition of used cooking oil used as raw material

Parameter	Unit	Cooking oil used in this study	Blending of used soybean, canola and palm oils(Nadeem et al., 2014)
Acid value	mg KOH/g	6.70 ± 0.07	1.25
Saponification index	mg KOH/g	203.67 ± 2.31	200
Kinematic viscosity (40 °C)	mm^2/s	42.09 ± 0.01	42.5
Density (15 °C)	g/cm^3	0.93 ± 0.00	0.898
Water content	ppm	41.47 ± 0.45	-
AGL	%	3.82	2.5
Molecular weight	g/mol	854.44	835

Source: Own Elaboration

The values of the parameters obtained presented values similar to those found in a study of a mixture of used oils (soybean, canola and palm) from various types of restaurants (Nadeem et al., 2014), except for the value of the acid value, which is approximately five times higher than that reported. Whereas, Mexican Standard NMX-F-101-SCFI-2012, defines the acid number or acid value as the milligrams of KOH needed to neutralize one gram of sample and is related to the amount of free fatty acids in the oil (FFA). In addition, the high temperatures of food cooking processes accelerate the hydrolysis of triglycerides and increase the amount of FFA (Vázquez-Garrido et al., 2023), therefore, the difference in the acid value of the samples could be attributed to the difference in the use of the oils, the one in this study comes only from a hamburger store. The average molecular weight (MPW) of the oil was calculated using equation (3), considering the saponification index (SI) and acidity index (AI) (Zhu et al., 2006).

$$PMP = (56.1)\,(1000)\left(\frac{3}{IS-IA}\right) \quad (3)$$

The fatty acid profile of the used cooking oil obtained in this study is presented in Table 3. It is observed that oleic acid predominates, i.e., there is a greater presence of monounsaturated fatty acids, comparing with the literature, a similar composition of a used cooking oil was found (Foroutan et al., 2019). This composition is preferably important to select an oil for biodiesel production (Aransiola et al., 2014).

Table 3 Fatty acid profile of cooking oil used as feedstock

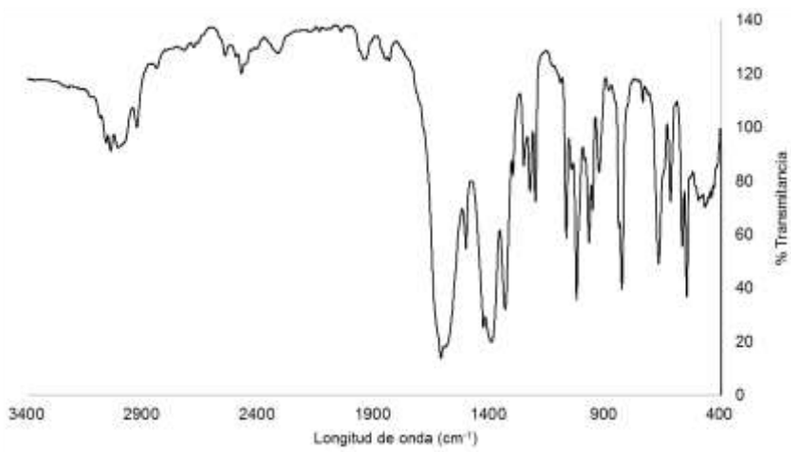
Fatty acid profile (%)	Oil used in this study (%)	Used cooking oil (Foroutan et al., 2019)
C 16:0 - Palmitic	8.48 ± 0.16	31.88
C 18:0 - Stearic	2.73 ± 0.04	6.45
C 18:1 - Oleic	66.79 ± 1.68	41.04
C 18:2 - Linoleic	20.14 ± 0.83	17.98
C:18:3 - Linolenic	1.86 ± 2.64	0.43

Source: Own Elaboration

3.2 Infrared (IR) spectroscopy of MOF-Zn-II

The IR spectrum of MOF-Zn-II is presented in Figure 2. The characteristic bands of pyridine C-H bond stretching were observed between 3000-3100 cm^{-1}, as well as CH_2- stretching of methylene groups between 2915 and 2935 cm^{-1}; at 1846 and 1948 cm^{-1} the bands corresponding to C-H stretching of aromatics are found. At approximately 1587 and 1359 cm^{-1} the bands corresponding to the asymmetric and symmetric stretching of the C-O bond of the carboxylate group attached to Zn are observed, respectively. Between 1274 and 1473 cm^{-1} is the C=N stretching band corresponding to pyridine, whose signal overlaps with the band corresponding to the symmetric C-O stretching (Toh et al., 2005).

Figure 2 Infrared spectrum of the MOF-Zn-II synthesized for the present study



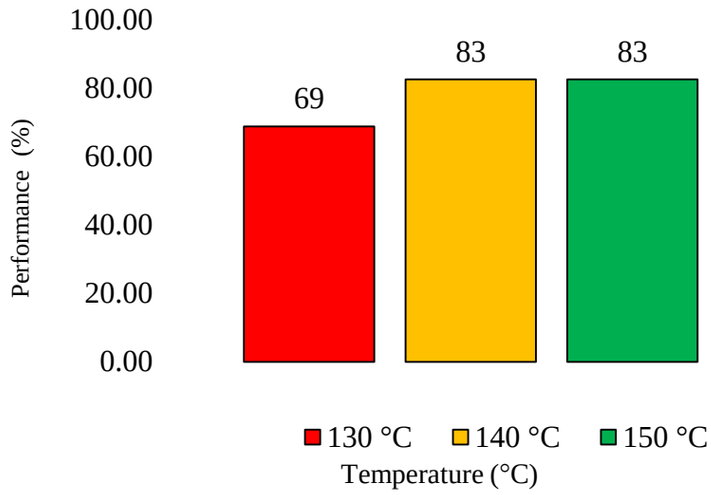
Source: Own Elaboration

3.3 Synthesis of biodiesel from used cooking oil using MOF-Zn-II

3.3.1. Temperature study

Reactions were carried out at 130, 140 and 150 °C, maintaining the optimum conditions reported in the previous study (4.5 h, molar ratio MeOH:Oil 12:1 and 0.68 % w/w of catalyst). The yields obtained for each temperature are shown in Graph 1. The yield at temperatures of 140 and 150 °C had similar values (82.65 and 82.68 %, respectively). A high reaction temperature facilitates mass transfer in the reactor and dispersion of the catalyst particles. However, a low temperature is considered economically more favorable since a lower amount of energy is required (Olutoye et al., 2016). Because of the above, the temperature of 140 °C was chosen to perform the reaction, due to the fact that it is the minimum temperature at which the maximum yield is also obtained.

Graph 1 Effect of temperature for obtaining biodiesel at 130, 140 and 150 °C

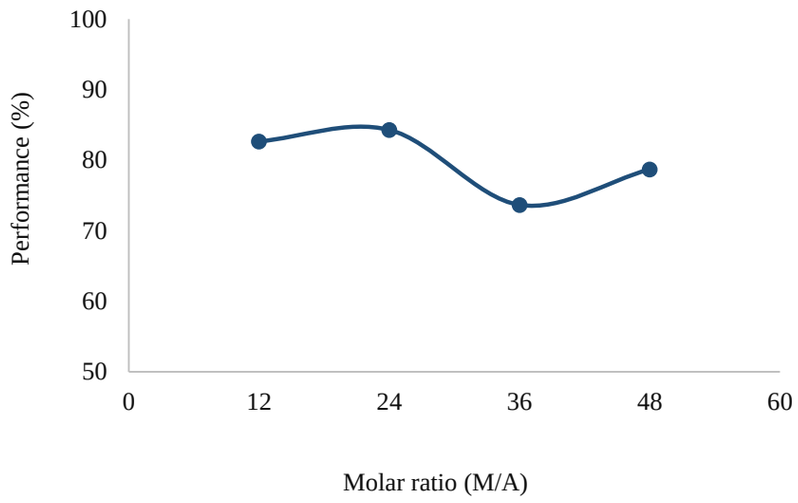


Source: Own Elaboration

3.3.2 MeOH: oil molar ratio study

With the temperature already established, the effect of the MeOH:Oil ratio on the transesterification of used cooking oil was evaluated. Reactions were carried out at molar ratios of 12:1, 24:1, 36:1 and 48:1, with 0.68 % w/w of catalyst, at 140 °C with reaction times of 4.5 h, Graph 2. The highest yield for this evaluation (84.28 %) was obtained when using the MeOH:Oil molar ratio of 24:1; increasing it (36:1) decreases the yield.

Graph 2 Evaluation of the molar ratio at 140 °C, 4.5 h with 0.68 % w/w catalyst



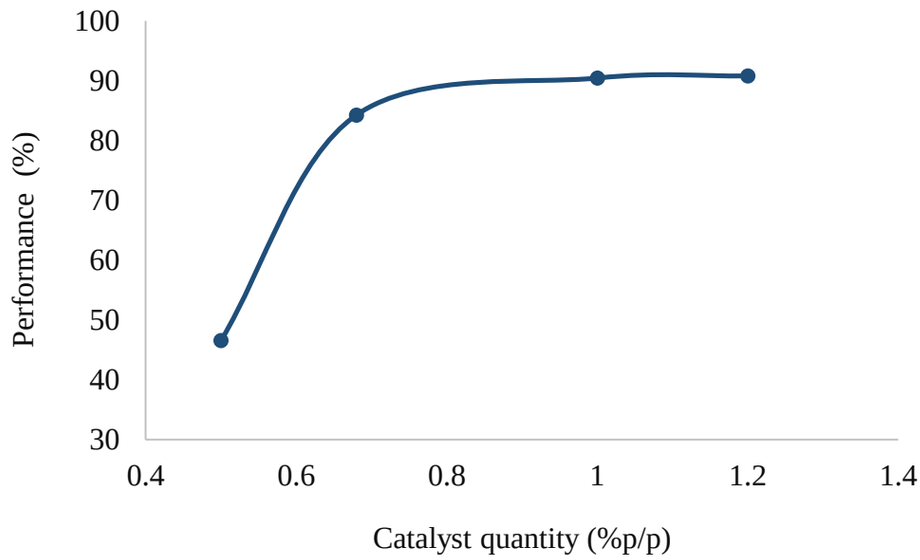
Source: Own Elaboration

In this study, the MeOH: Oil molar ratio of 24:1 was chosen as the best condition, although the difference in yield compared to the 12:1 ratio was 1.93 %, it was considered because having a higher amount of methanol in the solution could favor the displacement of the reaction towards the products, producing more methyl esters and, therefore, increasing the yield of the reaction (Olutoye et al., 2016). Although, also the solvent in excess can be conducive to the solubility of glycerol, which would lead to decrease its conversion to methyl esters (Narkhede et al., 2014). Which would explain the decrease in yield as the MeOH:Oil molar ratio increases from 24:1 to 36:1.

3.3.3 Study of the amount of catalyst.

Tests were carried out using MOF-Zn-II at a percentage of 0.5, 0.68, 1.0 and 1.2 % based on the weight of used cooking oil, using a MeOH:Oil ratio of 24:1, at 140 °C and 4.5 h of reaction. Graph 3 shows the data obtained, it is observed that the yield of methyl esters increases with increasing weight percentage of the MOF-Zn-II catalyst and stabilizes after the addition of 1 % w/w of catalyst, reaching a maximum yield of 90.82 %.

Graph 3 Effect of the catalyst on biodiesel production [MeOH:Oil (24:1), 140 °C, 4.5 h].



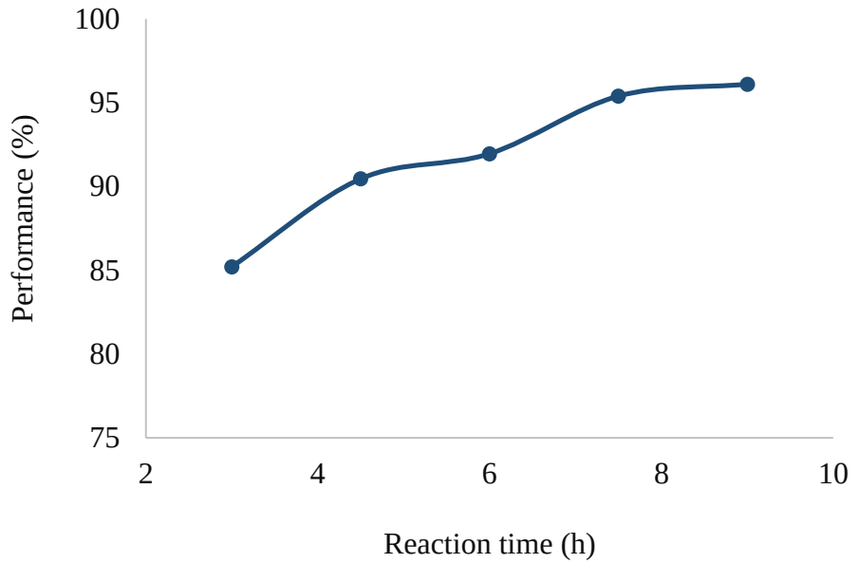
Source: Own Elaboration

The behavior of MOF-Zn-II in the production of biodiesel was similar to the transesterification of dimethyl carbonate using MOF as catalyst, where the reaction yield increased as the amount of catalyst increased, as long as the catalyst was not in excess (Zhou et al., 2009). Furthermore, this is attributed to the fact that there is a greater availability of active sites as the catalyst used in the reaction increases, thus increasing the reaction yield (Alhassan et al., 2013). However, an excess of catalyst no longer promotes product formation, because this behavior only occurs until the reaction reaches equilibrium (Zhou et al., 2009), which could explain the small difference in yield between 1 and 1.2 % catalyst. Therefore, the amount of 1 % w/w was chosen as the best condition, considering that the lower the amount of MOF Zn-II, the greater the economic savings in the process.

3.3.4 Reaction time study

Finally, for the study of the effect of reaction time, reactions were carried out at 3, 4.5, 6, 7.5 and 9 h, at the previously selected conditions (140 °C, molar ratio MeOH:Oil (24:1) and 1 % w/w catalyst), Graph 4. At 7.5 h of reaction time, a maximum yield of 94.31 % was reached and no significant change was observed if the time was increased to 9 h. In a study where the reaction time was varied between 5 and 9 h, it found that at 8 h of reaction, a maximum yield of 86 % was obtained, with no significant change with further increase in time (Narkhede et al., 2014). Furthermore, an excess in reaction time can lead to a decrease in yield due to hydrolysis of esters (Eevera et al., 2009). Therefore, 7.5 h was chosen as the best reaction time for this study.

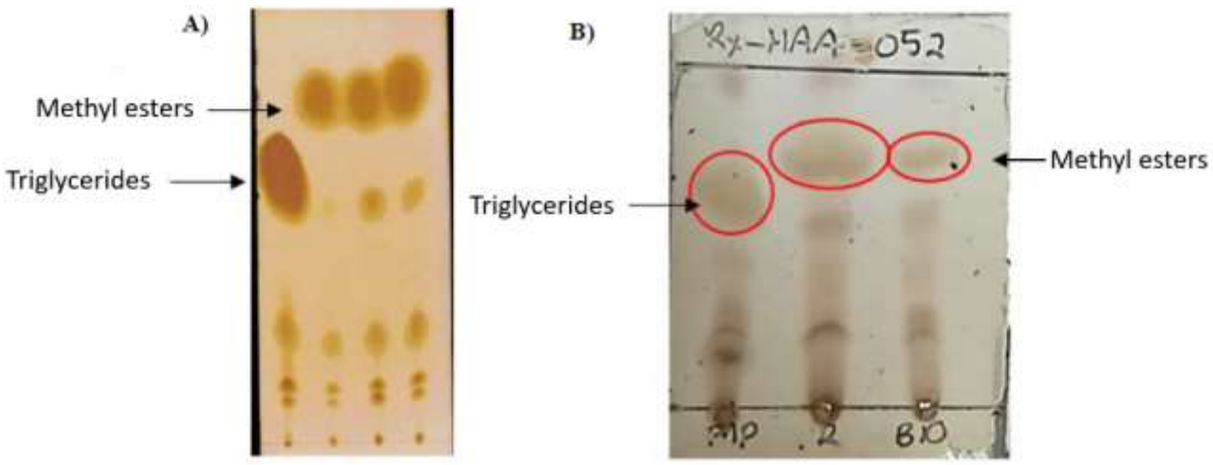
Graph 4 Effect of reaction time in obtaining biodiesel [MeOH:Oil (24:1), 140 °C, 1 % w/w catalyst]



Source: Own Elaboration

The biodiesel obtained was qualitatively analyzed by TLC following a methodology (Shah et al., 2004), where the difference between the adsorption on the chromatographic plate of triglycerides and methyl esters is indicated, Figure 3A. Figure 3B shows the chromatographic analysis of the reaction prepared with the best conditions, whose yield was 94.31 %. The difference between the appearance of the triglyceride signal and that corresponding to the methyl esters is observed, above the former.

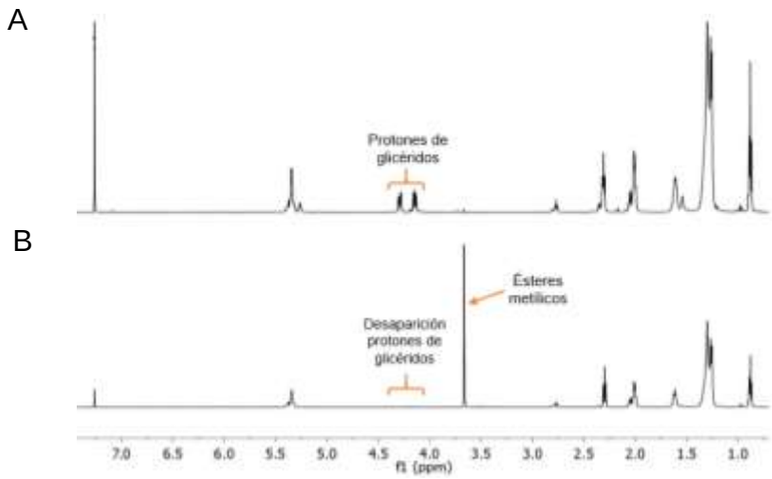
Figure 3 TLC of methyl esters. A) Analysis previously reported (Shah et al., 2004) and B) Reaction at 140 °C, 7.5 h, MeOH:Oil (24:1) and 1 % MOF-Zn-II; MP: Used cooking oil, R: Reaction, Bio: Biodiesel



Source: Own Elaboration

In Figure 4A, the appearance of the signal corresponding to the protons of the glycerides was observed between 4.07 and 4.35 ppm; in Figure 4B the disappearance of these can be seen, as well as the appearance of a signal at 3.67 ppm, which corresponds to the protons of the methyl esters. This behavior coincides with that reported by Savaliya et al. (2023), who obtained biodiesel from inedible castor oil and proved, through the appearance of the peak of the protons of the methoxy group, at 3.54 - 3.60 ppm, the conversion of the oil to biodiesel.

Figure 4 ^{1}H NMR spectra of A) used cooking oil; B) reaction at 140 °C, 7.5 h, MeOH:Oil (24:1) and 1 % MOF-Zn-II

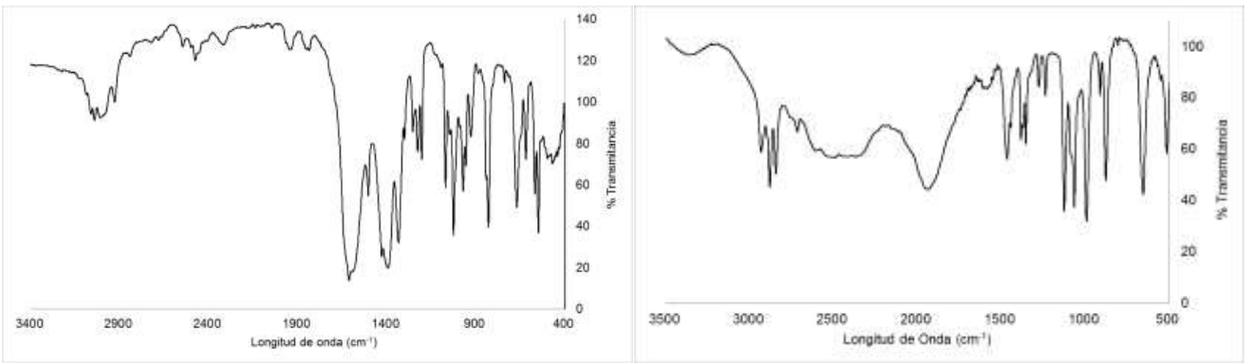


Source: Own Elaboration

3.4 Reuse of the catalyst

To check the reuse of MOF-Zn-II in biodiesel synthesis, the structure of the material was analyzed by infrared spectroscopy, before and after the transesterification reaction, Figure 5.

Figure 5 IR spectra of biodiesel: before the transesterification reaction (left) and after the transesterification reaction (right).



Source: Own Elaboration

It can be observed that in the spectrum of the MOF-Zn-II recovered from the reaction (right), the bands did not coincide completely with the spectrum of the newly synthesized MOF (left). Possibly due to the remnants of biodiesel and/or glycerol from the reaction because the presence of the CH_3, CH_2 and CH stretching signals of biodiesel was observed at 2843, 2879 and 2932 cm-1, respectively (Tariq et al., 2011). It could even be due to the restructuring of MOF-Zn-II, since zinc-containing MOFs have exhibited instability in aqueous solution (Rivera et al., 2016). In another study, $Zn_4O(BDC)_3$, known as MOF-5, presented stability when the water content is low, but at percentages ≥ 4 % water there is an opening of the structure (Greathouse & Allendorf, 2006).

On the other hand, it was found that MOF-Zn-II maintains its catalytic activity during three reaction cycles, with yields ranging from 92 to 94 %, so it can be reused in simultaneous esterification and transesterification reactions for biodiesel production.

3.5 Biodiesel characterization

The biodiesel obtained was characterized to compare its viscosity, density and acid number properties with the specifications established in the ASTM D6751 and ASTM D1298 standards (Sakthivel et al., 2018), Table 4. It can be observed that the biodiesel obtained in this work complied with the parameters established in the standards. Likewise, the reduction of the acid number evidenced that MOF-Zn-II carried out the transesterification of triglycerides, as well as the esterification of free fatty acids simultaneously, since the latter was significantly reduced, from 6.70 to 0.840 mg KOH/g.

Table 4 Comparison of parameters of biodiesel obtained from used cooking oil with those established in the biodiesel standards

Property	Unit	Biodiesel obtained	Theoretical value	Standard (Sakthivel et al., 2018)
Density at 15 °C	kg/m^3	853	880	ASTM D1298
Viscosity at 40 °C	mm^2/s	5.85	1.9 – 6.0	ASTM D6751
Acid number	mg KOH/g	0.840	0.5	ASTM D6751

Source: Own Elaboration

On the other hand, in the detection and quantification of fatty acid methyl esters (FAME) carried out by gas chromatography, Table 5. It was observed that the product consisted of methyl esters of oleic acid (50.96 %), linoleic (20.20 %), palmitic (6.79 %), linolenic (4.27 %), stearic (2.60 %) and others (2.0 %).

Table 5 Composition of the methyl esters of the biodiesel obtained.

FAME	Concentration
C 16:0 - Palmitic	6.79
C 18:0 - Stearic	2.60
C 18:1 - Oleic	50.96
C 18:2 - Linoleic	20.20
C:18:3 - Linolenic	4.27
Other	2.0

Source: Own Elaboration

The product obtained is mainly composed of monounsaturated fatty acid methyl esters (50.96 %), followed by polyunsaturated (24.47 %) and saturated (9.39 %). The properties of biodiesel depend on the fatty acid composition, these being comparable to petroleum diesel when the biofuel contains a large amount of mono-unsaturated FAME, a controlled amount of polyunsaturated FAME and low concentrations of saturated FAME. (Wang et al., 2011) From the above, the effectiveness of using MOF-Zn-II in obtaining biodiesel from used cooking oil can be attributed.

Acknowledgement

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Conclusions

The used cooking oil, coming from a store, presented the quantity of free fatty acids of 3.82 %, which catalogs it as a raw material of low quality. Its initially calculated acid number was reduced from 6.70 mg KOH/g to 0.840 mg KOH/g without pretreatment, thus proving that MOF-Zn-II carried out esterification and transesterification simultaneously. Through the evaluation of the reaction parameters, the conditions at which the highest yield of methyl esters was obtained were determined, which was 94.31 % at a temperature of 140 °C, in a reaction time of 7.5 h, MeOH:Oil ratio of 24:1 and a catalyst amount of 1 % w/w. In addition, it can be recovered and reused for up to three reaction cycles with a minimal decrease in conversion to methyl esters, which can promote a reduction in biodiesel production costs.

Finally, the parameters of acidity index, viscosity and density of the biodiesel obtained were found to be within the values established in ASTM D6751 and ASTM D1298 standards.

Therefore, MOF-Zn-II can be used as a catalyst in the production process of biodiesel from used cooking oil, since the biodiesel obtained not only meets the specifications required in the market to be marketed, but is also obtained from waste raw materials, contributing to sustainability and environmental care.

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Chapter 9 Solar energy monitoring system using a SEPIC converter for possible application in Nanosatellites

Capítulo 9 Sistema de Monitoreo de energía solar utilizando un convertidor SEPIC para posible aplicación en Nanosatélites

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Abstract

Nanosatellites are mobile objects that orbit the Earth and are distinguished by their size and solar energy source. They consist of two main parts: the payload, which is the main reason for completing the mission, and the platform, which consists of the subsystems that enable proper operation. The most important subsystem is the electrical system (EPS), which is responsible for distributing power to the various modules and converting the energy produced by the energy recovery system. However, there are also factors that cause conversion losses, so there is an opportunity to develop solar energy monitoring systems using SEPIC converters. In this research, a monitoring system was developed that included multiple stages such as solar cell module, SEPIC converter and PWM control to emulate their behavior individually and collectively. From a certain point of view, we analyzed the parts used in the converter, evaluated the electrical circuit of the solar cell array and the SEPIC converter with variable power and the solar cells through simulation, and then performed tests in a physical environment. The monitoring system uses computer tools to measure the input and output data of the converter, saving the data in Excel software to create performance graphs.

Nanosatellites, SEPIC Converters, PWM Control, Electrical system, **Monitoring system**

Resumen

Los nanosatélites son objetos móviles que orbitan alrededor de la Tierra y se distinguen por su tamaño y su fuente de energía solar. Constan de dos partes principales: la carga útil, que es la principal razón para llevar a cabo la misión, y la plataforma, formada por los subsistemas que permiten su correcto funcionamiento. El subsistema más importante es el sistema eléctrico (EPS), que se encarga de distribuir la energía a los distintos módulos y de convertir la energía producida por el sistema de recuperación de energía. Sin embargo, también existen factores que provocan pérdidas de conversión, por lo que existe la oportunidad de desarrollar sistemas de monitorización de la energía solar utilizando convertidores SEPIC. En esta investigación, se desarrolló un sistema de monitorización que incluía múltiples etapas como el módulo de células solares, el convertidor SEPIC y el control PWM para emular su comportamiento de forma individual y colectiva. Desde cierto punto de vista, analizamos las piezas utilizadas en el convertidor, evaluamos el circuito eléctrico del conjunto de células solares y el convertidor SEPIC con potencia variable y las células solares mediante simulación, y después realizamos pruebas en un entorno físico. El sistema de monitorización utiliza herramientas informáticas para medir los datos de entrada y salida del convertidor, guardando los datos en el software Excel para crear gráficos de rendimiento.

Nanosatélites, convertidores SEPIC, control PWM, sistema eléctrico, Sistema de monitorización

1. Introduction

Currently, artificial satellites exist indirectly in people's lives, although artificial satellites were created in 1957, they have evolved over the years, improving their functions and dimensions (Patel, 2004). In response to these changes, small satellites have been developed that belong to a particular type known as nanosatellites due to their dimensions. Nanosatellites are designed to allow the reception and transmission of information to any part of the world, in addition to providing functions such as heat dissipation, position and motion correction and temperature regulation, the most common applications used in small satellites include telephony, weather, communications and military applications (Fernandez, 2004). Similarly, nanosatellites can be deployed in space individually or as part of a network of interconnected nanosatellites to perform specific functions defined as payloads.

All nanosatellites have built-in photovoltaic systems that allow them to capture solar energy in space (Abella, 2021). However, because they are exposed to much harsher environmental conditions than the Earth's surface, they are equipped with a power energy system (EPS) with direct current to direct current (DC-DC) power conversion that take into account factors such as power consumption, mission and life cycle of the nanosatellite (Tamasi, 2003).

However, the amount of energy available to nanosatellite solar cells depends on the irradiance and temperature of the sun. At low solar intensities, the energy conversion within the electrical system can cause losses in the life cycle, and the energy recovered is not constant and is affected by factors such as rotational motion and partial shading. These factors can cause energy imbalances in nanosatellites, which can eventually exhaust the energy to operate and become space debris.

Therefore, we have developed a SEPIC-type DC-DC converter design characterized by its ability to provide a non-inverting output voltage and maintain a minimum input-output ripple, allowing to obtain an output of higher voltage and equal or lower than the input.

The purpose of this research was to obtain information on the maximum energy recovery values of solar cells and the performance of SEPIC converters. The methodology, design and simulation used to analyze the exact converter components and solar module properties are presented. In addition, the behavior of a series array of solar cells acting as the main power source for the converter is simulated. The physical results of the implementation of the converter with the control stage and the solar cell module are observed in the results, likewise this work can lay the groundwork for future research topics related to the efficiency of DC-DC converters, the effects of partial shading in moving nanosatellites, energy recovery in space, etc.

2. Metodology

In the present work a solar energy monitoring system capable of collecting and storing the input and output data from the SEPIC converter will be addressed, considering some parts such as a solar cell module and a PWM control, as a load for the design of the energy recovery system a possible application in Nanosatellites is considered. These parts are interrelated with the objective of capturing the maximum amount of energy coming from four solar cells, connected in series to operate a SEPIC converter controlled by PWM proportional duty cycle modulation.

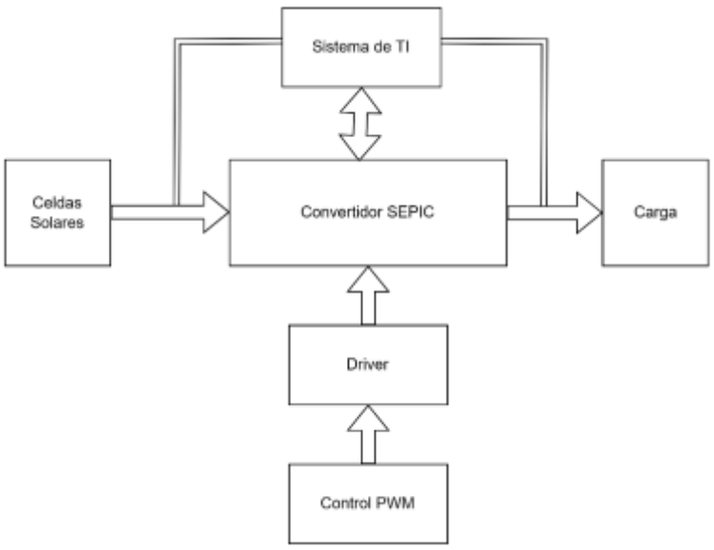
The methodology to be followed is a sequence of steps described below, starting with an analysis of the load and system requirements that determine the reasons and effects of energy harvesting, which determines the model of the solar cells to be used. After determining the input source, an analytical analysis of the constituent elements of the SEPIC converter was performed.

Subsequently, the design and simulation of the solar cells and the SEPIC converter was carried out using PSIM Version 9.1 and Proteus Version 8.12 software. In PSIM, the electrical circuits of the solar cell array and the behavior of the SEPIC converter in its two operating modes known as elevator and reducer in continuous conduction mode were evaluated by simulation, using four solar cells as input source. A PWM controller with an integrated SEPIC converter was designed and evaluated in Proteus to monitor its two operating modes. At the end of the simulation, the physical and functional construction of the SEPIC converter was carried out by performing experiments with a variable power supply and a series array of solar cells, and an IT monitoring system was designed to test the operation of the SEPIC converter and monitor the variable conditions throughout the day

3. Design and simulation

The solar energy monitoring system using a SEPIC converter is composed of different stages which conclude to a main objective which is based on a possible application in nanosatellites.

Figure 1 Design stages of a SEPIC converter in draw.io



Source: Own Elaboration

– The first stage consists of a solar cell module, which serves to capture light radiation by the impact of photons on the cell surface (Céspedes, 2012), used as the main energy source for the converter.

– The PWM control stage is a modulation technique generated by the TL494 element that compares two signals, the internal tracker reference signal and the capacitor charge/discharge signal, to generate a pulse signal. The signal is internally coupled to the IR2184 driver, which is responsible for regulating the current to start the internal MOSFET of the SEPIC converter.

– The SEPIC converter in addition to taking into account the input voltage of the solar cell, is responsible for converting the continuous voltage to another voltage level of higher or lower value (Montero, 2013), depending on the operating conditions of the PWM control, allowing to observe the behavior in its static mode.

– The IT system in use can sample the SEPIC converter over a period of time, using software and hardware components that read measurements from the converter and store the data for later use.

– Charging is a target for nanosatellite missions, i.e., a device or tool to which power is supplied (Space, 2020). In the SEPIC converter design, the load is emulated as a resistor.

The above steps require analysis, design and simulation processes, which are described below.

3.1 Solar cell selection

The objective of solar cells is to feed the systems of a nanosatellite considering some criteria of efficiency, radiation resistance, dimensions and weight, as well as capacity to withstand shocks and vibrations in space (Plá, 2017), the main materials used in space photovoltaic devices are triple junction, some examples are GaInP and GaAs/Ge (Saucedo, 2016).

To characterize the cells, an analysis of the physical parameters corresponding to their data sheets was developed, which are presented in Table 1, where the open circuit voltage (V_{OC}), short circuit current (I_{SC}), maximum power voltage (V_{mpp}ó V_{mp}) were evaluated, maximum power current (I_{mpp} ó I), conversion efficiency (η), fill factor (FF) and the ratio between the maximum power generated by the cell and the product$I_{SC}V_{OC}$,, these parameters were considered for the selection of suitable SM141K10LV cells for powering the SEPIC converter.

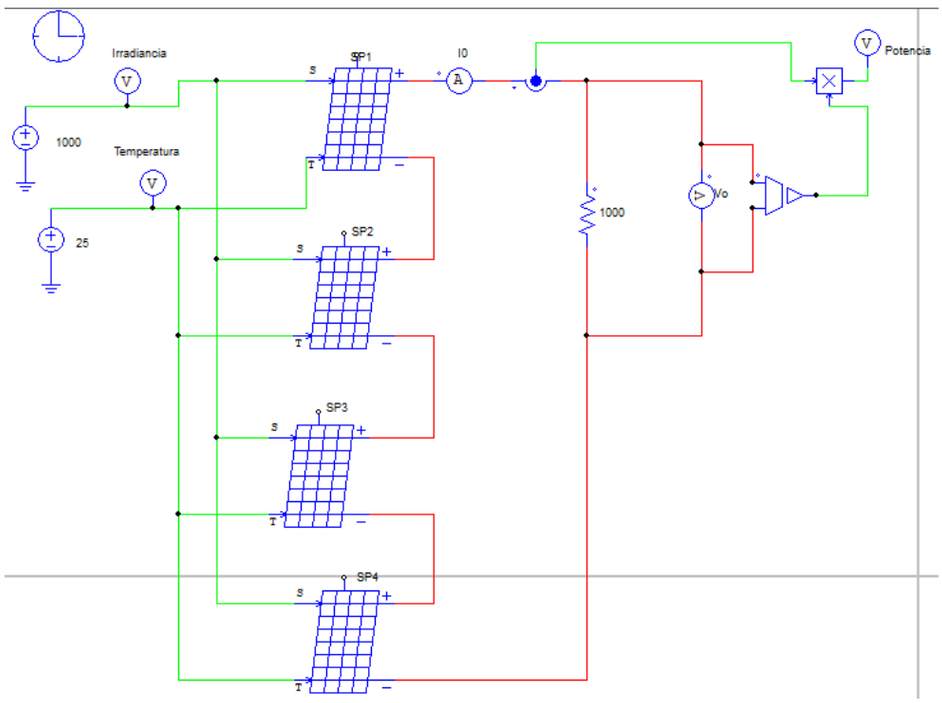
Table 1 SM141K10LV switchgear specifications

Symbol	Cell Parameter	Typical Ratings	Units
V_{OC}	Open circuit voltage	6.91	V
I_{SC}	Short circuit current	58.6	mA
V_{mpp}	Voltage at max. power point	5.58	V
I_{mpp}	Current at max. Power point	55.1	mA
P_{mpp}	Máximum peak power	307	mW
FF	Fill factor	> 70	%
η	Solar cell efficiency	25	%
$\Delta V_{OC}/\Delta T$	Open circuit voltage temp. Coefficient	-17.4	mV/K
$\Delta I_{SC}/\Delta T$	Max power temp. Coefficient	26.5	uA/K
S	Irradiancia	1000	W/m^2
T	Temperatura	1 a 25	°C

Source: Own Elaboration

A series connection of four solar cells as input source was analyzed and the schematic diagram shown in Figure 2 was created in PSIM to characterize the SM141K10LV cell.

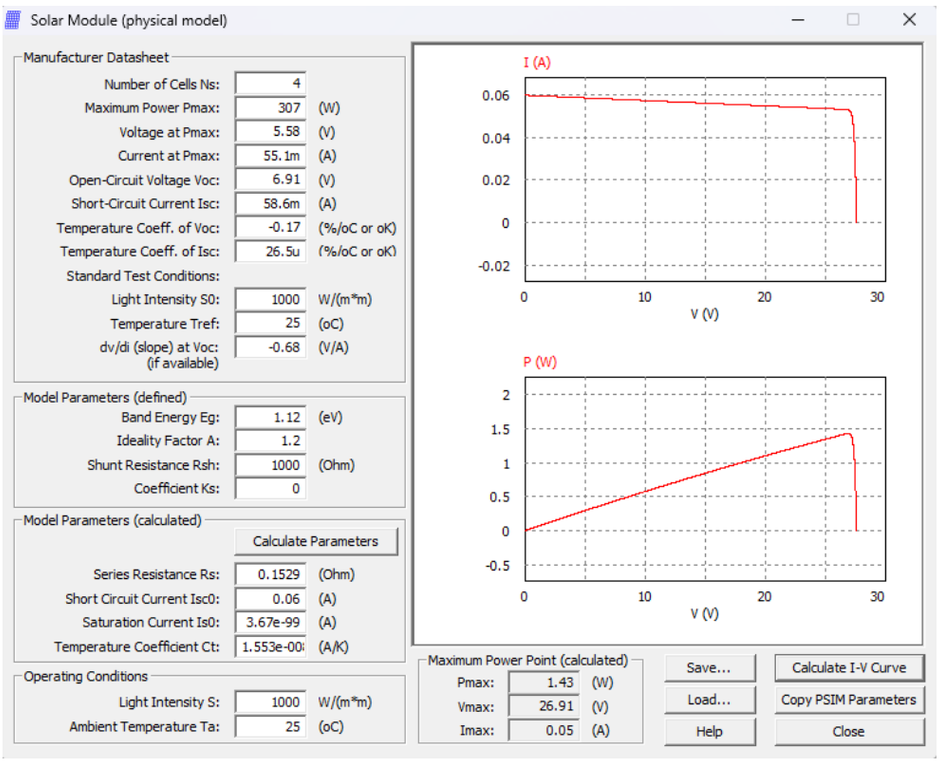
Figure 2 Series arrangement of SM141K10LV cells in PSIM



Source: Own Elaboration

Using PSIM's Physical model tool, the electrical behavior of the cells was simulated under ideal conditions of 1000 W/m^2 and an average temperature of 25°C. With the help of its data sheet, the following parameters shown in Table 1 were defined. Consequently, the current-voltage and power-voltage characteristic curves of the cell array were obtained, as shown in Figure 3, obtaining the values of maximum power (($P_{máx}$)) of 1.43W, maximum current (I_{max}) of 0.05 and maximum voltage (V_{max}) of 26.91V.

Figure 3 Physical model with 4 cells in PSIM



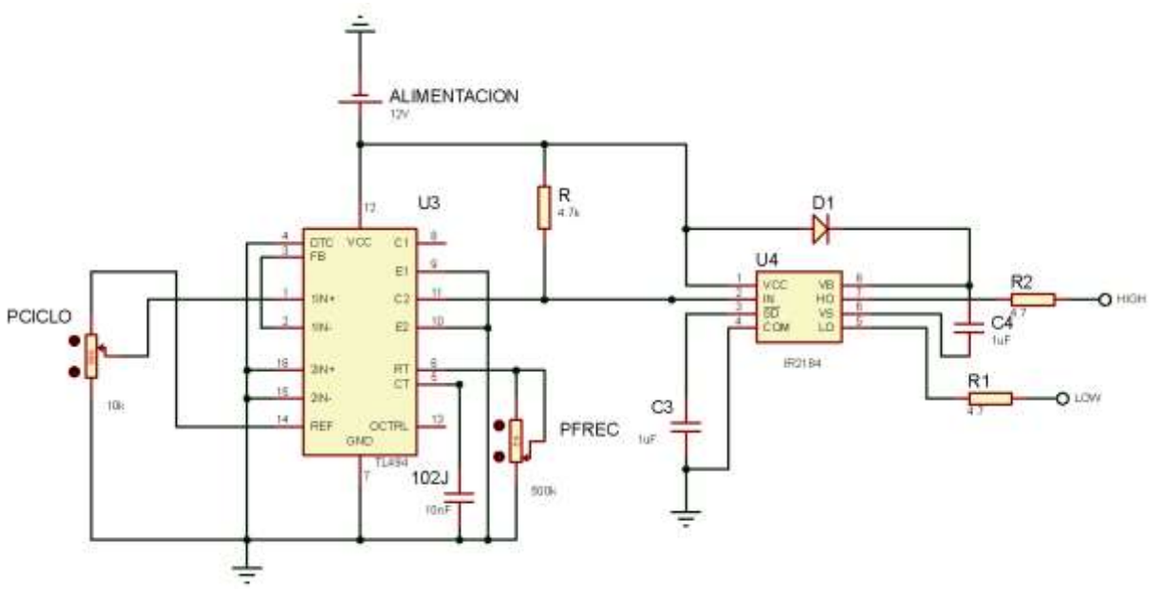
Source: Own Elaboration

3.2 Design of the PWM control stage

Proteus software was used to emulate the converter behavior. This requires a modulation technique that controls the power delivered to the load and allows the converter to maintain a steady state mode of operation.

As shown in Figure 4, the control stage was implemented with a PWM modulation technique using a TL494 circuit coupled through an IR2184 gate driver as an enabling device for the MOSFET of the SEPIC converter.

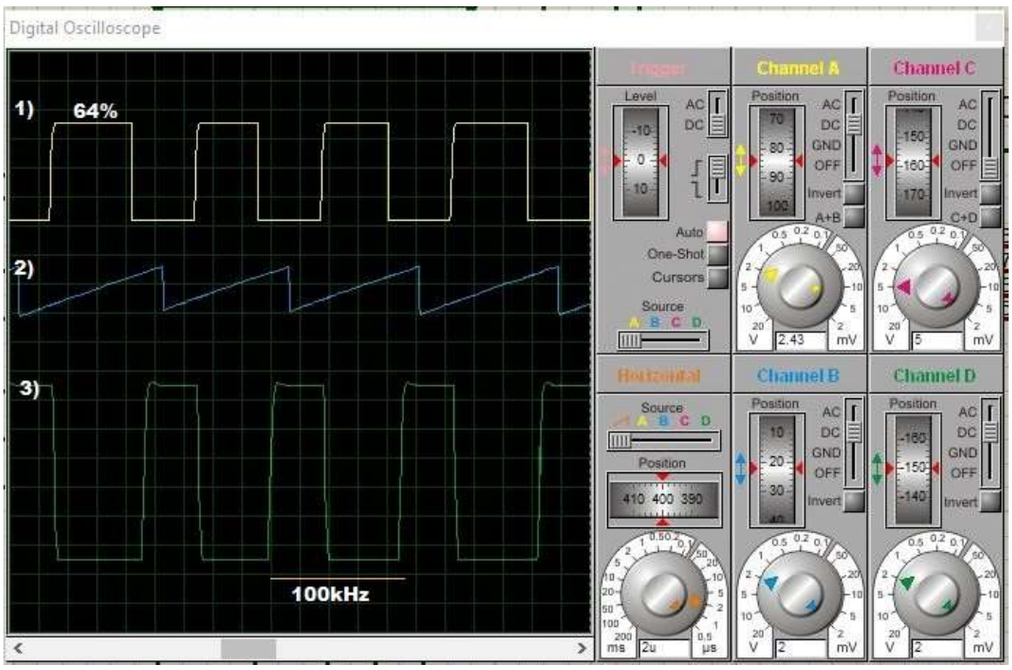
Figure 4 Schematic diagram of PWM control in Proteus



Source: Own Elaboration

The variable resistance values on pins 1,14 and 6 were adjusted to observe the duty cycle, frequency and power of the controller, for both operation modes, and a frequency of 100 kHz was also determined.

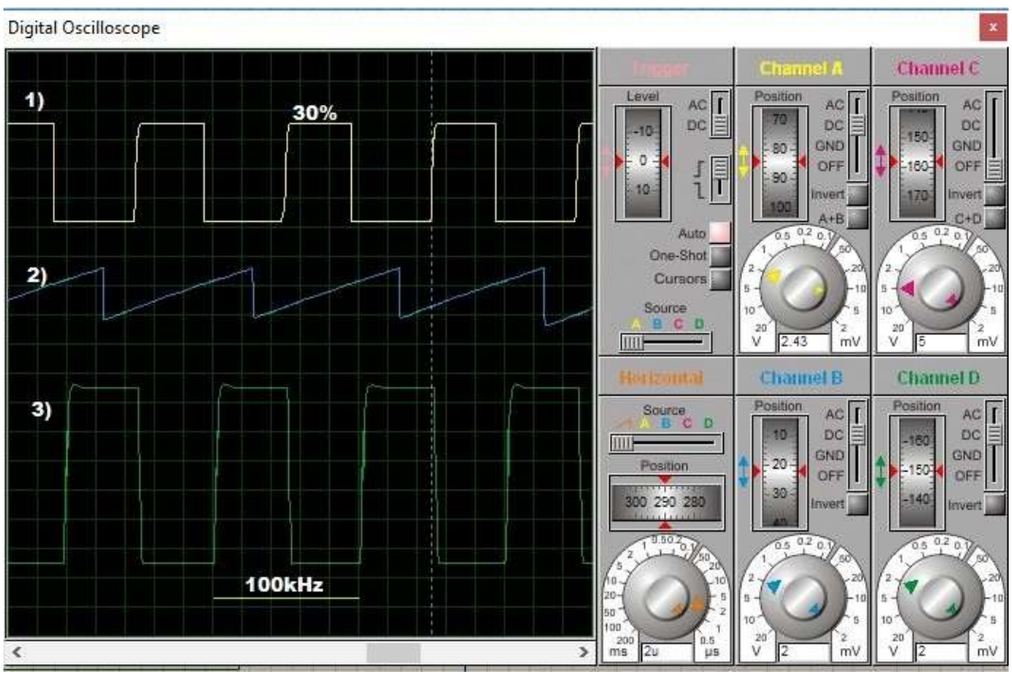
Figure 5 PWM control in the rising state in Proteus



Source: Own Elaboration

As shown in Figure 5 in step-up mode, three signals are represented, the first yellow signal comes from the TL494 output with a duty cycle of 64%, the sawtooth wave is generated from the resistor-capacitor ratio and the third green signal is from the low side (LOW) of the IR2184 controller.

Figure 6 PWM control in reducing state in Proteus



Source: Own Elaboration

In Figure 6, the first and third signals have the same duty cycle in derating mode with a value of 30%, but the yellow signal belongs to the TL494 output and the green signal belongs to the lower output of the controller.

3.3 SEPIC converter design

The purpose of a SEPIC DC-DC converter is to convert a DC voltage to a voltage level of different value, higher or lower, depending on the operating conditions of the PWM control (Flores, 2017).

In the design of the SEPIC converter, a calculation of the elements that compose the SEPIC converter was developed using the input parameters of the solar cell to determine the maximum power of the recovery system. The parameters corresponding to the converter were calculated according to Table 2 based on the design of the converter in continuous driving mode (Lopez, 2018).

Table 2 Equations and characteristic parameters of the components

Components/Parameters	Equation	Where:
Duty cycle	$D = \frac{V_o}{V_{in}+V_o}$	$V_o =$ Output voltage in Volts (V). $I_o =$ Average output current in Amperes (A) $R_o =$ Output resistance or load (Ω=V/A) $f =$ Frecuency (Hz) $D =$ Duty cycle $\Delta V_{C1} =$ Voltage ripple of the first capacitor in Volts (V). $\Delta V_{C2} =$ Voltage ripple of the second capacitor in Volts (V). $\Delta i_{L_1} =$ Current swing of the first inductor in Amperes (A). $\Delta i_{L_2} =$ Current curl of the second inductor in Amperes (A). $L_1, L_2 =$ Inductors in Hertz $((V * s/A)$ $V_{in} =$ Input voltage in Volt Volts (V)
Inductor 1	$L_1 = \frac{V_{in}D}{\Delta i_{L_1} f}$	
Inductor 2	$L_2 = \frac{V_{in}D}{\Delta i_{L_2} f}$	
Load	$R_o = \frac{V_o}{I_o}$	
Capacitor 1	$C_1 = \frac{V_o D}{\Delta V_{C1} R_o f}$	
Capacitor 2	$C_2 = \frac{V_o D}{\Delta V_{C2} R_o f}$	

Source: Own Elaboration

Using Table 2, component estimation was carried out, under step-up and step-down mode conditions with an input voltage provided by the solar cell series array of approximately 27V for both modes and a step-down output voltage (V_{out}) of 12V and step-up of 48V. In addition to considering recommended parameters such as a frequency of 100 *kHz*, ΔV_{c1} of 100mV and ΔV_{c2} of $10mV$, determining in Table 3 the construction components of a SEPIC converter.

Table 3 Definition of components

Components	Elevator	Reducer
Duty cycle	0.30	0.64
Capacitor 1	$3.69\mu F$	$1.92\mu F$
Capacitor 2	$36.90\mu F$	$19.2\mu F$
Inductor 1	$4.90mH$	$10mH$
Inductor 2	$2.19mH$	$19mH$
Load	97.56Ω	1.6kΩ

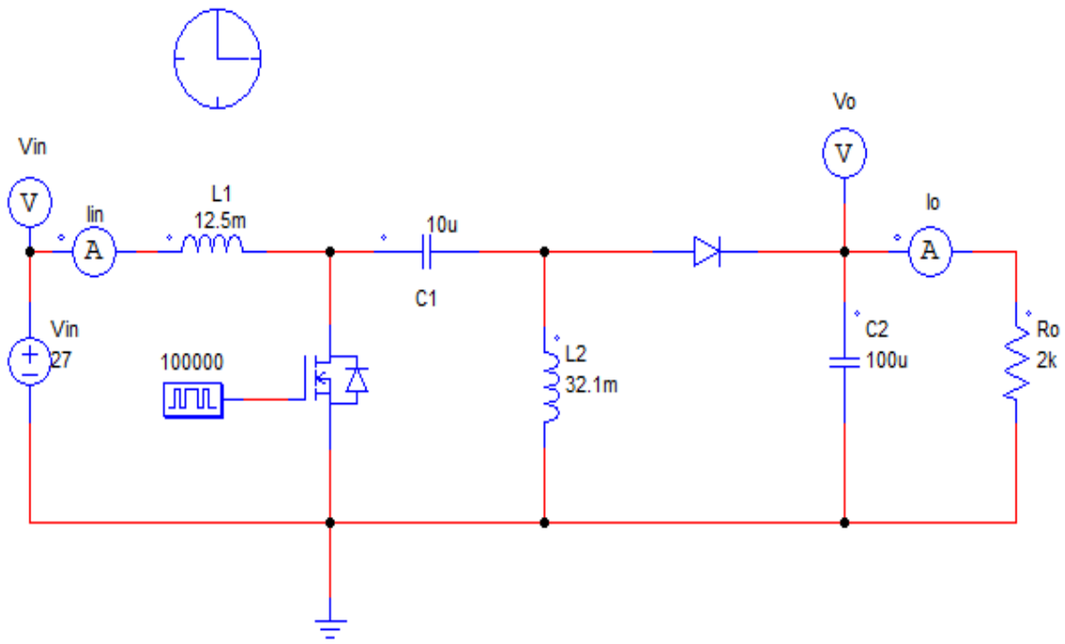
Source: Own Elaboration.

The definition of the components allowed the comparison between the elements of the reducing and elevating mode, considering the component with the maximum value in the design. As an example, the capacitor 1 value is 3.69μF in elevating mode and 1.92μF in reducing mode, so the one with the higher value is chosen. In these cases the higher value is the one determined, however, due to the existing commercial values, the elements are replaced by components with approximate values.

3.3.1. SEPIC variable input

Following the component definitions shown in Table 3, a simulation of the SEPIC converter was run in PSIM using a variable power supply as shown in Figure 7 to plot plots of input voltage, output voltage, second capacitor and converter output current.

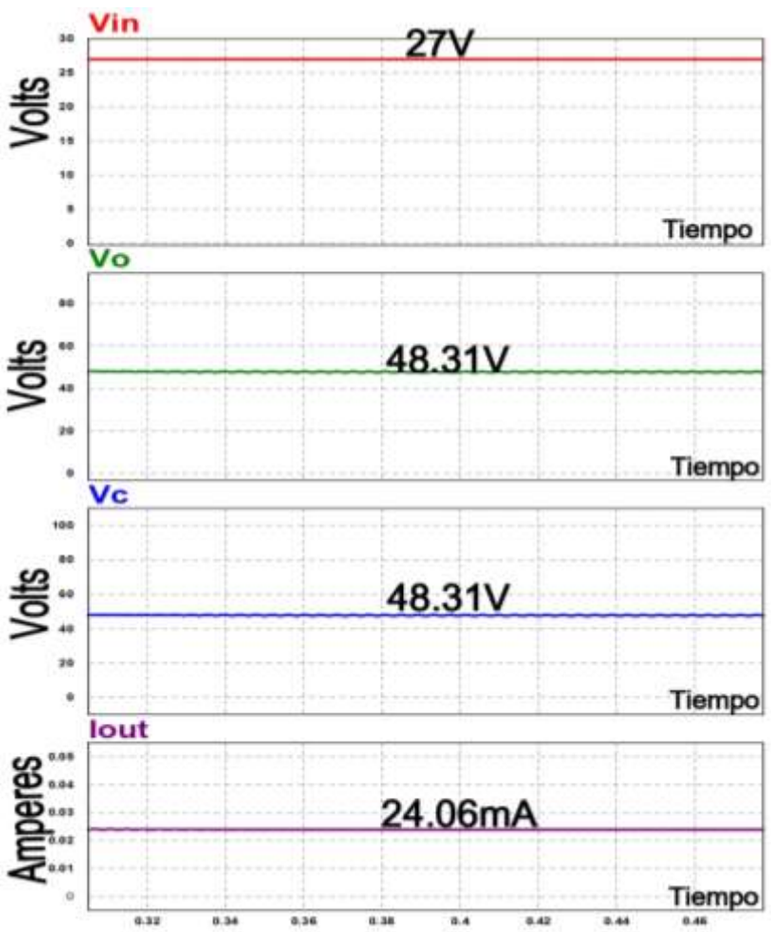
Figure 7 Simulation of SEPIC converter in PSIM



Source: Own Elaboration

As an example of SEPIC converter operation in boost mode, a duty cycle of 0.64 and a maximum input voltage of 27V are considered, as shown in Graph 1. In this case the output and second capacitor voltages (V_c)) are equal, resulting in an output current (I_{out}) of 24.06mA for a voltage of 48.31V.

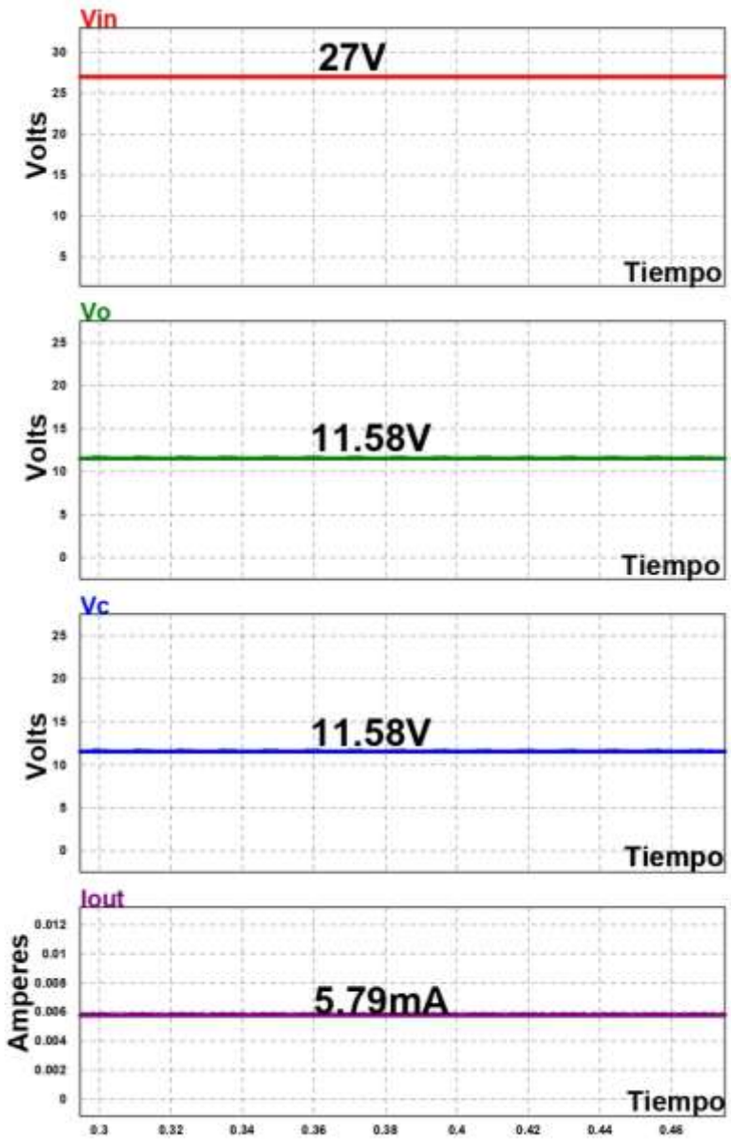
Graph 1 Behavior of the SEPIC converter in boost mode with variable source in PSIM



Source: Own Elaboration

As an example of operation of the SEPIC converter in step-down mode, a duty cycle of 0.30 and a maximum voltage of 27V were considered, obtaining the same voltage in the second capacitor and in the output resulting in a value of 11.58V and an I_{out} of 5.79mA, as shown in Graph 2.

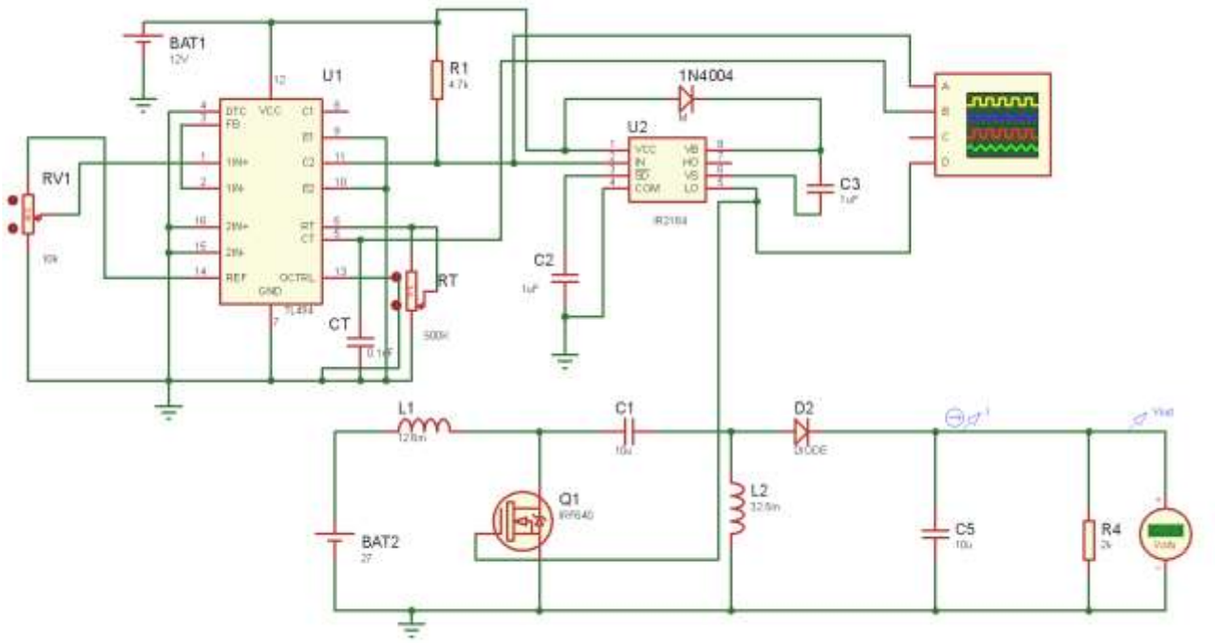
Graph 2 Behavior of the SEPIC converter in step-down mode with variable source in PSIM



Source: Own Elaboration

On the other hand, a simulation of a SEPIC converter with variable power supply was developed in Proteus software, shown in Figure 8. This software incorporates the control stage designed in Section 3.2, performing several behavior tests by adjusting the frequency to 100kHz and the duty cycle according to its operation mode.

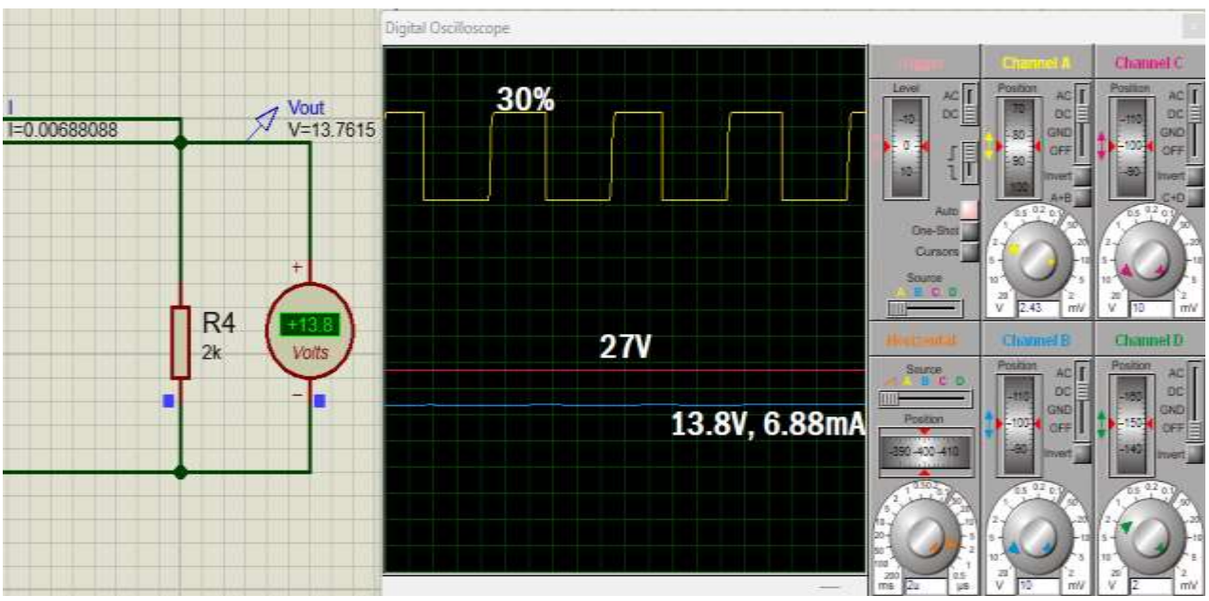
Figure 8 Simulation of the SEPIC converter with control stage in Proteus



Source: Own Elaboration

As shown in Figure 9, one of the tests performed to a SEPIC converter in reducer mode was performed with a V_{in} associated to the series array of solar cells with a voltage of $27V$ shown in the C channel signal and a duty cycle at 30% shown in the yellow signal, the V_{out} of the converter is 13.8V and an I_{out} $6.88mA$.

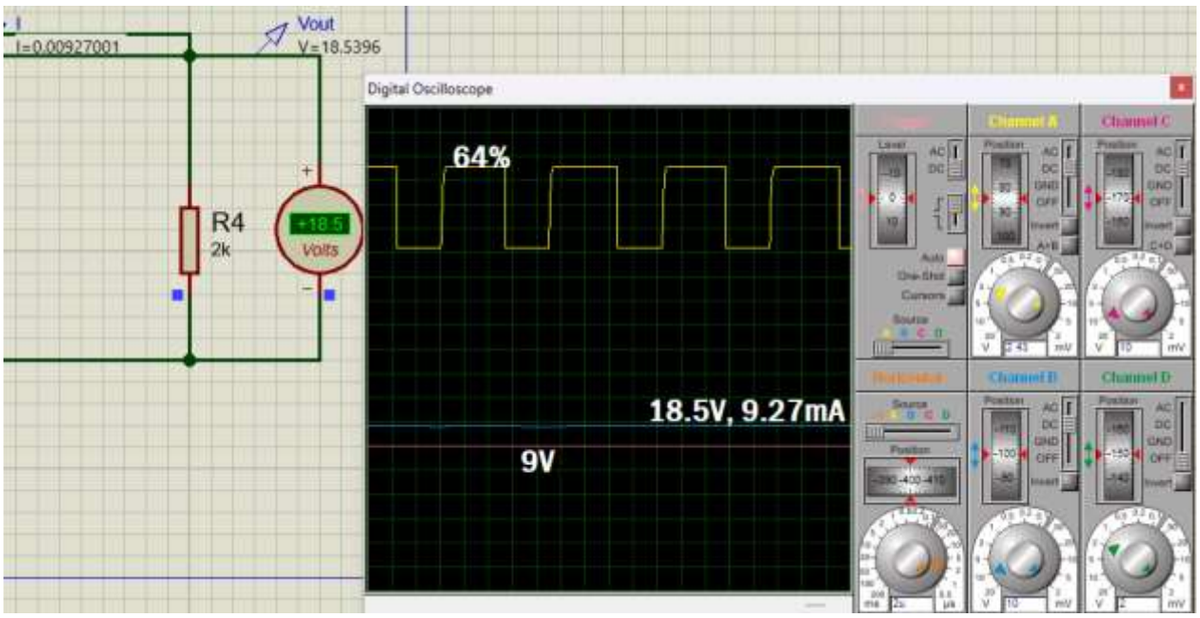
Figure 9 Reducer mode behavior in Proteus



Source: Own Elaboration

Figure 10 shows a test of the converter in boost mode with a V_{in} of $9V$ and a duty cycle of 64%, resulting in an output of 18.53V and an I_{out} $9.27mA$.

Figure 10 Boost mode behavior in Proteus

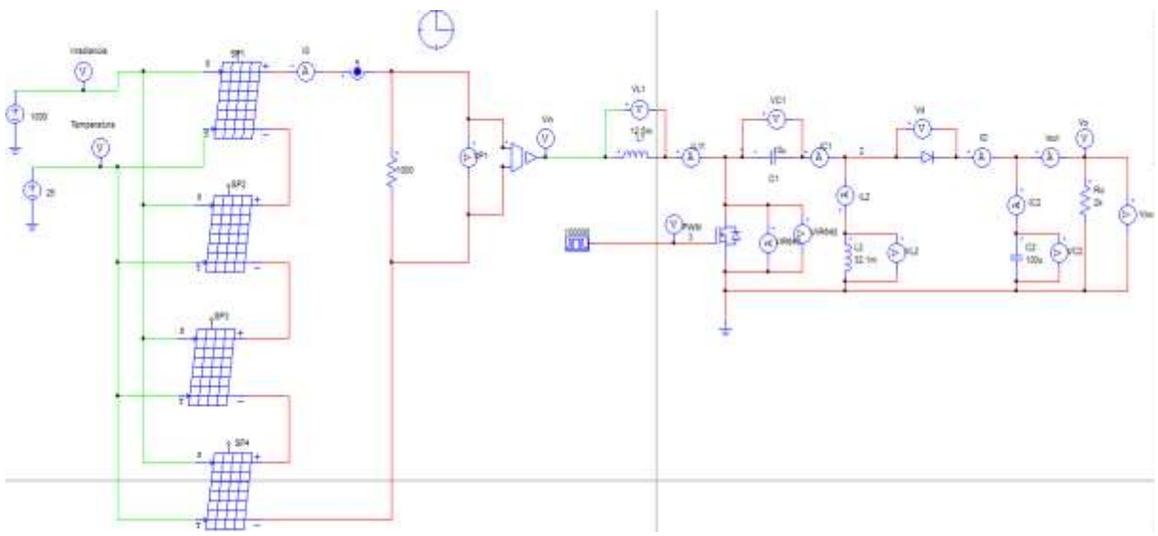


Source: Own Elaboration

3.3.2 SEPIC with solar cells

The incorporation of the series array to the electrical circuit of the SEPIC converter in PSIM considered the characteristics of the cells, including the maximum voltage of the array. Figure 11 shows the SEPIC converter with a power supply coming from the solar cell array, thus eliminating the variable power supply.

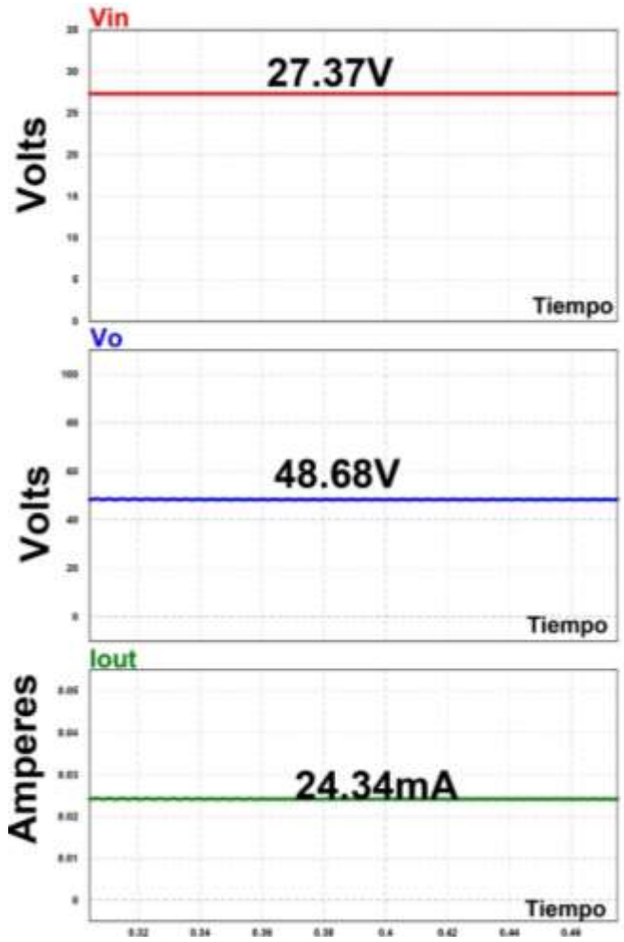
Figure 11 SEPIC converter with solar cells in PSIM



Source: Own Elaboration

Figure 14 shows the operation of the SEPIC converter in elevating mode with the array of solar cells in series, likewise the square signal was adjusted with a frequency of 100kHz and a duty cycle of 0.64, which produced a V_{in} of 27.37V of the array of cells, an I_{out} of 24.34mA and a V_{out} de 48.68 V.

Graph 3 SEPIC behavior in riser mode in PSIM

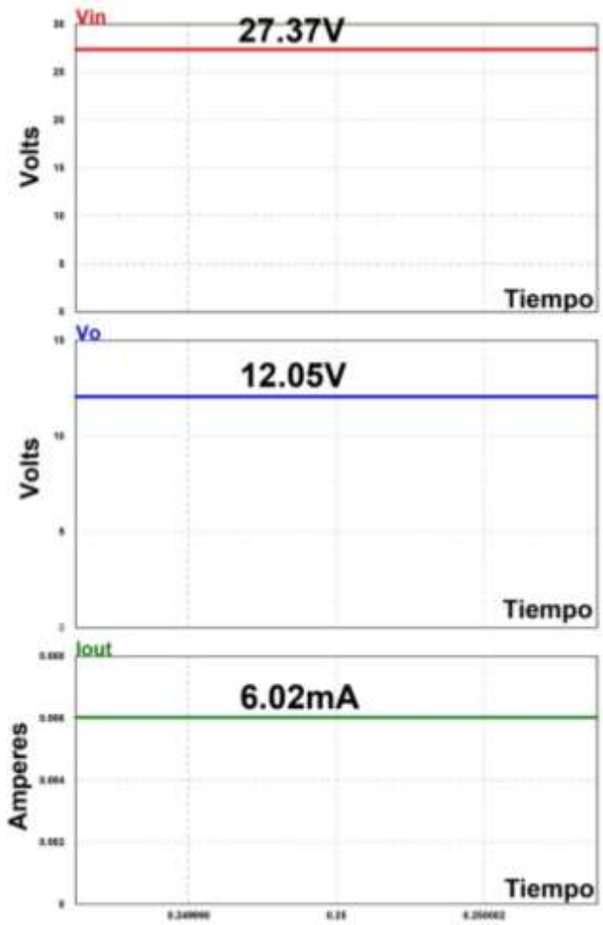


Source: Own Elaboration

As shown in Graph 3, the SEPIC converter in geared mode obtained an input voltage of 27.37V, an I_{out} of 6.02mA and V_o of 12.05V, for the simulation the duty cycle was reset to 30%.

In step-down mode, the SEPIC converter received an input voltage of 27.37V, an 12.05V of 6.02mA and V_o of 12.05V, as shown in Figure 4, readjusting the duty cycle to 30%.

Graph 4 SEPIC behavior in step-down mode in PSIM

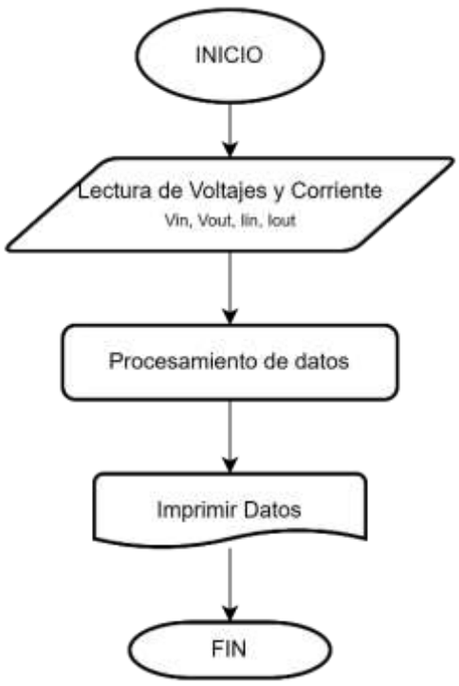


Source: Own elaboration

3.4. IT System

The purpose of the IT-based monitoring system is to use software and hardware elements to sample the SEPIC converter during its operation.

Figure 12. IT System Diagram in draw.io.



Source: Own Elaboration

As shown in the flowchart in Figure 12, the system was implemented from Arduino code version 2.0.1 and data reading using two types of sensors known as voltage sensor and current sensor model ACS712 to take readings of V_{in}, V_{out},, input current I_{in}, I_{out}. Once the data is received, it is processed in Excel software using Stream Data tool, the data saved in Excel was used to create a .TBL file to get a graph of the readings in PSIM.

4. Results

4.1 Array array of solar cells

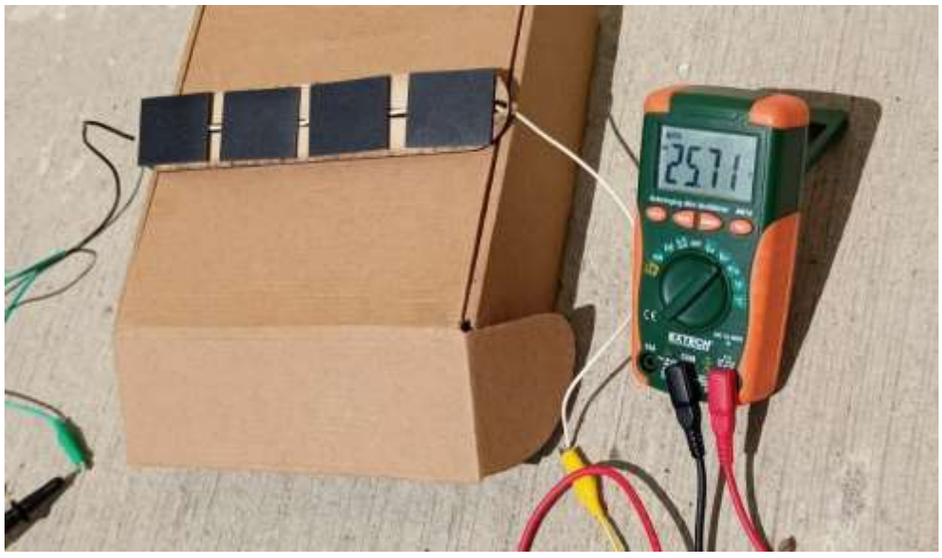
Figure 13 shows the physical layout of the SM141K10LV solar cells arranged on a wooden base with an inclination of 16.78° degrees. The tilt of the cells was determined with respect to the tilt angle methods in Mexico around latitude.

Figure 13 Construction of series array of SM141K10LV cells.

Source: Own Elaboration

The solar cell array was subjected to several operational tests at different times of the day, to observe different irradiance captures. For example, on May 5, 2023 at 12:20 pm a maximum voltage of 21.31V was reached and at 18:30 pm a minimum voltage of 0.69V was reached. Another test performed on April 21, 2023 at 13:00 pm reached a maximum voltage of 25.71V as shown in Figure 14, but reached a minimum voltage of 0.10V at 18:50 pm.

Figure 14 Series array voltage test



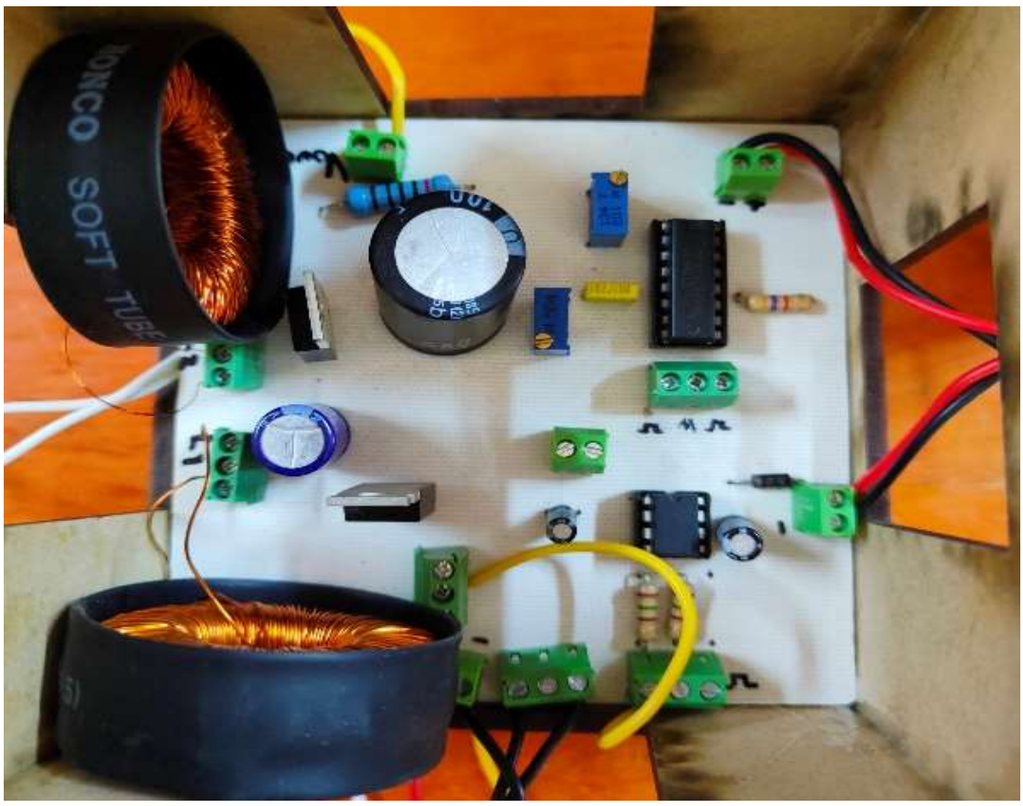
Source: Own Preparation

4.2 Behavior of SEPIC converter with variable power source

A variable power supply was used in the SEPIC converter to observe the physical behavior of the converter at various voltages, in its two step-up and step-down modes, considering for both a frequency of 100 kHz.

Figure 15, shows the physical implementation of the PWM control stage and the SEPIC converter implemented on a phenolic board with THT construction technology and one dimension environment the power systems of a nanosatellite.

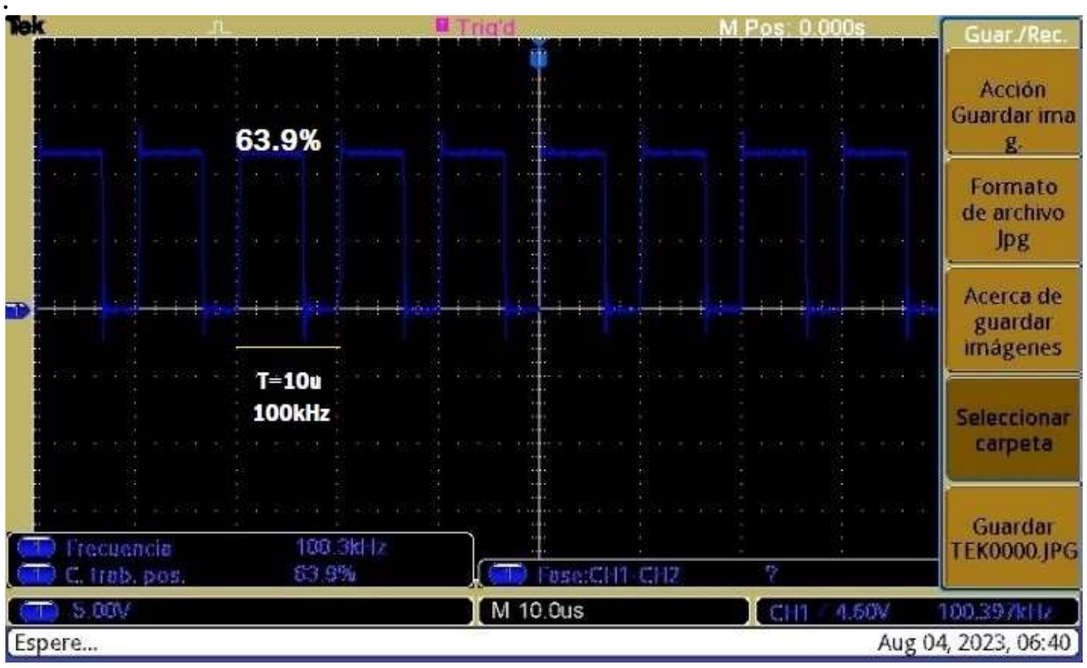
Figure 15 PWM control circuit and SEPIC converter



Source: Own Elaboration

The oscilloscope screen was captured at the output of the IR2184 controller, whose signal is shown in Figure 16, the driver output is a PWM modulation with operating conditions of 100kHz in frequency and a duty cycle of 63.9%.

Figure 16 PWM control in elevator mode seen in oscilloscope



Source: Own Elaboration

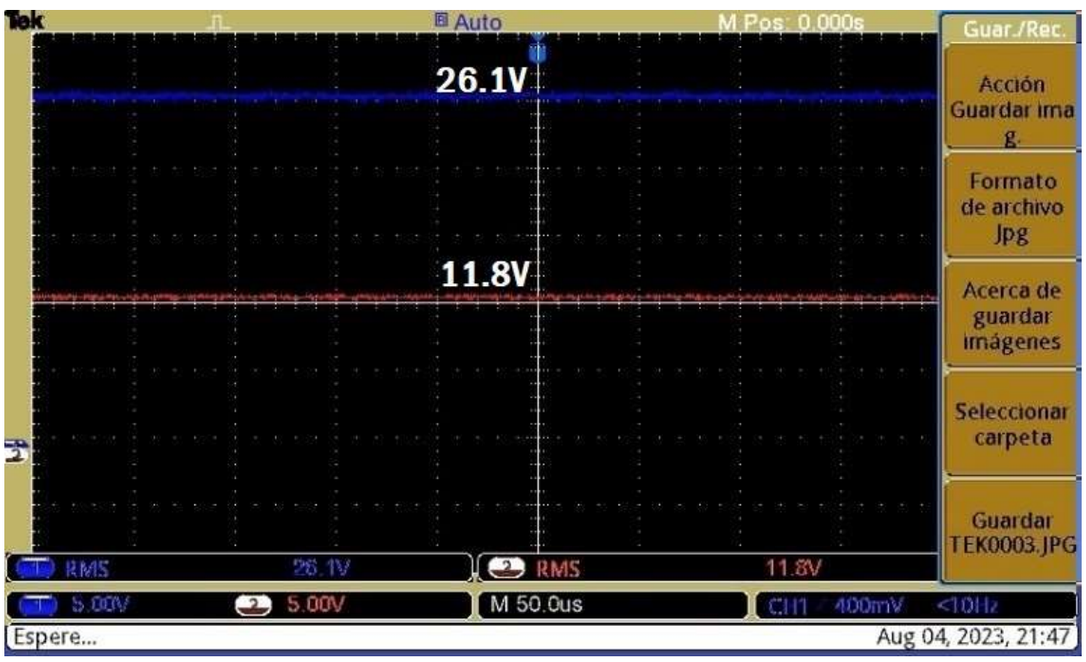
For the operation of the converter in step-down mode, the duty cycle was adjusted to 30% of the PWM control, performing several tests. The first voltage reduction test was performed with a low input voltage of 8.28V, which resulted in a V_{out} of 4.13V, as shown in Figure 17.

Figure 17 Reducer mode with low V_{in}seen in oscilloscope

Source: Own Elaboration

In Figure 18, the variable power supply was modified by increasing it to 26.1*V*, giving 11.8*V* at the output of the SEPIC converter.

Figure 18 Reducer mode with 26.1V seen in oscilloscope



Source: Own Elaboration

To operate in lift mode of the SEPIC converter, the control stage was reset with a duty cycle of 63.9% and 23*V* input, resulting in a lift voltage of 44.7*V*, as shown in Figure 19.

Figure 19 Lifting mode with 23V seen in oscilloscope

Source: Own Elaboration

Among several tests of the SEPIC converter in boost mode, the second test was performed with a V_{in} of 7.90V, obtaining a V_{in} of 14.7V, as shown in Figure 20.

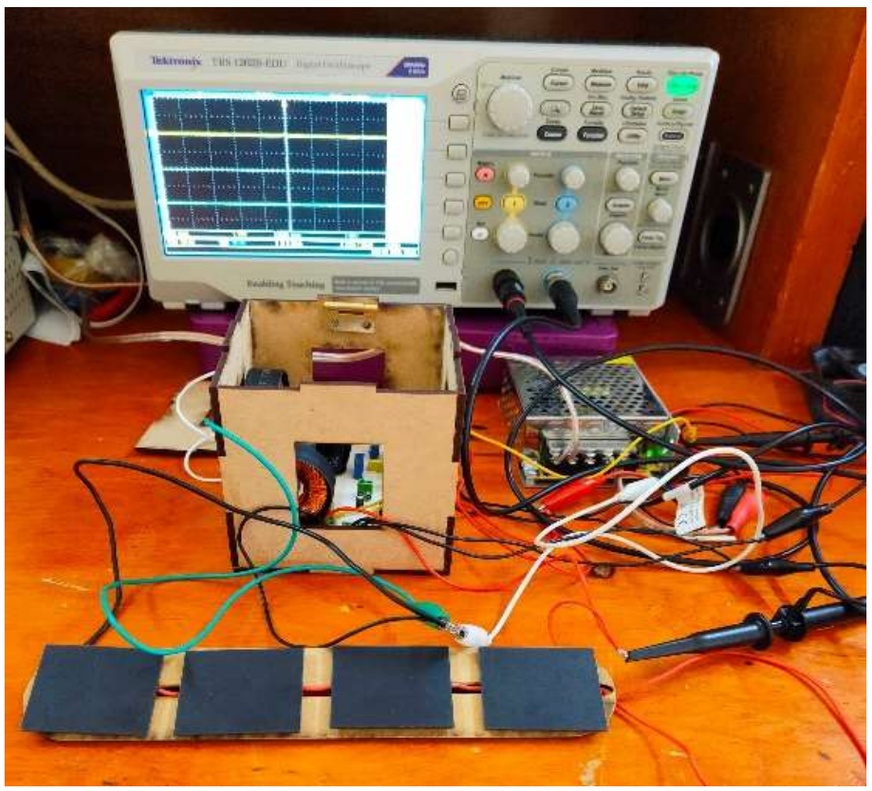
Figure 20 Boost mode at 7.90V seen in oscilloscope

Source: Own Preparation

4.3. Behavior of SEPIC converter with solar cells

The physical structures of the design stage such as the series array of solar cells, the control stage and the SEPIC converter, were integrated to allow performance testing by incorporating TI.

Figure 21 SEPIC converter and solar cell array

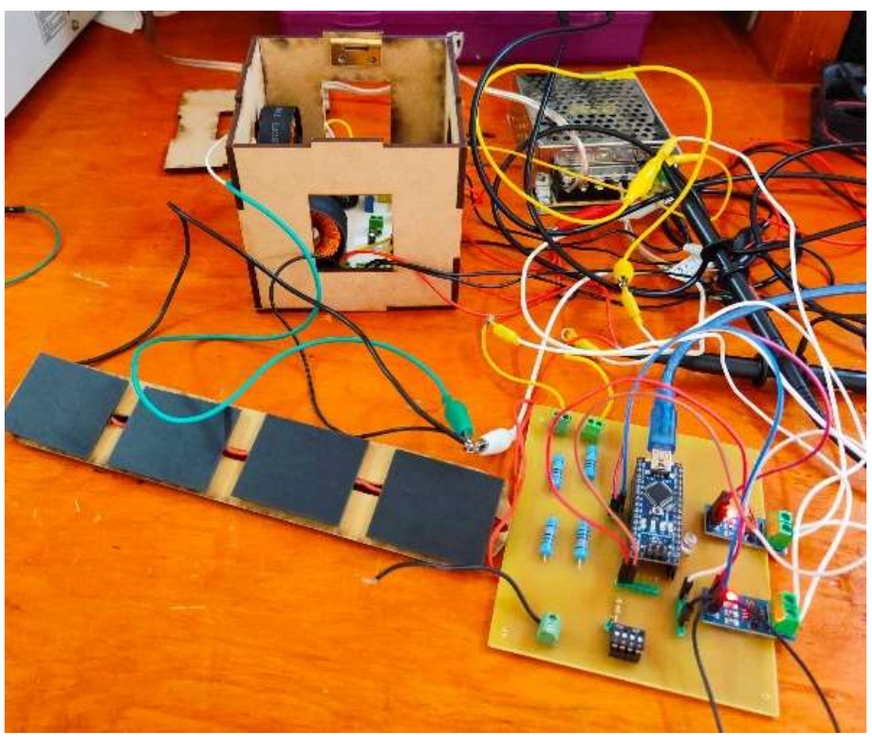


Source: Own Elaboration

As shown in Figure 21, the series circuit was integrated into the power input of the converter, while the PWM control power supply came from a separate 12*V* power supply.

Figure 22 shows the TI system connected to a SEPIC converter with the hardware part contained on a phenolic board consisting of an arduino nano, two ACS712 current sensors, two voltage sensors designed with a voltage divider. The software used was Excel with the Stream Data tool to collect, store the data to be measured. Subsequently, the data were used to obtain the behavioral graphs.

Figure 22 Physical incorporation with the hardware of the IT system



Source: Own Elaboration

4.4 Use Case I

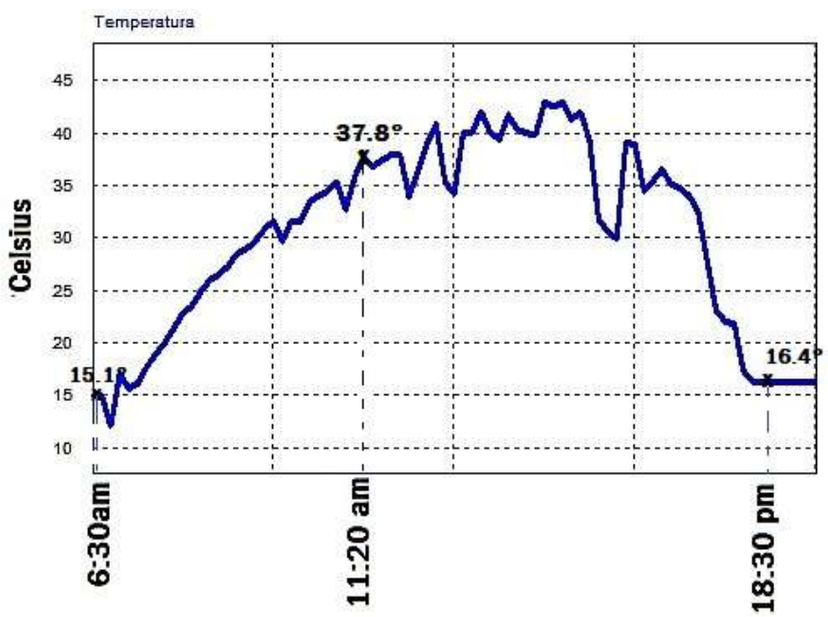
One of the use cases was carried out on June 18, 2023, from 6:30 am to 18:30 pm, with a sampling every 10 minutes, in elevator mode by the SEPIC converter. Solar irradiance was measured with the Fluke IRR1-SOL instrument which allows measuring irradiance and temperature of photovoltaic cells with a 16.5° degree inclination on the instrument. The monitoring system also recorded V_{in}, V_o, I_{in} and I_{out} measurements. Power, temperature, and voltage graphs were generated using data collected from the TI system and the Fluke IRR1-SOL instrument. As shown in Graph 5, the measurement started at 6:30 am with an irradiance of 17 W/m^2, as the day progressed the maximum power point (M_{ppt}) was reached at 11:20 am with a value of 1018 W/m^2, however, by 18:30 pm there was a low irradiance of 10W/m^2.

Graph 5 Irradiance on June 18, 2023 at PSIM

Source: Own Elaboration

Graph 6 shows that the temperature started at 15.1°C at 6:30am, and reached 37.8°C at 11:20am at the point of maximum power. The temperature rose and fell throughout the day, reaching 16.4°C at 18:30pm.

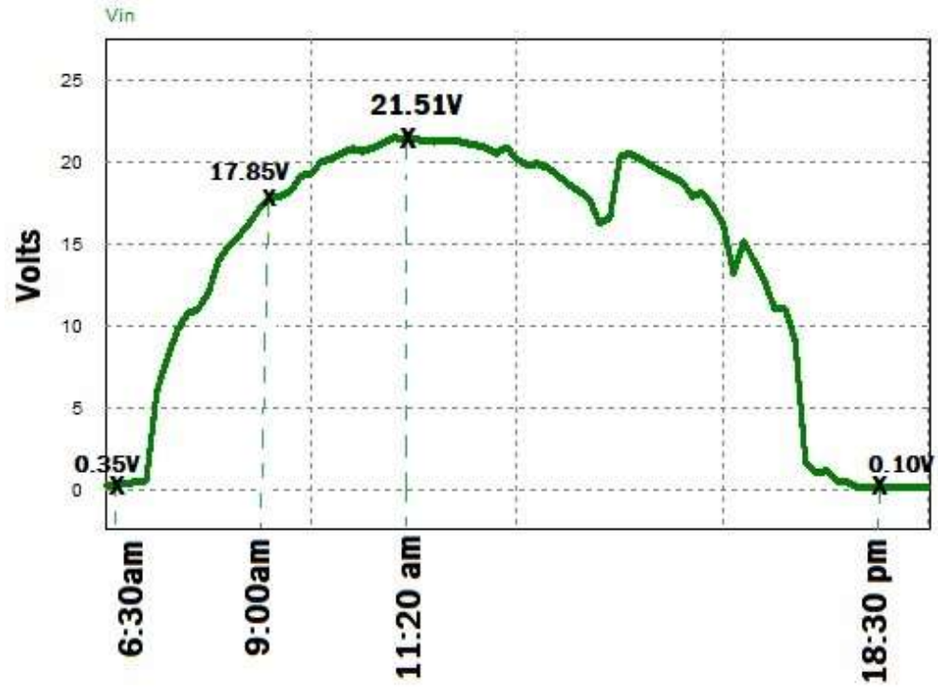
Graph 6 Temperature on June 18, 2023 at PSIM



Source: Own Elaboration

The input voltage recorded at the beginning of the samples was very low due to the irradiance of the sun, so 0.35V was obtained. The voltage detected at 9:00 am was 17.85V, while the voltage obtained at the point of maximum power was 21.51V, as shown in Graph 7.

Graph 7 Input voltage on June 18, 2023 at PSIM



Source: Own Elaboration

As shown in Graph 8, we obtain a V_{out} at the output of the SEPIC converter. The first high voltage measurement was 1V and at M_{ppt} the V_{out} reached 41.72V, while at 17:00pm the V_{out} was 32.76V.
Graph 8. Output voltage on June 18, 2023 at PSIM.

Source: Own Elaboration

4.5 Use Case II

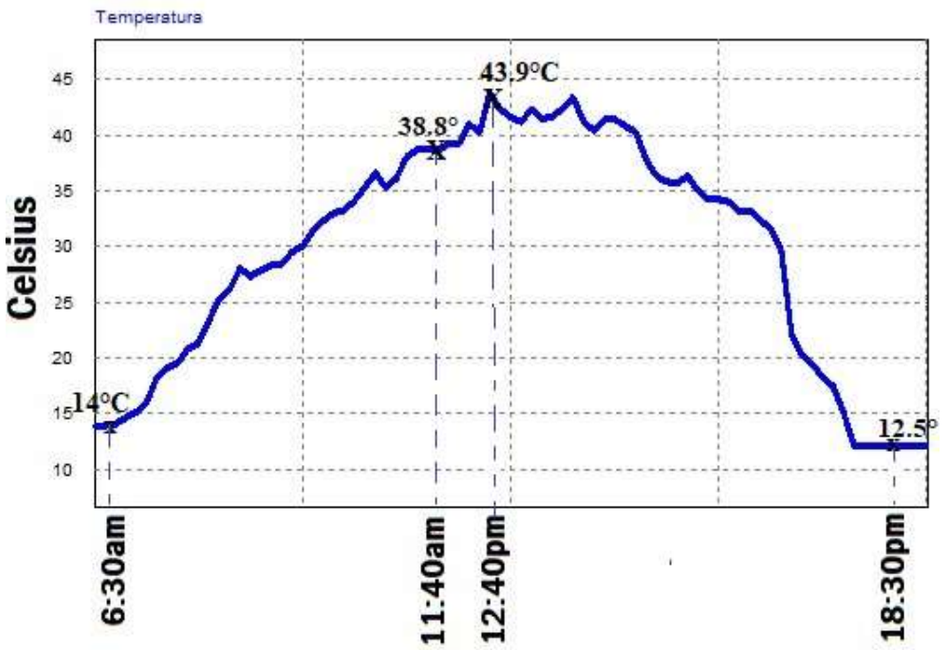
The second use case was carried out on June 26, 2023 from 6:30 am to 18:30 pm, sampling every 10 minutes the SEPIC converter in step-down mode. The irradiance was measured with the Fluke IRR1-SOL with an inclination of 16.1° degrees, with the data collected by the IT system and the Fluke, the power, temperature, $V_{out}$and V_{in} graphs were made. As shown in Graph 9, the values began to be measured at 6:30 am with an irradiance of 8 W/m^2, reaching the M_{ppt} of 1007 W/m^2 at 11:40 am, by the end of the samples the irradiance was 9 W/m^2.

Graph 9 Irradiance on June 26, 2023 at PSIM

Source: Own Elaboration

In Graph 10, the initial temperature of the samples started at 14°C, reaching 38.8°C at M_{ppt}. The maximum temperature of the day was obtained at 12:40pm with a value of 43.9°C.

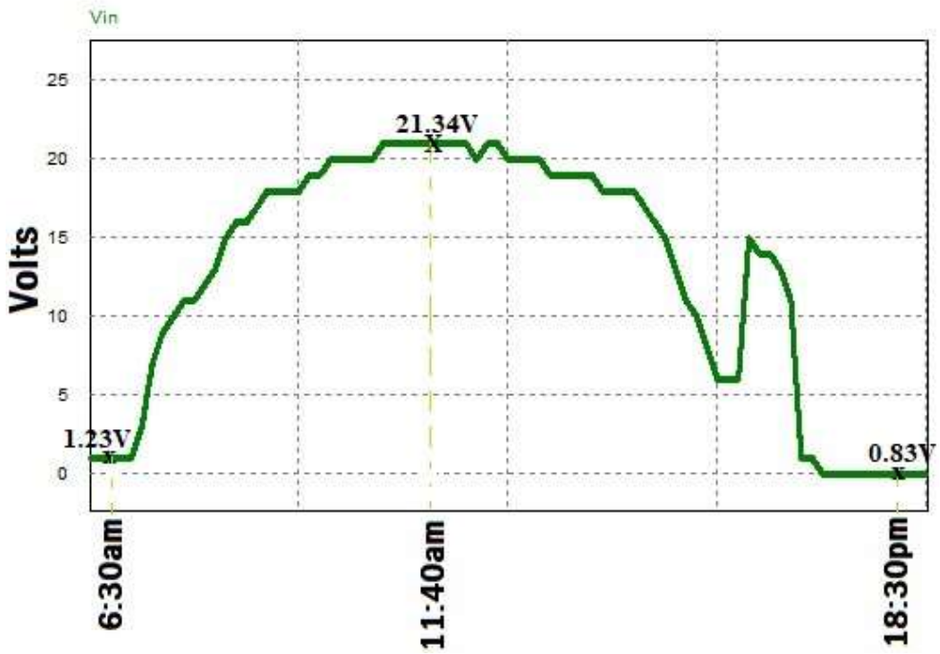
Graph 10 Temperature on June 26, 2023 at PSIM



Source: Own Elaboration

The V_{in} started at 1.23V due to the low irradiance at the beginning of the samples, however, at the point of maximum power the V_{in} was 21.34V, by 18:30pm the voltage obtained was very low with a value of 0.83V, as shown in Graph 11.

Graph 11 Input voltage on June 26, 2023 in PSIM



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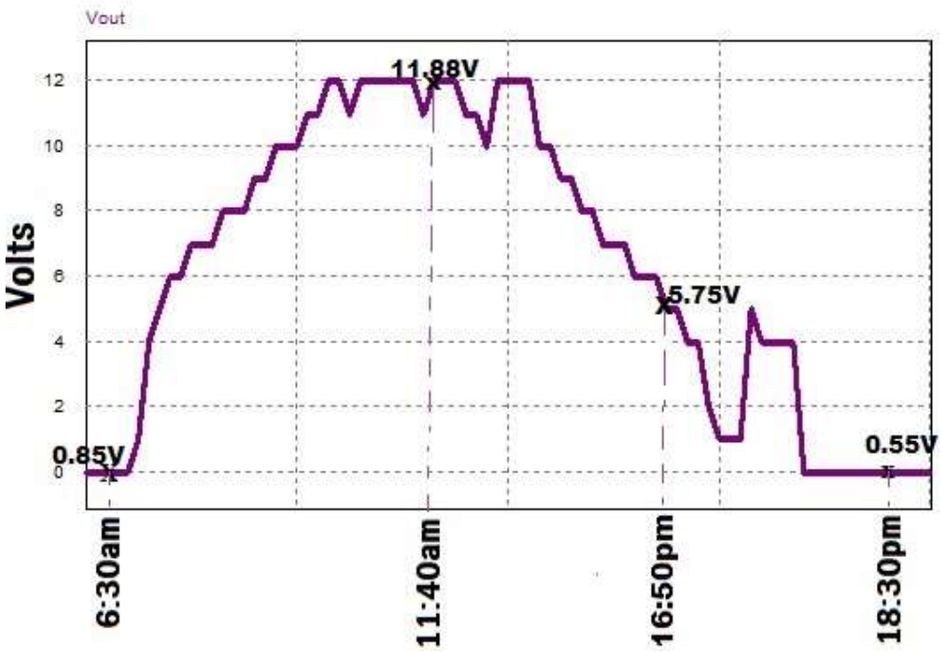
Source: Own Elaboration

As shown in Graph 12, the first reduced output voltage was 0.85V, for the maximum power point the V_{out} reached 11.88V, while the V_{out} measured at 16:50pm was 5.75V.

Graph 12 Output voltage on June 26, 2023 at PSIM



Source: Own Elaboration

5. Acknowledgements

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6. Conclusions

The prototype fulfills the main objective of this work, which was to develop a solar energy monitoring system using a SEPIC converter for nanosatellite applications. However, the development of the prototype went through a series of stages that led to an analytical analysis to obtain the precise components, as well as simulations of its operation individually, to later unify all the stages to obtain a monitoring system with a SEPIC converter and a power supply from solar cells.

As can be seen in the results, the stages were tested individually until a total incorporation, for this purpose, operation tests were carried out with variable power supplies and the solar cell module tested on different days in May, June and July 2023. Taking into account the spatial conditions, measurement tests were performed using tilt characteristics related to the latitudinal positions where the tests were performed.

The use cases foreseen for this work are in elevating and reducing mode, we observed that the irradiance during the measurement day reached values higher than those estimated by the simulations, the simulated irradiance was 1000 W/m^2 and the values measured by the Fluke instrument were up to 1018 W/m^2. Also the maximum temperature between the two predicted cases was between 30 and 48 degrees Celcius being higher than that given by the simulation.

Depending on the conditions during the course of a day, there will be changes such as partial shadows caused by clouds, objects, among others, causing that the solar cells will not receive the same light intensity, the input voltage will not always be the maximum of the solar cells and the amount of solar radiation and the temperature will not be constant.

However, the tests started with a low voltage until it reached a maximum voltage and then decreased again until it showed very low irradiance levels in the afternoon-evening. Based on the tests conducted on different days, it was confirmed that the SEPIC converters maintain their step-up and step-down characteristics even in static series connection. In this regard, physical considerations regarding the dimensions and characteristics of the nanosatellites were evaluated in the overall context of the project. For example, key design features were the mounting of the PWM controller and SEPIC converter on a small phenolic plate in proportion to a nanosatellite in addition to the integration of solar cells..

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V_C	Volumen de Compra	20000
P_c	Postura de Compra	485.39
P^{Uh}	Precio último Hecho	491.61
V_o	Volumen Operado	1241979
P_u	Precio/Utilidad	0
P^{VL}	Precio/Valor Libro	0
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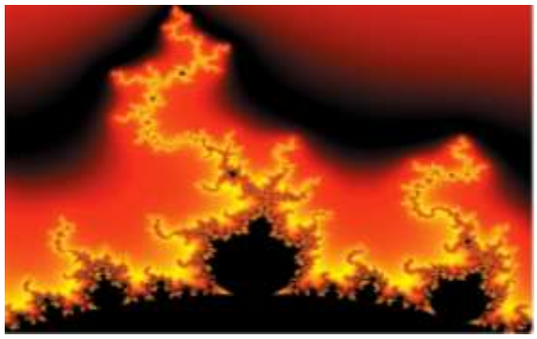

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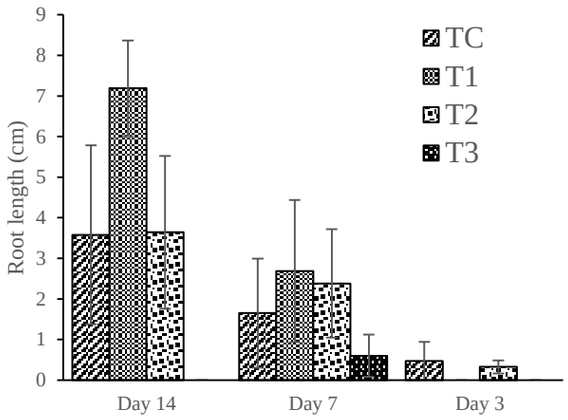

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