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## Presentation of the Content

In the first chapter we present, *Expansion and improvement of modular workstation for advanced PLC analysis and operation* by Rodríguez-Franco, Martín Eduardo, Jara-Ruiz, Ricardo, Zacarías-Rodríguez, Luis Gerardo and López-Álvarez, Yadira Fabiola, with ascription in the Universidad Tecnológica del Norte de Aguascalientes, Universidad de Guadalajara and Universidad Tecnológica del Norte de Aguascalientes, as the following article we present, *Evaluation of EPDM scrap/ natural fiber vulcanization by solvent swelling analysis* by Kantun-Uicab, María Cristina, Estrada-Monje, Anayansi and Rodríguez-Sánchez, Isis, with ascription in the Universidad Politécnica de Juventino Rosas, Centro de Innovación Aplicada en Tecnologías Competitivas and Guanajuato del Instituto Politécnico Nacional, as the following article we present, *Study of cooling system performance on lithium-ion batteries for an electric vehicle* by Zúñiga-Cerroblanco, José Luis, Conejo-Chavando, Luis Daniel, Huerta-Gámez, Héctor and Pérez-García, Víctor Lauro, with ascription in the Universidad Politécnica de Juventino Rosas, as the following article we present, *Selecting a suspension system for a mini-baja vehicle* by Sánchez-Lerma, Josué Rafael, Cerrito-Tovar, Iván De Jesús, Torres-Rico, Luis Armando and Huerta-Gámez, Héctor, with ascription in the Universidad Politécnica Juventino Rosas, as the following article we present, *Determination of design specifications of an amashito chili seed fracturing machine using QFD tool* by Cervantes-Castro, Cintya Margarita, García, Alejandro, Angulo-Córdova, Raquel and Domínguez-García, Arquímides de Dios, with ascription in the Universidad Politécnica del Golfo de México, as the following article we present, *Thermodynamic and mechanical of the mezcal distillation phase using theorems and software* by López-García, Claudio, Valverde-Cedillo, Luis Manuel and Rojas-Cruz, Alin Montserrat, with ascription in the Tecnológico de Estudios Superiores de Chalco.

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# Expansion and improvement of modular workstation for advanced PLC analysis and operation

## Expansión y mejora de estación de trabajo modular para análisis y manejo avanzado de PLCs

Rodríguez-Franco, Martín Eduardo\*<sup>a</sup>, Jara-Ruiz, Ricardo<sup>b</sup>, Zacarías-Rodríguez, Luis Gerardo<sup>c</sup> and López-Álvarez, Yadira Fabiola<sup>d</sup>

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### Abstract

This work provides continuity to the development of a modular workstation for the advanced operation of the programmable logic controller (PLC), through incorporation of the functions of master-slave communication, proportional-integral-derivative (PID) controller and high-speed counters (HSC); and its use as a support element for teaching process of related topics. The operation of the workstation constituted from the integration of a speed control system in a three-phase alternating current motor is analyzed; whose test parameters are entered from a graphical interface executed through a touch screen. Such application was implemented through a communication network between controllers; in addition, it uses a variable frequency drive (VFD) and an encoder as power and perception elements, respectively. The performance observed during the tests carried out confirms an adequate follow-up of assigned parameters, by reaching and settling real response of system in these. While, with regard to the use of the developed modular workstation as a teaching tool for analysis of advanced automation solutions, its relevance is confirmed.

### Resumen

El presente trabajo brinda continuidad al desarrollo de una estación modular de trabajo para el manejo avanzado del controlador lógico programable, a través de la incorporación de las funciones de comunicación maestro-esclavo, controlador proporcional integral derivativo (PID) y contadores de alta velocidad; y su utilización como elemento de apoyo al proceso de enseñanza de tópicos relacionados. Se analiza la operatividad de la estación conformada a partir de la integración de un sistema de control de velocidad en un motor de corriente alterna trifásica, cuyos parámetros son ingresados desde una interfaz gráfica ejecutada a través de una pantalla táctil. Tal aplicación fue implementada a través de una red de comunicación entre controladores; además, de emplear un variador de frecuencia y un encoder como elementos de potencia y de percepción, respectivamente. El desempeño observado durante las pruebas ejercidas constata un adecuado seguimiento de los parámetros asignados, al establecerse en éstos la respuesta real del sistema. Mientras que, en lo que respecta al uso de la estación modular de trabajo desarrollada, como herramienta didáctica para el análisis de soluciones avanzadas de automatización, se confirma su pertinencia.

Objectives	Methodology	Contributions
Expand the functionality of an existing modular workstation for advanced PLC operation.  Use the modular workstation as support in the teaching-learning process.	<ul style="list-style-type: none"> <li>✓ Identify the functionality of existing electrical panels and the functions and devices to be incorporated.</li> <li>✓ Establish the redistribution of electrical panels and carry out the physical modification process.</li> <li>✓ Integrate an industrial control system for the application of the added functions.</li> </ul>	<ul style="list-style-type: none"> <li>Enable and have an improved modular workstation for advanced PLC analysis and operation.</li> <li>Introduce the participant to the current trends and scope of automation and industrial control systems.</li> </ul>

### Programmable logic controller, PLC advanced functions, modular PLC workstation

Objetivos	Metodología	Contribuciones
Ampliar la funcionalidad de una estación modular de trabajo para el manejo avanzado de PLCs existente.  Utilizar la estación modular como apoyo en el proceso de enseñanza-aprendizaje.	<ul style="list-style-type: none"> <li>✓ Identificar la funcionalidad de los tableros eléctricos existentes y las funciones y dispositivos a incorporar.</li> <li>✓ Establecer la redistribución de los tableros eléctricos y ejercer el proceso de modificación física.</li> <li>✓ Integrar un sistema de control industrial para la aplicación de las funciones agregadas.</li> </ul>	<ul style="list-style-type: none"> <li>Habilitar y disponer de una estación modular mejorada para el análisis y manejo avanzado de PLCs.</li> <li>Encarar al participante con las tendencias y los alcances actuales de la automatización y los sistemas de control industrial.</li> </ul>

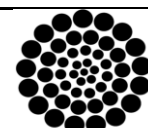
### Controlador lógico programable, funciones avanzadas del PLC, estación modular de trabajo con PLC

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## Introduction

Mechatronics Engineering synergistically integrates knowledge from the areas of mechanics, electronics, computing and control, for automation of processes and optimization of the use of resources, based on design, planning and construction of instruments and tools. In this way, a mechatronics professional must have an analytical, critical and creative capacity, oriented to design, implementation and innovation of automated systems; in addition to integrating, operating and maintaining them (Aquino Robles, Corona Ramírez, & Trujillo, 2013; Bolton, 2017; Baque Castro, Marcillo Pinales, Cedeño Ferrín, & Gutiérrez García, 2022). Companies receiving Mechatronics Engineers will generally require, in addition to the aforementioned skills, other added values, depending on functions to be performed (Breaz, Bologa, & Racz, 2014; Benavides Bastidas, Mosquera Terán, Peluffo Ordóñez, & Terán Pineda, 2017).

A highly sought-after skill in the industrial environment for Mechatronics Engineer is the operation of programmable logic controller (PLC). This is an industrial computer for process automation, which allows the implements to which it is adapted to effectively develop the functions of each system that constitutes them. This device has been vital for incorporation of automation in industrial systems. Its main function is the management of control systems, basis of automation; some of which will be closed-loop (Ephrem & Mohammad, 2016; Kelemen & Sinčák, 2020; Channi, Kumar, & Dhingra, 2024).

However, despite the recent advances promoted by introduction of Industry 4.0 paradigm and hyperconnection of devices, PLC has competitive characteristics that have allowed it to remain the industrial controller par excellence. Even so, recent industrial developments have made increasingly more demanding to take advantage of advanced functions that PLC may have, which allow operations to be carried out in real time, based on a reduced reaction period (Aquino Robles, Corona Ramírez, & Fernández Nava, 2019; Langmann & Stiller, 2019; Sehr et al., 2021).

Among the advanced functions that a PLC can have, it can be mentioned: handling of analog inputs and outputs, use of PID (proportional-integral-derivative) controller instruction, management tasks through HMI – SCADA (Human-Machine Interface – Supervisory Control & Data Acquisition) systems and interaction with other control devices, or regulation of actuators, through different communication protocols, to form industrial networks. To the extent that functions described are adequately applied in process management, the permissible level of automation will be established (Baniyounis & Alshabi, 2015; Mhetraskar, Namekar, Holmukhe, & Tamke, 2020; Hermans, 2023).

## Background and purpose of the intervention

Due to the low availability of industrial equipment required for development of advanced automation practices, as part of training of Mechatronics Engineers graduated from Technological University of Northern Aguascalientes, the convenience of implementing a series of electrical panels, made up of the minimum components, dictated by topics of subject Advanced Logic Control, has been analyzed for some time. It is worth mentioning that this subject concentrates a large part of contents related to the current trend of industrial automation; it being vital for the future professional to have a previous and significant contact with related devices, which at some point will have to be manipulated.

Thus, the purpose of this intervention was to expand the functionality of an existing modular PLC workstation, made up of two electrical test panels, or modules, integrated from Allen Bradley components. Housed inside the first panel were a PLC Micrologix 1500, an analog input and output module 1769-IF4XOF2, an Ethernet module 1761-NET-ENI, and an operator's interface PanelView Plus 600. The second panel housed a variable frequency drive (VFD) PowerFlex 40. Both panels were fitted with easy-to-connect terminals, in order to save as much time as possible in their operation; given that, originally, there was only one workstation, which was used to provide service to at least two groups, whose population fluctuates between 20 and 30 students.

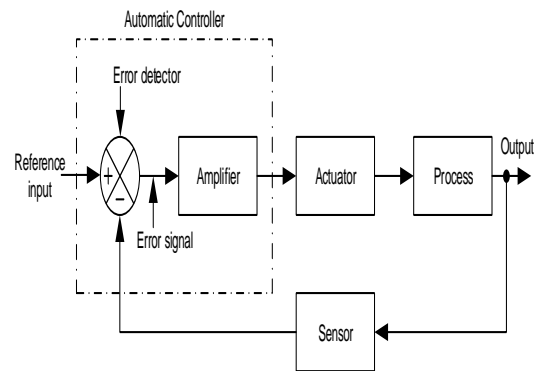
With the intention of promote a radical improvement in function of existing panels, it was agreed that they could be modified, either to adapt other devices or to provide a different organization to those that were already in place. In general, it was intended that, after this intervention, panels could be used to develop a greater number of educational applications; in addition, to generate a more significant impact on training of the participant. Innovation would focus on strengthening programming capabilities of available PLCs, to emphasis them on automatic process control, through use of PID instruction and high-speed counters (HSC); in addition, to incorporate some other controller to implement a hierarchical communication architecture between them.

Given the functions available in modular PLC workstation, after its modification, a series of practical exercises were proposed that could be developed with it, and that were then used, initially, for practical evaluation of subject Advanced Logic Control. Among the proposals assumed, one in particular was analyzed, which required the use of all the existing software and hardware elements, and which also served as a reference to establish the respective setting process. It was determined that the implementation of a closed-loop system for speed control on shaft of a three-phase motor would fulfill the given purpose; which is documented in this work, to account for adaptations made to the original modular PLC workstation.

### Control system preparation

In an industrial control system, the structure of which is shown in Figure 1, automatic controller compares the value obtained at the output of process to be controlled, with the reference input, to determine error signal between them. In relation to deviation detected and by applying a relevant control action, the same controller will set control signal so that detected error be reduced to a very low value or zero.

### Box 1



**Figure 1**

Block diagram of an industrial control system

Source: Ogata, 2010

Error signal usually has a very low power level, so controller amplifies it. Controller output is conducted to actuator, so that the latter produces a signal that, in turn, is routed to process to be controlled, in order to influence output signal in it to be controlled to approach the given reference signal. For its part, sensor interprets the process output signal, so that it can be compared with the reference signal (Ogata, 2010).

For purposes of control system to be implemented, a three-phase motor powered at 220 VAC (voltage of alternating-current) was used as an actuator, which provides a nominal speed of 1800 revolutions per minute (RPM); while sensor to be used would be a quadrature encoder, which provides 600 pulses per revolution. Encoder was adapted to the rear portion of motor shaft, from a mechanical coupling made with polylactic acid (PLA) filament, using 3D printing, and an aluminium base, as shown in Figure 2.

### Box 2



**Figure 2**

Motor used and encoder adapted to its shaft

Source [Own elaboration, 2024]

In turn, the use of a PLC for acquisition of speed data emitted by encoder was determined; therefore, to make an adequate interpretation of them, the respective programming was developed in RSLogix 500 software. Given the frequency of pulses generated, it was necessary to enable their reading from high-speed counters, which were set as programmable limit switches (PLS) in the digital input terminals of PLC, to which encoder was connected. Figure 3 shows the window for setting high-speed counters in RSLogix 500 software.

### Box 3

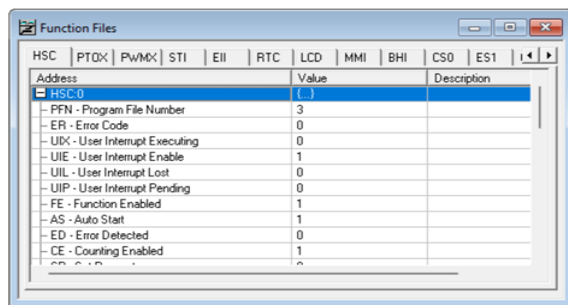


Figure 3

High-speed counters setting in RSLogix 500 software.

Source [Own elaboration, 2024]

## PID Instruction Configuration

In order to be used, PID instruction requires the association of specific addresses to the parameters: PID File, Process Variable and Control Variable, which are shown in Figure 4. PID File stores data necessary for execution of the instruction itself, with a length of 23 characters; so, it must be entered as an integer file address. Also, it is recommended to use a unique data file for PID File, so that accidental reuse of program addresses can be avoided. In PID File, given setpoint can be configured or deleted, preferred operating mode (time, manual/automatic and control) can be imposed, or enabled output can be limited.

### Box 4

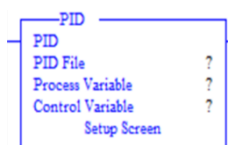


Figure 4

PID instruction in RSLogix 500 software.

Source [Own elaboration, 2024]

Process Variable stores the control system reference value or setpoint, which can come from a register containing reading obtained from an analog input terminal, or another associated with it, once processed. Finally, Control Variable records the value emitted by PID instruction itself or control signal, after processing system reference. It is worth mentioning that PID instruction does not allow floating-point values in any of its parameters, but rather these must be represented in integer format, between 0 and 16383, which corresponds to values between 0 and 100% of both process variable and control variable, as appropriate. The window for setting PID instruction in RSLogix 500 software is shown in Figure 5.

### Box 5

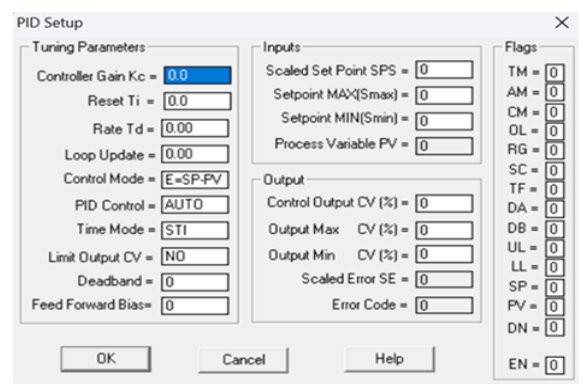


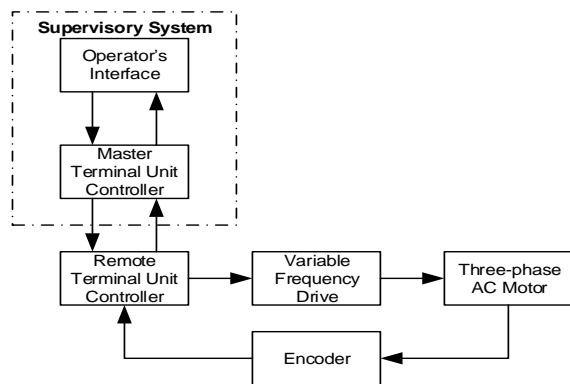
Figure 5

PID instruction parameters in RSLogix 500 software.

Source: Own elaboration, 2024

## Proposed communication architecture between devices

As part of control system to be implemented, integration of a communication architecture was contemplated that would establish a hierarchical relationship between two PLCs: a master terminal unit (MTU) controller and a remote terminal unit (RTU) controller, which would be located in different electrical test panels, or modules. Likewise, an operator's interface would be incorporated, to manage the operation of the entire modular PLC workstation. Figure 6 presents proposed distribution for components of the control system to be implemented.

**Box 6****Figure 6**

Original architecture of the proposed speed control system.

Source: Own elaboration, 2024

Originally, it was considered that direct control function would entirely executed by remote terminal unit controller; in whose programming, the emission of control signal that would lead to regulating speed reached on motor shaft, by means of the VFD used, as well as the interpretation of signal associated with such variable, acquired from encoder adapted to the motor shaft itself, would be ensured. Therefore, PID instruction would also be included in the programming of remote controller.

Control commands, or references, would be entered from operator's interface, and would also be guided to remote terminal unit controller through master terminal unit controller. Consecutively, information regarding speed reached on motor shaft would also be presented in operator's interface itself, after having been acquired by the same master controller from remote controller. In this way, both operator's interface and master controller would conform a supervisory system for direct control exercised on the motor.

### Adapting the communication architecture to existing devices

For physical integration of the planned communication architecture, it was agreed to use both operator's interface PanelView Plus 600, as well as two Allen Bradley PLCs, as master terminal unit and remote terminal unit controllers, respectively.

Also, in order to speed up interaction between devices described, it was proposed to use Ethernet/IP protocol, which is supported by all of them; in addition, to establish a physical connection between them through a switch.

Ideally, two PLCs to be integrated were supposed to be of the same model, with PLCs Micrologix 1400 being initially chosen; however, only one of these was available. Instead, a PLC Micrologix 1500 was chosen, to which a 1761-NET-ENI module was adapted to ensure its access to an Ethernet network. Under the new device organization, PLC Micrologix 1400 would act as master terminal unit controller; while PLC Micrologix 1500 would be remote terminal unit controller; consequently, analog input and output module 1769-IF4XOF2 would also be adapted to the latter, to carry out action of VFD incorporated. It is worth mentioning that configuration assigned to PLC Micrologix 1500 corresponded entirely to that adopted in the first available electrical panel.

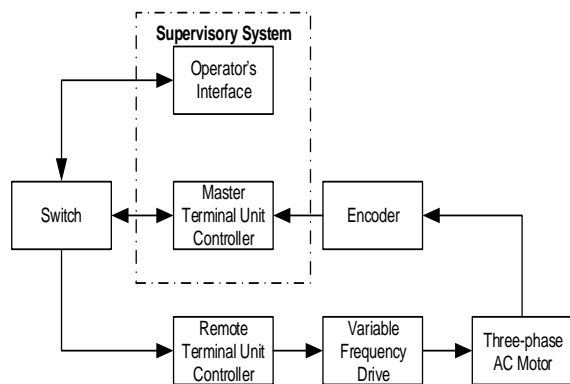
On the other hand, arrangement of high-speed digital inputs on PLC Micrologix 1400 and not on PLC Micrologix 1500, influenced to the designation of the first one to acquire data from encoder. Therefore, to improve the organization of devices and their connections, in the last network proposal to be implemented, it was decided to replace PLC Micrologix 1500 in the first existing electrical panel with PLC Micrologix 1400. This decision led to the creation of another electrical panel to house PLC Micrologix 1500 and the associated Ethernet and analog input and output modules, which is shown in Figure 7. In this way, the final proposal for distribution of components of control system to be implemented was integrated, which is shown in Figure 8.

**Box 7**



**Figure 7**  
Electrical panel for PLC Micrologix 1500.  
*Source: Own elaboration, 2024*

**Box 8**



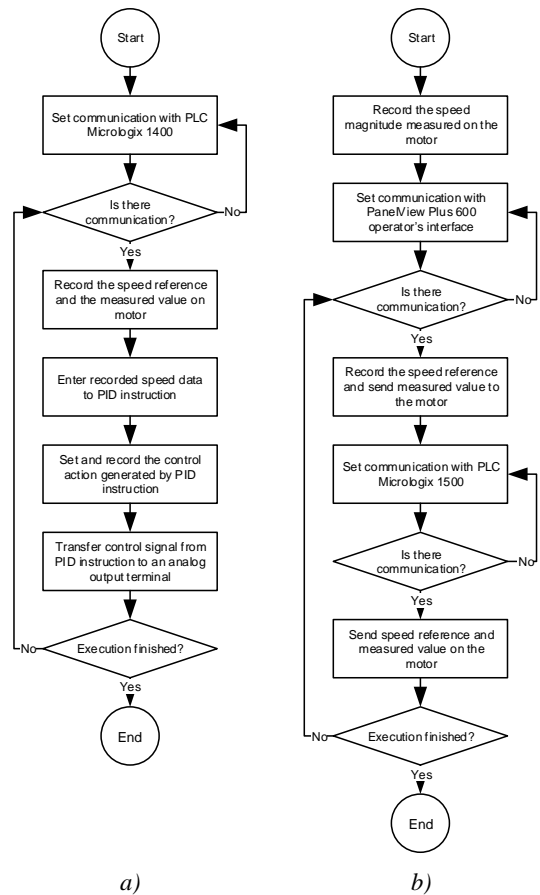
**Figure 8**  
Final architecture of the proposed speed control system.  
*Source: Own elaboration, 2024*

The application of Ethernet/IP protocol in hierarchical architecture shown in the figure above requires a Producer/Consumer dialogue mode between component devices. Producer role is assumed by the highest-ranking device, that is, the one around which communication structure itself is established; for purposes of system analyzed, this would correspond to master terminal unit controller (PLC Micrologix 1400); while remote terminal unit controller (PLC Micrologix 1500) would be considered as Consumer, as it responds to Producer's requests.

**Programming of controllers and operator's interface**

Dialogue setting between both PLCs used was integrated into the corresponding programming code, developed in RSLogix software. Mainly two types of instructions were incorporated: one for messaging, to manage sending of data from Producer to Consumer, and another for routing, which would allow the constant updating of exchanged information. And, since PLC Micrologix 1400 would also acquire speed data recorded in motor, also in the corresponding programming, it would be assumed that such information would be sent to PLC Micrologix 1500, as a feedback signal in the corresponding control system. The programming developed for both controllers is shown in flow charts in figure 9.

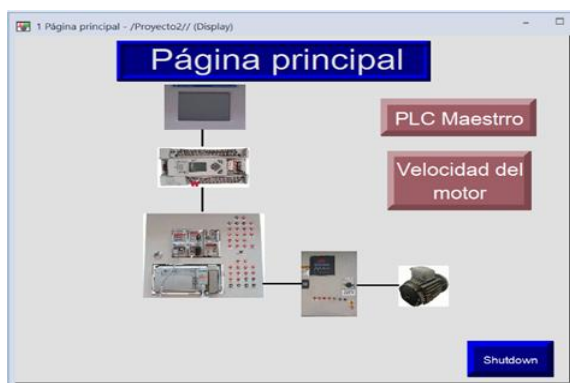
**Box 9**



**Figure 9**  
Programming flowchart for: a) PLC Micrologix 1500 and b) PLC Micrologix 1400.  
*Source: Own elaboration, 2024*

On the other hand, graphical interface was also developed to manage the operation of control system, from operator's interface PanelView Plus 600, using Factory Talk software. Through this interface, control setpoints, or references, could be admitted, as well as magnitude of the actual motor speed, or feedback, could be displayed. In the case of main screen design, interaction between the different modules used was taken as a reference, as shown in figure 10. Operator's interface also assumes the role of Consumer in the network integrated.

### Box 10



**Figure 10**

Main screen of control system graphical interface.

*Source: Own elaboration, 2024*

Two alternate screens were also developed. From the first alternate screen, a specific speed value would be applied to the motor used, through PLC Micrologix 1500, by means of a start and stop automation, which would use a different button for execution of each function. The second alternate screen would display speed magnitude measured on motor shaft, in revolutions per minute (RPM), acquired by PLC Micrologix 1400. For navigation through graphical interface, it was decided that from main screen it would be possible to access both alternate screens or to turn off the system; while from the first alternate screen it would be possible to go to main screen, or to the other alternate screen, and from the latter only main screen could be accessed.

### Operation of the communication network and the modular workstation

After completing the development of programming codes for devices to be used, these would be downloaded to the respective PLC and operator's interface.

Subsequently, the interaction between both controllers would be established, based on integration of a peer-to-peer network. Operator's interface PanelView Plus 600 would be added to this communication architecture, to manage the operation of control system. Initial performance tests focused on ensuring the proper functioning of device network, through the associated graphical interface, thereby validating both the correct operation of each node, as well as the establishment of communication between them, as shown in figure 11.

### Box 11

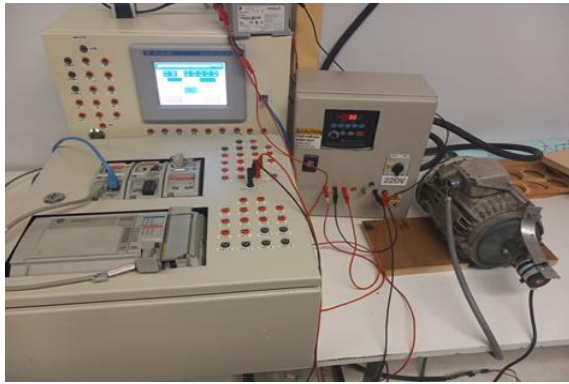


**Figure 11**

Communication between operator's interface and device network

*Source: Own elaboration, 2024*

For performance tests of the complete modular PLC workstation, connection was made between PLC Micrologix 1500 terminals and VFD PowerFlex 40, which would regulate the operation of motor. In this case, control signal generated by PID instruction programmed in PLC would be destined to an analog output terminal. Variable voltage magnitude generated by terminal used would be the reference for motor speed adjustment by the VFD used. Figure 12 shows the use of each electrical panel of modular workstation, modified or configured, in the development of operation tests of the proposed control system.

**Box 12****Figure 12**

Test development with the complete modular PLC workstation.

*Source: Own elaboration, 2024*

As part of tests carried out, motor activation would be executed from the developed graphical interface, while magnitude of the actual speed reached on motor shaft could be monitored; both data would be entered as parameters to PID instruction, while the respective output signal would be destined to VFD, in order to regulate the speed of motor shaft to the desired value. It is worth mentioning that operating tests carried out determined the expected behaviour both in each device involved, as well as in the interaction between them, as part of modular PLC workstation.

**Conclusions**

Despite the technological advances promoted by the Industry 4.0 paradigm, the PLC continues to be the controller par excellence used to constitute automated systems. However, it can be said that a basic understanding of PLC operation is not enough for future professionals in areas such as Mechatronics Engineering to be able to face the challenges posed by the current scope of automation. For example, at this time, automated systems do not operate as isolated entities, but rather, on the contrary, they form a vast distributed organization that ensures the operation of increasingly complex production processes. Therefore, it is vital to delve deeper into the study of the advanced functions that a PLC has.

In this case, the following were analyzed: the PID instruction, high-speed counters and hierarchical communication systems.

On the other hand, the configuration of the PID instruction in a PLC not only marks the incursion into the application of industrial automatic controllers, but also provides an idea of their operation in a device that, at an educational level, is not usually used for this purpose. Likewise, the existence of high-speed counters could potentially be unknown, until both the need to acquire signals at high frequencies and the fact that only some PLCs have them are determined. Finally, the establishment of communication between PLCs, based on a hierarchy, constitutes the principle for the integration of huge distributed systems, which in operational reality incorporate a wide variety of levels.

In this way, the modular PLC workstation exposed, and whose functionality has been extended from the intervention documented in this work, is outlined as a tool that will allow, even on a small scale, to involve the student of Mechatronics Engineering of the Technological University of Northern Aguascalientes in the current trends and scope of automation, with application in industrial control systems. This is a reality that is frequently misunderstood and little sought after, within the classroom, even in technological education institutions; in which, the minimum equipment required for the development of practices may not be available.

The update has enabled a means to be put into operation through which not only can each incorporated device be experimented with, but also, through the programming and functionality of each formulated application, the advanced functions available can be analyzed in greater depth. On this occasion, it is a pleasure to exhibit a sample of what can be integrated through the use of the advanced functions of the PLC, in combination with the capabilities of other devices, such as an industrial control system. Thus, the commitment after this intervention will be to continue improving the existing modular PLC workstation, evaluate the options for its application as support material in related subjects and analyze the possibility of integrating some others, to provide greater attention to the students.

### Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this document.

### Authors' Contribution

The contribution of each researcher in each of the points developed in this research, was defined based on:

*Rodríguez-Franco, Martín Eduardo:* Contributed to the project idea, research and experimentation methods, devices acquisition, physical devices redistribution planning into electrical panels and the writing of the article.

*Jara-Ruiz, Ricardo:* Contributed to the project idea, research and experimentation methods, physical devices redistribution planning into electrical panels and the configuration of controllers in software.

*Zacarias-Rodriguez, Luis Gerardo:* Contributed to the physical redistribution and electrical connection of devices into electrical panels, the development of graphical interface and the workstation operation tests.

*López-Álvarez, Yadira Fabiola:* Contributed to the project idea, literature research, technical information reviewing and scientific supervision of the writing of the article.

### Availability of data and materials

The devices and equipment used were acquired by the researchers for the purposes of the exposed application and the programs and graphical interfaces developed by themselves.

### Funding

The research did not receive any funding.

### Abbreviations

HSC	High-speed counters
HMI	Human-machine interface
MTU	Master terminal unit
PLA	Polylactic acid

PLS	Programmable limit switch
PLC	Programmable logic controller
PID	Proportional-Integral-Derivative
RPM	Revolutions per minute
RTU	Remote terminal unit
SCADA	Supervisory control & data acquisition
VFD	Variable frequency drive
VAC	Voltage of alternating-current

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## Evaluation of EPDM scrap/ natural fiber vulcanization by solvent swelling analysis

## Evaluación de la vulcanización de scrap de EPDM/fibras naturales mediante análisis de hinchamiento por solventes

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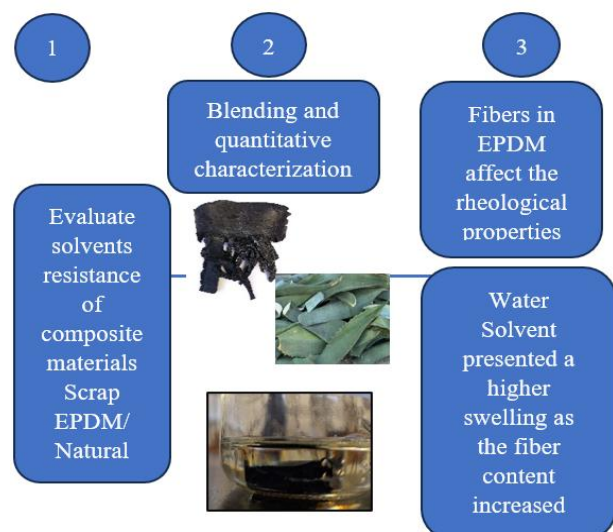
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## Abstract

In the rubber industry there is an opportunity to reuse unvulcanized rubber scrap generated during the formulation process, as well as to find alternatives for its use. For this reason, in this work the characterization of EPDM/natural fiber scrap with different proportions is studied through rheological and swelling studies according to the Flory Rehner Equation. The solvents used were distilled water, cyclohexane and toluene at different exposure times. The results found allow us to conclude that the fiber content in EPDM rubber does not affect the scorch time, the maximum vulcanization time. In the case of swelling analysis, the observed changes had a maximum increase of approximately 3% when the fiber content in the composite material increased when they were exposed to water and toluene, this was attributed to the characteristics of the EPDM studied in this work.

## Resumen

En la industria del caucho existe el área de oportunidad para el reaprovechamiento de scrap de caucho no vulcanizado que se genera durante el proceso de formulado, así como el encontrar alternativas para su uso. Es por ello, que en este trabajo se estudia la caracterización de scrap de EPDM/fibras naturales con diferentes proporciones mediante estudios reológicos y de hinchamiento de acuerdo con la Ecuación de Flory Rehner. Los solventes utilizados fueron agua destilada, ciclohexano y tolueno a diferentes tiempos de exposición. Los resultados encontrados, permiten concluir que el contenido de fibra en el caucho EPDM no afecta en el scorch time, en el tiempo máximo de vulcanizado y que en el caso del estudio hinchamiento los cambios observados tuvieron un incremento máximo del 3% aproximadamente al incrementarse el contenido de fibra en el material compuesto cuando fueron expuestos al agua y al Tolueno, esto se atribuyó a las características del EPDM estudiado en este trabajo.



EPDM, Flory Rehner, Natural fibers



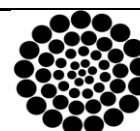
EPDM, Flory Rehner, fibras naturales

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## Introduction

Elastomers are unique materials, which makes them highly attractive materials for industrial and technical applications. The properties they possess are ideal for use in coatings, footwear, tyres, gaskets or insulation. In order for them to have these properties, crosslinks, covalent bonds between the vulcanising agent and the atoms of the polymer chain through the vulcanisation reaction, are necessary. The monitoring of the vulcanisation performance can be done by rheological analysis where three main stages are monitored: burn-in time, 90% vulcanisation time ( $T_{s90}$ ) and overcuring. The latter is observed in the results if the material is further heated.

EPDM is the fastest growing elastomer in production among synthetic rubbers as it has exceptional resistance to oxygen and ozone. It has low moisture adsorption, excellent weather and chemical resistance, good compressive deformation and very good fatigue resistance. The main use of EPDM is in automotive industry applications, such as door seals, window seals, body seals, cooling system circuit hoses and others.

On the other hand, lignocellulosic fibres or fibres of plant origin include fibres from stems, leaves, fruits, wood and cereals. At the end of their useful life, there is a potential source of economic raw material of non-wood origin. As is well known, the source of Tequila is the Agave Tequilana Weber or Azul process in which only the useful part of the agave is the pineapple. Therefore, during the Jima, the leaves are cut, source of fibres that are normally burnt or left to accumulate. Its characterisation and the study of its addition in polymeric materials or for obtaining biofuels have been reported in other works. The aim of this work is to study the effect of the incorporation of natural fibres into EPDM on vulcanisation and its effect on solvent resistance.

## Methodology

The materials used for the elaboration of the composites were: Scrap of non-vulcanised EPDM APD70 for applications in the automotive sector and fibres from Blue Agave stalks previously ground and sieved, donated by local producers in the state of Guanajuato, Mexico.

The solvents used for the swelling study were Meyer Cyclohexane, Karal Toluene and Ecopura distilled water, reagent grade.

The fibre concentrations studied were 10, 15 and 20 phr defined on the basis of 100 parts of rubber, in this case EPDM.

For the preparation of the compound, a BRABENDER mixing chamber equipped with a Banbury rotor, operated at a speed of 60 rpm and a temperature of 90°C was used. The mixing process was carried out for 7 minutes.

For the manufacture of the compression vulcanised sheets, a mould with a thickness of 3 mm, a temperature of 180°C and a pressure of 22,000 lbf was used.

The rheological study was carried out on a PROTECH cone and plate rheometer. For the study, 5 g of each unvulcanised sample was used, programming a time of 5 minutes for the test to be carried out.

In the case of the solvent resistance study, the equations used in this study are presented below.

The calculation of the degree of swelling was carried out using the following formula:

(1)

$m_s$  and  $m_r$  represent the weight of the swollen and initial rubber sample.

The measurement of the volume fraction of polymer in the swollen sample ( $v_x$ ) was carried out using three times 24, 48 and 72 h. using ASTM D6814-02 as a reference.

(2)

Where  $m_s$  and  $m_r$  are the weight of the swollen and initial rubber sample,  $\rho_s$  and  $\rho_r$  are the densities of the solvent and rubber, respectively. The crosslink density of the vulcanised samples was determined by the Flory-Rehner Equation:

$$v_x = - \frac{[\ln(1-v_r) + v_r + \chi v_r^2]}{\left[ V_1 (v_r^{\frac{1}{3}} - v_r) / 2 \right]} \quad (3)$$

Where  $V_1$  is the molar volume of the solvent,  $\chi$  el polymer-solvent interaction parameter or Flory-Huggins solubility parameter.

In Table 1, the theoretical data used for the calculations of the crosslink density and the EPDM Swell Degree are presented. The theoretical data for the solvent Toluene are also given, as well as the rubber/solvent interaction parameter used.

### Box 1

**Table 1**

Theoretical data used for calculations of crosslink density and Swelling Degree of EPDM and composite materials

Data	EPDM	Tolueno
Density (g/cm <sup>3</sup> )	0.86	0.87
Molar volume (cm <sup>3</sup> /mol)	-	106.13
Flory Huggins rubber/solvent interaction parameter ( $\chi$ )	-	0.496

Source: Own elaboration

## Results

**Table 2** shows the results obtained from the study of the rheological properties of EPDM and composites. The tests were carried out at 180°C to ensure the vulcanisation of the rubber.

### Box 2

**Table 2**

Curing properties of EPDM and composites at 180°C.

Fibre (phr)	$M_L$ (dN.m)	$M_H$ (dN.m)	$\Delta M$ (dN.m)	$T_{S2}$ (min)	$T_{S90}$ (min)
0	5.02	16.51	11.49	0.53	1.81
10	5.33	10.79	5.46	0.44	1.78
15	5.67	10.6	4.93	0.5	1.81
20	4.47	8.65	4.18	0.54	1.77

Source: Own elaboration

For the analysis of these results it is important to mention the meaning of each rheological parameter:

$M_H$ : Maximum torque (dNm), maximum applied force.

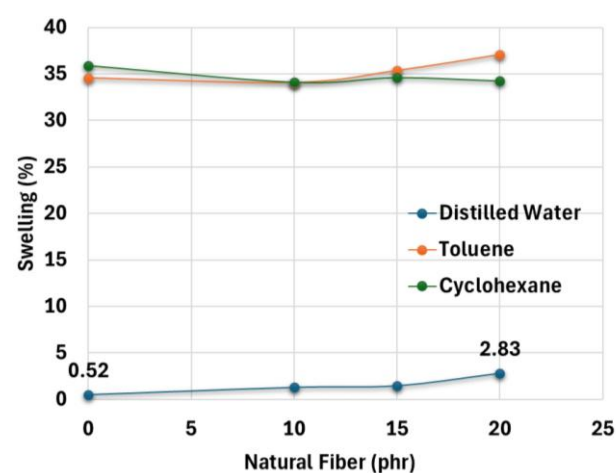
$M_L$ : Minimum torque (dNm), minimum applied force.

$T_{S2}$ : Scorch time (min), Time that elapses before vulcanisation begins at an elevated temperature. It can also be called induction or burn-in time.

$T_{S90}$ : Optimal vulcanisation time in minutes. It is the time to reach 90% vulcanisation at the indicated temperature.

From **Table 2**, it can be seen that one of the most important parameters during the study of vulcanisation is the value of  $T_{S90}$ . According to the data, by incorporating Agave Fibres in EPDM, the value of the optimum vulcanisation time remains practically without a significant variation. Something very similar in the case of **Ts2**, which indicates that the presence of the fibres is not affecting the speed of the reaction, since in other works, for example with sawdust, the reaction speed increased. The authors mention that the hydrophilic properties of the sawdust influenced this behaviour. In the case of  $M_L$ , a similar behaviour can be observed, which indicates that the initial viscosity is not affected by the presence of agave fibres, which is unexpected since it has been reported that the addition of fibres promotes an increase in viscosity. The opposite is true for  $M_H$ , where there is a decrease of approximately 50% with respect to the control EPDM. It is important to mention that the EPDM and the composites studied were not dried during the rheological tests. However, despite being studied in this way, it did not seem to influence the acceleration of vulcanisation significantly.

### Box 3



**Figure 1**

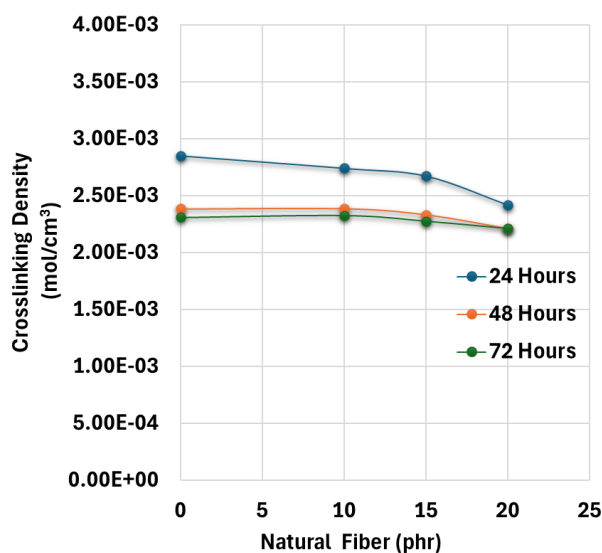
Swelling Degree (%) Vs Natural Fibre Content (phr) as a function of solvent type after 72 hours of treatment.

Source: Own elaboration

**Figure 1** shows the change in Swelling Degree (%) Vs Natural Fibre Content (phr) for EPDM and composite materials after 72 hours (considered the equilibrium swelling time of the materials) of exposure to 3 different solvents: Distilled water, Toluene and Cyclohexane. According to the results, it can be observed in general that the solvents to which the materials are more sensitive are the non-polar ones, reaching values of up to 35% swelling, in contrast to the polar solvent in which swelling reached about 3%. These significant differences between the solvents are attributed to the characteristics of EPDM.

In the case of distilled water, the increase is favoured by increasing the phr content of agave fibre in the composite. However, in the case of the solvents Toluene and Cyclohexane, an increase of 3% and a minimal change in the percentage respectively are observed.

#### Box 4



**Figure 2**

Crosslink density (mol/cm<sup>3</sup>) Vs Natural Fibre Content (phr) as a function of treatment time studied with Toluene.

Source: Own elaboration

In **Figure 2**, it can be seen that as the exposure time to the solvent toluene increases, there is a decrease in the crosslink density in all the materials analysed, being more important after 24 h, in contrast to the results at 72 h, where a stabilisation of the density is already observed, regardless of the fibre content in the composite.

Analysing these last results, it can be appreciated that the crosslinking density between EPDM and the composites was insignificant, which can be correlated with the rheological results, since no values with important differences were obtained in  $\tau_{s2}$  and  $\tau_{s90}$ , which corroborates that the agave fibres with the characteristics investigated in this work do not affect the kinetics of vulcanisation, a fundamental factor in the performance of EPDM rubber.

## Conclusions

The incorporation of fibres in EPDM does not affect the rheological properties of the composite material. Composites exposed to water showed a higher degree of swelling as the fibre content increased. The solvents toluene and cyclohexane showed 3% and no significant differences in the degree of swelling of the materials with respect to EPDM, respectively. The crosslinking density calculated according to the Flory-Rehner equation showed that at least 72 hours were required to reach an equilibrium value.

The presence of agave fibres in the EPDM did not affect the vulcanisation kinetics, however, further material characterisation is needed. Future work will analyse the effect of reactive compatibilising agents during vulcanisation in the EPDM/natural fibres composite material on its rheological properties.

## Declarations

### Conflict of interest

The authors declare no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

### Author contribution

The contributions of each researcher to the points developed in this research were defined based on:

*Kantun-Uicab, María Cristina:* Contributed to the project idea, research method and technique and the writing of the article.

*Estrada-Monje, Anayansi:* Contributed the type of research, the approach, and the method.

Rodríguez-Sánchez, Isis: Contributed to the research method, technique as well as writing the article.

### Availability of data and materials

EPDM was donated by a company that is not mentioned due to formulation rights. Blue Agave leaves were donated by local producers in Guanajuato, Mexico. The characterisation of the materials was carried out in the laboratories of CIATEC, León and in the laboratories of UPJR.

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### Abbreviations

EPDM            Ethylene-propylene-diene  
                         Monomer

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# Study of cooling system performance on lithium-ion batteries for an electric vehicle

## Estudio del desempeño de un sistema de enfriamiento en baterías de iones de litio para un vehículo eléctrico

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### Abstract

The acquisition of electric vehicles has grown considerably, as a result, autonomy and safety became an opportunity for improvement, one of the main systems that involve autonomy and safety are batteries. The safety and the performance of the batteries are directly related to the temperature reached during charge and discharge operation. In this paper, a CFD study is carried out on the thermal and hydrodynamic performance of a cooling system used to prevent overheating of lithium-ion batteries used in electric vehicles. Air as cooling fluid is used, which is directed towards the battery cells to remove the heat generated by each of these cells. An in-line arrangement for the batteries is analyzed, different velocities and discharge rate to obtain temperature profiles on the cell surface are used, as well as a total pressure drop along the cell array. The minimum inlet velocity which the working fluid must work to ensure adequate temperature of the battery cells in operation is found.

### Resumen

La adquisición de automóviles eléctricos ha crecido considerablemente, esto ha traído consigo algunas necesidades en el área de seguridad y autonomía del automóvil eléctrico, uno de los principales sistemas que involucra ambos temas son las baterías, ya que la seguridad y sobre todo su rendimiento está relacionado directamente con la temperatura que alcanzan durante su funcionamiento de carga y descarga. En el presente trabajo se realiza un estudio usando CFD del desempeño térmico e hidrodinámico de un sistema de enfriamiento, usado para evitar el sobrecalentamiento de las baterías de iones de litio usadas en los vehículos eléctricos. Se utiliza aire como fluido de enfriamiento, el cual es direccionado hacia las celdas de la batería para remover el calor generado por cada una de estas celdas. Se analiza un arreglo en línea para las celdas de la batería, se utilizan diferentes velocidades y diferentes razones de descarga, para obtener los perfiles de temperatura sobre las superficies de las celdas, así como también la caída de presión total a lo largo del arreglo de las celdas. Se encuentra la velocidad mínima a la cual debe trabajar el fluido de enfriamiento para garantizar una adecuada temperatura de las celdas de la batería en operación.

Objective	Methodology	Contributions
Thermal and hydrodynamic performance study.	Geometric configuration.	Results analysis
Battery temperature control.	Computational model.	Cooling system configuration.
	Model solution and validation.	

Objetivo	Metodología	Contribuciones
Estudio del desempeño térmico e hidrodinámico.	Configuración geométrica.	Análisis de resultados.
Control de temperatura de baterías.	Modelo computacional.	Configuración de sistema de enfriamiento.
	Solución y validación del modelo.	

Lithium-ion battery, CFD, Cooling system

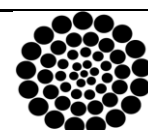
Batería de iones de litio, CFD, Sistema de enfriamiento

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## Introduction

Global warming, which impacts the planet worldwide, is one of the main problems that must be tackled with immediate and concrete actions. In order to implement actions to mitigate climate change, a large amount of resources have been allocated to study its causes and effects. It is known that one of the main causes of climate change is the emission of greenhouse gases, where one of the main sources of these gases is the transport industry, specifically the automotive industry, which mainly uses internal combustion engines (L. Li et al., 2018), which use fossil fuels as their main source of energy. One of the actions that have been implemented is the replacement of internal combustion engines with electric motors, which represents a benefit in reducing greenhouse gas emissions (Shi et al., 2019). With the advancement of technology, the use of electric motors instead of internal combustion engines has increased in recent decades, especially in compact cars and motorbikes that do not require high power to operate.

With the use of electric motors in automobiles, different problems and challenges have arisen that must be addressed, one of the main problems has to do with the batteries used for the operation of the electric motor, these batteries must work properly and under certain operating conditions, which have a direct impact on the performance of the batteries during their charging and discharging operation. It is for this reason that during this operating cycle, the heat generated must be regulated, as this heat reduces the performance of the battery, also affecting the safety and useful life of the battery.

Due to the above, it is necessary to have a cooling system for the battery used in electric or hybrid vehicles. One of the batteries commonly used is the lithium-ion battery, which must be kept at an operating temperature range between 15-40 °C (288-313 K), working within this range avoids performance problems and above all safety problems, since if any of the battery cells explode there can be serious consequences for the crew.

In recent years, cooling systems have been used for batteries, these systems use air as the cooling fluid and the heat transfer mechanism by natural or forced convection.

### Box 1

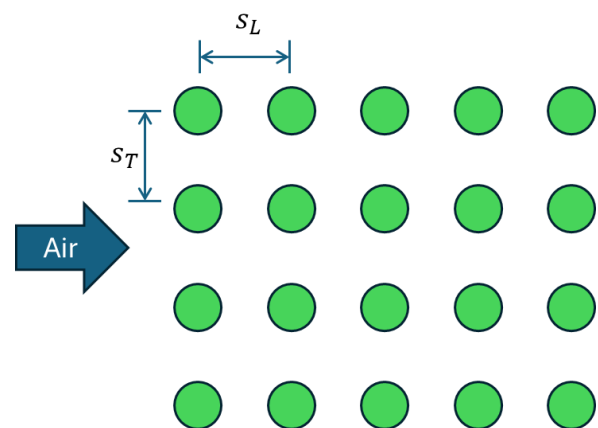


**Figure 1**  
Lithium-ion cell

Source: Own elaboration.

The battery is composed of several cells, which are arranged according to the current and voltage requirements of the engine, in Figure 1 shows a lithium-ion cell, an arrangement of these cells makes up what is the battery..

### Box 2



**Figura 2**  
Cell arrangement for the battery.

Source: Own elaboration.

A type of arrangement is used in the battery configuration to place the different cells, which arrangement must contain certain spaces to ensure air circulation through the battery cells. Usually the in-line arrangement is used which is shown in Figure 2. It can be seen that one of the important parameters is the transverse distance ( $s_T$ ) and the longitudinal distance ( $s_L$ ). There may be another arrangement known as staggered arrangement, for the purpose of this study only the in-line arrangement is considered for analysis.

The design of the cooling system of a battery is crucial for its correct operation, its sizing must be configured to the use of the vehicle and the behaviour of the battery charging and discharging. Therefore, in this paper, a cooling system is analysed to ensure that the battery to be used in a motorbike works in a suitable temperature range.

## Background

Nowadays the sale of electric vehicles has increased worldwide, due to this, areas of opportunity for improvement have been identified in the different systems that integrate an electric vehicle, one of the main systems that have been identified as possible improvements is the cooling system of the batteries, because the batteries can present an excessive heating during its operation cycle, some solutions have been implemented to remove the heat that is generated with the work of the batteries, since the increase of the temperature can affect the performance and the useful life of these.

The heat generated during the operation of batteries in electric vehicles significantly raises the temperature of the batteries, which directly affects the performance of the battery, especially if it is not maintained within a certain operating range, also the presence of high temperatures generates problems in safety and affects the life of the battery, it can also cause a thermal leakage, which represents a potential danger, which is why the heat generated has been identified as one of the main causes of increased operating costs of electric and hybrid vehicles.

In this paper, they focus on the development of a cooling system specifically designed for lithium-ion batteries, widely used in the automotive industry, the main proposal of their work consists of three cooling strategies, the first one is air cooling, the second one is liquid cooling and the third one is a flat heat pipe system. These strategies offer complementary solutions for battery heat dissipation. They conducted their thermal analysis of the battery, which allowed them to identify the critical areas where the most heat is generated during operation. This analysis allows them to maximise heat dissipation by focusing on cooling these identified regions. To evaluate their proposals, they use fluid dynamics models (CFD) validated with the surface temperature of the cells that make up the batteries.

Their results report that the flat heat pipe approach provides up to 42.7% better cooling during discharge. As expected, the liquid cooling system and the heat pipe show better performance compared to natural air cooling.

Achieving a mathematical model of an efficient design of a cooling system for batteries used in electric vehicles is not straightforward, because several variables must be considered at the same time, which generates a multi-objective optimisation problem. they present a mathematical model for a battery cooling system, in their model they consider air as a cooling fluid and fins for better heat dissipation. The aim of their research is to reduce three key parameters in heat dissipation in lithium-ion batteries: the average temperature, the standard deviation of the battery temperature and the pressure drop of the cooling system. Minimising the average temperature ensures that the battery operates within a safe range and thus avoids overheating. When the standard deviation is minimised, a uniform temperature distribution is achieved throughout the battery, thus avoiding hot spots that could cause thermal runaway. Finally, decreasing the pressure drop helps to improve the pressure drop in the cooling system, thus requiring less energy to maintain the battery temperature within the desired range. As results, they report the optimised parameters of the cooling system, which presents a balance between cooling efficiency, system volume and energy consumption.

Similarly, they propose a mathematical model designed to improve the accuracy of the data obtained by numerical analysis of the temperature inside the battery cells. The above aims to realise a proper design of a battery cell that leads to an increase in the lifetime of the battery cells and the energy efficiency of the electric vehicle under the specific traffic operating conditions. By comparing their results they obtain that the use of the proposed mathematical model provides more accurate calculations of the local thermal performance of the air-cooling system, with a direct influence on the optimisation of its design and construction.

Several researches have taken into account the thermal analysis during high current demand charging and discharging.

They construct an air cooling system based on heat pipes to control the temperature of the lithium-ion (Li-ion) battery cell and module for a high current discharge rate (184 A). They perform an analysis of the cell temperature experimentally and numerically, evaluating different cooling strategies, such as natural convection, forced convection and evaporative cooling. According to the experimental results, natural convection reduces the average cell temperature by 6.2%, however, forced convection, which uses air as the cooling fluid, is significantly more effective, reaching up to 33.7% in reducing the average cell temperature. The results of the simulations are validated with the experimental results for natural and forced convection. The evaporative cooling method improves the cooling system, it is shown to be the most effective strategy, reducing the maximum cell temperature by 35.8 %, while for the full battery the reduction is 23.8 %. This reduction is due to the high heat transfer coefficient associated with evaporation.

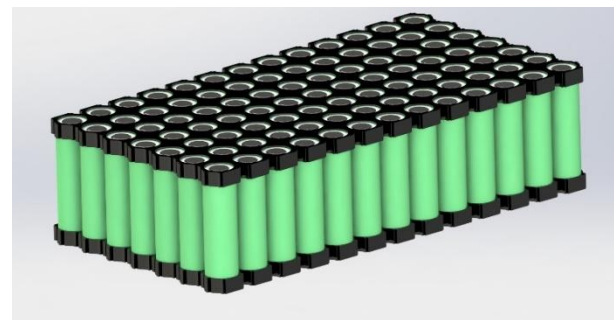
In electric vehicles the robustness of each of the systems must be taken care of, in the case of electric vehicles special attention must be paid to the battery system and the cooling system of these batteries. Therefore, they propose 4 novel cooling system designs based on liquid-cooled plates, which flow through microchannels to improve the dissipation of heat generated by the batteries. They consider a 35 V battery composed of 12 LiFePO<sub>4</sub> type cells connected in series. The proposed designs are evaluated and compared using various criteria, such as discharge rate, thermal contact resistance and external short-circuit. In the results of their study they identify the most efficient design, which achieves the best cooling with the lowest energy consumption during discharge. This design achieves a maximum temperature of 30°C, with a maximum temperature difference of less than 5°C between cells, which is important to ensure a homogeneous temperature and prevent hot spots. As for the thermal contact resistance, the results do not show a significant effect for each of the designs. They report that care must be taken in the selection of the coolant flow rate, which must be adequate, as this parameter is key to maintain the maximum temperature and the temperature gradient in the battery, an inefficient flow rate could cause overheating of the cells.

In relation to the arrangement of the battery cells, they present a proposal for a cooling system, which is based on countercurrent air for a staggered configuration, this proposal seeks to improve the low heat transfer efficiency of the air cooling module in the lithium-ion battery, as well as to reduce the temperature difference between the cells. In their results they identify and analyse the main factors affecting the temperature distribution inside the cell. Their results show that both the maximum temperature and the temperature difference of the battery gradually decreased with increasing flow channel height. As expected, the higher the channel height, the higher the flow rate of the cooling fluid and consequently the higher the heat dissipation capacity. The number of flow channels had a negligible effect on the reduction of the maximum coil temperature. The optimal parameters identified in their research were: channel height of 4 mm, flow velocity of 3 m/s and a total of 6 channels. With this configuration, the cooling system achieved a better temperature distribution, which ensures a more efficient and safer operation.

### Geometric model

A typical arrangement of the lithium-ion cells that make up a battery is shown in Figure 3 below.

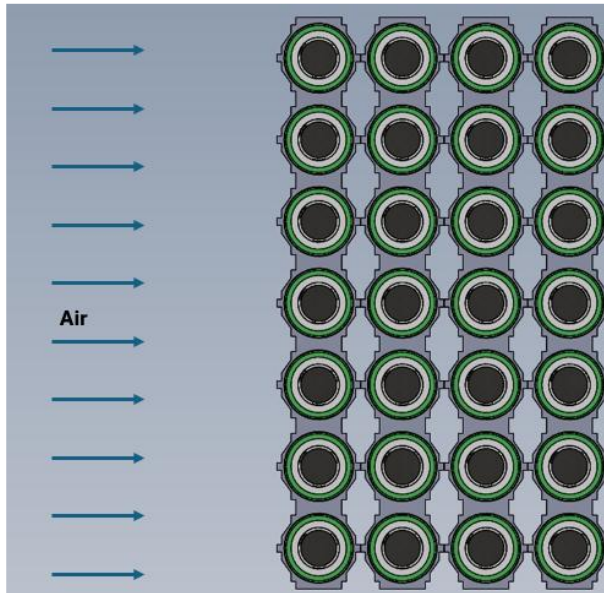
#### Box 3



**Figure 3**

Cell arrangement for the battery.

*Source: Own elaboration.*

**Box 4****Figure 4**

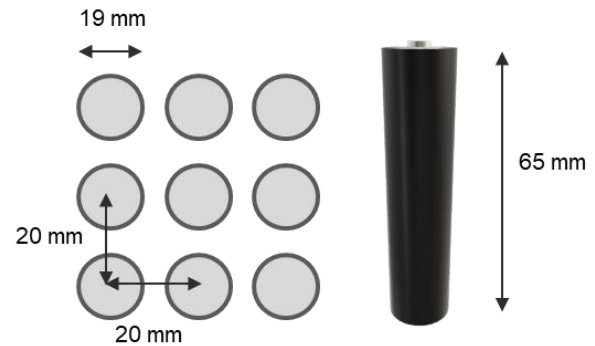
Cell arrangement for the battery, top view

Source: Own elaboration.

Figure 4 shows a partial view of the in-line arrangement of each of the cells that make up the battery, this arrangement presents both vertical and horizontal alignment of the different cells, this causes the cooling air to flow through the cells, completely surrounding them with the cooling fluid, which will help the air to remove the heat generated by each of the cells.

The battery built to run the motorbike must provide enough power to run a 72 Volt, 3000 W Kunray engine. The cells used for the construction of the battery are a 3.7-4.2 Volt rechargeable cell, with a capacity of 9800mAh of Lithium Ion material.

The dimensions of one of the cells that make up the battery are shown in Figure 5, it has a diameter of 19 millimetres and a height of 65 millimetres. The in-line array has the dimensions shown, a longitudinal and transverse distance of 20 millimetres, the array is composed of 10 cells wide by 20 cells long.

**Box 5****Figure 5**

Cell and battery array dimensions

Source: Own elaboration.

Figures 6 and 7 present the battery constructed to operate the engine.

With this arrangement the 72 volt motor can be driven, which requires a battery consisting of 20 cells connected in series and 20 cells connected in parallel, plus the battery provides power for a DC-DC voltage converter from 72 Volts to 12 Volts. This converter in turn powers the accessories such as the headlights, stop lights, turn signals, the BMS display and the digital speedometer.

The weight of the battery is 16 kilograms, which is less than the weight of some commercial batteries, which is up to 20 kilograms. The performance parameters of the battery are as follows, nominal voltage of 3.7 Volts, nominal capacity of 9800 mAh, equivalent density of  $2018 \text{ kg/m}^3$ , volume of  $1.654 \times 10^{-5} \text{ m}^3$ .

**Box 6****Figure 6**

Constructed arrangement of cells for the battery

Source: Own elaboration.

**Box 7****Figure 7**

Battery built by cells.

Source: Own elaboration.

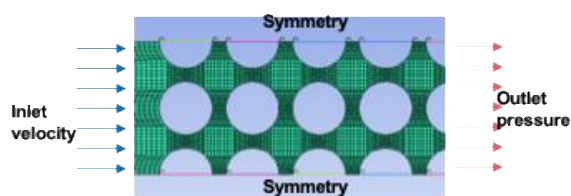
**Methodology and materials**

Once the geometry of the battery cell arrangement is built in CAD, the model is exported to ICEM ANSYS, where the mesh required for the CFD analysis is created. Figure 8 shows the computational domain generated, taking as boundary conditions an input velocity and as an output condition an output pressure, as well as the symmetry condition, this will reduce the number of elements and therefore save computational time required for the solution.

**Box 8****Figure 8**

Computational domain built

Source: Own elaboration.

**Box 9****Figura 9**

Mesh constructed in the computational domain and boundary conditions assigned

Source: Own elaboration.

**Box 10****Table 1**

Mesh independence study.

Mesh elements	$T$ [K]	$\frac{\Delta T^i - \Delta T^{i+1}}{\Delta T^i}$
668,945	307.605	$5.468 \times 10^{-3}$
1,105,188	307.512	$1.8574 \times 10^{-4}$
1,387,097	307.510	-----
1,507,474	307.510	-----

Source: Own elaboration

Figure 9 shows the boundary conditions used for the computational analysis; there is an input velocity, an output pressure and the symmetry condition is assigned to simplify the computational model. It is also possible to appreciate the mesh built on the computational domain, a mesh dependence analysis is performed, for which the temperature variable is monitored for different numbers of elements of the generated mesh, Table 1 shows temperature variation as a function of the number of elements used in the model. It is observed that, from 1,105,188 elements, there is no longer a significant variation in the temperature, this indicates that using a mesh with a higher number of elements than indicated will not improve the accuracy of the analysis, but it will require a higher computational capacity. It is for this reason that the indicated mesh is considered suitable for computational analysis as it has a balance between accuracy and computational efficiency.

In the analysis, air is used as the cooling fluid, for which a density of  $1.225 \text{ kg/m}^3$ , a specific heat of  $1006.43 \text{ J/kgK}$ , a thermal conductivity of  $0.0242 \text{ W/mK}$  and a viscosity of  $1.7894 \times 10^{-5} \text{ kg/ms}$ .

For the analysis a volumetric heat generation per cell is considered as shown in Table 2, three different scenarios will be analysed, each at different discharge rates of the battery, for which it is assumed that it is discharged at a rate of 1C, 2C and 3C. According to the demand required by the motorbike, the discharge ratios are estimated to be 1C and 2C, the discharge ratio of 3C is when the battery is already used in a car, as a higher power is required.

**Box 11****Table 2**

Volumetric heat generated by battery cells for different discharge ratios.

Reason for discharge	Volumetric heat generation
1C	5318 W/m <sup>3</sup>
2C	19,452 W/m <sup>3</sup>
3C	42,400 W/m <sup>3</sup>

Source: Own elaboration

The governing equations to be solved are presented below.

For the solid, we have the energy equation, equation (1):

$$\rho C \frac{\partial T}{\partial t} = k \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) + \dot{Q} \quad (1)$$

In the above equation,  $\rho$  is the density,  $C$  is the specific heat,  $T$  is the battery temperature,  $k$  is the thermal conductivity and  $\dot{Q}$  in volumetric heat generation.

For the fluid we have equation (2), which is the energy equation, equation (3) is the continuity equation and equation (4) is the momentum equation..

$$\rho_f C_f \frac{\partial T_f}{\partial t} + \nabla(\rho_f C_f \vec{v} T_f) = \nabla(k_f \nabla T_f) \quad (2)$$

$$\nabla(\vec{v}) = 0 \quad (3)$$

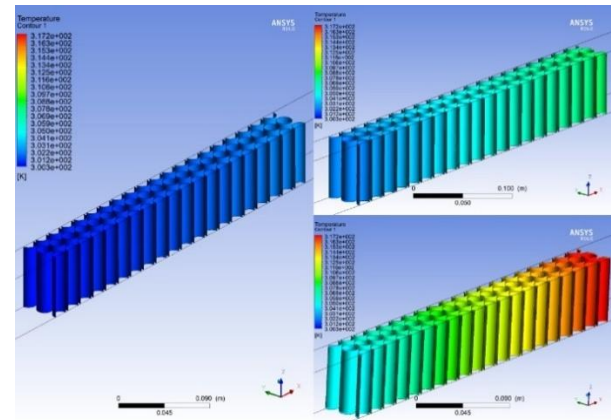
$$\rho_f \left[ \frac{\partial \vec{v}}{\partial t} + (\vec{v} \nabla \vec{v}) \right] = -\nabla P + \mu \nabla^2 \vec{v} \quad (4)$$

In the above equations,  $\rho_f$  is the density of the fluid,  $C_f$  is the specific heat of the fluid,  $T_f$  is the temperature of the fluid,  $k_f$  is the thermal conductivity of fluid,  $\mu$  is the dynamic viscosity of the fluid and  $\vec{v}$  is the flow rate of the fluid.

For the analysis, air velocities from 0.1 m/s to 1 m/s are considered, this for each of the volumetric heat generated according to the discharge ratio, the assigned outlet pressure is 0 Pa. The coupling between the solid and the fluid is considered and the walls are taken as no slip, the turbulence model taken is the (Renormalisation Group). The time step of 1 second is considered, where the number of iterations for each time step is 50.

**Results**

The results obtained from the analysis are presented below, showing the temperature contours for each of the study cases, the maximum temperature reached and the total pressure drop across the battery for each case.

**Box 12****Figure 10**

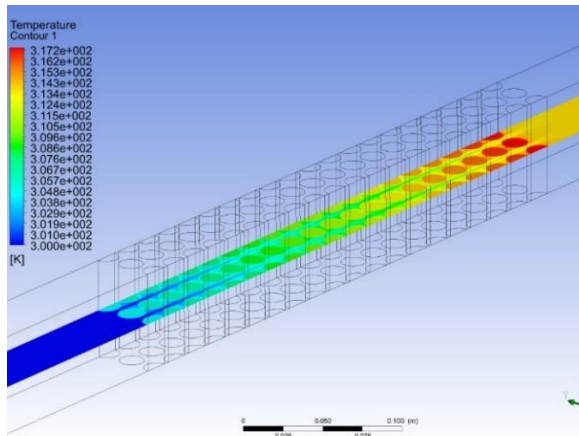
Temperature contours for an inlet velocity of 0.5 m/s and for a discharge rate of 1C, 2C y 3C.

Source: Own elaboration.

Figure 10 shows the temperature contours of the battery array for an analysis speed of 0.5 m/s for the different discharge ratios analysed. It is observed that the maximum temperature reached is 302.19 K, 308.02 K and 317.32 K for a discharge rate of 1C, 2C and 3C, respectively.

The temperature contours for a plane through the battery cells and the cooling fluid are shown in Figure 11, for a speed of 0.5 m/s and a discharge rate of 3C, the temperature of the battery cells and also the temperature of the fluid can be observed, it can be seen how the fluid enters at a temperature of 300 K and increases as it removes the heat produced by the battery cells until it exits the battery and has a temperature of 315 K.

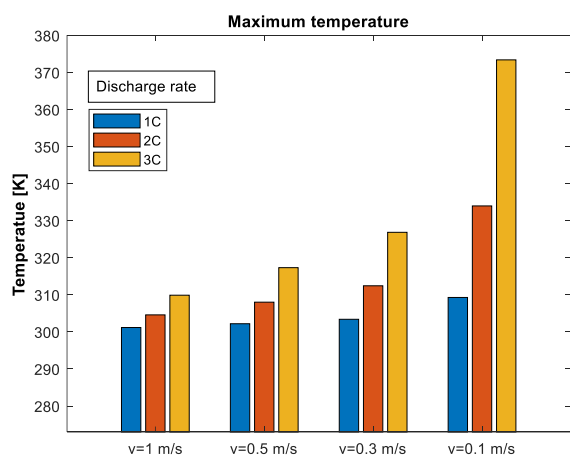
**Box 13**



**Figure 11**  
Temperature contour for battery cells and fluid.  
*Source: Own elaboration.*

Figure 12 shows the maximum temperature that can be reached in the final section of the battery for speeds of 1, 0.5 0.3 and 0.1 m/s, for the battery discharge ratios of 1C, 2C and 3C. From the graph it is deduced that for the discharge rate of 1C the temperature of 313 K is not exceeded, remembering that working above this temperature affects the performance, safety and useful life of the battery; for the discharge rate of 2C it is found that when the speed is 0.1 m/s the temperature of 313 K is exceeded, therefore it is recommended that for this discharge rate the cooling fluid has a speed greater than 0.1 m/s. Finally, for the discharge rate of 3C it is deduced that the cooling fluid must work above 0.5 m/s, since below this speed, the maximum temperature reaches values up to 373.4 K.

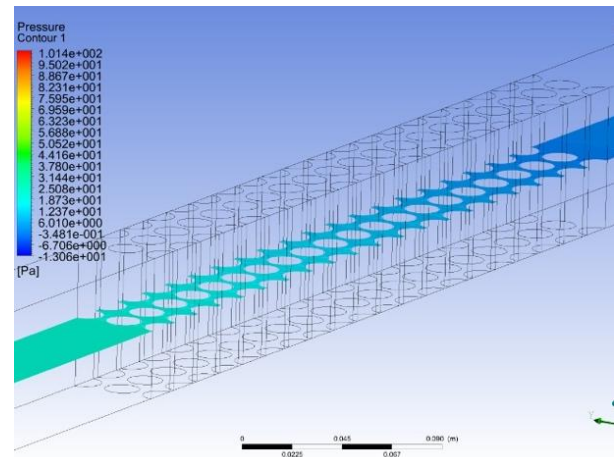
**Box 14**



**Figure 12**  
Maximum temperature reached by the battery for different discharge rates and ratios.  
*Source: Own elaboration.*

Another variable of interest in the battery cooling system is the pressure required for the movement of the cooling fluid. Figure 13 shows the pressure contour of the fluid along the battery cell array for a velocity of 0.5 m/s, showing a maximum pressure of 22.9 Pa at the inlet of the cell array and decreasing as it moves out of the battery.

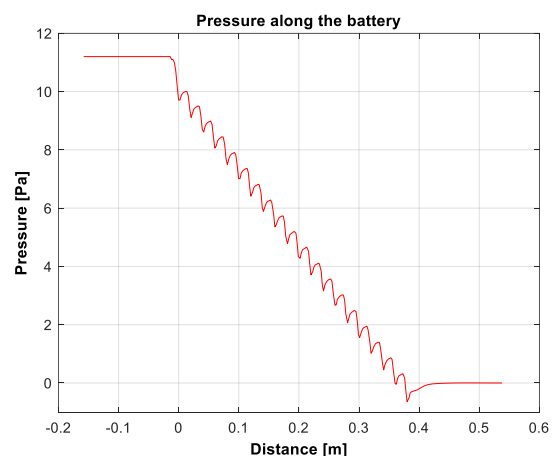
**Box 15**



**Figura 13**  
Fluid pressure contour through the coil for a velocity of 0.5 m/s.  
*Source: Own elaboration.*

The fluid pressure along the battery for a speed of 0.3 m/s is shown in Figure 14, the behaviour is observed, it can be seen how the pressure decreases as the fluid enters the battery arrangement and how slight increases are observed each time the fluid collides with any of the cells of the battery.

**Box 16**



**Figure 14**  
Fluid pressure contour through the coil for a velocity of 0.5 m/s  
*Source: Own elaboration.*

## Box 17

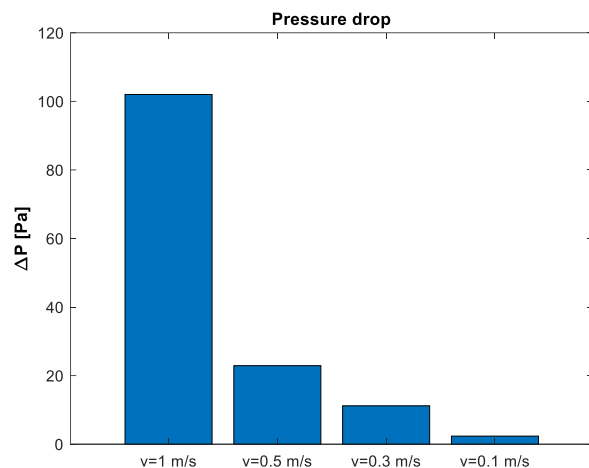


Figure 15

Fluid pressure contour through the coil for a velocity of 0.5 m/s

Source: Own elaboration

Figure 15 shows the pressure drop of the cooling fluid across the coil for the velocities of 1, 0.5, 0.3 and 0.1 m/s. As expected, the higher the velocity, the higher the pressure drop. As expected, the higher the speed, the higher the pressure drop, a considerable increase in the pressure drop from 0.5 m/s to 1 m/s is observed, so that the speed of 0.5 can be considered as the appropriate speed for the cooling fluid, since also at this speed the maximum temperature for a discharge rate of 2C is around the 313 K allowed.

## Conclusions

In conclusion, a numerical model that simulates the cooling of the lithium-ion cells that make up the battery is available. The battery is analysed for different discharge ratios and different cooling fluid velocities. It is found that when the discharge ratio of the battery is 1C, the battery works within the temperature range suitable for its operation, when the discharge ratio is 2C the cooling fluid is required to have a minimum velocity of 0.3 m/s and for a discharge ratio of 3C a cooling fluid velocity above 0.5 m/s is required. The pressures and pressure drop across the coil arrangement are reported. It is found that for the cooling fluid to flow at a velocity of 0.5 m/s a pressure of 22.9 Pascals is required.

As future work, experimental tests will be carried out on the constructed battery, which will be installed on an electric motorbike, and the corresponding tests will be carried out. The experimental results will be compared with the numerical results.

The battery cooling solutions are considered to be temporary solutions, as the electric vehicle industry is working on and expecting a breakthrough in electric energy storage technology in terms of performance, lifetime, safety, specific energy and above all cost.

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### Basics

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Selecting a suspension system for a mini-baja vehicle

Selección de un sistema de suspensión para un vehículo de tipo mini-baja

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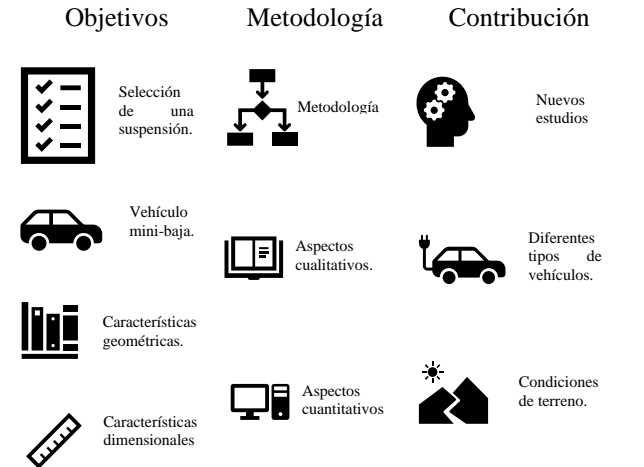
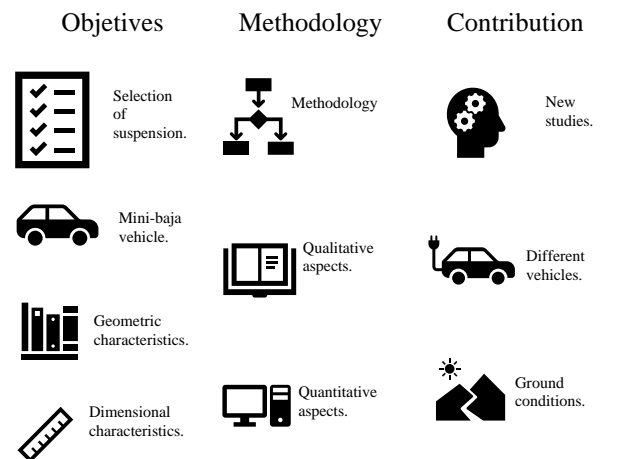
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Abstract

The general objective of this work is to select a suspension system for a mini-baja vehicle. Among the specific objectives is the development of an analysis of the geometric and dimensional characteristics of the semi-independent suspension system and McPherson suspension system. The type of methodology that was used had a quantitative and qualitative approach, since it was not only intended to select the suspension system based on mathematical data provided by the simulation, but also on certain physical characteristics that the suspension system possesses. This work contributes to the development of new prototypes in terms of suspension systems, since it opens the way for competitive vehicles to analyze the suspension system that best adapts to both the conditions of their vehicles and the of the land itself, considering the qualitative and quantitative analyses.

Resumen

El objetivo general del presente trabajo es seleccionar un sistema de suspensión para un vehículo tipo mini-baja. Dentro de los objetivos específicos se encuentra el desarrollo de un análisis de las características geométricas y dimensionales del sistema de suspensión semi-independiente y sistema de suspensión McPherson. El tipo de metodología que se utilizó tuvo un enfoque cuantitativo y cualitativo, ya que no sólo se pretendía seleccionar el sistema de suspensión en base a datos matemáticos que arrojara la simulación, sino también a ciertas características físicas que el sistema de suspensión posee. Este trabajo contribuye al desarrollo de nuevos prototipos en lo que a sistemas de suspensión se refieren, ya que se abre el panorama para que los vehículos de competencia puedan analizar el sistema de suspensión que mejor se adapte tanto a las condiciones de sus vehículos como a las de los propios terrenos, considerando los análisis cualitativos y cuantitativos.



Suspension system, Geometric features, Finite elements

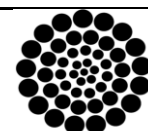
Sistema de suspensión, Características geométricas, Elementos finitos

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## Introduction

Mini-low vehicles have become an important part of the educational sector, as it is here that students can demonstrate their knowledge and skills in the handling and design of mechanical elements.

Within the vehicles, various systems can be found, which require continuous study with the aim of improving them according to the needs that arise.

There are a variety of vehicles that are designed and structured to perform different tasks; these tasks will indicate the characteristics of the elements that make up a system.

Vehicles have different types of systems, which can be: steering system, braking system, transmission system, suspension system, among others.

This study will focus on studying the suspension system, which is an important point for the performance of any vehicle, as it is the one that gives stability to the whole system that integrates the car.

One of the objectives of this study will be to choose the suspension system option that best suits the needs of the mini baja type vehicle.

The suspension system to be analysed will be proposed for a competition vehicle; therefore, it is necessary to take into account certain parameters that the system must have, among which the weight allowed by the competition must be considered, as well as the size it must have. The above without losing sight of the safety that the system must have, as this is one of the priorities when studying its behaviour.

The BAJA SAE competition is an event that has as one of its objectives to design 'all terrain' type vehicles, which must meet and accredit certain static and dynamic tests. Within the design of the vehicle, the type of material to be used, the vehicle model, the dimensional characteristics, among others, must be considered, as well as its manufacture and costs. Therefore, this type of activity, such as the BAJA SAE competition, also seeks to develop collaborative work among students, as it is a group of students who develop the project in all its stages.

## Methodology

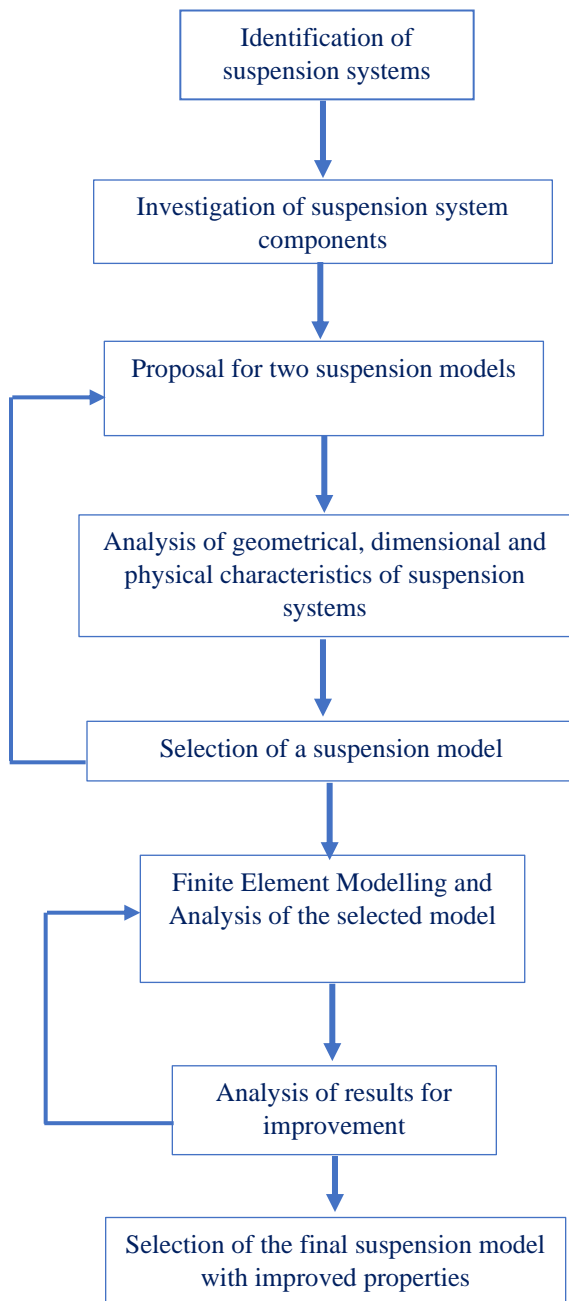
The process that was carried out with the aim of achieving satisfactory results is shown in Figure 1. This methodology helped to structure the steps to be followed within the project, in such a way that it supported the clarification of the objectives and in this way to have reliable and valid results. The points shown in Figure 1 are points that were considered key when analysing the system and what it was intended to achieve. To guide the project, it was decided that the methodology to be followed should have a quantitative and qualitative approach, i.e. the analysis to determine the best option to consider for the system should be based on both numerical data and perceptions or experiences, the latter due to knowledge of the subject.

In the first instance, the vehicle was analysed as a complete system, so it was concluded that the elements to be analysed were those that make up the suspension.

Since there was some knowledge of the elements that make up the suspension system, it was considered that it was not enough, to such an extent that an investigation of these elements was carried out; among what was investigated, information was obtained such as the material of each of the elements of the suspension system, its operation, the response it has when subjected to forces, among others.

Based on the characteristics found in the elements that make up the suspension system and the conditions that were required, a couple of suggestions were proposed to analyse and thus be able to determine the one that best suits the vehicle.

A fundamental tool in the process of this work was the use of CAD software, which was a tool that simplified the work, giving satisfactory results without neglecting the improvement in the design processes.

**Box 1****Figure 1**

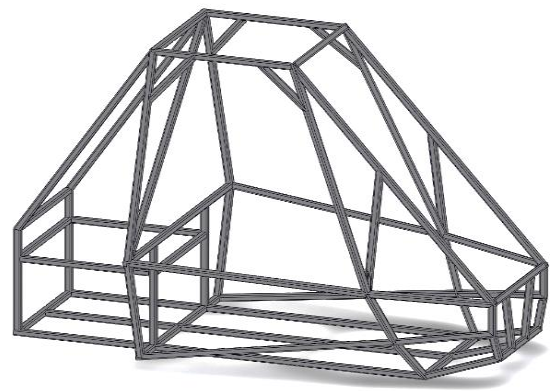
Methodology for the selection of the suspension system

Source: Own elaboration

Like the CAD software, the CAE tool was important in the complete study of the system, as it helped to give a numerical and reliable response to the parameters indicated according to the behaviour of the elements that make up the suspension system, i.e. it helped to solve the complete system subjected to various loads or physical phenomena, in such a way that it allowed various adjustments to be made and thus obtain the expected results.

**Development***Generalities of modelling of suspension systems*

The suspension model to be considered had to be capable of adapting to the circumstances of the vehicle of interest, i.e. to absorb impacts, as well as to guarantee user comfort, without neglecting the stability and safety of the vehicle. In order to define the characteristics of the suspension system, it was necessary to know the type of vehicle on which the system would be assembled, i.e., it was specifically necessary to know the chassis on which the suspension system would be mounted, in order to know the geometric characteristics on which it would work. Figure 2 shows the chassis on which the system would be assembled.

**Box 2****Figure 2**

Model chassis for suspension mounting.

Retrieved from: Huerta, H., et al., 2020.

The chassis shown corresponds to a single-seater competition vehicle, which has the characteristic that the elements that form it are tubular; likewise, it has a weight of around 187 kg, which makes it an extremely light vehicle, which helps to have a better performance in competitions due to the low weight and thus a reduction in fuel consumption without losing the necessary power. In addition, the chassis has a wheelbase of 150 cm.

It is worth mentioning that, in order to make the right choice, 2 types of suspension systems were considered: semi-independent suspension system and McPherson suspension system. The suspension system used inside the vehicle must be sufficiently robust, as the conditions to which the vehicle is subjected tend to be extreme.

The importance of selecting a suitable suspension system for the vehicle lies in the fact that it must be capable of absorbing certain irregularities that may occur on the roads where the vehicle travels and thus have an adequate level of comfort, as well as excellent stability.

Suspension systems are basically composed of two elements: elastic elements and damping elements. Therefore, suspension systems are governed by Equation [1] (Beer, F. et al., 2021):

The above can be explained as follows: a mass vehicle has a suspension system which is made up of a spring with an elastic coefficient, damper with a damping coefficient, which will cause the body to be exposed to forced vibrations with damping when the vehicle travels over uneven areas.

Due to the nature of the damper systems, the spring will absorb the unevenness of the terrain, while the damper dissipates the energy so that prolonged oscillations are precisely avoided.

#### *Main characteristics of semi-independent and independent suspension systems*

An important point to consider in the selection of the appropriate suspension system was the review of the main characteristics of each of the two suspension systems under consideration. The semi-independent suspension system is a system that is mechanically simple and has a good dynamic performance, in addition to being inexpensive in relation to other types of suspensions on the market, it is also light, which would complement the vehicle very well, since the vehicle is intended to be light.

One of the disadvantages that can be observed in this type of suspension system is that it lacks precision when cornering, as well as the same comfort on uneven roads. This does not help much in terms of control and dynamic response. On the other hand, there is the independent suspension system which, due to its characteristics, offers better performance, stability and comfort.

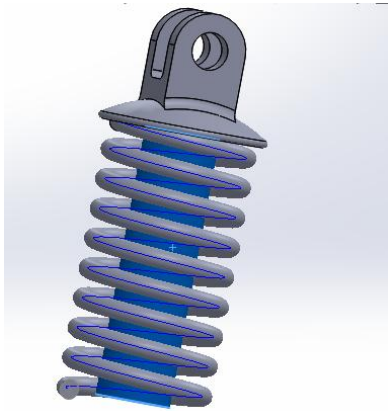
This type of system has the characteristic that, on uneven roads, only the wheel (together with the suspension system) that is affected by the terrain situation acts; this helps each wheel to adapt to the terrain, thus improving the traction of the wheel with the ground. Among the disadvantages of this system is the cost, which is higher, as well as the weight, which is higher than the semi-independent suspension system.

#### *Modelling of parts of the semi-independent suspension system*

The semi-independent suspension system was one of the proposals that were put forward, because it is a mechanism that supports high loads, as well as having the appropriate conditions to adapt it to the vehicle chassis. On the other hand, the McPherson suspension system is a system that can be adapted to different types of vehicles, as well as being cost-effective, since it requires a low maintenance cost, and also has a low degree of difficulty to assemble and disassemble from the vehicle. The McPherson system tends to be used in light vehicles, which is one of the reasons why it was decided to analyse this option, as the vehicle we worked with is light in weight.

In the first part of the development of the work, the parts that make up the suspension system were created with the help of CAD software. The most important parts (of the semi-independent damping system) are the spring and the outer cylinder.

The spring and inner axle system together perform the function of compression, rebound and stabilisation of the system, which helps to absorb and release energy, while keeping the wheels on the ground and maintaining control of the vehicle. The integrated shock absorber and spring assembly makes it possible to reduce the space required for a small vehicle size. Figure 3 shows the spring together with its inner axle, on which much of the force is applied when the vehicle passes over an uneven surface.

**Box 3****Figure 3**

Spring and inner axle of the semi-independent suspension system

*Source: Own elaboration*

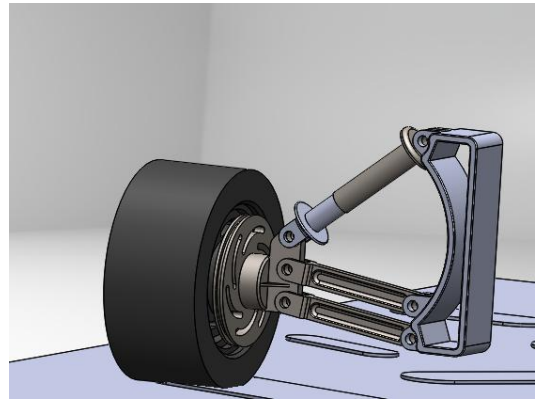
Figure 4 shows the outer cylinder of the shock absorber, which has among its objectives to maintain spring stability, together with the inner shaft; in the same way, the cylinder maintains the working fluid at a constant pressure and volume. Another of the functions of the outer cylinder is to give a certain rigidity and support to the shock absorber, as well as helping to dissipate the heat that is generated during the action of compression and expansion of the internal fluid.

**Box 4****Figure 4**

Outer shock absorber cylinder of the semi-independent suspension system

*Source: Own elaboration*

Subsequently, the assembly of the complete semi-independent suspension system was carried out, which is shown in Figure 5. In this assembly, all the parts that make up the suspension system are found, including the rim and tyre.

**Box 5****Figure 5**

Semi-independent suspension system assembly

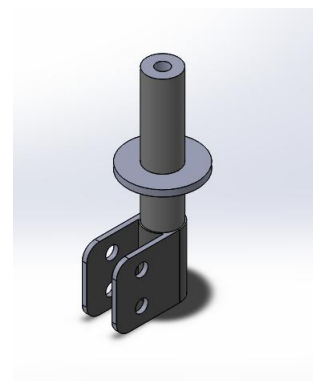
*Source: Own elaboration*

*Modelling of parts of the McPherson strut system*

On the other hand, the McPherson suspension system falls into the category of independent suspension systems. Among the elements that make up the system are: springs, stabiliser bar, ball joints, among others.

To this work, the elements that are part of the McPherson suspension system were modelled. Figure 6 shows the external axle.

One of the functions of the external axle is that it helps the stability and alignment of the vehicle, which allows a better adherence of the tyres to the ground in a curve; within this element, an internal axle is introduced, which is the one that performs a displacement when the suspension system is subjected to a load, whether constant or variable.

**Box 6****Figure 6**

McPherson strut outer axle

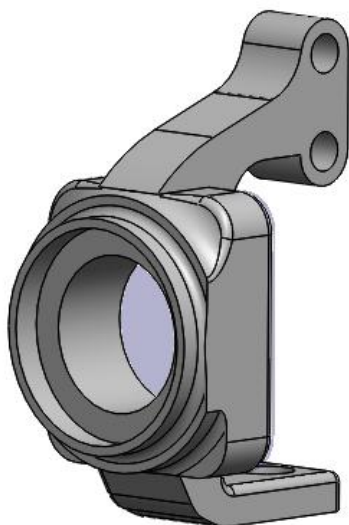
*Source: Own elaboration*

Figure 7 shows the stub axle, which plays an important role in the suspension system, because it is where several elements are connected, such as: the wheel with the steering linkage, in other words, it is at the stub axle where the suspension and steering are connected, so that the wheels can perform their function properly even on uneven roads.

This element has the task within the suspension system of acting as a central point connecting the suspension to the rim. Due to its geometrical characteristics the design is easily adapted to the McPherson suspension system. On the other hand, due to its mechanical properties, the stub axle is designed to withstand significant mechanical loads, which makes it a versatile element with a long service life.

In summary, this element is important within the McPherson strut suspension system because it adds value to the user's comfort and the care of the vehicle itself.

### Box 7



**Figure 7**

McPherson strut suspension system

Source: Own elaboration

The simulation of a physical phenomenon makes sense when most of the possible circumstances are considered, so that the analysis approaches a real situation; therefore, the model of the track on which the suspension system model would move was developed in order to carry out the virtual tests.

The material of which the track is made was analysed, and it was concluded that the material best suited to the conditions sought was concrete. It is worth mentioning that the surface of the track has some "imperfections", due to the fact that the aim was to bring the model closer to a real environment and thus obtain the expected results. The track was considered to be bumpy and uneven, which would give more accurate parameters on the behaviour of the vehicle under extreme dynamic loads that the vehicle can face. Under these conditions the dynamic stability of the mini baja can be thoroughly analysed.

### Materials used

Within the finite element analysis, a situation that takes relevance is to identify and characterise correctly the materials that will be used, since these will give the guideline to obtain the expected results. For the analysis of the springs, a material commonly used in the manufacture of compression springs was used, which has the mechanical characteristics shown in Table 1; this material is considered to be a high carbon steel:

### Box 8

**Table 1**

Mechanical characteristics of springs.

Common name	Alambre de piano
Specification	ASTM A228
modulus of elasticity (E), psi	$30 \times 10^6$
Shear modulus of elasticity (G), psi.	$11.5 \times 10^6$
Density ( $\rho$ ), lbm/in <sup>3</sup>	0.283
Maximum Service Temperature °F	250
Main Characteristics	High strength, excellent fatigue life.

Data obtained: Nisbett, R., 2008

The mechanical properties of the materials used in the suspension system components are presented in Table 2:



**Future work**

Due to the projects that are being carried out within the Department of Automotive Systems Engineering of the Polytechnic University Juventino Rosas, the possibility of implementing the chosen suspension system in an electric vehicle has been considered, which is why the McPherson system was selected, because it is a system that adapts to various types of vehicles. It is also a flexible system, which can help the elements that make up the system to adjust to changes.

**Acknowledgement**

We would like to thank the UPJR and the Department of Automotive Systems Engineering for the time and space given for the development of this work.

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## Determination of design specifications of an amashito chili seed fracturing machine using QFD tool

## Determinación de las especificaciones de diseño de una máquina fracturadora de semillas de chile amashito utilizando la herramienta QFD

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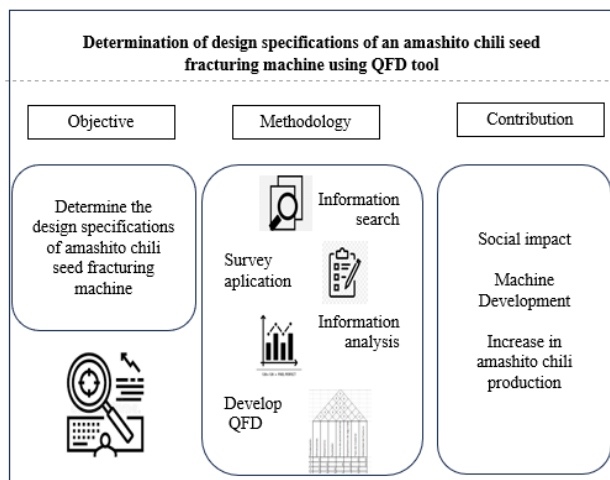


### Abstract

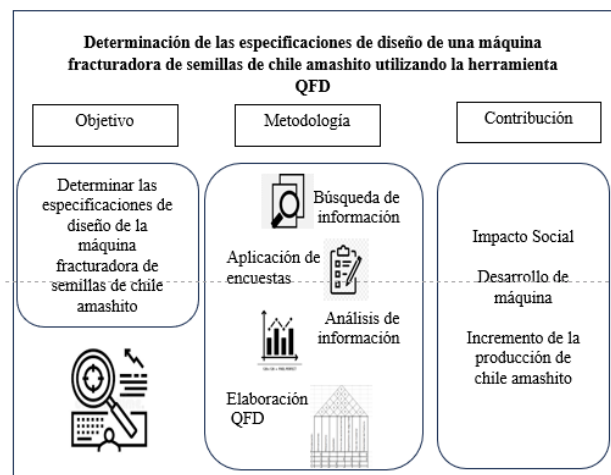
The objective of this work is to determine the design specifications of the amashito chili seed fracturing machine to facilitate its cultivation and provide farmers with a system that meets their needs. A survey was carried out in order to know the opinion of farmers. The survey was carried out in the public markets of Paraíso, Comalcalco and Jalpa de Méndez Tabasco, among merchants and producers who are dedicated to the sale and planting of chili. In the analysis of the results, the specifications that are necessary for the machine are found. The results show that sellers and/or producers of amashito chili require a seed fracturing machine to facilitate cultivation. The specifications were translated based on what the client needs using the Total Quality Deployment QFD tool.

### Resumen

El objetivo de este trabajo es determinar las especificaciones de diseño de la máquina fracturadora de semillas de chile amashito para facilitar su cultivo y proporcionar a los agricultores un sistema que cumpla con sus necesidades. Se realizó una encuesta con la finalidad de conocer la opinión de los agricultores. La encuesta se realizó en los mercados públicos de Paraíso, Comalcalco y Jalpa de Méndez Tabasco, a los comerciantes y productores que se dedican a la venta y siembra del chile. En el análisis de los resultados, se tienen las especificaciones que para ellos son necesarias en la máquina. Los resultados muestran que los vendedores y/o productores de chile amashito si requieren una máquina fracturadora de semillas para facilitar el cultivo. Se procedió a la traducción de las especificaciones con base en lo que el cliente necesita utilizando la herramienta QFD Despliegue de la Calidad Total.



### Machine, Specifications, QFD, Design



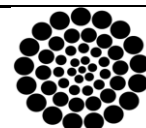
### Máquina, Especificaciones, QFD, Diseño

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## Introduction

At the Polytechnic University of the Gulf of Mexico, it is essential to develop projects that have a social impact, under this situation arises the project that seeks to design and build a fracturing machine for amashito chilli seeds.

The study mentions that the amashito chilli is a widely consumed species in southeastern Mexico and is obtained from the wild, so there is an area of opportunity, as the seed contains a hard, waxy cuticle that easily prevents germination. In the study, the product Biozyme TF® was used as a seed germination inducer.

According to the study, the low germination of wild chilli seeds, associated with the impermeability of their testa, is one of the factors limiting their propagation.

The use of seed germination techniques has been investigated and used with some other species, and he mentions that seed breaking in maize seed reduces germination. Using three different maize seed varieties with moisture contents between 12 and 20%, subjected to axial compression, there was no cracking at embryo level, but there was cracking at endosperm level, which resulted in reduced germination. The percentage of humidity also affected seed germination. Therefore, it is important to give the necessary force for seed fracture, which does not affect germination.

The authors indicate that the vitabosa seed is an alternative source of protein in animal feed, but the lack of study of this seed has led to its scarce use. They also state the importance of knowing the mechanical and structural characteristics for the creation of post-harvesting machinery.

Regarding the germination of Amashito chilli seeds, he explains that through a statistical analysis of 28 samples of Amashito chilli subjected to different measures of pressure and force, the best results were obtained with an  $F=239.7878$  N and a  $P=3.75$  N/cm<sup>2</sup>, achieving germination in 92.857% of the samples and with an  $F=280.3872$  N and a  $P=4.38$  N/cm<sup>2</sup> 89.286% of the seeds germinated in 9 days.

Research has also been carried out to facilitate the sowing and cultivation processes. The study mentions that many of the agricultural processes are manual and are complemented by the use of impact and cutting tools. Many seeds, including tagua seeds, require a process to separate the shells and this is done manually, affecting health and causing musculoskeletal injuries, so Pineda developed a prototype of a tagua seed shelling machine to improve artisanal production, reducing the shelling time and avoiding the risk of injury.

In his article on the higuerrilla hulling machine, he aims to design a higuerrilla hulling machine that works without electricity and is easy to transport and operate, with the aim of providing a solution to the cultivation problems in the Bajío region of Mexico. For the design of the machine, a mechanical design methodology was applied, including a series of steps consisting of preliminary, basic and detailed design, prototypes and tests, final design and communication. Through the research, efficient results were obtained in terms of the creation of the designed machine.

We can observe that there are already different methods to facilitate the harvesting or manipulation of other types of seeds, however, specifically for the Amashito chilli seed, we only found the use of chemical and natural methods. Therefore, the implementation of the amashito chilli seed cracking machine can be a good option to continue production and to be able to offer a greater variety of derived products.

The QFD Total Quality Deployment is a tool that allows us to translate customer needs into technical specifications. According to 'Quality Function Deployment is a method of product and service design that takes customer demands and expectations and translates them, in successive steps, into satisfactory technical and operational characteristics'.

Conducted research on the use of QFD in service sector companies and 'how it can help these organisations to achieve customer satisfaction, as well as provide them with the necessary information that allows them to know what the customer really values in the service and how this tool can make them more competitive'.

Points out that QFD 'is an important strategic planning technique, capable of changing a company's position in the market and raising it to world-class competitive levels'.

The QFD methodology seeks to 'translate user requirements into quality characteristics, from quality characteristics into part characteristics, from part characteristics into process parameters and from process parameters into production requirements, through a series of phases and matrices'.

This tool has been used in several areas, 'implemented QFD to determine the design requirements of the experimental units to be evaluated at bench scale, during the degradation of oiled waste by different treatments of biobattery ecotechnology.' For his part, he applied the QFD methodology to the design and commercialisation of the product called 'Cuy Faenado'. The application of the tool is also observed in the design of machines, he presents the development of a 3D printer using the QFD methodology approach, emphasising the needs and requirements of the clients who are the students of the engineering faculty of the University of Pamplona.

QFD is a tool that consists of matrices in which information is evaluated and analysed. The information presented contains customer requirements, technical specifications and competitors. This information is evaluated and related to obtain the best design considering the customer. The QFD also called house of quality lists the customer requirements and relates them to the engineering characteristics or technical specifications and shows the correlation between the technical specifications.

The difficulty of germination of the Amashito chilli seed is a constraint for producers to move towards a greater commercialisation of this regional chilli variety. It is important to evaluate the economic, social and ecological potential of the various species of Amashito chilli in order to propose a model that increases productivity and development in the region with a focus on sustainability.

With the construction of the prototype, the aim is to fracture considerable volumes of seeds that can be cultivated in greenhouses and obtain seedlings to be marketed or donated to farmers in programmes in the Tabasco region.

With the previous studies on the necessary force to fracture the chilli seeds and achieve satisfactory results with the sowing and cultivation, we proceeded to follow the steps for the design of systems that goes from the search for similar systems in the market, the detection of the user's needs, the translation into technical specifications, the conceptual design, the detailed design and the realisation of the prototype.

This document aims to translate user needs into technical specifications using the QFD (Quality Function Deployment) tool.

## Methodology

### *Survey application*

A survey of 8 multiple-choice questions was carried out, which was applied personally, with the support of students from the Automation and Industrial Control Engineering course at the UPGM, to 42 vendors and/or producers of amashito chilli in the public markets of the municipalities of Paraíso, Comalcalco and Jalpa de Méndez, in the state of Tabasco, with the objective of determining the needs they have with respect to the production of amashito chilli seeds.

It was explained to the respondents that with the results of a previous investigation, the force necessary to fracture the seeds of the amashito chilli was studied and the greatest number of plants were able to grow and be productive. Therefore, there is a concern to be able to offer producers and/or sellers an alternative to improve sowing and cultivation, for which it is necessary to know their needs.

Respondents mentioned that it has been increasingly difficult to grow the seeds in the wild, so they have had to opt for other methods such as chemical products or leaving the chilli to dry for later sowing.

The questions they were asked were aimed at obtaining information on how they currently sow, whether it is really a good business and whether they would like to have the option of a machine that would make sowing easier and what characteristics they would like it to have.

**Conducting QFD**

An analysis of the surveys was carried out and based on the results, the QFD (Quality Function Deployment) technique was used to determine the specifications of the amashito chilli seed breaking machine. The QFD is a tool that helps us to translate the voice of the customer, i.e. to understand what sellers and/or producers need and convert it into technical specifications, in this case for the design of an amashito chilli seed cracking machine. For the elaboration of the QFD, the first thing we need to do is to determine the requirements of the customers, which were obtained from the surveys applied. Subsequently, an analysis was carried out by the researchers and a weighting of 1 to 5 was assigned to each requirement, with 1 being the least important and 5 the most important. The next phase of the QFD consisted of translating the customer requirements into technical specifications. The relationship between the requirements and the stated specifications was then analysed, assigning 9 for a strong relationship, 3 for a medium relationship and 1 for a weak relationship. No rating was given when no relationship was recognised. See table 1.

**Box 1**

**Table 1**

Assessing the relationship between customer requirements and technical specifications.

Customer requirements	Weighting	Technical specifications						
		Dimensiones	Mechanism	Bra	Drive form	Safety devices	Type of material	Fracture rate
Medium Size	3	9					3	9
Semi-automatic operation	5	3	9		9	9		9
Movable	5	9	9	9		3	9	
Practical	3	9	9	9	3		3	
Safe	4	3	9	3	9	9	3	3
Ease	5	9	9	9	3			3
Do not affect the quality of the chilli	5		9				9	
Shorter time	3		9	3	9			9

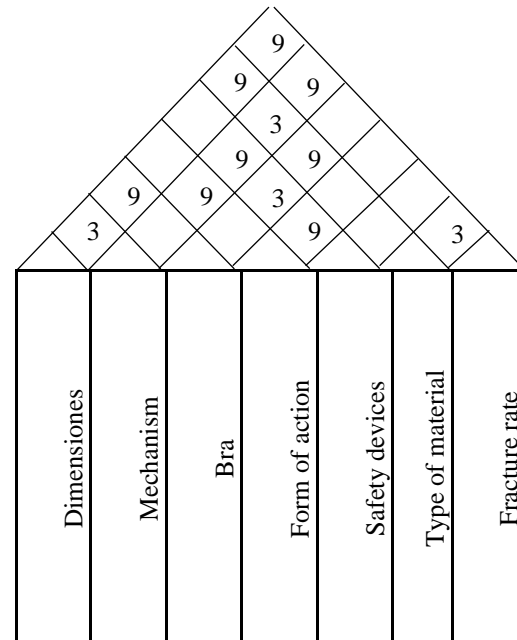
Source: Own elaboration

The correlation between the technical specifications was also analysed, with a 9 for a strong correlation and a 3 for a low correlation. We did not assign a score to those where there is no correlation.

**Box 2**

**Figure 1**

Correlation between technical specifications



Source: Own elaboration

Finally, the absolute weights were obtained by adding the columns of each technical specification and the relative weights by adding the multiplication of the respective weighting with the rating of each column.

**Results**

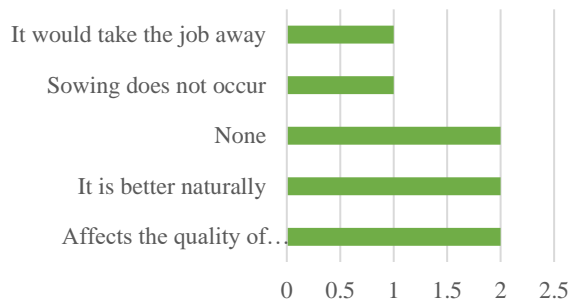
*Surveys*

The results obtained from the application of the survey to sellers and/or producers of amashito chilli are described below.

Of the total number of respondents, 52% were men and 42% were women; there is an equal relationship in gender participation in the sowing and cultivation of amashito chilli. Regarding the reason for the research, which is whether they would like to have a machine to facilitate the sowing of chilli, 81% answered yes and 19% showed no interest in such a machine.

We analysed the reason why they would not like the machine and what they answered can be seen in Figure 2. Of the 8 people who answered that they would not like it, we can conclude that they have no knowledge of the fracturing method, as their comments are based on fear that things will not work out well.

**Box 3**

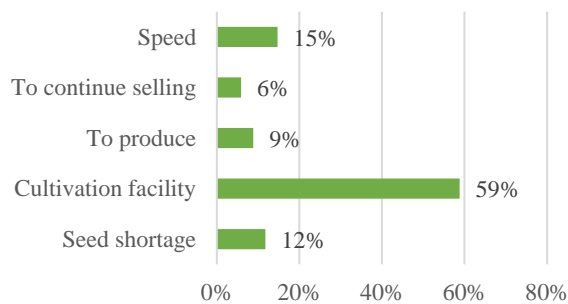


**Figure 2**

Reasons why they would not like the fracking machine  
*Source: Own elaboration*

Of the 81% of the people who would like to have a fracking machine, the majority answered that it would be easier to plant and cultivate, with 59%. This was followed by the speed with which they could produce, with 15%, and 12% answered that it would be easier to produce chilli amashito because of the shortage that currently exists in the production of chilli. Nine percent answered that they would be able to produce their own chilli amashito and 6% that they would be able to continue selling it. Therefore, we can analyse that most of the people are aware that the machine would bring them benefits. See Figure 3.

**Box 4**

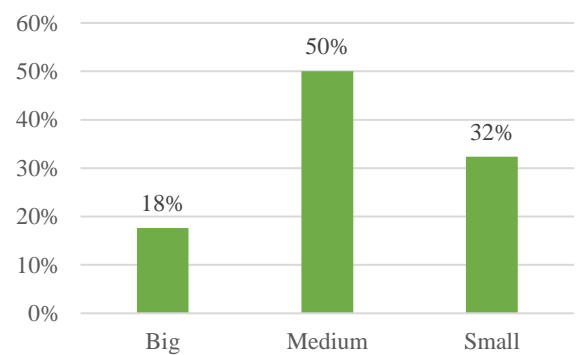


**Figure 3**

Reasons why they would like the fracking machine  
*Source: Own elaboration*

With regard to the characteristics of the amashito chilli cracker, they were asked about the size (dimensions), the way they would like it to operate and the type of structure they would prefer. In Figure 4 we can see that of the 34 people who agree with the idea of having a fracturing machine, 50% prefer the size of the machine to be medium, 32% prefer it to be small and only 18% prefer it to be large.

**Box 5**

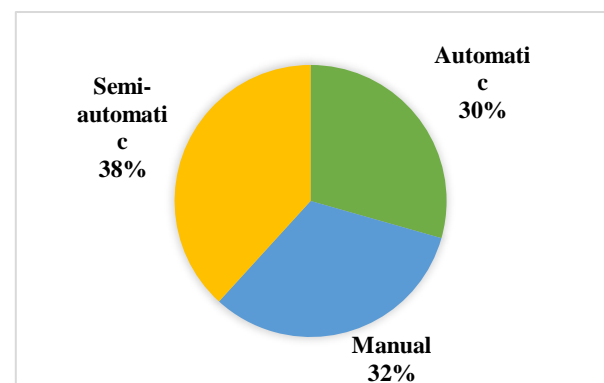


**Figure 4**

Ideal size for amashito chili seed crushing machine  
*Source: Own elaboration*

Regarding the mode of operation, the percentages do not show a great difference, they are very even. Figure 5 shows that for 38% of the sellers and/or producers, a semi-automatic machine would be the best option. Followed by 32% who mentioned that the manual method would be the most appropriate, and lastly, 30% mentioned a fully automatic machine.

**Box 6**

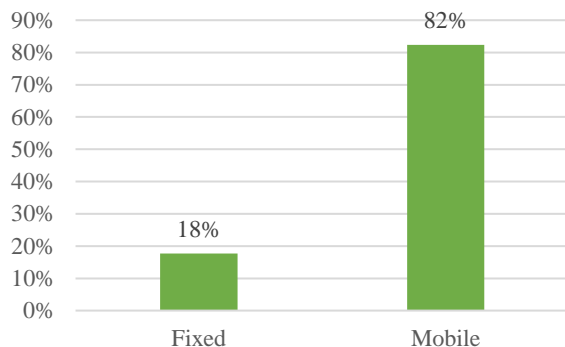


**Figure 5**

Preferred mode of operation for the machine  
*Source: Own elaboration*

In relation to the type of structure that would be most useful for them, 82% responded that a mobile structure would be the best option and only 18% considered that a fixed structure would be the best option. See Figure 6. It can be seen that the sellers and/or producers prefer a machine that can be moved when necessary.

### Box 7



**Figure 6**

Structure type for amashito chilli seed cracker machine

*Source: Own elaboration*

Regarding the amashito chilli business, 36% of the vendors and/or producers do have the sale of amashito chilli as their primary source of income, and 64% of the respondents are also involved in the sale of other types of products from which they earn more income. When asked whether they consider the sale of amashito chilli to be a good business, 86% answered yes, while only 14% answered no. Those who answered that it is a good business are not. Those who answered that it is a good business, if they are interested in taking more advantage of chili production, it would be good to ask why it is not their main source of income if they consider it a good business; there is probably a lack of production to be able to offer a variety of products.

Finally, they were asked about the way in which they currently sow the Amashito chilli and the products they sell. 79% of them use the sowing method. Seventy-nine percent use natural sowing, followed by the use of chemical products with 15%, and only 6% use seed fracturing, which is considered important to make this method and the results achieved in the production of chilli peppers known. 86% of the sellers and/or producers responded that the product they offer is natural amashito chilli, only 6% mentioned that they offer processed chilli or both types of product.

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There is an area of opportunity here, as they can look for other ways to offer their product and thus increase their income.

### QFD

From the QFD conducted we can see the correlation between some technical specifications, for example the dimensions with the fastener, as it is necessary to determine how the machine can be fastened depending on how big it is. In the same way, the mechanism has a strong correlation with the way the device is to be operated, with the safety devices and with the fracture speed.

In terms of customer requirements and technical specifications we can observe that:

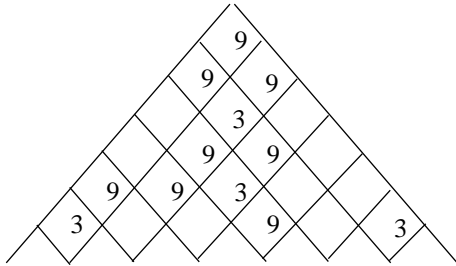
- The size has a very strong relation with the dimensions and the speed of fracture.
- Semi-automatic operation with the mechanism, the form of drive and the safety devices to be fitted to the machine.
- The movable device is strongly related to the dimensions, the mechanism, the way of clamping and the type of material.
- Practicality is strongly related to the dimensions, the mechanism and the way of fastening.
- Safety is related to the type of mechanism, the form of actuation and the safety devices.
- Ease is related to the dimensions, the mechanism and the way of fastening.

Finally, the mechanism and the type of material affect the quality of the chilli and fracture in less time is related to the mechanism, the way of actuation and the speed of fracture.

**Box 8**

**Table 2**

QFD for the amashito chilli seed cracking machine prototype



	Technical specifications							
	Weighting	Dimensions	Mechanism	Bra	Form of action	Safety devices	Type of material	Fracture rate
Customer requirements								
Medium size	3	9					3	9
Semi-automatic operation	5	3	9		9	9		9
Movable	5	9	9	9		3	9	
Practical	3	9	9	9	3		3	
Safe	4	3	9	3	9	9	3	3
Ease	5	9	9	9	3			3
Do not affect the quality of the chilli	5		9				9	
Less time	3		9	3	9			9
Absolute weight		42	63	33	33	21	27	33
Relative weight		17	27	13	13	9	12	12
		1	0	8	2	96	0	6

Source: Own elaboration

The analysis of the information generated in the QFD allows us to have a more complete view of the technical specifications that we must consider for the amashito chili fracturing machine and how the selection of one or the other performer of the function impacts on the other specifications.

The most important specifications are the mechanism, the dimensions, the fastener and the form of drive. The following are the choices of function performers that could meet the required specifications.

**Box 9**

**Table 3**

Function executors for the heavier specifications.

Functional specifications	Function executors		
Mechanism	Electromechanical	Tyre	Hydraulic
Dimensions	Small	Medium	Large
Fastener	Handle	Without handle	Wheels
Actuating form	Button	Lever	Sensor

Source: Own elaboration

Based on the experience of the researchers, it was determined that the prototype of the Amashito chilli seed breaker will have an electromechanical mechanism, it will be medium-sized with a dimension of 25 cm wide, 35 cm high and 16 cm deep, it will be held by a handle and the device will be operated by means of a button with its respective emergency stop.

**Conclusions**

According to the surveys carried out, the producers and sellers of Amashito chilli are in favour of having a seed-cracking machine to facilitate the sowing and cultivation of Amashito chilli.

It was noted that there is a lack of knowledge about the technique of seed fracturing as a support for obtaining large quantities of seedlings and therefore increasing the production of amashito chilli. It would be interesting to provide a small amount of training to producers and/or sellers so that they can learn about the technique, see the results that can be achieved and have greater confidence when using it.

With this research, we were able to identify the client's requirements in order to translate them into technical specifications and proceed with the creation of the prototype of the amashito chili pepper fracturing machine. The QFD tool allowed us to better understand the potential users of the fracturing machine in order to have a clearer idea of the characteristics to be considered.

With the specifications determined, we can now proceed with the design and generate a prototype that can increase the production of amashito chilli for subsequent sale.

Equal gender participation (women and men) in the planting, cultivation and sale of amashito chilli was also found to be positive. However, there is an area of opportunity, as most of them offer natural chilli, but they could offer a variety of products with prepared chilli. (May Guillen, 2014) proposes a methodology to develop skills and abilities in rural women and social entrepreneurs in areas such as agribusiness, marketing and organisational management with the aim of creating social enterprises based on the transformation of plant species representative of Tabasco.

The generation of sustainable solutions to improve agricultural activities is fundamental nowadays. The amashito chilli seed fracturing plant aims to contribute to the development and commercialisation of this species.

## Declarations

## Conflict of interest

The authors declare that they have no conflicts of interest. They have no known competing financial interests or personal relationships that might have appeared to influence the article reported in this paper.

## Authors' contribution

*Cintya Margarita Cervantes Castro*: Contributed to the project idea, research development and data analysis.

*Alejandro García García*: Contributed to the development of the research and analysis of the information.

*Raquel Angulo Córdova*: Contributed to the analysis of the information, revision and editing.

*Arquímedes de Dios Domínguez García*: Contributed with the analysis of the information, revision and editing.

## Availability of data and materials

The data obtained in this research are available on request.

## Funding

The research was financed with own resources.

## Acknowledgements

We thank the Polytechnic University of the Gulf of Mexico for their support in the publication of this research article.

## Abbreviations

QFD	Quality Function Development.
TF	Phytohormone Polytechnic
UPGM	University of the Gulf of Mexico

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### Background

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#### *Support*

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#### *Discussions*





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## Thermodynamic and mechanical of the mezcal distillation phase using theorems and software

### Validación termodinámica y mecánica de la fase de destilación del mezcal mediante teoremas y software

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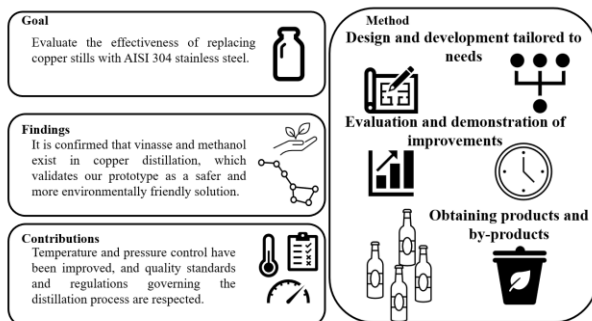
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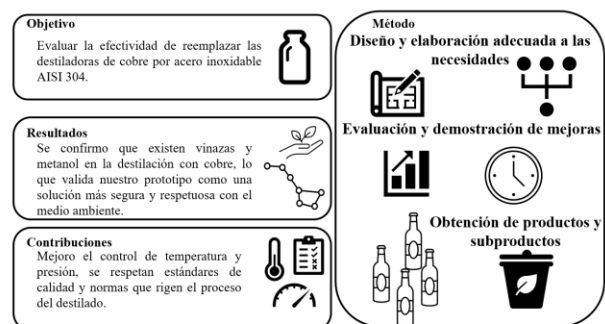
#### Abstract

Mezcal Production in Mexico: Evaluating the Efficacy of Stainless Steel AISI 304 Distillation Equipment. This cross-sectional study investigates the challenges faced by Mexico's mezcal industry, specifically the formation of toxic methanol and vinases during distillation. We evaluated the effectiveness of replacing traditional copper stills with stainless steel AISI 304 equipment, utilizing computational fluid dynamics simulations (Ansys Fluent and Solid Works Flow simulation). A 5-year study confirmed deficiencies in copper distillation, validating our prototype as a safer, environmentally friendly alternative. Results demonstrate improved temperature and pressure control, reduced harmful substance formation, and optimized raw material utilization. Our findings indicate that design and safety system enhancements meet regulatory standards and quality norms governing distillation processes.



#### Resumen

La producción de mezcal en México tiene un impacto económico significativo, pero enfrenta desafíos en la destilación debido a la formación de metanol y vinazas tóxicas. Esta investigación transversal busca evaluar la efectividad de reemplazar las destiladoras de cobre por acero inoxidable AISI 304, utilizando software de simulación como en el módulo Fluent Ansys y Flow simulation de Solid Works. Después de 5 años de estudio, se confirmaron deficiencias en la destilación con cobre, lo que valida nuestro prototipo como una solución más segura y respetuosa con el medio ambiente. Los resultados muestran que este cambio mejora el control de temperatura y presión, reduciendo la formación de sustancias nocivas y optimizando el aprovechamiento de la materia prima. Se concluyó que las mejoras en el diseño y sistema de seguridad respetan estándares de calidad y normas que rigen el proceso del destilado.



Distillation, Validating, Simulations, enhancements

Destilación, Validación, Simulación, Mejoras

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## Introduction

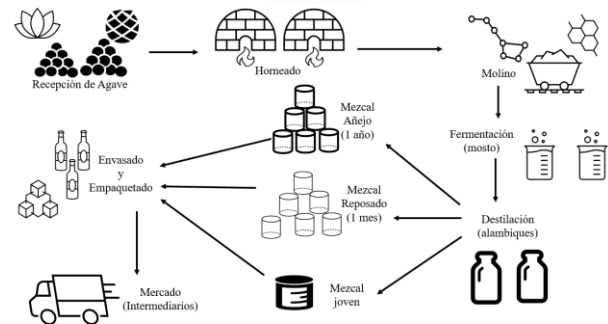
The demand for mezcal consumption seeks to speed up the process and make better use of the raw material in the distillation without causing significant damage to the environment, mainly in the regions included in the designation of origin given by NOM-070 (Pérez, 2023), as well as the Mezcal Regulatory Council. There is a state development plan mainly in the state of Oaxaca, (Government of Mexico, n.d.), the aim is to extend this link with the government to the rest of the states, with the aim of being an independent and multidisciplinary body, seeking a common good, with the purpose of supporting producers so that they can generate jobs (Sánchez, 2024), (García, 2024), in this state the production of mezcal implies a great economic spillover, and consequently a great generator of jobs.

To obtain 1 liter of mezcal, 12.7 kg of already crushed agave are needed, with the results of the tests it has been achieved that only 7.5 kg are used. Some producers, on their own initiative, have made some of the phases of the process more technical, however, deficiencies have been found in most of the equipment that directly impact the quality of the product and in turn are reflected in the economy of the producer. This project uses theoretical, mechanical and thermal validations that allow us to achieve optimal operation and better quality. This allows us to reduce product losses and facilitates monitoring of heat transfer and pressure levels in the system.

A barrier to project development is the ideas and customs rooted within this productive sector. However, technology is a strategic factor to achieve competitive and innovative capacity in companies, it involves human and financial resources. This set of processes is definitely of an intensive and agro-industrial nature. In the case of mezcal production, it is possible to delve into different stages (reception of the agave, baking, crushing, fermentation, distillation and packaging) (Manuel, 2014), CEDRSSA. (March 2019)., although it is not permitted by regulatory bodies to modify the entire process, other than in the distillation stage, that is why this research has focused solely on the distillation process, however, there is knowledge of the advances, benefits and deficiencies of: Automation of grinding in the artisanal manufacture of mezcal, (Pamela, 2016).

Redesign of a mezcal distiller, (Perla, 2016); Cooked agave grinder, (Magdaleno, 2014); agave pineapple cutter, (Martin, 2016); and the Traditional Method for more than half a century, see Figure 1.

### Box 1



**Figure 1**

Diagram of the mezcal production process

Source: Own elaboration

By applying engineering knowledge considering the production costs of a direct line mezcal distillation plant with the maximum use of its capacity and with the implementation of technology in the mezcal production process to achieve an improvement in its profitability and through verifying through this research work the validation in software: that a copper still generates a greater alteration in the process than an AISI 304 stainless steel distillation machine.

## Methodology

Software design: Alin: Contributed to the design of different still prototypes, varying parameters such as the collector material, the type of insulator, the angle of inclination and the volume of the still.

Variables:

- Independent: Collector material, type of insulator, inclination angle, still volume (qualitative and quantitative variables).
- Dependents: Distillation time, alcohol yield, distillate quality, thermal efficiency (quantitative variables).

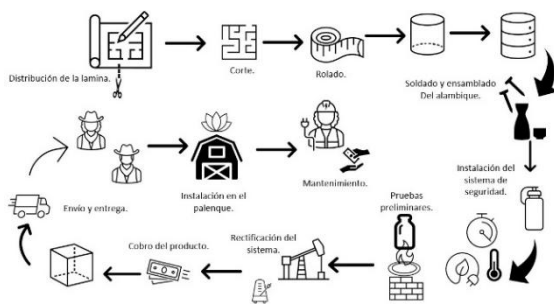
Procedure: Distillation tests are performed with each prototype. Data such as temperature and distillation time are recorded. See Figure 1.

Claudio: He established through the development of engineering skills that the distillation machine would be made up of the still, return tank, coil, vat, fiberglass thermal insulation, spiral resistance and its respective pipe, made of AISI 304 stainless steel gauge 12.

The still developed in the present project is sectioned into several parts, we will start from the spiral-shaped resistance system, placed just below the base, properly of the still we have the base, which has a truncated spherical segment with a diameter of 260 mm rounded to a diameter of 50 mm, attached to a cylinder with a diameter of 260 mm by 268 mm high joined by means of Electrode and TIG inverter welding, [Zatezalo & Norris \(2019\)](#).

For stainless steel, after the cylinder we have a truncated cone with an angle of  $8.9^\circ$  starting with a diameter of 260 mm to reduce to 203 mm, which will also be welded and completely covered with fiberglass. Inside this structure there will be three half-circle trays, the first one will be at the limit of the cylinder and the start of the cone, and the next two in the conical part. The trays will not be fixed to the still, they will be removable to improve the entry, as well as the extraction of material. We move on to the upper section which will be separated by a cylinder attached to a circular segment of 203 mm. See Figure 2, ([Eguiarte et al., 2003](#)).

### Box 2



**Figure 2**

Process diagram of the distiller

Source: Own elaboration

### Box 3



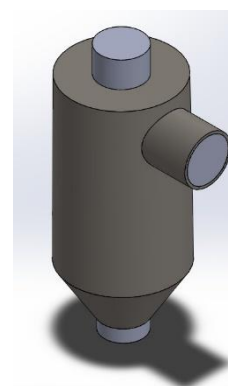
**Figure 3**

Cross section showing the internal structure of the still and its lid

Source: Own elaboration

The return tank outlet to the condenser will have a solenoid valve that will activate when the pressure switch has detected the necessary and ideal pressure to begin condensation, the outlet pipe will also be threaded to facilitate cleaning, this will reach a 1 "to 1/4" reducer for the coil, the reducer will be threaded on the 1 "part and welded on the 1/4" part to facilitate installation, cooling will be by means of water circulation, the tub will have a base that will support the weight and movement of the water. See Figure 4.

### Box 4



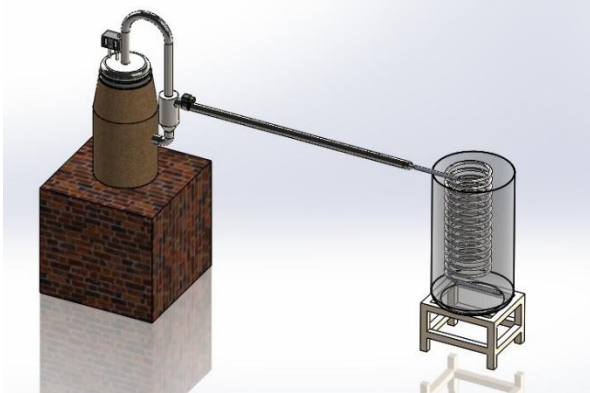
**Figure 4**

Return tank

Source: Own elaboration

The still, the return tank and the condenser. It will be validated from formulas, physical theorems and engineering applications, such as: determination of the heat demand, Pascal's principle and the first law of thermodynamics; as well as the software which will be Solid Works (simulation and Fluence modules). This is to demonstrate the efficiency of the elements that we will implement, specifically the proper use of food grade stainless steel AISI 304 gauge 12 type 2B, both for local and mass production, we investigate to have a clean and efficient production, this with the sole purpose of improving the product, see Figure 5.

### Box 5



**Figure 5**

Still installation: presentation of the still, the return tank and condenser

Source: Own elaboration

Alin: Contributed to the realization of quantitative field research for data collection, with a sample size of over 200 mezcal house owners. The type of sampling is stratified random. With a margin of error: approx. 6.17% for a confidence level of 95%. (Universe > 100,000), with the purpose of knowing the deficiency that existed in the process normally used, as well as the impact. We analyzed this data and compared it with what the authorities required, and it was concluded that in order to have a comparison of results it was necessary to apply the procedure in the modeling described below. The still is sized on a wire frame and then revolved to obtain the final shape. It is important to observe angles and the correct dimensions to make cuts and bends for later assembly. The lamina operation was applied to the revolution. In another section, the 1" outlet pipe was made using the lamina operation and the saw string was made to join the next 180° double.

The 180° elbow, which is also 1" was made with a sweeping pose and lamina operation. After this, the same joining system was used for the adjacent tube, which is the union of the elbow with the return tank. The latter is made in a wired manner and then revolutionized to obtain the cylinder and cone by applying a sheet metal operation. This same one has two outlets, one for return to the tank, which is a 90° elbow, and an outlet section that has a diameter of 1". A solenoid valve is incorporated into the outlet section that is responsible for opening the system when it has the adequate pressure. The solenoid valve design is made by us since the download libraries ask for many requirements to obtain these designs. After this solenoid valve we have a pipe 1.5m long and 1" in diameter, which reaches a 1/4" reducing coupling specially designed to achieve good steam conduction. The coil is 1/4" to speed up the process, a circle is swept through a spiral to which a sheet metal operation is applied. The base of the still is made from a stone base that is normally used in a distillation plant. The base of the vat is made from tubular PTR, this part is designed according to the weight and volume requirements of the condensate vat. The simulations were carried out at a temperature of 160°C because the boiling point for the formation of ethanol is at 150°C.

### Results

Luis: I contribute by performing the calculations that validate our variables, which are the following:

For the calculation of the total volume, 5 sections were taken.

In Section 1 there is a truncated spherical segment Eq. 1, the volume of this figure was obtained. Where we are asked for the value of the radius of the smaller base, the radius of the larger base and its height.

$$V = \frac{\pi}{6} h(3a^2 + 3b^2 + h^2) \quad [1]$$

$$V = \frac{\pi}{6} (0.05m)(3(0.086m)^2 + 3(0.130m)^2 + (0.05m)^2)$$

$$V = 0.019736532m^3$$

For Section 2, Eq. 2 was used, which gives us the volume of a cylinder, by means of its diameter and height. It is worth mentioning that these two areas are those that will support the liquid in the initial state of the distillation.

$$V = \frac{\pi}{4} d^2 h \quad [2]$$

$$V = \frac{\pi}{4} (0.2602m)^2 (0.268m)$$

$$V = 0.070661m^3$$

In obtaining the volume of Section 3, a slightly different equation was used which gave us the volume of a truncated cone; Eq. 3, which asks us for the major diameter, minor diameter and height to obtain its value.

$$V = \frac{\pi}{12} h(D^2 + Dd^2 + d^2) \quad [1]$$

$$V = \frac{\pi}{12} (0.15m)((0.2602)^2 + (0.2602)(0.270)^2 + (0.270)^2)$$

$$V = 0.008272m^3$$

In the case of Section 4 and 5, Eqs. 2 and 1 respectively are used again. Where we again have a cylinder and a truncated spherical segment, this time with smaller dimensions.

$$V = \frac{\pi}{4} d^2 h$$

$$V = 0.003361m^3$$

$$V = \frac{\pi}{6} h(3a^2 + 3b^2 + h^2)$$

$$V = \frac{\pi}{6} (0.05m)(3(0.0685m)^2 + 3(0.1035m)^2 + (0.05m)^2)$$

$$V = 0.00127m^3$$

We obtain the value of the Total Volume (Vt), by adding the partial volume of each section of the still.

$$Vt = 0.0197m^3 + 0.0706m^3 + 0.0082m^3 + 0.0033m^3 + 0.0012m^3 = 0.103m^3$$

Therefore, a total of 103 Liters is checked, of which we will only introduce 90.3 Liters. It is important to know what volume we must handle in our design. To continue with the principles and laws that will govern our system. Applying the hydrostatic principle in Eq. 4 we will obtain the total pressure at depth.

$$P_H = \rho g h \quad [4]$$

Where: PH=the total pressure at depth; h=depth;  $\rho$ = the density of the fluid and g= the acceleration of gravity.

Therefore, by substituting the corresponding values, we have two results: that of distilled water and that of ethanol.

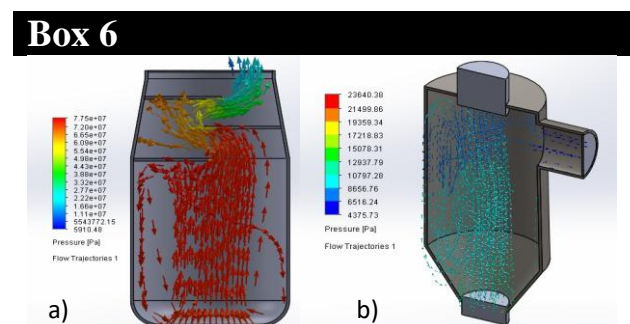
$$P_{H(H_2O)_{distilled}} = (998 \text{ kg/m}^3) (9.81 \text{ m/s}^2) (0.318m)$$

$$P_{H(H_2O)_{distilled}} = 3113.34084 \text{ N/m}^2 = 3113.34084 \text{ Pa}$$

$$P_{H(C_2H_5OH)_{ethanol}} = (790 \text{ kg/m}^3) (9.81 \text{ m/s}^2) (0.318m)$$

$$P_{H(C_2H_5OH)_{ethanol}} = 2464.4682 \text{ N/m}^2 = 2464.4682 \text{ Pa}$$

The theoretically calculated pressures are checked using the Flunce module with SolidWorks software, resulting in a color-coded diagram, with red being the highest values and blue being the lowest values, with the displacement of our fluid being Pa as the unit. See Figure 6.



**Figure 6**

Representation of the pressure simulation according to the hydrostatic principle, a) The zone of highest pressure at the bottom, b) return tank in which no points with excessive pressure are observed

Source: Own elaboration

Likewise, for the determination of the heat demanded by the system, Eq. 5 was used..

$$q_c = \frac{m_a C p_a \Delta T_a}{t_c} \quad [5]$$

Where:  $m_a$  is the mass quantity of the product to be cooked;  $C p_a$  its specific heat;  $\Delta T_a$  its temperature difference between the cooking temperature and the initial temperature of the product;  $t_c$  the time required for cooking..

$$q_c = \frac{(90)(150)(60)}{4} = 202.5 \text{ Kcal/h}$$

Finally, we will address the First Law of Thermodynamics that we will use to know the increase in the internal energy of the system from Eq. 6 and that we will later validate with the thermal test in SolidWorks.

$$\Delta U = U_{final} - U_{inicial} \quad [6]$$

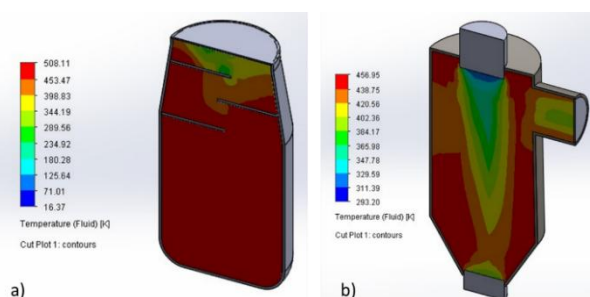
Where:  $\Delta U$  = Increase in internal energy of the system;  $U_{final}$  = Final internal energy of the system;  $U_{inicial}$  = Initial energy of the system..

$$\Delta U = 293.85 - 281.60$$

$$\Delta U = 12.25 J$$

The temperature behaved and was controlled according to the results obtained in the simulation. These allow us to understand the behavior of our previous calculations and realize that the design and the selected material are adequate for the requirements of our machine. See Figure 7. Therefore, the design was made considering a volume of 103 L or 0.103 m<sup>3</sup>, at a temperature of 160 °C and a constant pressure of 122 787.66 Pa. This in order to withstand the temperature that the production of ethanol requires, which is 150 °C.

### Box 7



**Figure 7**

Representation of the thermal simulation, according to the First Law of Thermodynamics, a) temperature inside the still, b) Temperature in the return tank

Source: Own elaboration

### Conclusions

As mentioned in the development, this project broadly covers various contexts that in turn brought us benefits:

- As mentioned in the development, this project broadly covers various contexts that in turn brought us benefits:

- Environmental context: by controlling the temperature and pressure, we will avoid the excessive formation of methanol in the distilled liquid, which will prevent the waste fiber from damaging the land where it is normally deposited and the fact that we can reuse the water taken from the rivers and dams adjacent to the palenques as if it were drinkable, so that we will not generate emissions of any kind.

Engineering context: This study has chosen stainless steel with a chromium-nickel content necessary to ensure corrosion resistance for the manufacture and manufacturing of the distillation machine. Verification by means of the simulation in SolidWorks of our calculations. Maintaining 12.25 J in the increase of the internal energy of the system.

Future work includes the possibility of exploring different phases of mezcal production. This would improve the processing of raw materials and make it possible to plan reforestation, harvesting and optimize resources.

### Declarations

### Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

### Author contribution

The contribution of each researcher in each of the points developed in this research, was defined based on:

*Rojas-Cruz, Alin Montserrat:* Contributed to the project idea, She supported the design of the distillation machine. She carried out as writing the article and design of the diagrams and figures used in the paper.

*López-García, Claudio:* Carried out the systematisation of the background for the state of the art. He also contributed to the writing of the article. He carried out research method and technique.

*Valverde-Cedillo, Luis Manuel*: worked on the application of the field instrument, data collection and systematisation of the results. He also worked on the writing of the paper.

### Availability of data and materials

The pressure and temperature data measured in the field were requested from Master Mezcalera Araceli García Mendoza from the State of Oaxaca.

### Funding

The key institutions that have supported this project are the Government of the State of Mexico and the National Technological Institute of Mexico, with financial support. CONAHCyT for the computer equipment provided to Rojas Cruz Alin Montserrat through the program "Support for Mothers Heads of Households."

### Acknowledgements

I would like to express my deep gratitude to several key institutions that have supported our project. Firstly, to the Government of the State of Mexico, for its generous financial support and commitment to education. Also to the National Institute of Technology of Mexico, for its financial contribution and research opportunities that have enriched our professional training. I would like to thank the Technological Institute of Higher Education of Chalco, for promoting our project and to Mtra. mezcalera Araceli García Mendoza for giving us her unconditional support. Finally, but equally important, to CONAHCyT for the valuable support provided through the program "Support for Mothers Heads of Families".

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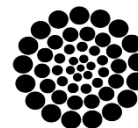
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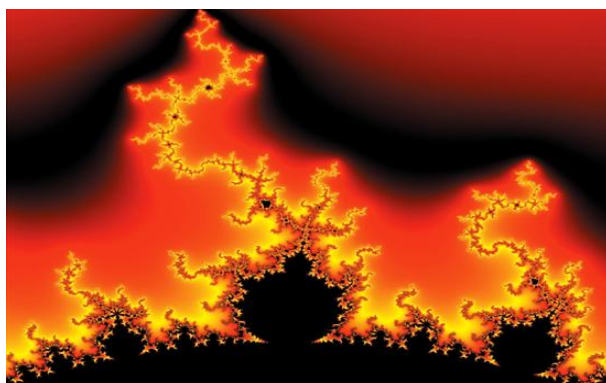
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### Box

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$$Y_{ij} = \alpha + \sum_{h=1}^r \beta_h X_{hij} + u_j + e_{ij} \quad [1]$$

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## Methodology

Develop give the meaning of the variables in linear writing and important is the comparison of the used criteria.

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The results shall be by section of the article.

## Conclusions

Clearly explain the results and possibilities of improvement.

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Tables and adequate sources.

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*Benoit-Pauleter, Gerard*: Contributed to the project idea, research method and technique.

## Availability of data and materials

Indicate the availability of the data obtained in this research.

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ANN                      Artificial Neural Network

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