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Email: inquide@ug.edu.ec
francisco.duquea@ug.edu.ec

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Letter from the Editor

Dear Readers and Researchers,

It is an honor to present the new issue of INQUIDE – Chemical Engineering and Development, volume 7, issue 1. This edition offers a selection of five scientific articles addressing topics of great relevance in the broad field of engineering and development.

The first article presents the thermo-hydraulic design of a horizontal shell and tube condenser for methanol condensation. This study provides detailed calculations of key parameters such as heat transfer area, number of tubes, and overall heat transfer coefficient, thus contributing to advancements in the design of refrigeration systems and power plants.

The second work explores the purification and characterization of reagent-grade NaCl obtained from Crucita seawater. This research stands out for its focus on obtaining high-purity sodium chloride, complying with the United States Pharmacopeia (USP) standards, which has significant implications for the pharmaceutical and chemical industries.

The third article evaluates and proposes an Environmental Management System (EMS) for a mango plantation in Ecuador. This study highlights the importance of implementing sustainable practices in agriculture, offering a proposal based on the ISO 14001:2015 standard to improve environmental performance and facilitate compliance with environmental regulations.

The fourth work presents the thermo-hydraulic design of a helical coil heat exchanger for ethanol cooling. This study provides detailed calculations of various parameters, demonstrating the effectiveness of this configuration in achieving high heat transfer coefficients in confined spaces.

Finally, the fifth article addresses the implementation of gastrodiplomacy as a strategic axis for tourism development and contribution to the cultural dissemination of Ecuador. This research explores the potential of gastronomy as a tool to promote Ecuadorian culture internationally, presenting viable strategies for its implementation.

Readers are cordially invited to explore these fascinating articles, which offer valuable contributions to the field of engineering and development. Each study presents innovative findings and practical applications that will undoubtedly enrich knowledge in their respective areas.

INQUIDE – Chemical Engineering and Development takes pride in being a platform for the dissemination of high-quality research. An invitation is extended to researchers to consider submitting their work to our journal. As a publication indexed in Latindex 2.0, it offers an excellent opportunity to give visibility and recognition to innovative research in the broad field of engineering.

Without further ado, we wish you a pleasant reading experience and thank you for your support of our journal.

Sincerely,

Francisco Javier Duque-Aldaz
Editor-in-Chief
Chemical Engineering and Development

Universidad de Guayaquil

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Carta del Editor

Estimados lectores e investigadores:

Es un honor presentar el nuevo número de INQUIDE – Ingeniería Química y Desarrollo, volumen 7, número 1. Esta edición ofrece una selección de cinco artículos científicos que abordan temas de gran relevancia en el campo amplio campo de la ingeniería y el desarrollo.

El primer artículo presenta el diseño termo-hidráulico de un condensador horizontal de carcasa y tubos para la condensación de metanol. Este estudio proporciona cálculos detallados de parámetros clave como el área de transferencia de calor, el número de tubos y el coeficiente global de transferencia de calor, contribuyendo así al avance en el diseño de sistemas de refrigeración y plantas de energía.

En el segundo trabajo, se explora la purificación y caracterización del NaCl de grado reactivo obtenido del agua de mar de Crucita. Esta investigación destaca por su enfoque en la obtención de cloruro de sodio de alta pureza, cumpliendo con los estándares de la Farmacopea de los Estados Unidos (USP), lo que tiene implicaciones significativas para la industria farmacéutica y química.

El tercer artículo evalúa y propone un Sistema de Gestión Ambiental (SGA) para una plantación de mango en Ecuador. Este estudio resalta la importancia de implementar prácticas sostenibles en la agricultura, ofreciendo una propuesta basada en la norma ISO 14001:2015 para mejorar el desempeño ambiental y facilitar el cumplimiento de las regulaciones ambientales.

El cuarto trabajo presenta el diseño termo-hidráulico de un intercambiador de calor de serpentín helicoidal para el enfriamiento de etanol. Este estudio proporciona cálculos detallados de diversos parámetros, demostrando la eficacia de esta configuración para lograr altos coeficientes de transferencia de calor en espacios reducidos.

Finalmente, el quinto artículo aborda la implementación de la gastrodiplomacia como eje estratégico del desarrollo turístico y contribución a la difusión cultural de Ecuador. Esta investigación explora el potencial de la gastronomía como herramienta para promover la cultura ecuatoriana a nivel internacional, presentando estrategias viables para su implementación.

Se invita cordialmente a los lectores a explorar estos fascinantes artículos, que ofrecen valiosas contribuciones al campo de la ingeniería y el desarrollo. Cada estudio presenta hallazgos innovadores y aplicaciones prácticas que sin duda enriquecerán el conocimiento en sus respectivas áreas.

INQUIDE – Ingeniería Química y Desarrollo se enorgullece de ser una plataforma para la difusión de investigaciones de alta calidad. Se extiende una invitación a los investigadores para que consideren enviar sus trabajos a nuestra revista. Como publicación indexada en Latindex 2.0, se ofrece una excelente oportunidad para dar visibilidad y reconocimiento a investigaciones innovadoras en el amplio campo de la ingeniería.

Sin más, les deseamos una feliz lectura y les agradecemos su apoyo a nuestra revista.

Atentamente,

Francisco Javier Duque-Aldaz.
Director - Editor
Ingeniería Química y Desarrollo

Universidad de Guayaquil

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Carta do Editor

Prezados leitores e pesquisadores:

É uma honra apresentar o novo número da INQUIDE – Engenharia Química e Desenvolvimento, volume 7, número 1. Esta edição oferece uma seleção de cinco artigos científicos que abordam temas de grande relevância no amplo campo da engenharia e do desenvolvimento.

O primeiro artigo apresenta o projeto termo-hidráulico de um condensador horizontal de casco e tubos para a condensação de metanol. Este estudo fornece cálculos detalhados de parâmetros-chave como a área de transferência de calor, o número de tubos e o coeficiente global de transferência de calor, contribuindo assim para o avanço no projeto de sistemas de refrigeração e usinas de energia.

No segundo trabalho, explora-se a purificação e caracterização do NaCl de grau reagente obtido da água do mar de Crucita. Esta pesquisa destaca-se por seu enfoque na obtenção de cloreto de sódio de alta pureza, cumprindo os padrões da Farmacopeia dos Estados Unidos (USP), o que tem implicações significativas para a indústria farmacêutica e química.

O terceiro artigo avalia e propõe um Sistema de Gestão Ambiental (SGA) para uma plantação de manga no Equador. Este estudo ressalta a importância de implementar práticas sustentáveis na agricultura, oferecendo uma proposta baseada na norma ISO 14001:2015 para melhorar o desempenho ambiental e facilitar o cumprimento das regulamentações ambientais.

O quarto trabalho apresenta o projeto termo-hidráulico de um trocador de calor de serpentina helicoidal para o resfriamento de etanol. Este estudo fornece cálculos detalhados de diversos parâmetros, demonstrando a eficácia desta configuração para alcançar altos coeficientes de transferência de calor em espaços reduzidos.

Finalmente, o quinto artigo aborda a implementação da gastrodiplomacia como eixo estratégico do desenvolvimento turístico e contribuição para a difusão cultural do Equador. Esta pesquisa explora o potencial da gastronomia como ferramenta para promover a cultura equatoriana a nível internacional, apresentando estratégias viáveis para sua implementação.

Convidam-se cordialmente os leitores a explorar estes fascinantes artigos, que oferecem valiosas contribuições ao campo da engenharia e do desenvolvimento. Cada estudo apresenta descobertas inovadoras e aplicações práticas que, sem dúvida, enriquecerão o conhecimento em suas respectivas áreas.

A INQUIDE – Engenharia Química e Desenvolvimento orgulha-se de ser uma plataforma para a difusão de pesquisas de alta qualidade. Estende-se um convite aos pesquisadores para que considerem enviar seus trabalhos à nossa revista. Como publicação indexada no Latindex 2.0, oferece-se uma excelente oportunidade para dar visibilidade e reconhecimento a pesquisas inovadoras no amplo campo da engenharia.

Sem mais, desejamos-lhes uma feliz leitura e agradecemos seu apoio à nossa revista.

Atenciosamente,

Francisco Javier Duque-Aldaz
Editor-Chefe
Engenharia Química e Desenvolvimento

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Thermo-hydraulic design of a horizontal shell and tube condenser for methanol condensation

Diseño térmico-hidráulico de un condensador de tubo y coraza horizontal para la condensación de metanol

Amaury Pérez Sánchez [1] * ; Yerelis Pons García [2] , Daynel Basulto Pita [3] , Elizabeth Ranero González [4] & Eddy Javier Pérez Sánchez [5]

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* Author for correspondence.

Abstract.
Shell and tube condensers are considered to be a significant part of refrigeration and power plants systems, as well as other petrochemical applications where the heat exchangers are usually employed. This article presents the thermo-hydraulic design of a one shell pass: two tube passes (1-2) horizontal shell and tube heat exchanger to condense a stream of pure methanol vapours using chilled water as a coolant. Several design parameters were calculated such as the heat transfer area (119.33 m2); the number of tubes (285); the shell internal diameter (800.56 mm) and the overall heat transfer coefficient (618.47 W/m2.K). The calculated heat duty for this heat exchange service was of 8,272.5 kW, while the required flowrate for chilled water was of 151.59 kg/s. The calculated pressure drops for the condensing methanol and chilled water streams were 7,372.55 Pa and 84,289.69 Pa respectively, which are below the maximum limit values set by the process. The designed 1-2 shell and tube condenser was of pull-through floating head type, with a baffle cut of 45% and a baffle spacing equal to the shell internal diameter.

Keywords.
Heat Exchanger Area, Methanol Condensation, Pressure Drop, Shell And Tube Condenser, Thermo-Hydraulic Design

Resumen.
Los condensadores de tubo y coraza están considerados ser una parte significativa de los sistemas de refrigeración y plantas de potencia, así como de otras aplicaciones petroquímicas donde los intercambiadores de calor son usualmente empleados. Este artículo presenta el diseño térmico-hidráulico de un intercambiador de calor de tubo y coraza horizontal de un paso por la coraza y dos pasos por los tubos (1-2) para condensar una corriente de vapores de metanol puro usando agua fría como agente de enfriamiento. Varios parámetros de diseño fueron calculados tales como el área de transferencia de calor (119,33 m2); el número de tubos (285); el diámetro interno de la coraza (800,56 mm) y el coeficiente global de transferencia de calor (618,47 W/m2.K). La carga de calor calculada para este servicio de transferencia de calor fue de 8 272,5 kW mientras que el caudal requerido de agua fría fue de 151,59 kg/s. Las caídas de presión calculadas para las corrientes de metanol condensante y agua fría fueron 7 372,55 Pa y 84 289,69 Pa respectivamente, las cuales están por debajo de los valores límites máximos fijados por el proceso. El condensador de tubo y coraza 1-2 diseñado fue del tipo cabezal flotante, con un corte del deflector de 45 % y un espaciado del deflector igual al diámetro interno de la coraza.

Palabras clave
Área De Intercambio De Calor, Condensación De Metanol, Caída De Presión, Condensador De Tubo Y Coraza, Diseño Térmico-Hidráulico

1. Introduction

Transfer of heat from one fluid to another is an important operation for most of the chemical industries. The most frequent application of heat transfer is the design of heat transfer equipment to exchange heat from one fluid to another fluid. Such devices for effective transfer of heat are commonly named heat exchanger.

Heat exchangers are based on the principle of heat transfer taking place between the higher temperature fluid and the lower temperature fluid. Heat exchangers operate by permitting the first fluid at a higher temperature to interact with the second fluid either directly or indirectly at a lower temperature. This allows heat to transfer from the first to the second fluid, resulting in a reduction in the second fluid's temperature and an increase in the first fluid's temperature. Depending on whether heating or cooling is necessary, heat is transferred towards or away from the given system [1].

Typical applications include heating or cooling of a fluid stream of interest and evaporation or condensation of single- or multicomponent fluid streams. In other applications, the objective may be to recover or reject heat, or sterilize, pasteurize, fractionate, distill, concentrate, crystallize, or control a process fluid. In most heat exchangers, heat transfer between fluids takes place through a separating wall or into and out of a wall in a transient manner. In various heat exchangers, the fluids are separated by a heat transfer surface, and ideally, they do not mix or leak [2].

[1] University of Camagüey; Faculty of Applied Sciences; amaury.perez84@gmail.com; https://orcid.org/0000-0002-0819-6760; Camagüey; Cuba.
[2] University of Camagüey; Faculty of Applied Sciences; yerelis.pons@reduc.edu.cu; https://orcid.org/0009-0003-0440-1784; Camagüey; Cuba.
[3] Center of Genetic Engineering and Biotechnology of Camagüey; Department of Production; daynel.basulto@cigb.edu.cu; https://orcid.org/0009-0005-1629-8846, Camagüey; Cuba.
[4] University of Camagüey; Faculty of Applied Sciences; elizabeth.ranero@reduc.edu.cu; https://orcid.org/0000-0001-9755-0276; Camagüey; Cuba.
[5] Company of Automotive Services S.A.; Commercial Department; eddy.perez@reduc.edu.cu; https://orcid.org/0000-0003-4481-1262; Ciego de Ávila, Cuba.

The heat exchangers are classified according to the transfer process, number of fluids, degree of surface compactness, construction features, flow arrangements and heat transfer mechanisms. Heat exchangers are extensively used in many engineering applications such as power engineering, petroleum refining, refrigeration, air conditioning, food industry, and biotechnological and chemical process industries [3].

Among the different types of heat exchangers, shell and tube heat exchangers (STHE) are the most common used in industry. They are relatively easy to manufacture and have multipurpose application potentials for gaseous and liquid media in large temperature and pressure ranges [3], with operating temperatures of - 20 ºC to over 500 ºC, maximum operating pressure of 600 bar and diameters ranging from 60 to over 2,000 mm [4]. According to [5] the shell and tube heat exchanger is used when a process requires large amounts of fluids to be heated (or vaporized) or cooled (or condensed), while due to their design, they offer a large heat transfer area and provide high heat transfer efficiency.

The main components of a STHE are identified in Figure 1, showing a 1-2 heat exchanger, that is, a heat exchanger with one shell-side pass and two tube-side passes. The tube-side fluid enters the heat exchanger from the tube fluid inlet (1) into front-end head (11) and from there into the tubes (4). The tube fluid exits the tubes of the first pass into the rear-end head (6), continues back into the second tube-side pass from which it exits back into the front-end head, and finally out of the heat exchanger from the tube fluid outlet (9). The shell-side fluid enters the heat exchanger from the shell inlet (2), flows on the shell side in a cross-parallel flow pattern in respect to the first pass, and cross-counter flow in respect to the tube pass, guided by baffle plates (8), and eventually exits from shell outlet (7). The tube bundle is held in place by the tube sheets (5), and inside the shell supported by the baffle plates [6].

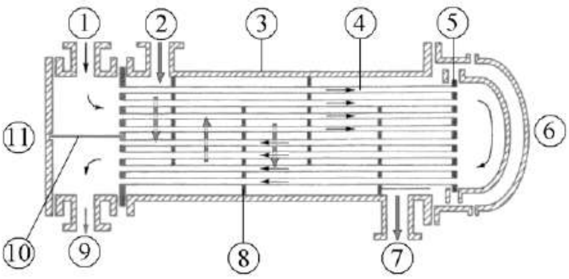

Fig 1. A shell and tube heat exchanger type 1-2.
Source: [6]

Condensers are used extensively in chemical and petroleum processing for distillation, refrigeration, and power generation systems. Condensers are an integral part of almost all the operations in the process industry. Condensers are basically two-phase flow heat exchangers in which the heat is generated when vapours are converted to liquid. The heat generated is rejected to a cooling medium, which acts as a heat sink. In condensers, the latent heat is given up by the process fluid and transferred to the cooling medium. Cooling water or surrounding air is generally used as cooling medium in most of the operations in the industry. Usually, the vapors that enter a condenser are saturated, although in many operations, the process fluid may enter the condenser in the form of superheated vapors. This normally happens when the vapors are not obtained as distillate of a distillation column. The superheated vapors are first desuperheated until saturation and then condensation takes place. The process fluid then leaves the condenser as a saturated or a sub-cooled liquid, depending upon the temperature of the cooling medium and the condenser design [7].

Condensers can also be classified as partial or total. When a pure component is considered, it will condense isothermally and will be totally condensed. If a mixture of components is considered, then it can be either be condensed totally or partially based on process conditions [7]. Condensers can be horizontally or vertically oriented with the condensation on the tube-side or the shell-side. The magnitude of the condensing film coefficient for a given quantity of vapor condensation on a given surface is notably different depending on the orientation of the condenser. The condensation normally takes place on the shell-side of horizontal exchangers and the tube-side of vertical exchangers. Horizontal shell-side condensation is normally chosen because condensing film transfer coefficients are usually higher [8].

Shell and tube condensers are the most commonly used heat exchangers in process industries because of their relatively simple manufacturing and their adaptability to different operating conditions. Although this condenser type differentiates itself by low-pressure drops with high flow velocities, its capital requirement, as well as the combined power and capital cost requirement due to pressure drops of the pumped and compressed streams in a unit, can be very expensive [9].

Shell-and-tube condensers with condensation on the shell-side are widely used in both process and refrigeration industries. This usually means that the condensing medium is fed to the top of a shell-and-tube heat exchanger, and then while flowing on the outside of the tubes it condenses, leaving its latent heat to the cooling medium flowing inside the tubes. The condensed liquid is collected at the bottom of the shell where it leaves the condenser. The heat transfer in a shell-and-tube condenser is difficult to predict. Factors such as the complex geometry of the tube bank, effect of the tube surface geometry, vapour shear effects and condensate inundation from the tubes above all have an effect on heat transfer [10].

In a broad sense, the design of a new heat exchanger means the determination/selection of an exchanger construction type, flow arrangement, tube material, and the physical size of an exchanger to meet the specified heat transfer and pressure drops within all specified constraints. For a STHE a sizing problem generally refers to the determination of shell type, diameter and length; number of tubes; tube layout; pass arrangement; heat exchange area; overall heat transfer coefficient; pressure drop, fluids velocities and Reynolds number of both fluids; as well as many other parameters. Inputs to the sizing problem are fluid flow rates, inlet and outlet fluid temperatures, fouling factors; diameters, length and material of tubes, and maximum possible pressure drop of the two fluids involved [2].

There are several studies reported where a shell and tube condenser is designed, sized or studied for a particular heat exchange service. In this sense, in [11] a shell and tube heat exchanger was designed to condense 0.03 kg/s of a superheated steam stream from 320 ºC (2 bar) to 120 ºC, using water as coolant. Also, [7] designed a shell and tube desuperheater-condenser for ammonia-water system by using standard correlations based on Kern's method, while the results were compared with HTRI Xchanger Suite Educational 6.0 software. Likewise, [2] carried out the geometry optimization of a shell and tube heat exchanger working as a condenser in a brewing company, where 6,000 kg/h of steam enters at 160 ºC on the shell side to heat cooled water to an outlet temperature of 35.5 ºC. Several parameters were calculated such as heat load, pressure drop, optimum insulation cost, tube length, thickness and tube patterns, among others, thus selecting the allowable design from the thermal design point of view. In [12] a conceptual technological design aspect of a super vacuum hybrid surface steam condenser was theoretically analyzed. Similarly, in [13] the redesign and construction of a shell and tube condenser intended for the study of forced convection, with and without changing phase, was developed with the purpose of providing a laboratory of an equipment to perform practical experiences that could be used to analyze such phenomena. In this study, the research was conducted in three phases: 1) diagnosis, carried out through survey techniques; 2) the techno-economic feasibility, which involved the redesign, material selection, and cost determination; and 3) construction and operational testing of the redesigned condenser. In [14] an optimization of a shell and tube condenser was performed for a low temperature thermal desalination plant. Also, in [15] a procedure was proposed for the design of the components of a heat exchanger network, including the condensers of the network, using pinch analysis to maximize heat recovery for a given minimum temperature difference, and using genetic algorithm in order to minimize its total annual cost. Other authors [9] studied the effect of baffle spacing on heat transfer area and pressure drop for shell side condensation in the most common types of segmentally baffled shell and tube condensers (TEMA E and J types with conventional tube bundles), while a set of correlations were also presented to calculate the optimum baffle spacing. In [16] a shell and tube condenser was designed from both the thermal and mechanical points of view, for its application in a steam turbine of a thermal power plant. In [10] a detailed 2D Computational Fluid Dynamics (CFD) calculation for vapour flow field and condensation rate was carried out for geometry similar to a real full-scale shell-and-tube condenser with 100 tubes, with condensation occurring on the shell-side. The differences in vapour flow behaviour were investigated for pure R22 and for a binary mixture of R32 and R134a. In [17] a dynamic mathematical model of a shell-and-tube condenser operating in a vapour compression refrigeration plant was presented and validated. The model was formulated from mass continuity, energy conservation and heat transfer physical fundamentals by using a lumped-parameter formulation for the condenser that is similar to the ones presented in previous studies, but with some differences in the selection of control volumes and including the refrigerant dynamics in a simplified way. In [18] a thermo-economic optimization of a shell and tube condenser was presented, based on two new optimization methods, namely genetic and particle swarm (PS) algorithms. The procedure was selected to find the optimal total cost including investment and operation cost of the condenser. Initial cost included condenser surface area and operational cost involved pump output power to overcome the pressure loss. In [19] a moving-boundary lumped parameter (MB) dynamic model of a shell-and-tube condenser was proposed, where the mean void fraction (MVF) correlation used can be changed in order to analyze the influence of the MVF correlation on the model performance, comparing the predictions obtained with experimental data using MVF correlations frequently mentioned in the literature. The experimental data used consisted of transients obtained varying the working conditions in a wide range, and being the MVF correlations used derived from different local void fraction expressions which allowed a relatively easy analytical or numerical integration. In [20] the energy, exergy and economic assessments of a shell and tube condenser of 580 MW nuclear power plant was carried out using different water-based hybrid nanofluids as coolant. The effect of nanoparticle concentration on reductions of coolant requirement, pumping power and operating cost was also investigated. Similarly, in [21] the constructal design of a shell-and-tube condenser with ammonia-water as the working fluid was studied based on constructal theory. A complex function (CF) formed by entropy generation rate (EGR) and total pumping power (TPP) was minimized, and the tube diameter was optimized, while the parameter that influences on the optimal results were researched. In [22] a horizontal shell and tube condenser was designed from the thermo-hydraulic point of view using the calculation approach reported by [23], in roder to condense ethanol vapours usign chilled water as coolant. Finally, in [24] a linear design optimization approach was presented for the first time for horizontal shell and tube condensers that guarantees global optimality. The numerical results obtained in this study indicated that the proposed approach can present solutions with lower heat transfer areas than two design procedures presented in chemical process design textbooks.

There are textbooks [8,25,26,27] that present several design methodologies related with the design of condensers using heuristics based on choices made by the designer. The main concept is to find one viable exchanger, not necessarily the optimal one [24].

In certain chemical processing plant, a vapour stream of pure methanol is obtained at the overhead of a distillation column, and it is desired to condense it using a shell and tube heat exchanger. In this context, in the present paper a 1-2 shell and tube condenser was designed from the thermo-hydraulic point of view, in order to condense methanol vapours by using chilled water as coolant. To accomplish this task, the calculation approach described in [23] was applied, where several important design parameters were calculated such as the number of tubes, heat exchange area, shell internal diameter, overall heat transfer coefficient and the pressure drops of both fluids.

2. Materials y methods.

2.1. Problem statement.

It's desired to condense 30,000 kg/h of methanol vapours that comes from the overhead of a distillation column at a temperature of 120 ºC. Chilled water is available at 2 ºC for this service, while the temperature rise is to be limited to 13 ºC for this coolant. According to plant standards, stainless steel tubes with a nominal diameter of ¾ inch 40ST are required, with a length of 5.0 m. The condenser is to operate at 5.0 bar, the vapours are to be totally condensed and no subcooling is required. The pressure drop of the chilled water and methanol should not exceed 100,000 Pa and 10,000 Pa, respectively. Design a suitable horizontal one shell, two tube pass (1-2) shell and tube heat exchanger for this condensation service, using a flow arrangement of countercurrent type.

2.2. Calculation methodology.

2.2.1. Heat exchange area of the condenser.

The calculation steps included in the calculation procedure to design the horizontal shell and tube heat condenser are presented below, specifically to determine the heat exchange area.

Step 1. Definition of the initial parameters:

- Vapour flowrate (m_v): [kg/h].
- Operating pressure of the condenser (P_c): [bar].
- Inlet temperature of vapour (T_1): [ºC].
- Condensation temperature of vapour at the operating pressure of condenser (T_c): [ºC].
- Molecular weight of methanol (M_v): [kg/kmol].
- Enthalpy of vapour methanol at T_c and P_c (h_v): [kJ/kg].
- Enthalpy of liquid (condensate) methanol at T_c and P_c (h_L): [kJ/kg].
- Inlet temperature of chilled water (t_1): [ºC].
- Outlet temperature of chilled water (t_2): [ºC].
- Inside diameter of tubes (d_i): [m].
- Outside diameter of tubes (d_e): [m].
- Length of tubes (L_t): [m].
- Thermal conductivity of the tubes material (k_w): [W/m.K].
- Fouling factor of water (R_w): [K.m^2/W].
- Fouling factor of condensing methanol (R_m): [K.m^2/W].
- Number of tube side passes (n_t).

Step 2. Heat duty (Q):

$$Q = \frac{m_v}{3{,}000} \cdot (h_v - h_L) \tag{1}$$

Step 3. Assumption of the overall heat transfer coefficient (U_a).

Step 4. Location of fluids inside the shell and tube heat exchanger.
The vapours will be located in the shell side, while the chilled water will flow inside the tubes.

Step 5. Log mean temperature difference ($LMTD$):

$$LMTD = \frac{(T_1 - t_2) - (T_c - t_1)}{ln\frac{(T_1 - t_2)}{(T_c - t_1)}} \tag{2}$$

Step 6. Factor R:

$$R = \frac{T_1 - T_c}{t_2 - t_1} \tag{3}$$

Step 7. Factor S:

$$S = \frac{t_2 - t_1}{T_1 - t_1} \tag{4}$$

Step 8. Temperature correction factor (F_t):
For a 1 shell: 2 tube pass heat exchanger, the correction factor is given by the following equation:

$$F_t = \frac{\sqrt{(R^2+1)} \cdot ln\left[\frac{(1-S)}{(1-R\cdot S)}\right]}{(R-1)\cdot ln\left[\frac{2-S\left[R+1-\sqrt{(R^2+1)}\right]}{2-S\left[R+1+\sqrt{(R^2+1)}\right]}\right]} \tag{5}$$

Step 9. True temperature difference (ΔTm):

$$\Delta T_m = LMTD \cdot F_t \tag{6}$$

Step 10. Trial heat exchange area (A_o):

$$A_o = \frac{Q \cdot 1{,}000}{U_a \cdot \Delta T_m} \quad (7)$$

Step 11. Surface area of one tube (a_t):
Ignoring the tube sheet thickness [23]:

$$a_t = \pi \cdot d_e \cdot L_t \quad (8)$$

Where d_e and L_t are given in m.

Step 12. Number of tubes (N_T):

$$N_T = \frac{A_o}{a_t} \quad (9)$$

Step 13. Tube pitch (p_t):
A square pitch is selected. Thus:

$$p_t = 1.25 \cdot d_e \quad (10)$$

Where $d_e$is given in mm.

Step 14. Tube bundle diameter (D_b):

$$D_b = d_e \cdot \left(\frac{N_T}{K_1}\right)^{1/n1} \quad (11)$$

Where $d_e$is given in mm, while K_1 and $n1$ are constants that depend on the type of pitch selected and the number of tube passes [23].

Step 15. Number of tubes in centre row (N_r):

$$N_r = \frac{D_b}{p_t} \quad (12)$$

Where both D_b and p_t are given in mm.

Step 16. Assume a condensation film coefficient ($h_{c(a)}$).

Step 17. Mean temperature of both the shell-side ($\bar{T}$) and tube-side ($\bar{t}$) fluids:

- Shell side (methanol vapours):

$$\bar{T} = \frac{T_1 + T_c}{2} \quad (13)$$

- Tube side (chilled water):

$$\bar{t} = \frac{t_1 + t_2}{2} \quad (14)$$

Step 18. Tube wall temperature (T_w):

$$T_w = \bar{T} - \frac{(\bar{T} - \bar{t}) \cdot U_a}{h_{c(a)}} \quad (15)$$

Step 19. Mean temperature condensate (T_w):

$$\bar{T}_C = \frac{\bar{T} + T_w}{2} \quad (16)$$

Step 20. Physical properties of the liquid methanol at the mean temperature condensate (T_w):

- Viscosity (μ_L) [Pa.s].
- Density (ρ_L) [kg/m^3].
- Thermal conductivity (k_L) [W/m.K].

Step 21. Density of vapour methanol at mean vapour temperature (ρ_v):

$$\rho_v = \frac{M_v}{22.4} \cdot \frac{273}{273 + \bar{T}} \cdot \frac{P_c}{P_o} \quad (17)$$

Where P_o is 1.0 bar.

Step 22. Condensate loading on a horizontal tube (Γ_h):

$$\Gamma_h = \frac{m_v}{3{,}600 \cdot L_t \cdot N_T} \quad (18)$$

Step 23. Average number of tubes in a vertical tube row (N_{tr}):

$$N_{tr} = \frac{2}{3} \cdot N_r \quad (19)$$

Step 24. Calculated mean condensation film coefficient for a tube bundle ($h_{c(b)}$):

$$h_{c(b)} = 0.95 \cdot k_L \cdot \left[\frac{\rho_L \cdot (\rho_L - \rho_v) \cdot g}{\mu_L \cdot \Gamma_h}\right]^{1/3} \cdot N_{tr}^{-1/6} \quad (20)$$

Where g is the gravitational acceleration = 9.81 m/s^2.

Step 25. Verification of the mean condensation film coefficient calculated in step 24 [$h_{c(b)}$] with the mean condensation coefficient assumed in step 16 [$h_{c(a)}$].
In this approach, if the value of $h_{c(b)}$ is close enough to the assumed value [$h_{c(a)}$] then no correction of T_w is necessary.

Step 25. Tube cross-sectional area (a_{ct}):

$$a_{ct} = \frac{\pi}{4} \cdot d_i^2 \cdot \frac{N_T}{n_t} \quad (21)$$

Where d_i is given in m.

Step 26. Density of tube-side fluid (chilled water) at $\bar{t}$ (ρ_t).

Step 27. Heat capacity of the tube-side fluid (chilled water) at $\bar{t}$ (Cp_t).

Step 28. Required flowrate of the tube-side fluid (chilled water) (m_t):

$$m_t = \frac{Q}{(t_2 - t_1) \cdot Cp_t} \quad (22)$$

Where Q is given in kW.

Step 29. Velocity of the tube-side fluid (u_t):

$$u_t = \frac{m_t}{\rho_t \cdot a_{ct}} \quad (23)$$

Step 30. Film coefficient for the tube side fluid (h_t):

- Specifically for water:

$$h_t = \frac{4{,}200 \cdot (1.35 + 0.02 \cdot \bar{t}) \cdot u_t^{0.8}}{d_i^{0.2}} \quad (24)$$

Where d_i is given in mm.

Step 31. Overall heat transfer coefficient calculated (U_c):

$$U_c = \frac{1}{\frac{1}{h_{c(b)}} + R_m + \frac{d_e \cdot ln\left(\frac{d_e}{d_i}\right)}{2 \cdot k_w} + \frac{d_e}{d_i} \cdot R_w + \frac{d_e}{d_i} \cdot \frac{1}{h_t}} \quad (24)$$

Where d_e and d_i are given in m.

Step 32. Compare the calculated overall heat transfer coefficient (U_c) with the overall heat transfer coefficient assumed in step 3 (U_a).
If the values are significantly different, then the calculation procedure should be repeated using a new trial assumed value for U_a which could be close enough to U_c.

2.3. Pressure drops.

2.3.1. Shell side pressure drop.

Step 33. Selection of the heat exchanger.
Step 34. Selection of the baffle spacing (l_B) and cut.
Step 35. Clearance (C_t).
Step 36. Shell internal diameter (D_s):

$$D_s = D_b + C_t \quad (25)$$

Where both D_b and C_t are given in mm.
Step 37. Cross-flow area (A_s):

$$A_s = \frac{(p_t - d_e)}{p_t} \cdot D_s \cdot l_B \quad (26)$$

Where all the parameters are given in m.

Step 38. Mass velocity of the vapour (G_v):

$$G_v = \frac{m_v}{3,600 \cdot A_s} \quad (27)$$

Step 39. Viscosity of the methanol vapour (μ_v) at the mean temperature $\bar{T}$.

Step 40. Linear velocity of the vapour (u_v):

$$u_v = \frac{G_v}{\rho_v} \quad (28)$$

Step 41. Shell-side equivalent diameter (D_{eq}):

- For square pitch arrangement:

$$D_{eq} = \frac{1.27}{d_e} \cdot (p_t^2 - 0.785 \cdot d_e^2) \quad (29)$$

Where both d_e and p_t are given in m.

Step 42. Reynolds number of the vapour (Re_v):

$$Re_v = \frac{G_v \cdot D_{eq}}{\mu_v} \quad (30)$$

Step 43. Shell-side friction factor (j_s)
Step 44. Pressure drop of the shell-side fluid (vapour) (ΔP_v):
The pressure drop of the shell side fluid can be assumed as 50% of that calculated using the inlet flow. Thus:

$$\Delta P_v = \frac{1}{2} \cdot \left[8 \cdot j_s \cdot \left(\frac{D_s}{D_{eq}}\right) \cdot \left(\frac{L_t}{l_B}\right) \cdot \frac{\rho_v \cdot (u_v)^2}{2} \cdot \left(\frac{\mu_v}{\mu_w}\right)^{-0.14}\right] \quad (31)$$

Where D_s and d_e are given in mm, while L_t and l_B are given in m. The term $\left(\mu_v/\mu_w\right)^{-0.14}$, which is the viscosity correction factor, could be neglected [23].

2.3.2. Tube side pressure drop.

Step 45. Viscosity of tube-side fluid (chilled water) at $\bar{t}$ (μ_t).

Step 46. Reynolds number of tube-side fluid (chilled water) (Re_t):

$$Re_t = \frac{u_t \cdot \rho_t \cdot d_i}{\mu_t} \quad (32)$$

Where d_i is given in m.
Step 47. Tube-side friction factor (j_t).

Step 48. Pressure drop of the tube-side fluid (chilled water) (ΔP_t):

$$\Delta P_t = n_t \cdot \left[8 \cdot j_t \cdot \left(\frac{L_t}{d_i}\right) \cdot \left(\frac{\mu_t}{\mu_w}\right)^{-0.14} + 2.5\right] \cdot \frac{\rho_t \cdot u_t^2}{2} \quad (33)$$

Where the term $\left(\mu_t/\mu_w\right)^{-0.14}$ can be neglected [23] and L_t and d_i are given in m.

3. Results

3.1. Heat exchange area of the condenser

Step 1. Definition of the initial parameters
Table 1 shows the initial parameters required to design the horizontal shell and tube condenser.

Table 1. Initial parameters required to design the horizontal shell and tube condenser.

Parameter	Symbol	Value	Unit
Vapour flowrate	m_v	30,000	kg/h
Operating pressure of the condenser	P_c	5.0	bar
Inlet temperature of vapour	T_1	120	ºC
Condensation temperature of vapour at the operating pressure of condenser[1]	T_c	110.73	ºC
Molecular weight of methanol[1]	M_v	32.04	kg/kmol
Enthalpy of vapour methanol at T_c and P_c[1]	h_v	1,134.12	kJ/kg
Enthalpy of liquid methanol at T_c and P_c[1]	h_L	141.42	kJ/kg
Inlet temperature of chilled water	t_1	2	ºC

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Outlet temperature of chilled water	t_2	15	ºC
Inside diameter of tubes[1]	d_i	20.93	m
Outside diameter of tubes[1]	d_e	26.67	m
Length of tubes	L_t	5.0	m
Thermal conductivity of the tubes material[2]	k_w	16	W/m.K
Fouling factor of water[2]	R_w	0.00035	K.m²/W
Fouling factor of condensing methanol[2]	R_m	0.00020	K.m²/W
Number of tube side passes	n_t	2	

[1]As reported by [28].
[2]As reported by [23].
Source: Own elaboration.

Table 2 presents the results of the parameters calculated in steps 2-15.

Table 2. Results of the parameters calculated in steps 2-15.

Step	Parameter	Symbol	Value	Units
2	Heat duty	Q	8,272.5	kW
3	Assumption of the overall heat transfer coefficient[1]	U_a	650	W/m².K
5	Log mean temperature difference[2]	$LMTD$	106.87	ºC
6	Factor R	R	0.713	-
7	Factor S	S	0.110	-
8	Temperature correction factor	F_t	0.998	
9	True temperature difference	ΔTm	106.65	ºC
10	Trial heat exchange area	A_o	119.33	m²
11	Surface area of one tube	a_t	0.419	m²
12	Number of tubes	N_T	~ 285	-
13	Tube pitch	p_t	33.34	mm
14	Tube bundle diameter[3]	D_b	707.56	mm
15	Number of tubes in centre row	N_r	~ 22	-

[1]As reported by [26] in the range of 550-1,100 W/m².K for the condensation of organic solvents in shell and tube, water-cooled condensers.
[2]The condensation range is small and the change in saturation temperature will be linear, so the log mean temperature difference can be used [23].
[3]The constants K_1 and $n1$ have values of 0.156 and 2.291 respectively, for a square pitch and two tube passes [23].
Source: Own elaboration.

Step 16. Assume a condensation film coefficient ($h_{c(a)}$). According to the range reported by [8] of 1,000-2,500 W/m².K for the condensation of low viscosity organic compounds, a value of 1,600 W/m².K was assumed for the condensation film coefficient of methanol on the shell side.

Table 3 displays the results of the parameters calculated in steps 17-24.

Table 3. Results of the parameters calculated in steps 17-24.

Step	Parameter	Symbol	Value	Units
17	Mean temperature of methanol	$\bar{T}$	115.36	ºC
	Mean temperature of chilled water	$\bar{t}$	8.50	ºC
18	Tube wall temperature	T_w	71.95	ºC
19	Mean temperature condensate	T_w	93.66	ºC
20	Viscosity of liquid methanol[1]	μ_L	0.000269	Pa.s
	Density of liquid methanol[1]	ρ_L	717.38	kg/m³
	Thermal conductivity of liquid methanol[1]	k_L	0.1806	W/m.K
21	Density of vapour methanol at $\bar{T}$	ρ_v	5.027	kg/m³
22	Condensate loading on a horizontal tube	Γ_h	0.0058	kg/s.m
23	Average number of tubes in a vertical tube row	N_{tr}	~ 15	-
24	Calculated mean condensation film coefficient for a tube bundle	$h_{c(b)}$	1,611.97	W/m².K

[1]As reported by [28].
Source: Own elaboration.

Step 25. Verification of the mean condensation film coefficient calculated in step 24 [$h_{c(b)}$] with the mean condensation coefficient assumed in step 16 [$h_{c(a)}$].
Since the calculated mean condensation film coefficient ($h_{c(b)}$ = 1,611.97 W/m².K) is close enough to the assumed

value in step 16 ($h_{c(a)}$ = 1,600 W/m^2.K), then no correction of the tube wall temperature (T_w) is needed.

Table 4 describes the results of the parameters calculated in steps 25-31.

Table 4. Results of the parameters calculated in steps 25-31.

Step	Parameter	Symbol	Value	Units
25	Tube cross-sectional area	a_{ct}	0.049	m^2
26	Density of chilled water at $\bar{t}$	ρ_t	999.818	kg/m^3
27	Heat capacity of chilled water at $\bar{t}$	Cp_t	4.1977	kJ/kg.K
28	Required flowrate of chilled water	m_t	151.59	kg/s
29	Velocity of chilled water	u_t	3.094	m/s
30	Film coefficient for chilled water	h_t	8,576.87	W/m^2.K
31	Calculated overall heat transfer coefficient	U_c	618.47	W/m^2.K

Source: Own elaboration.

Step 32. Comparison of the calculated overall heat transfer coefficient (U_c) with the overall heat transfer coefficient assumed in step 3 (U_a):
The value of the overall heat transfer coefficient calculated in step 31 (U_c = 618.47 W/m^2.K) is close enough to the overall heat transfer coefficient assumed in step 3 (U_a = 650 W/m^2.K), so there is no need to repeat the calculation procedure and carry out a new trial, and the heat exchanger area of the condenser will be 119.33 m^2.

3.2. Pressure drops.

3.2.1. Shell side pressure drop

Step 33. Selection of the heat exchanger.
In this study we select a pull-through floating head heat exchanger, with no need for close clearance. The reported advantages of these heat exchangers include that they are more versatile than fixed head and U-tube exchangers, are suitable for high temperature differentials and, as the tubes can be rodded from end to end and the bundle removed, are easier to clean and can be used for fouling liquids [23].

Step 34. Selection of the baffle spacing (l_B) and cut.
As specified by [23], the baffle spacings used in commercial shell and tube heat exchangers range from 0.2 to 1.0 shell internal diameter (D_S). Close baffle spacing will give higher heat-transfer coefficients, but at the expense of higher pressure drops. The optimum spacing will usually be between 0.3 to 0.5 times the shell diameter. However, although the construction of a condenser is similar to other shell and tube exchangers, wider baffle spacings are applied, typically l_B =D_S [23]. In this study we obeyed this last rule-of-thumb, that is, we selected a value for the baffle spacing equal to the shell internal diameter.

The term "baffle cut" is used to specify the dimensions of a segmental baffle. The baffle cut is the height of the segment removed to form the baffle, expressed as a percentage of the baffle disc diameter. Baffle cuts from 15 to 45 % are commonly used [23]. In this study, we chose a baffle cut of 45%.

Step 35. Clearance (C_t).
According to [23], for a value of the tube bundle diameter (D_b) of 707.56 mm (0.707 m), the clearance will be 93 mm for a pull-through floating head heat exchanger.

Step 36. Shell internal diameter (D_s):

$$D_s = D_b + C_t = 707.56 + 93 = 800.56\ mm \quad (25)$$

Thus, the baffle spacing (l_B) will be 800.56 mm.

Table 5 exhibits the results of the parameters calculated in steps 37-44.

Table 5. Results of the parameters calculated in steps 37-44.

Step	Parameter	Symbol	Value	Units
37	Cross-flow area	A_s	0.128	m^2
38	Mass velocity of the vapour	G_v	65.10	kg/m^2.s
39	Viscosity of the methanol vapour at the mean temperature $\bar{T}$	μ_v	0.0000128	Pa.s
40	Linear velocity of the vapour	u_v	12.95	m/s
41	Shell-side equivalent diameter	D_{eq}	0.0263	m
42	Reynolds number of the vapour	Re_v	133,760.15	-
43	Shell-side friction factor[1]	j_s	0.023	-
44	Pressure drop of methanol (vapour)	ΔP_v	7,372.55	Pa

[1]For a baffle cut of 45% and a Reynolds number of 1.34x10^5 [23].
Source: Own elaboration.

3.2.2. Tube side pressure drop.

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Table 6 shows the results of the parameters calculated in steps 45-48.

Table 6. Results of the parameters calculated in steps 45-48.

Step	Parameter	Symbol	Value	Units
45	Viscosity of chilled water at $\bar{t}$	μ_t	0.001364	Pa.s
46	Reynolds number of chilled water	Re_t	47,467.47	-
47	Tube-side friction factor	j_t	0.0033	-
48	Pressure drop of the chilled water[1]	ΔP_t	84,289.69	Pa

[1]For a Reynolds number of 4,74x10^4 [23].
Source: Own elaboration.

4. Discussion.

The heat duty for this heat exchange service was 8,272.5 kW, with a true temperature difference of 106.65 ºC. In [7] a shell and tube desuperheater-condenser was designed to condense a stream of ammonia using cooling water as coolant, and by using the standard correlations based on Kern's method. In this study, the calculated heat duty is 903.78 kW. In [23] the heat duty is 4.368.8 kW for a horizontal shell and tube condenser designed to condense a stream of mixed light hydrocarbon vapours using cooling water. In [8] a horizontal shell and tube condenser is designed to condense acetone vapours on the shell side by using cooling water as coolant, thus obtaining a calculated heat duty of 2,865 kW. In another study [22], a value for the calculated heat duty of 6,578.47 kW was obtained for a horizontal shell and tube condenser designed to condense a stream of ethanol vapours.

The calculated film coefficient for chilled water (8,576.87 W/m^2.K) was 5.32 times higher than the calculated mean condensation film coefficient for the condensing methanol vapours (1,611.97 W/m^2.K). This result doesn't agree with the findings of [7], where the mean condensation film coefficient of an ammonia stream condensing on the shell side (11,836.73 W/m^2.K) is 1.80 times higher than the heat transfer coefficient of the cooling water on the tube side (6567.32 W/m^2.K). It's worth mentioning that in this study [7] the horizontal shell and tube heat exchanger was also designed using the HTRI software, and the results obtained by this software regarding the calculation of the film heat transfer coefficients for both streams agree with those reported on the present study, that is, the value of the film heat transfer coefficient for cooling water (7,081.82 W/m^2.K) is higher (1.41 times) than the mean condensation film coefficient of condensing ammonia on the shell side (4,995.21 W/m^2.K). In [23] the calculated film coefficient for cooling water flowing inside the tubes (7,097 W/m^2.K) is 4.90 times higher than the calculated mean condensation film coefficient (1,447 W/m^2.K) for the mixed light hydrocarbon stream condensing on the shell side. In [8], the calculated film coefficient for a cooling water stream flowing on the tube side (7,483 W/m^2.K) is 5.02 times higher than the calculated mean condensation film coefficient (1,491 W/m^2.K) for the acetone stream condensing on the shell side. In [22] the value of tube side heat transfer coefficient for chilled water is 6,265.59 W/m^2.K, which is 7.55 times higher than the mean condensation film coefficient for the ethanol condensing vapours (829.38 W/m^2.K). The value of the film coefficient for chilled water calculated in this study is higher than the range suggested by [8] of 2,000-6,000 W/m^2.K, while the value of the mean condensation film coefficient for the condensing methanol vapours agrees with the range reported by the same author of 1,000–2,500 W/m^2.K.

Respecting the overall heat transfer coefficient calculated in this study (618.47 W/m2.K), its value agrees with the range reported by [26] of 550-1,100 W/m^2.K; the range reported by [25] of 300-1,000 W/m^2.K, and the range reported by [28] of 568-1,136 W/m^2.K, while it's slightly lower than the range reported by [23] of 700-1,000 W/m^2.K.

About 151.59 kg/s of chilled water will be needed in this study to carry out the condensation of the pure methanol vapours. In [8], a flowrate of cooling water of 68.54 kg/s is needed to condense 5.8 kg/s of acetone vapours. In [23] a flowrate of cooling water of 104.5 kg/s is needed to condense 12.5 kg/s of mixed light hydrocarbon vapours. In [22] about 157 kg/s are needed to condense 6.94 kg/s of pure ethanol vapours. In [7] the flowrate of cooling water required to condense 0.6841 kg/s of ammonia vapours is 35.97 kg/s.

The shell and tube condenser designed in this paper will have the following parameters:

- Heat exchange area: 119.33 m^2.
- Number of tubes: 285.
- Tube bundle diameter: 707.56 mm.
- Number of tubes in centre row: 22.
- Shell internal diameter: 800.56 mm.

In [7], the horizontal desuperheater-condenser designed to carry out the condensation of ammonia vapours, has the following design parameters:

- Heat exchange area: 116.62 m^2.
- Number of tubes: 784.
- Shell internal diameter: 840 mm.

In [8], the horizontal shell and tube condenser designed to condense acetone vapours using cooling water, has the following design results:

- Heat exchange area: 96.0 m^2.
- Number of tubes: 488.
- Shell internal diameter: 623 mm.

In [23] the horizontal shell and tube heat exchanger condenser designed to condense a stream of mixed light hydrocarbon vapours has the following design parameters:

- Heat exchange area: 364 m^2.
- Number of tubes: 1194.
- Shell internal diameter: 1130 mm.

In [22] the horizontal shell and tube heat exchanger condenser designer to condense a stream of ethanol vapours has the design parameters presented below:

- Heat exchange area: 223.68 m^2.
- Number of tubes: 731.
- Tube bundle diameter: 744.57 mm.
- Shell internal diameter: 1,684 mm.

The calculated pressure drop for the chilled water was 84,289.69 Pa, which is 11.43 times higher than the calculated pressure drop of the condensing methanol (7,372.55 Pa). Both values of the pressure drop are below the limits established by the heat transfer process. In [23] the pressure drop of the cooling water flowing inside the tubes (53,000 Pa) is 40.77 times higher than the pressure drop of a mixed light hydrocarbon vapours condensing on the shell side (1,300 Pa). Likewise, in [7] the pressure drop of cooling water flowing inside the tubes (49,130 Pa) is 40.16 times higher than the pressure drop of condensing ammonia on the shell (1,223.4 Pa). In [22], the pressure drop of the chilled water stream located in the tubes (42,192.63 Pa) is 4.19 times higher than the pressure drop of the condensing ethanol on the shell side (10,069.25 Pa).

5. Conclusions.

In the present work a 1-2 horizontal shell and tube condenser was designed from the thermo-hydraulic point of view to condense a stream of pure methanol vapours using chilled water as coolant. The design calculation methodology employed to carry out the design task was the reported in [23]. Several key design parameters were calculated such as the heat transfer area (119.33 m^2); the number of tubes (285); the tube bundle diameter (707.56 mm) and the shell internal diameter (800.56 mm). Other important thermal parameters were also computed such as the heat duty (8,272.5 kW), the overall heat transfer coefficient (618.47 $W/m^2.K$) and the required flowrate of chilled water (151.59 kg/s). The calculated values of the pressure drop of both the shell-side (7,372.55 Pa) and tube-side (84,289.69 Pa) fluids were below the maximum limit set by the heat exchanger process. The designed 1-2 shell and tube condenser is of pull-through floating head type, with a tube length of 5.0 m, a baffle cut of 45% and a baffle spacing of 800.56 mm.

6.- Author Contributions.

1. Conceptualization: Amaury Pérez Sánchez.
2. Data curation: Heily Victoria González, Elizabeth Ranero González.
3. Formal analysis: Amaury Pérez Sánchez, Arlenis Cristina Alfaro Martínez, Eddy Javier Pérez Sánchez.
4. Acquisition of funds: Not applicable.
5. Research: Amaury Pérez Sánchez, Heily Victoria González, Eddy Javier Pérez Sánchez.
6. Methodology: Amaury Pérez Sánchez, Arlenis Cristina Alfaro Martínez, Elizabeth Ranero González.
7. Project management: Not applicable.
8. Resources: Not applicable.
9. Software: Not applicable.
10. Supervision: Amaury Pérez Sánchez.
11. Validation: Amaury Pérez Sánchez.
12. Writing - original draft: Eddy Javier Pérez Sánchez, Elizabeth Ranero González.
13. Writing - revision and editing: Amaury Pérez Sánchez, Heily Victoria González.

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Nomenclature

a_{ct}	Tube cross-sectional area	m2
a_t	Surface area of one tube	m2
A_o	Heat exchange area	m2
A_s	Cross-flow area	m2
Cp	Heat capacity	kJ/kg.K
C_t	Clearance	mm
d_i	Inside diameter of tubes	m
d_e	Outside diameter of tubes	m
D_b	Tube bundle diameter	mm
D_{eq}	Shell-side equivalent diameter	m
D_s	Shell internal diameter	mm
F_t	Temperature correction factor	-
g	Gravitational acceleration	m/s2
G	Mass velocity	kg/m2.s
h	Enthalpy	kJ/kg
$h_{c(a)}$	Assumed condensation film coefficient	W/m2.K
$h_{c(b)}$	Calculated mean condensation film coefficient for a tube bundle	W/m2.K
j_s	Shell-side friction factor	-
j_t	Tube-side friction factor	-
k	Thermal conductivity	W/m.K
K_1	Constant	-
l_B	Baffle spacing	mm
$LMTD$	Log mean temperature difference	ºC
L_t	Length of tubes	m
m	Mass flowrate	kg/h
M	Molecular weight	kg/kmol
$n1$	Constant	-
n_t	Number of tube side passes	-
N_r	Number of tubes in centre row	-
N_{tr}	Average number of tubes in a vertical tube row	-
N_T	Number of tubes	-
p_t	Tube pitch	m
P_o	Atmospheric pressure	bar
P_c	Operating pressure of the condenser	bar
ΔP	Pressure drop	
Q	Heat duty	kW
R	Factor	-
Re	Reynolds number	-
R_m	Fouling factor of condensing methanol	K.m2/W
R_w	Fouling factor of water	K.m2/W
S	Factor	-
t	Temperature of cold fluid	ºC
$\bar{t}$	Mean temperature of cold fluid	ºC
T_1	Inlet temperature of vapour	ºC
T_c	Condensation temperature of vapour at the operating pressure of condenser	ºC
$\bar{T}$	Mean temperature of hot fluid	ºC
T_w	Mean temperature condensate	ºC
T_w	Tube wall temperature	ºC
ΔTm	True temperature difference	ºC
u	Velocity	m/s
U_a	Assumed overall heat transfer coefficient	W/m2.K
U_c	Calculated overall heat transfer coefficient	W/m2.K

Greek symbols

ρ	Density	kg/m^3
μ	Viscosity	Pa.s
Γ_h	Condensate loading on a horizontal tube	kg/s.m

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Subscripts

1	Inlet
2	Outlet
L	Liquid or condensate
t	Tube-side fluid
v	Vapour

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Purification and characterization of reagent grade NaCl obtained from Crucita seawater

Purificación y caracterización de NaCl grado reactivo obtenido del agua de mar de Crucita

Antonella Ferrin [1] * ; Thalía Caicedo [2] ; Segundo García [3] ; Ramón Cevallos [4] & Ariana García [5]

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* Author for correspondence.

Abstract

The main objective of this work is to analyze and apply the processes to obtain sodium chloride (NaCl) in a seawater sample form Crucita-Manabí and bring it to a higher purity in accordance with the Pharmacopoeia standards of the United States (USP). USP establishes quality standards and specifications for a wide range of pharmaceutical, chemical and health products. Therefore, the research was developed in three stages: the first corresponded to the purification of NaCl through the compilation of information from bibliographic sources that allowed investigating the different industrial and artisanal processes for the purification of NaCl, through this research it was possible to determine that to carry out this process separation, crystallization, distillation and filtration techniques were applied that allow the elimination of impurities present in the sample. The second stage corresponded to the analysis established based on the results obtained in the purification process; Therefore, it was essential to evaluate the conditions that allowed the impurities present to be eliminated, making it necessary to perform physical and chemical tests to determine the percentage of purity of the final product. Finally, the third stage consisted of analyzing the final product to establish whether it met the proposed objective based on the USP regulations on NaCl.

Solo25&%

Keywords

Sodium Chloride, Purification, Crystallization, Distillation, Filtration.

Resumen

El presente trabajo, tiene como objetivo principal analizar y aplicar los procesos para la obtención del cloruro de sodio (NaCl) grado reactivo en muestra de agua de mar de Crucita-Manabí y llevarlo a una pureza más elevada acorde a los estándares de Farmacopea de los Estados Unidos (USP, por sus siglas en inglés). La USP establece estándares y especificaciones de calidad para una amplia gama de productos farmacéuticos, químicos y de salud. Por tanto, la investigación se desarrolló en tres etapas: la primera correspondió a la purificación del NaCl a través de la recopilación de información de fuentes bibliográficas que permitieron poder analizar los diferentes procesos industriales y artesanales para la purificación del NaCl, mediante esta investigación se pudo determinar que para llevar a cabo este proceso se aplicaron técnicas de separación, cristalización, destilación y filtración que permiten la eliminación de impurezas presentes en la muestra. La segunda etapa, correspondió al análisis establecido en base a los resultados obtenidos en el proceso de purificación; por tanto, fue fundamental evaluar las condiciones que permitieron eliminar las impurezas presentes, siendo necesario realizar pruebas físicas y químicas para determinar el porcentaje de pureza del producto final. Finalmente, la tercera etapa consistió en analizar el producto final para establecer si este cumplía con el objetivo propuesto basado en las normativas USP sobre el NaCl.

Palabras clave

Cloruro de Sodio, Purificación, Cristalización, Destilación, Filtración.

1. Introduction

NaCl is a simple chemical compound, composed of a sodium ion (Na+) and a chlorine ion (Cl-), known as common or table salt; it is a crystalline solid and soluble in water [1].

Reactive sodium chloride is a purified and superior variant of the conventionally used NaCl. This NaCl is used in laboratories and industries that demand a higher level of purity than that offered by common salt. For its use, reactive NaCl must meet specific purity requirements (99% - 100.5%) according to USP standards and be free of impurities that could affect the chemical or biological processes in which it is applied.

This compound has a wide application in sectors such as the chemical and pharmaceutical industry, where it is used as a reagent, buffering agent and in the production of various chemical products. It is also used in scientific research and in the production of food, medicines and cosmetics.

The present research focused on obtaining reagent grade NaCl in Ecuador, the purpose was to obtain this product and bring it to the highest possible purity since the process and purification of this product has not been done before in the country despite having enough raw material available, and to study and analyze the theoretical principles behind the NaCl purification process, including physical analysis and the chemical reactions involved.

[1] Universidad Técnica De Manabí. https://orcid.org/0009-0007-5012-0632 , mferrin4180@utm.edu.ec ; Portoviejo; Ecuador.
[2] Universidad Técnica De Manabí. https://orcid.org/0009-0001-7103-9434 , tcaicedo6535@utm.edu.ec ; Portoviejo; Ecuador.
[3] Universidad Técnica De Manabí. https://orcid.org/0000-0002-8152-3406 , segundo.garcia@utm.edu.ec ; Portoviejo; Ecuador.
[4] Universidad Técnica De Manabí. https://orcid.org/0000-0002-8583-4674 , ramon.cevallos@utm.edu.ec ; Portoviejo; Ecuador.
[5] Universidad Técnica De Manabí. https://orcid.org/0000-0001-6893-0843 , agarcia4908@utm.edu.ec ; Portoviejo; Ecuador.

Manabí is a province with saline resources that are used for salt production; however, at present the national industry does not produce NaCl for reactive use and proof of this is that the country's universities are forced to acquire NaCl in its reactive grade from chemical companies that import it for use in various analyses or studies carried out in laboratories at the university level. In this sense, it is necessary to carry out an investigation on the NaCl purification process and analyze it in seawater samples from Crucita-Manabí to determine its purity level and bring it to a higher purity according to the mentioned standards.

For this, a punctual sampling of the water was carried out in which representative samples were obtained and physical-chemical analyses were carried out to determine the concentration of NaCl before and after the purification process and then analyze the purity of the NaCl obtained by the simple evaporation method, evaluating the effectiveness of the process and comparing the results obtained with the USP standards. The conditions to eliminate the impurities present in the NaCl obtained were evaluated [1].

2. Materials and methods.

Before the composition of matter was discovered, the word salt referred to any soluble, non-flammable solid, especially when referring to that which was formed as a result of the evaporation of seawater. Despite its ancient etymology, the word salt is still used today with two distinct meanings. One is the specific name of the chemical compound sodium chloride, while the other is the generic name of the group of chemical substances formed from acids in which metals have partially or completely replaced hydrogen atoms [2]. The salt purification process begins with brine deionization or evaporation, where the ions are treated to remove impurities and sometimes purified before crystallization. It occurs in open-air salt pans that favor sodium chloride crystallization when evaporation begins [1].

A new technique to purify sodium chloride is by two-dimensional gel electrophoresis. The technique allows obtaining NaCl nanoparticles uniform in size and of high purity, which could be used in a variety of areas such as medicine and catalysis [3]. In the present work, a study was conducted that analyzed how operational parameters affect the purification of NaCl by ultrasound-assisted crystallization. The results showed that this technique can produce high purity NaCl crystals with lower energy consumption than conventional techniques [4]. A very novel technique was found to account for the use of modified zeolites as adsorbents to purify NaCl from wastewater. The technique allowed the recovery of high purity NaCl while reducing the impact of wastewater effect on the environment [5]. Similarly, purification of reactive NaCl by evaporation, simple distillation and ion exchange was performed.

The detailed process for obtaining reagent grade NaCl from seawater is described below. The method employed involves a series of successive stages, including initial physical-chemical analysis, evaporation, recrystallization, dissolution, filtration, distillation, ion exchange, washing of crystals and finally drying. The NaCl obtained was characterized by physicochemical analysis to determine purity, reaching a classification that is considered reactive.

The initial sampling and analysis consisted of collecting 20 liters of seawater and performing initial physical and chemical analyses to determine the characteristics of the seawater. Then, precipitation and primary crystallization were performed, which consisted of evaporating 12 liters of seawater at 100ºC for 8 hours. Evaporation caused the precipitation of dissolved chemical compounds, resulting in primary crystallization; 500 ml of distilled water were added to dilute the sample, and then vacuum filtration was performed to eliminate the non-soluble solids that precipitated as the temperature increased. Next, distillation and softening were carried out in which a simple distillation was implemented to obtain a concentrated brine which was analyzed detecting a high hardness in which an ion exchange was applied using a cationic resin to eliminate calcium and magnesium ions.

After this, fractional recrystallization and washing was applied, where the brine was diluted again with 500 ml of distilled water, evaporated at 100ºC for 10 minutes with constant agitation, the solution was passed through columns of regenerated cationic resin to eliminate the calcium and magnesium ions (repeated 3 times), Evaporation was carried out to obtain a fractional recrystallization, the crystals were washed with 500 ml of additional distilled water applying once again a new vacuum distillation and the evaporation and recrystallization stage was repeated. Finally, the drying and final analysis was carried out, which consisted of taking the sample obtained to an oven at 105ºC for 5 hours. Once the sample was dry, it was weighed and 562.45 g of NaCl was obtained, and finally, to determine its percentage of purity, physical-chemical analysis was carried out, where 97.23% of NaCl GR was obtained.

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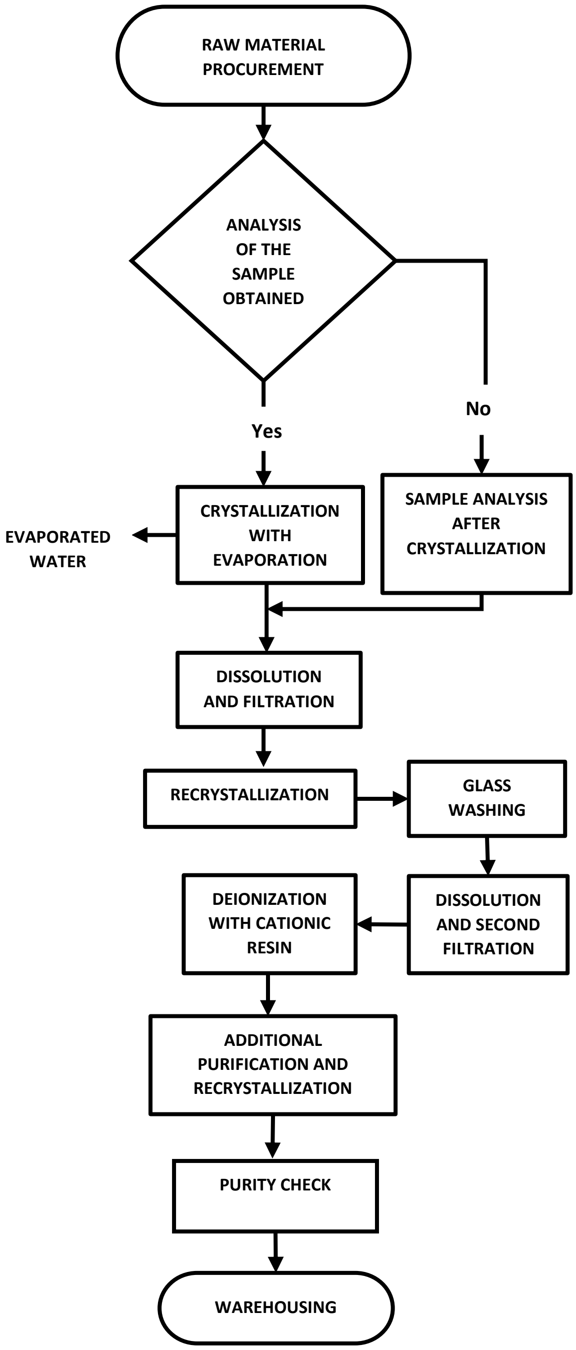

Fig. 1. Reagent-grade NaCl purification process flow diagram

2.1. Composition of seawater.

Seawater is a solution in water (H_2 O) of many different substances. Up to 2/3 of the natural chemical elements are present in seawater, although most of them only as traces. Six components, all of them ions, account for more than 99% of the solute composition [6].

Table 1. Percentage composition of solid solutes in seawater.

Anions	%	Cations	%
Chlorides (Cl^-)	55,07	Sodium (Na^+)	30,62
Sulfates (SO_4^{2-})	7,72	Magnesium (Mg^{++})	3,68
Bicarbonates (HCO_3^-)	0,41	Calcium (Ca^{++})	1,18
Bromide (Br^-)	0,19	Potassium (K^+)	1,14
Fluorine (F^-)	0,01	Strontium (Sr^{++})	0,02

Source: Osorio Arias & Álvarez Silva, 2006.

Information was gathered that allowed us to broaden our knowledge about the different methods and techniques that can be used in the process of obtaining NaCl Reactive Grade.

2.2. Selection of raw material

The seawater selected for the extraction of NaCl G.R. was collected in the sea of Crucita in the canton of Portoviejo, province of Manabí, Ecuador (Fig. 1). These samples were transferred to the chemistry laboratory of the Faculty of Engineering and Applied Sciences.

Fig. 2. Panoramic view of the sea locality of Crucita.

2.3. Experimentation

The experimental work began by taking seawater samples from the parish of Crucita for their respective physical-chemical characterization in the aforementioned laboratory.

Physical-chemical analysis: alkalinity, chlorides, conductivity, hardness, salinity, total solids, pH and temperature.

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Table 2. Physical and chemical analysis of seawater samples.

Components	Results	Units
Alkalinity	96	mg/L
Chlorides	20020	mg/L
Conductivity	64000	us/cm
Hardness	4764	mg/L
Salinity	0,14	%
Total Solids	1380	mg/L
pH	6,27	
Temperature	27.5	ºC

The main methods applied during the experimentation were gravimetric and volumetric: in the volumetric method the ion contained in a given product was determined quantitatively; by measuring the volume of a solution of known concentration or standard solution that reacts with a known amount of solution containing the element under study and gravimetric method which is based on the precise and accurate measurement of the mass to be determined, which was separated from the rest of the components of the sample being NaCl. Although most of the substances were found in very low concentration, there were two important substances that are commercially extracted from seawater: sodium chloride (table salt) and magnesium [7].
The different physical analyses of the water sampled were obtained using the multi-parameter equipment (BLE-9909).

Alkalinity: The alkalinity of seawater plays a crucial role in buffering the pH of the ocean against acidification caused by CO2. The alkalinity of seawater is mainly determined by two components: carbonate ions and borate ions. These ions neutralize the hydrogen ions produced by CO2 dissolution, which limits the decrease in pH [8].

Alkalinity consists of the ability to neutralize acids and is the sum of all titratable bases, it prevents water pH levels from becoming too acidic or basic, giving rise to carbonates and bicarbonates in seawater [9].

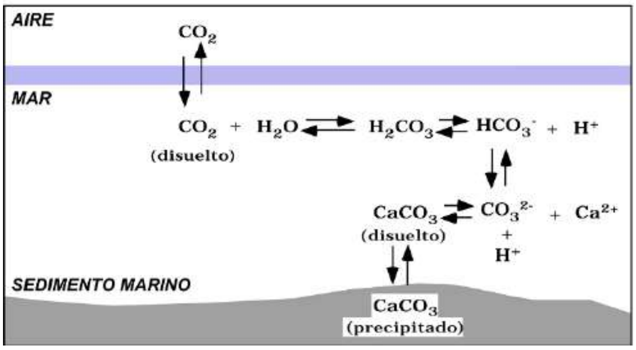

Fig. 3. Origen de bicarbonato y carbonato en el ambiente marino.

Hardness: Although seawater is an essential resource for life on earth, its high salinity and hardness prevent it from being used for human consumption or agricultural irrigation. The removal of salt from seawater, or desalination process, has become an increasingly important technology. The ability of seawater to dissolve a soap is measured in terms of because of its hardness. The presence of magnesium and calcium ions is the main cause. The hardness of seawater in the Pacific Ocean ranges from 200 to 400 mg/L CaCO3, with higher values in coastal areas and lower values in the open ocean [10]. Hardness can be temporary or permanent; the water may contain calcium and magnesium bicarbonate, iron or magnesium. It is characterized because its softening is achieved by boiling, which consists of the bicarbonate precipitating, releasing carbon dioxide and lowering the pH value by carbonic acid formations [11].

The analysis of total hardness by titration with EDTA (ethylenediaminetetraacetic acid), allowing the quantification of Ca and Mg ions and their subsequent conversion to total hardness expressed as CaCO3 was carried out as follows:

10 ml of the sample water was taken in a flask, 1 ml of Buffer solution pH 10 was added and as an indicator a pinch of eriochrome black T (ENT) was used, the same which is intended to form a purple colored mixture; to proceed to titrate with EDTA; until the appearance of blue color.

Reactions:
$Ca^{+2} + Mg^{+2}$ + Buffer pH10 $\longrightarrow$

$Ca^{+2} + Mg^{+2}$ + ENT $\longrightarrow$ (Ca^{-} Mg^{-} ENT) purpura

(Ca^{-} Mg^{-} ENT) + EDTA $\longrightarrow$ (Ca^{-} Mg^{-} EDTA) + ENT

During the titration 56.2 ml of 0.01M EDTA were consumed, where 53.5 ml corresponded to MgCO3 and 2.7 ml for CaCO3.

Calcium hardness: With the Buffer pH 10 the total concentration of the sample hardness such as Ca and Mg was determined. To determine the concentration of calcium present in the sample, 1 ml of Buffer pH 10 was added to the sample and then 20 drops of KOH were added to regulate the pH 10 to pH 12. From this result, the total hardness was subtracted to obtain the Mg concentration value.

Consumption = 2,7 ml de EDTA 0,01M en $CaCO_3$.
Consumption = 53,5 ml de EDTA 0,01M en $MgCO_3$.

$$CaCO_3 = \frac{C * M * pM * 1000}{Vm} \quad (1)$$

$$Ca = \frac{2{,}7 * 0{,}01M * 100 * 1000}{10} = 270\frac{mg}{L}$$

$$MgCO_3 = \frac{53{,}5 * 0{,}01M * 84 * 1000}{10} = 4494\frac{mg}{L}$$

$$(270 + 4494)\frac{mg}{L} = 4764\frac{mg}{L} Total\ hardness$$

$$Ca = \frac{2,7 * 0,01M * 20 * 1000}{10} = 54\frac{mg}{L}$$

Total hardness: 4764 mg/L - Calcium hardness: 270 mg/L= 4494 mg/L of Mg
$MgCO_3$ = 4494 mg/L

It was determined that the hardness present in the sample was found in higher percentage in Mg.

Sulfates (SO_4^{-2}): With an average concentration of about 2.7 g/L, sulfate is one of the most present inorganic anions in seawater. It plays an important role in seawater chemistry and has a major impact on marine life. The complex process of sulfate cycling in the Pacific Ocean involves a variety of physical, chemical and biological interactions [12]. Sulfates are minerals whose structural unit is (SO_4^{-2}) groups, cations of Al, Na, Ca, K, Mg, Fe, and others can be bonded to sulfates. Among them are anhydrite and gypsum, which are quite common in the earth's crust [13].

Table 3. Absorbance and concentration data for sulfate

Absorbance	Concentration
280,904	0,481
281,455	0,486
284,789	0,487

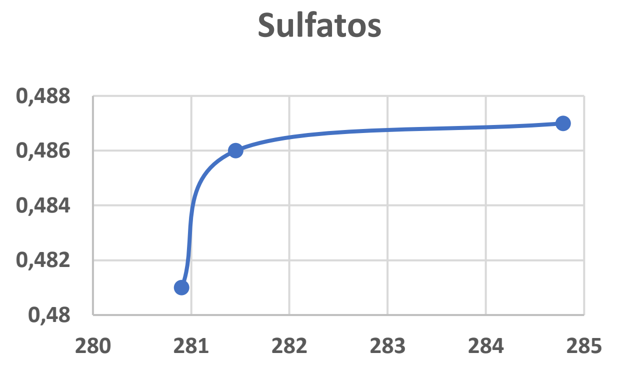

Fig. 4. Sulfate ion calibration curve.

The linearity obtained experimentally in the calibration curve for the sulfate ion shows a correlation coefficient r2=0.991 (Fig. 3). The curve was prepared with five concentration levels and a blank in the concentration range 48,000-312,000 ppm.

Chlorides: With an average concentration of about 19.4 g/L, chloride is the most present inorganic anion in seawater. It plays a fundamental role in seawater chemistry with great impact on marine life. The chloride cycle in the Pacific Ocean is a complex process involving a series of interactions [14].

Its analysis and concentration determination can be performed by several methods; in the present work, Mohr's method was used, which involves the quantitative determination of chloride, bromide or cyanide ions by titration with a standard solution of silver nitrate using Na_2CrO_4 or K as endpoint chemical indicator [15].

5 ml was taken and diluted in 95 ml of distilled water; from this dilution, 10 ml was used, 3 drops of K_2CrO_4 was added as end point indicator because AgCl is less soluble than Ag_2CrO_4 since the latter cannot be formed until Cl is fully reacted. There are three ways to determine the end point of the reaction: when a precipitate is produced, color change and disappearance of turbidity.

When the color change occurred, the titrant $AgNO_3$ made a consumption of 20 ml, then the chloride calculation was performed:

$$Cl^{-1} = \frac{C * N * mEq * 100}{Vm} \qquad (2)$$

$$Cl^{-1} = \frac{20 * 0,0141 * 0,0355 * 100}{0.05} = 20,02g\ Cl^{-1}$$

100 ml M ------------ 2,002 g Cl^{-1}
1000 ml M ----------- x = 20,02 g Cl^{-1}

Interpretation:
For every 100 ml of sample there was 2.002g Cl-1.

Sodium chloride (NaCl) extraction: Water is a liquid, odorless, colorless and tasteless; it has a bluish tint and can only be detected in very deep layers. At atmospheric pressure, the freezing point of water is 0°C and the boiling point is 100°C. Water reaches its maximum density at 4°C and expands as it freezes, thus reducing its density, the same happens when the temperature increases from 4°C [16].

The evaporation of the water that was applied in the NaCl extraction process was that of the boiling point, in which 12 L of sea water was evaporated (fig.4); in the course of hours; forming a first crystallization.

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Fig. 5. Evaporation process.

Subsequently, NaCl was dissolved in distilled water to separate the insoluble solids that precipitated during the evaporation process; a vacuum filtration process was applied to this solution.

Vacuum filtration: is an instrumental technique used in laboratories to separate solids from liquids or solutions. This type of filtration is used when solids are of interest or when gravity filtration is very slow; it is also an essential technique in recrystallization processes [17].

Recrystallization: is a common purification technique for NaCl, where an impure NaCl solution is dissolved in a suitable solvent, allowed to evaporate slowly to increase the NaCl concentration and then induce the precipitation of pure crystals. The study of Li et al. (2023) proposes a new NaCl recrystallization process by controlled evaporation which consists of optimized control system and optimized vessel design [18]. It was performed by simple distillation (Fig. 5); this is the most widely used procedure for the separation and purification of liquids, and it is the one that is always performed aiming to separate a liquid from its impurities [19].

Fig. 6. Simple distillation process.

When the first recrystallization was obtained, we proceeded to perform the analysis of chlorides to determine the percentage of purity of the sample obtained; here we dissolved 0.5 g of sample with humidity in 95 ml of distilled water, obtaining the following calculation:

$$\%NaCl = \frac{V * N * mEq * 100}{Pm} \quad (3)$$

$$\%NaCl = \frac{51 * 0{,}0142 * 0{,}0585 * 1000}{0{,}5} = 8{,}4734$$

100 ml ----------- 8,413g NaCl
1000 ml -----------x = 84,13g NaCl

Obtaining a purity of 84.13% of NaCl.

Ion exchange: According to Degremont (1979), ion exchange is a reversible chemical reaction that takes place when an ion in a solution is exchanged for another ion of the same sign that is reattached to an immobile solid particle. Ion exchangers are a process that consists of taking advantage of the ability of resins to exchange ions between a solid phase and a liquid phase in a reversible way, that is to say that it returns to its original state and without permanent change in the structure of the solid. Generally, the great usefulness of ion exchange lies in the fact that ion exchange materials can be used over and over again since the exchanger material can be regenerated as the change it undergoes in the 'operation phase' is not permanent.

Strong acid cationic resin: Although abundant, seawater is not suitable for human consumption or for numerous industrial uses due to its high concentration of dissolved salts, including Ca and Mg ions, which cause it to have hardness. Ion exchange with cationic resin has become an effective method to remove these ions, softening seawater and making it useful for a variety of applications. Seawater contains Ca and Mg, salt-forming salts and increasing the hardness of the water; for this, the cationic resin of strong acid was used with its abbreviation SAC which is used in the form of sodium (Na), which performs an ion exchange allowing the hardness of the water produced by Ca and G and when saturated with hardness allows its regeneration with NaCl.

The reaction is as follows:

$$2R_1\text{-}Na + Ca^{2+} \longleftrightarrow R_2\text{-}Ca + 2Na^{+}$$

$$2R_1\text{-}Na + Mg^{2+} \longleftrightarrow R_2\text{-}Mg + 2Na^{+}$$

Producing a balance.

The hardness of the water decreased from 39.6 ml of EDTA consumption as a very high hardness; subsequently after the reaction with the resin the consumption was 2.1 ml of

EDTA, presenting high results in the removal of the hardness of our sample:
Hardness without resin:

$$Hardness = \frac{C * M * pM * 1000}{Vm} \quad (4)$$

$$hardness\ CaCO_3 = \frac{1,9 * 0,01M * 100 * 1000}{10} = 190 \frac{mg}{L}$$

$$hardness\ MgCO_3 = \frac{37,7 * 0,01M * 84 * 1000}{10} = 3166,8 \frac{mg}{L}$$

At 2.1 ml of 0.01 M EDTA consumption, where the decrease in hardness of the sample water can be seen.

Hardness with resin:

$$Hardness\ CaCO_3 = \frac{0,10 * 0,01M * 100 * 1000}{10} = 10 \frac{mg}{L} \quad (5)$$

$$Hardness\ MgCO_3 = \frac{2 * 0,01M * 84 * 1000}{10} = 168 \frac{mg}{L}$$

Total hardness: 178 mg/L - Calcium hardness: 10 mg/L= 168 mg/L of Mg.
MgCO3=168 mg/L.
The hardness present in the sample is almost null.

For the analysis of chloride in the sample obtained, the following calculation is analyzed:

$$Cl^{-1} = \frac{C * N * mEq * 100}{Vm} \quad (6)$$

$$Cl^{-1} = \frac{24,3 * 0,0141 * 0,0355 * 100}{0,5} = 2,432673g\ Cl^{-1}$$

100 ml M ------------- 2,432673 g Cl^{-1}
1000 ml M ------------ x=24,32673 g Cl^{-1}

Avogadro's law states that "equal volumes react in the same way as long as their concentration is equal".

Calculation for sodium chloride (NaCl):

$$V * N * mEq = g \quad (7)$$

$$100 * 0,0142 * 0,0585 = 0,0830$$

$$25 * 0,0142 * 0,0585 = 0,02076$$

Reactions with silver nitrate for the determination of the purity of NaCl by titration of the sample obtained.

$NaCl+AgNO_3=AgCl+NaNO_3$

$$\%NaCl = \frac{V * N * mEq * 100}{Pm} \quad (8)$$

Consumption: 24,3 ml de $AgNO_3$

$$\%Purity\ NaCl = \frac{24,3 * 0,0142 * 0,0585 * 100}{0,02076} = 97,23\%\ de\ Pureza\ de\ NaCl$$

3. Results.

Table 4. Final physical-chemical analysis of NaCl obtained from the seawater sample.

Components	Results	Units
Alkalinity	60	mg/L
Chlorides	24326,73	mg/L
Conductivity	1558	us/cm
Hardness	50	mg/L
Salinity	0,14	%
Total Solids	779	ppm
pH	6,22	
Temperature	27.5	ºC

The presence of CaCO3, CaSO4, NaCl, MgSO4, KCl, MgCl2 and MgBr2; indicates that the water sample is mineralized, i.e., it contains a significant amount of dissolved salts. The initial purity of NaCl in the sample was 84.7314%, which means that there was a considerable amount of impurities present. The sample was observed to have a high hardness, possibly due to the presence of calcium and magnesium ions. These ions can have negative effects in various industrial and domestic processes. Ion exchange with a strong cation resin was effective in removing calcium and magnesium ions, which increased the purity of the NaCl. Vacuum filtration and recrystallization were performed to obtain purer crystals.

0.0824 g of the NaCl crystals were dissolved in 100 ml of distilled water and the NaCl concentration was calculated, obtaining a value of 97.23%. The final purity of NaCl, 97.23%, is significantly higher than the initial purity, demonstrating the effectiveness of the purification process.

The different analyses and techniques used were carried out with the purpose of obtaining the highest degree of purity of NaCl; and to be able to use it in the laboratories allowing to develop and improve the techniques used for the purification of reagent grade NaCl decreasing the excessive use of chemicals that can affect the composition of NaCl. Sulfate results were 0.0 in the final NaCl sample. The market is also driven by the extensive use of NaCl as a raw material in the chemical industry to produce various chemicals, including chlorine, sodium hydroxide and

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sodium carbonates. These chemicals have a wide range of applications, which is further driving the demand for salt.

3.1. Comparison of initial and final analyses.

Table 5. Initial Analysis

Components	Units
Alkalinity	96 mg/L
Chlorides	20020 mg/L
Conductivity	64000 us/cm
Hardness	4764 mg/L
Salinity	0,14%
Total Solids	1380 ppm
pH	6,27
Temperature	27,5 °C

Table 6. Final Analysis.

Components	Units
Alkalinity	60 mg/L
Chlorides	24326,73 mg/L
Conductivity	1558 us/cm
Hardness	50 mg/L
Salinity	0,14%
Total Solids	779 ppm
pH	6,22
Temperature	27,5 °C

4. Discussion.

The salt market has few formally constituted Ecuadorian companies that share the local market for the supply of all the industrial and human consumption salts required at the national level, as we can see below:

Table 7. Distribution of the salt market.

Companies	Products	Annual Production Tons	Participation %	Average Dollar Price
Ecuasal C.A.	Cris-Sal	150.000	76%	18.000.000.00
Famosal S.A.	Sea And Salt	12.000	6%	1.440.000.00
Jueza S.A.	Pacific Salt	15.000	8%	1.800.000.00
Proquipil S.A.	Delisa	20.000	10%	2.400.000.00
Total, Sales And Production In Ecuador		197.000	100%	23.640.000.00

Source: Superintendencias De Compañías. Year 2013 Prepared by: Tammy Rodríguez Balseca.

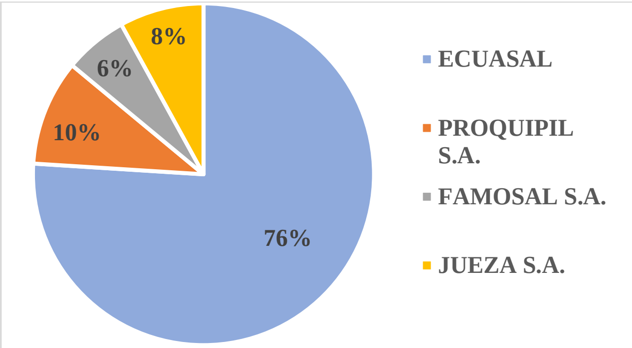

Fig. 6. Annual Production Tons.
Source: Superintendencia De Compañía. Year 2013 Prepared by: Tammy Rodríguez Balseca.

Artisanal salt production has become a neglected trade because traditional salt producers are unable to compete with the large production industries established in the market. Faced with such problems, the association of salt producers of Manta, Ecuador has developed a proposal for a refined salt production process that will contribute to the achievement of this objective. A technical and operational study is provided which is structured in the following components: product characterization, flow chart of the salt production process, geographic and micro location, and study of salt production capacities. The aim is for the association of salt producers to establish a business model to enter the local and national market [22].

NaCl is an important raw material in the chemical industry, since it has several uses. In the laboratory involved in the study, NaCl is used as raw material to manufacture parenteral solutions, such as: 0.9% NaCl injection and injection of 5% dextrose with 0.9% NaCl (mixed solution). These solutions are of great importance in the health field, they are used in rehydration therapies in cases of acute diarrhea and cholera, also for trauma, burns, when patients have a deficit of body Na+ and control the distribution of water in the organism.

According to the study conducted by Wang et al. (2020), a novel method for purification of reagent grade NaCl is by a combination of simple distillation and ion exchange membranes. This technique combines the advantages of these methods to effectively remove impurities such as organic compounds, heavy metals and inorganic salts [23].

It can be stated that the standards for reagent grade NaCl have a percentage of 99% to 100.5% purity both for pharmacopoeia and those that require even higher percentages such as ISO, however, there are standards that indicate that reagent grade NaCl can have a minimum of 95% purity, these are usually specific especially in local standards of certain countries which can accept this minimum level of purity such as the Mexican Official Standard (NOM) and the Ecuadorian Technical Standard (NTE) INEN 1204.

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A comparison of NaCl purity standards established by the USP, the Codex Alimentarius and INEN 1234 showed some significant differences:

The USP indicates that its standards are the most demanding, especially when it comes to the degree of purity, since these grades are used in applications where high purity and reliability are required, such as in the manufacture of drugs, the minimum purity grade allowed by the Pharmacopeia is 99.0% [24].

The Codex Alimentarius standards are focused on food safety and establish a purity level that guarantees that the NaCl used in food does not compromise the health of the consumer; the accepted purity grade is 97.0% as a minimum [25].

INEN 1234, which is a national standard, establishes specific requirements for industrial grade NaCl, which is used in a wide variety of applications. The required purity level is lower compared to pharmaceutical and food standards in this case it allows 95% purity as a minimum [26].

5. Conclusions.

The initial characterization that was carried out allowed obtaining the values of the different components present in the sample to be analyzed and to start the present research, with this it was demonstrated that it is possible to obtain reactive grade NaCl using different techniques and analysis where the use of reagents is not excessively applied, since they change the composition of the different components found in the sample.

It was possible to obtain reagent grade NaCl from seawater from Crucita-Manabí, Ecuador, with a purity of 97.23%, although it did not exceed USP international standards (99% - 100.5%), it was demonstrated that it does exceed local standards, which allows its application. The key finding of this research shows that the seawater from Crucita-Manabí has a chemical composition suitable for NaCl extraction.

The purification technique used, which combines evaporation, recrystallization and ion exchange, was effective in eliminating the impurities present in the seawater and obtaining high purity NaCl, which determined that the ion exchange stage with cation resin was crucial for eliminating calcium and magnesium ions, The final physical-chemical analysis of the NaCl obtained confirmed that it meets purity standards, which makes it suitable for use in laboratories and industries that demand a high degree of purity.

The contributions of the present study demonstrate the feasibility of obtaining reagent grade NaCl from Ecuadorian seawater, which represents a significant contribution to the local industry, since this study can now be replicated to obtain high purity NaCl from other seawater sources, with potential application in various industries. The results obtained provide valuable information on the chemical composition of Crucita-Manabí seawater and its potential for NaCl extraction, which can contribute to the development of new industrial initiatives in the region. The relevance for local industry consists of the great impact of being able to obtain reactive grade NaCl from Ecuadorian seawater, since it reduces dependence on imports of this product, which translates into foreign exchange savings for the country. Promote the development of new industries and even existing industries that require high purity NaCl, such as the pharmaceutical, cosmetic and chemical industries, generating new employment opportunities in the industrial and scientific sector.

The regulations based on the present research are high quality international regulations; however, there are local regulations in different countries where a minimum percentage of 95.0% of reagent grade NaCl is allowed, which shows that the 97.23% of NaCl obtained in the present work can be useful as a reagent use.

In short, this study opens new possibilities for the use of seawater as raw material to obtain reactive grade NaCl, contributing to the industrial and scientific development of Ecuador.

6.- Author Contributions.

1. Conceptualization: Antonella Ferrin; Ramón Cevallos
2. Data Curation: Thalía Caicedo; Ariana García
3. Formal analysis: Segundo García; Ariana García
4. Acquisition of funds: N/A.
5. Research: Thalía Caicedo; Ramón Cevallos
6. Methodology: Segundo García; Thalía Caicedo
7. Project administration: Antonella Ferrin
8. Resources: N/A.
9. Software: N/A.
10. Supervision: Antonella Ferrin; Ramon Cevallos
11. Validation: Antonella Ferrin; Ariana García
12. Visualization: Thalía Caicedo; Ariana García

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Evaluation and Proposal for an Environmental Management System in a Mango Plantation

Evaluación y Propuesta de un Sistema de Gestión Ambiental en una Plantación de Mango

José Estiven Pincay Moran [1] ; Jordán Francisco Ramírez Salcan [2] ; Armando Fabrizzio López Vargas [3] ; Francisco Javier Duque-Aldaz [4] * ; William Villamagua Castillo [5] ; Ricardo Sánchez Casanova [6]

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* Author for correspondence.

Abstract.
A mango farm in Los Ríos province, Ecuador, lacked an Environmental Management System (EMS) and had rudimentary management of fertilizers, pesticides and waste. The objective of the research was to design an EMS based on ISO 14001:2015 for the farm in order to improve its environmental performance and facilitate compliance with environmental regulations. For the development of the research, surveys were applied to workers to assess their knowledge of environmental management and a tour of the hacienda's facilities was conducted to observe its processes. The results were analyzed and an EMS based on ISO 14001:2015 was proposed. As a result, it was found that most of the workers had no knowledge of environmental management. The farm did not have an EMS in place and faced challenges in water management and waste management. The proposal to implement an EMS based on ISO 14001:2015 would allow the farm to improve its environmental performance and meet its certification objectives in the medium term. Therefore, it can be concluded that the proposal to implement an EMS based on ISO 14001:2015 would allow the farm to improve its environmental performance and meet its certification objectives in the medium term.

Keywords.
Environmental Management System (EMS), ISO 14001:2015 Standard, Mango farm, Sustainable agriculture, Good agricultural practices, Corporate Social Responsibility.

Resumen.
Una hacienda productora de mangos en la provincia de Los Ríos, Ecuador, carecía de un Sistema de Gestión Ambiental (SGA) y presentaba un manejo rudimentario de fertilizantes, pesticidas y residuos. La investigación tuvo como objetivo el diseñar un SGA basado en la norma ISO 14001:2015 para la hacienda, con el fin de mejorar su desempeño ambiental y facilitar el cumplimiento de las regulaciones ambientales. Para el desarrollo de la investigación se aplicaron encuestas a los trabajadores para evaluar su conocimiento sobre gestión ambiental y se realizó un recorrido por las instalaciones de la hacienda para observar sus procesos. Se analizaron los resultados y se propuso un SGA basado en la norma ISO 14001:2015. Como resultado se obtuvo que la mayoría de los trabajadores no poseían conocimientos sobre gestión ambiental. La hacienda no contaba con un SGA implementado y enfrentaba desafíos en la gestión del agua y en el manejo de residuos. La propuesta de implementar un SGA basado en la norma ISO 14001:2015 permitiría a la hacienda mejorar su desempeño ambiental y cumplir con sus objetivos de certificación a mediano plazo. Por lo que se puede concluir que la propuesta de implementar un SGA basado en la norma ISO 14001:2015 permitiría a la hacienda mejorar su desempeño ambiental y cumplir con sus objetivos de certificación a mediano plazo.

Palabras clave.
Sistema de Gestión Ambiental (SGA), Norma ISO 14001:2015, Hacienda productora de mangos, Agricultura sostenible, Buenas prácticas agrícolas, Responsabilidad social empresarial.

1.- Introduction

In the current context, environmental management has become increasingly important for many companies, due to the benefits it brings both economically and in the conservation of natural resources. Environmental management systems (EMS) provide a structured framework for companies to identify, evaluate and control the environmental impacts of their activities, facilitating a more sustainable operation and compliance with environmental regulations.

This study focuses on a mango farm located in the province of Los Ríos, canton Palenque, Ecuador, which faces significant environmental challenges. The farm, which covers 16.13 hectares (of which 15.82 hectares are dedicated to mango cultivation), does not have a formal environmental management system, which has led to inadequate waste management and problems related to fertilizer use and noise pollution. Currently, waste accumulates without classification, which complicates its management and can generate pollution problems [1].

[1] Investigado Independiente ; josepincay14@gmail.com ; Guayaquil, Ecuador.
[2] Investigado Independiente ; jordanramirez761@gmail.com; Guayaquil, Ecuador.
[3] Universidad Politécnica Salesiana, alopez@ups.edu.ec ; https://orcid.org/0000-0001-6520-8011 ; Guayaquil, Ecuador.
[4] Universidad de Guayaquil ; francisco.duquea@ug.edu.ec ; https://orcid.org/0000-0001-9533-1635 ; Guayaquil, Ecuador.
[5] Universidad de Guayaquil ; william.villamaguaca@ug.edu.ec ; https://orcid.org/0000-0002-1163-9606 ; Guayaquil, Ecuador.
[6] Universidad de La Habana; Profesor e investigador en el Centro de Estudios para el Perfeccionamiento de la Educación Superior (CEPES); ricardo.sanchez@matcom.uh.cu ; https://orcid.org/0000-0001-5354-6873 ; La Habana, Cuba.

In the absence of an EMS, farm management has difficulty making informed decisions and effectively addressing environmental risks. In addition, the lack of knowledge of the ISO 14001:2015 standard, both on the part of the manager and staff. The environmental management system, however, limits the farm's ability to implement effective environmental controls and mitigation measures. These challenges highlight the need to develop an appropriate environmental management system that will enable the farm to improve its environmental performance, comply with regulations and lay the groundwork for environmental certification in the medium term.

The objective of this study is to design an Environmental Management System (EMS) based on ISO 14001:2015 for the mango farm in the Palenque canton. The purpose of this EMS is to improve the environmental performance of the farm, promote sustainable practices among its workers, and facilitate compliance with current environmental regulations.

The implementation of an EMS at this farm will not only help mitigate the environmental impacts of its agricultural activities, but will also optimize the use of resources such as water and energy, reducing costs and improving its competitiveness in the market. This approach is in line with the current demands of consumers and regulators who favor products from companies with environmentally responsible practices.

1.1 The importance of environmental management on mango farms.

Environmental management is fundamental in the agricultural industry, especially on mango farms, as it allows the identification, evaluation and control of the environmental impacts generated by their production activities. The implementation of an Environmental Management System (EMS) facilitates the adoption of sustainable practices and the efficient use of resources, helping companies to reduce their negative effects on the environment and comply with current regulations. In a context where sustainability and social responsibility are increasingly valued, environmental management becomes a key component for the competitiveness and longevity of farms, particularly those facing the challenges of intensive agriculture [2].

The environmental risks on these farms are multiple and are largely related to the intensive use of fertilizers and pesticides, which can lead to contamination of water sources and soil degradation. In addition, practices such as agricultural expansion without adequate planning can contribute to soil erosion and deforestation, threatening the biodiversity of rural areas. These factors not only affect crop productivity, but also impose environmental risks to surrounding communities and ecosystems. Thus, a well-structured EMS not only has the potential to mitigate these impacts, but also favors a more sustainable agriculture that respects the natural environment [3].

Likewise, adopting an environmental management approach to mango production brings economic benefits by optimizing the use of inputs such as water and energy, which reduces operating costs and improves long-term profitability. In addition, an EMS can improve the company's image, since today's consumers prefer products from environmentally responsible companies, which helps attract new customers and consolidate the loyalty of current ones. In this sense, environmental management not only responds to a regulatory obligation, but also to a market demand that values sustainability as a differentiating attribute [4].

The implementation of a well-structured EMS enables farms not only to meet their environmental responsibilities, but also to generate a positive impact on their environment and establish a sustainable production model. Aligning operations with environmental standards, such as ISO 14001:2015, encourages the adoption of good agricultural practices that protect natural resources and contribute to the sustainable development of the mango industry in the region.

1.1.1. Benefits of environmental management on mango farms.

The implementation of an Environmental Management System (EMS) in mango farms brings multiple benefits that go beyond regulatory compliance, optimizing internal processes and contributing to environmental well-being. One of the main benefits is the reduction of operating costs. By improving efficiency in the use of critical resources such as water and energy, farms can reduce significant expenses in these areas. For example, by employing efficient irrigation systems, water consumption is optimized, resulting in lower costs and improved crop sustainability [5].

In addition, the adoption of an EMS can improve the company's public image. In a context where consumers are increasingly informed and concerned about the environmental impact of the products they purchase, companies that demonstrate environmental responsibility are often preferred. This represents a competitive advantage in the marketplace, allowing mango farms to attract and retain customers who value environmental commitment and sustainable practices.

An EMS also facilitates compliance with environmental regulations, both nationally and internationally, which is essential to avoid penalties and ensure business continuity. In many countries, environmental regulations for the agricultural sector are becoming increasingly stringent, and an EMS provides a structure that enables companies to remain in compliance with these requirements on an ongoing basis. This compliance not only reduces the risk of sanctions, but also reinforces the farm's reputation as a reliable and ethical operator.

These benefits reflect how environmental management can transform the production approach of mango farms, promoting practices that not only reduce their ecological impact, but also strengthen their market position and improve their economic performance. A well-implemented EMS enables farms to respond to both regulatory demands and consumer expectations, strengthening their competitiveness and long-term sustainability.

1.1.2. Environmental impacts of agricultural activities in mango farms

Intensive agricultural activities on mango farms can generate significant environmental impacts if not properly managed. One of the main problems is water pollution, caused mainly by the excessive use of agrochemicals such as fertilizers and pesticides. These products, when applied in an uncontrolled manner, can leach into nearby bodies of water, affecting both surface sources and subway aquifers. This water pollution represents a risk to aquatic ecosystems and to the communities that depend on these resources for their basic needs [6].

In addition to water pollution, the improper application of fertilizers and pesticides can lead to soil degradation, reducing its fertility and impacting the long-term productivity of crops. The accumulation of chemicals in the soil alters its natural properties, making it less suitable for agriculture and limiting its ability to support plant and microbial life. This phenomenon also contributes to soil erosion, as degraded soil is more susceptible to nutrient loss and erosion caused by wind and water.

Another significant impact is deforestation and biodiversity loss, which often occur when agricultural areas expand without proper management. Agricultural expansion can fragment essential natural habitats, leading to the extinction of native species and disrupting the balance of local ecosystems. Furthermore, deforestation for intensive agriculture contributes to climate change by increasing greenhouse gas emissions due to the loss of vegetation that normally acts as a carbon sink.

These environmental impacts are particularly concerning in the context of sustainable agriculture, where the goal is to minimize disruptions to the natural environment. The implementation of a well-designed and managed Environmental Management System (EMS) can help mango-producing farms mitigate these negative effects by promoting responsible agricultural practices that contribute to the protection of water, soil, and biodiversity. With an appropriate environmental management approach, it is possible to reduce the ecological footprint of agricultural production while ensuring the sustainability and resilience of mango cultivation in the face of current environmental challenges [7] [8].

1.2 Benefits of implementing an Environmental Management System (EMS) based on the ISO 14001:2015 standard.

The implementation of an Environmental Management System (EMS) in accordance with the ISO 14001:2015 standard provides significant benefits to mango-producing farms, both in terms of environmental sustainability and operational efficiency. The ISO 14001:2015 standard offers a systematic framework that enables organizations to identify, manage, and mitigate the environmental risks associated with their activities, while promoting continuous improvement and compliance with applicable environmental regulations. In the context of a mango farm, a well-implemented EMS facilitates the reduction of operational costs through efficient resource use, waste recycling, and process optimization [9] [10].

One of the key benefits of an EMS based on the ISO 14001:2015 standard is cost reduction, as efficiency in water and energy consumption significantly lowers operating expenses. For instance, by implementing energy-saving practices and efficient irrigation techniques, the farm can optimize its resources and reduce costs for essential inputs. Additionally, waste recycling and proper waste disposal help decrease management costs while simultaneously preventing pollution and resource waste [11].

Another important benefit is the improvement of the farm's public image, as consumers and business partners increasingly value sustainably sourced products and environmentally responsible business practices. An EMS based on the ISO 14001:2015 standard strengthens the farm's competitiveness in the market by highlighting its commitment to environmental stewardship and aligning with the expectations of environmentally conscious consumers. This positive image not only attracts new customers but also enhances the loyalty of existing ones, demonstrating that the company upholds high sustainability standards.

Compliance with environmental regulations is another fundamental benefit provided by an ISO 14001:2015 EMS, as it ensures that the farm's operations comply with both local and international environmental laws. This helps avoid penalties and legal issues arising from non-compliance, providing the farm with operational stability and a reputation as a responsible organization.

The ability to comply with regulations also facilitates the acquisition of environmental certifications, which can open doors to markets that require high sustainability standards [12].

Additionally, the ISO 14001:2015 standard promotes operational efficiency by helping farms identify and manage environmental risks, set clear objectives, and conduct periodic audits to assess progress and ensure continuous improvement. This structured approach not only enhances environmental performance but also increases employee engagement and satisfaction, as they can actively contribute to an important cause. Job satisfaction is enhanced when staff members are part of a sustainability effort that benefits both the environment and the community [13].

1.3. Practices and Technologies to Improve Water Management in Mango-Producing Farms

Efficient water management is one of the most significant challenges for mango-producing farms, especially in regions experiencing significant climate variability or where water availability is limited. The responsible and sustainable use of this resource is essential to ensure the continuity of agricultural activities and environmental protection. Implementing innovative technologies and practices allows farms to optimize water use, reduce consumption, and mitigate the negative effects of water scarcity [14] [15].

One key practice is the use of efficient irrigation systems, such as drip irrigation and sprinkler irrigation. These systems deliver water directly to the plant roots, minimizing evaporation and runoff, thereby enabling more effective resource use. Drip irrigation, in particular, is highly efficient in water delivery and can be controlled based on the specific needs of the plant, reducing waste and improving crop productivity. Installing efficient irrigation systems is an investment justified by savings in water consumption and improvements in crop quality.

Furthermore, rainwater harvesting is an effective strategy for farms, especially in areas where the rainy season is limited. By collecting rainwater, farms can accumulate reserves that can be used during dry periods. To implement this practice, farms can install gutter systems and storage tanks that capture water directly from rooftops or catchment areas, allowing for its subsequent use in irrigation activities. Green roofs, which also facilitate rainwater harvesting, provide the additional benefit of improving air quality and reducing the temperature within the facilities [16].

Another relevant practice is the reuse of greywater, which involves treating water from domestic or agricultural activities for use in irrigation. By using filtration and disinfection systems, farms can safely utilize this water and reduce the demand for potable water. This technique, in addition to being a sustainable alternative, helps conserve water resources and minimize environmental impact.

Proper management of fertilizers and pesticides is also essential for protecting nearby water sources. The controlled and efficient application of these inputs reduces the risk of water contamination, which is crucial for preserving biodiversity and the health of local ecosystems. Planning fertilizer and pesticide applications based on the actual needs of the crop and prevailing climatic conditions can minimize runoff into nearby water bodies and prevent soil degradation [17].

These practices, combined with the implementation of appropriate technologies, enable mango-producing farms to manage water efficiently, minimize environmental impact, and promote sustainable production. The adoption of these strategies not only contributes to the conservation of water resources but also enhances the farm's resilience to water scarcity, thus ensuring the long-term sustainability and competitiveness of mango cultivation [18].

1.4. Environmental Impacts of Agricultural Activities on Mango-Producing Farms

Intensive agricultural activities, such as those carried out on mango-producing farms, can have significant environmental impacts if not properly managed. Among the most important effects are water and soil pollution due to the excessive use of agrochemicals. Fertilizers and pesticides applied indiscriminately can leach into both surface and groundwater sources, altering their composition and negatively affecting aquatic ecosystems. This contamination poses risks not only to local biodiversity but also to the health of communities that rely on these water sources for drinking and irrigation.

Soil degradation is another critical environmental impact associated with intensive agriculture. The excessive use of chemicals and the lack of soil conservation techniques can lead to a decline in soil fertility, reducing its productivity over time. Moreover, degraded soils are more susceptible to erosion, which can result in the loss of fertile layers and, consequently, a diminished capacity of the land to sustain plant life. This degradation affects both the sustainability of the crop and the ecological structure of the area by eliminating habitats and reducing biodiversity.

Another relevant impact is deforestation and biodiversity loss, which often accompany the expansion of cultivated areas. The expansion of agricultural land to meet the growing demand for agricultural products frequently leads to the removal of native vegetation and the fragmentation of natural habitats, thereby compromising the survival of local species. The reduction of forest cover also contributes to climate change, as trees play a crucial role in carbon sequestration. The loss of these vegetative areas results in increased greenhouse gas emissions, thereby accelerating global warming [19].

Climate change, in itself, is an environmental impact stemming from conventional agricultural practices that generate significant emissions of greenhouse gases. From the use of agricultural machinery to the emissions from fertilizers, intensive agricultural activities contribute to the accumulation of gases in the atmosphere. This exacerbates climate variations, negatively affecting crop productivity and food security.

To address these impacts, mango-producing farms can implement an Environmental Management System (EMS) that integrates sustainable practices, such as the controlled use of agrochemicals, reforestation, and the conservation of water and soil resources. By doing so, it is possible to mitigate the negative effects of agriculture on the environment, promoting a more sustainable production model that does not compromise biodiversity or the availability of natural resources for future generations. The adoption of a responsible environmental management approach enables farms to operate in a more ethical and resilient manner, contributing to the preservation of the natural environment and reinforcing their commitment to sustainability [20] [21].

2. Materials and Methods

This research adopted a mixed-methods approach, integrating descriptive and analytical methods to thoroughly assess the state of environmental management on a mango-producing farm. The methodological design was structured into five interrelated phases, which allowed for a holistic view of the study subject:

2.1. Documentary Review

A systematic review of specialized literature was conducted, including:

- Indexed academic publications on Environmental Management Systems (EMS)
- Technical documentation of the ISO 14001:2015 standard
- Manuals and guidelines for best agricultural practices
- Applicable environmental legislation relevant to the sector

This phase established the necessary theoretical-conceptual framework for the development of the proposed EMS.

2.2. Primary Data Collection

Semi-structured Surveys

Data collection instruments were implemented targeting two primary groups:

- Administrative personnel: Focused on environmental management policies and strategies
- Operational personnel: Focused on daily practices and field procedures

The instruments assessed:

- Level of knowledge regarding environmental management
- Waste management practices
- Agricultural input usage protocols
- Perceptions of environmental impacts

Direct Observation

A systematic data collection process was conducted through:

- Detailed inspection of facilities
- On-site verification of operational procedures
- Identification of critical points in resource management [22].

2.3. Data Analysis and Interpretation

The collected data was processed using:

- Descriptive statistical analysis of quantitative data
- Content analysis for qualitative data
- Source triangulation to validate findings
- Identification of significant patterns and trends

This process enabled:

- Diagnosis of the current state of environmental management
- Identification of strengths and areas for improvement
- Establishment of intervention priorities
- Validation of the feasibility of the proposals

2.4. Development of the Proposal

Based on the comprehensive analysis of the data, a proposal for an Environmental Management System (EMS) aligned with ISO 14001:2015 was designed, which includes:

- Customized environmental policy
- Measurable strategic objectives
- Specific action programs
- Environmental performance indicators
- Monitoring and control procedures
- Phase-based implementation plan

The applied methodology ensured a comprehensive diagnosis of the current situation and facilitated the design of a proposal tailored to the specific needs of the organization.

3.- Analysis and Interpretation of Results

This section presents the main findings and results obtained from the surveys conducted with the workers of the mango-producing farm, aiming to diagnose the knowledge and perceptions of the staff regarding environmental management issues. The contributions of the personnel constitute a valuable source of primary data for identifying strengths and areas for improvement related to waste management, production practices, and input management.

Below, the quantitative and qualitative results derived from the responses provided by the consulted staff are detailed, allowing for the establishment of baseline data on their environmental awareness and the required capabilities.

3.1. Analysis of the Survey Conducted with the Farm Workers

Table 1. How much do you know about what an EMS ("Environmental Management System") is?

Responses	Number of people	Percentage
Nothing	15	75%
Little	5	25%
Quite	0	0
TOTAL	20	100%

Table 1 shows that 75% of employees have no knowledge of what an Environmental Management System (EMS) is, while only 25% possess basic understanding. This result reveals a significant lack of training on environmental topics, highlighting the need to implement a structured training program that covers the principles of environmental management. This training should be ongoing and tailored to the farm's context to ensure that all staff acquire the necessary knowledge for the proper implementation of an EMS.

Table 2. Have you received training on environmental topics?

Responses	Number of people	Percentage
YES	13	65%
NO	7	35%
TOTAL	20	100%

Table 2 indicates that **65% of employees** have received some form of environmental training, while **35%** have not been trained in these topics. Although the farm has made some efforts, it is clear that the scope and content of the training programs need to be expanded. It is essential to develop a comprehensive training plan that not only covers basic aspects but also addresses advanced topics such as waste management, energy conservation, and the ISO 14001:2015 standard. This program should include in-person workshops, seminars, and online training options to effectively reach all employees.

Table 3. What environmental training topics have you received?

Responses	Number of people	Percentage
Environmental laws	1	5%
ISO 14001:2015 Standards	0	0%
Waste handling	1	5%
None	12	60%
Others	6	30%
Total	20	100%

Regarding the topics covered in the training, Table 3 shows that most employees have received training in waste handling (60%), but critical topics such as ISO 14001:2015 standards (0%) and energy conservation have not been addressed. This gap indicates that the training has been partial and does not cover key areas of environmental management. To improve, it is necessary to include topics that promote the efficient use of resources and compliance with international standards, which will not only benefit the environment but also reduce operational costs.

Table 4. Are you aware if the estate cares about protecting and preserving the environment by developing and implementing an Environmental Management System?

Responses	Number of people	Percentage
YES	0	0%
NO	19	95%
Unaware	1	5%
TOTAL	20	100%

According to Table 4, 95% of employees are unaware if the estate has implemented an Environmental Management System (EMS), highlighting a lack of internal communication. This suggests that, although the estate may have some environmental initiatives, employees are neither involved in nor informed about these actions. To address this, the estate should establish more effective communication channels, such as publishing environmental reports, internal newsletters, and creating an environmental committee with employees from all levels.

Table 5. Based on the previous question, if you answered YES, please specify how it is carried out. If you answered NO, please indicate "none."

Responses	Number of people	Percentage
Recycles	0	0%
Saves energy	0	0%
There is separation according to the type of waste ("organic or inorganic")	0	0%
Follows the principle of paper conservation	0	0%
None	20	100%
Total	20	100%

In Table 5, the results show that none of the employees were able to identify specific environmental practices such as recycling or energy conservation. This confirms the absence of structured environmental management measures at the estate. It is essential to establish clear procedures for waste classification and energy use optimization. Additionally, the implementation of collection points is recommended to facilitate proper waste disposal.

Table 6. Does the estate have environmental regulations and measures?

Responses	Number of people	Percentage
YES	0	0%
NO	11	55%
Unaware	9	45%
TOTAL	20	100%

Table 6 reveals that 55% of employees believe the estate does not have environmental regulations, while 45% are unaware if such regulations exist. This high level of ignorance reflects a lack of transparency in communicating the company's environmental policies. It is crucial for the estate to implement clear policies and communicate them effectively to all staff. This can be achieved through informational sessions and the publication of easily accessible internal regulations.

Table 7. Does the estate have collection points (“sets of bins placed in a specific location for disposing of waste”) to store waste during harvesting and packing?

Responses	Number of people	Percentage
SI	2	10%
NO	10	90%
TOTAL	20	100%

According to Table 7, 90% of employees state that there are no collection points for waste management during harvesting. This is concerning, as proper waste management is key to reducing the environmental impact of agricultural operations. The estate should install collection points in strategic locations and ensure that all employees know how to use them correctly. This, along with hiring a company specialized in waste management, will ensure more efficient and sustainable waste handling.

Table 8. Knowing that environmental pollution is increasing every day due to various agricultural, industrial, and service processes, how important do you think it is to care for the environment?

Responses	Number of people	Percentage
Not important	0	0%
Slightly important	0	0%
Important	9	45%
Very important	11	55%
TOTAL	20	100%

Table 8 shows that **55% of employees** consider protecting the environment to be "very important," and **45%** consider it "important." Although there is a general environmental awareness, it is necessary to reinforce this through training that provides practical tools to enable employees to contribute effectively to the sustainability of the estate.

Table 9. Would you be willing to change your way of working in order to protect the environment?

Respuestas	Número de personas	Porcentaje
YES	20	100%
NO	0	0%
TOTAL	20	100%

100% of the employees surveyed are willing to modify their work practices to protect the environment. This is a positive indicator that the estate should leverage to implement an Environmental Management System (EMS) that has the support of the staff. The formation of an environmental committee made up of employees who act as change agents within their work areas could be an effective strategy.

Table 10. Knowing that an EMS ("Environmental Management System") allows an organization to control all its activities, services, and products that may cause an environmental impact, how do you think an EMS would benefit the organization?

Responses	Number of people	Percentage
Reduction of costs in waste management	0	0%
Facilitates compliance with environmental legislation	2	10%
Reduction of pollution	9	45%
Increases customer trust	1	5%
All of the above	8	40%
TOTAL	20	100%

According to Table 10, 45% of employees identify the reduction of pollution as the main benefit of an EMS, while 40% believe it facilitates compliance with legislation. However, only 10% mention cost reduction in waste management. This highlights the need to educate staff on the economic benefits that a well-implemented EMS can bring, such as resource optimization and reduced fines for non-compliance with regulations.

3.2. Employee Training on Environmental Management.

A training plan is essential to increase employees' knowledge and skills on environmental issues. Given the low level of knowledge detected in the surveys, it is a priority to design a training program that is accessible, practical, and low-cost. The estate can choose to develop an internal program using existing materials and resources or hire an external consultant specialized in environmental management to provide more structured training.
The objective of the plan is that the staff will be able to:

- **Identify the environmental impacts** of their daily activities.
- **Implement best practices** for waste management and efficient use of resources.
- **Actively contribute** to the proposed Environmental Management System (EMS).

Priority topics for training:
To ensure that workers acquire the necessary knowledge, the training will be structured into thematic modules delivered in one-hour weekly theoretical sessions, complemented by practical activities on the estate. The main topics include:

1. **Introduction to Environmental Management:** Key concepts, importance, and benefits of an Environmental Management System (EMS).
2. **Waste Management:** Classification and proper management of waste in the field.
3. **Efficient Resource Use:** Methods to reduce water and energy consumption on the estate.
4. **Pollution Prevention:** Measures to prevent soil and water pollution.
5. **Regulatory Compliance:** Relevant environmental legislation and principles of ISO 14001:2015.
6. **Audits and Continuous Improvement:** Procedures for internal audits and environmental performance monitoring.
7. **Biodiversity Conservation:** The importance of preserving local ecosystems.

These sessions should be adapted to the staff's educational level and the demands of their daily tasks, allowing for easy integration of daily work with new environmental practices.

Implementation of the Plan:
It is crucial that the training sessions be interactive and include practical field demonstrations. Additionally, periodic assessments are recommended to measure the effectiveness of the program and adjust content based on the results. The success of the training plan should be measured not only by the level of knowledge gained but also by the effective application of environmental practices in the estate's daily operations.

3.3. Development of a Recycling and Composting Program:

The development of a recycling and composting program on the estate is an effective and relatively accessible measure to reduce environmental impact. Although this initiative would not require large initial investments, its implementation needs to be planned in a structured way to ensure long-term sustainability.

The first step involves separating the waste into recyclable (plastics, metals, paper) and compostable (food and vegetable scraps) categories. The estate can set up collection points in strategic locations and later collaborate with a specialized waste management company to process these materials.

Components of the Recycling and Composting Program:

- **Clear and Measurable Objectives:**
  - Define specific targets, such as recycling 50% of the waste generated within one year or composting 25% of organic waste. These goals should be aligned with the overall objectives of the EMS.
- **Scope of Application:**
  - Include all sectors of the estate, from production areas to offices, covering waste types such as plastics, paper, organic waste, and hazardous waste.
- **Responsibility and Role Assignment:**
  - Appoint an environmental coordinator to oversee the implementation of the program and assign specific tasks to employees. For example, the field manager may be responsible for waste separation, while the logistics manager may coordinate the transportation of waste to recycling and composting facilities.
- **Operational Procedures:**
  - Develop detailed procedures specifying how waste should be separated, how containers should be used, and how safety should be ensured during the handling of hazardous waste. These procedures should be clearly documented and reviewed periodically to ensure their effectiveness.
- **Continuing education program:**
  - Train staff on the proper separation and handling of waste. It is essential that employees understand which types of waste can be recycled or composted, how to use the assigned containers, and how to follow safety procedures.
- **Monitoring and Evaluation:**
  - Implement a tracking system to measure the quantity of waste recycled and composted on a monthly basis. Key Performance Indicators (KPIs) would include the reduction of waste sent to landfills, waste management costs, and benefits

derived from compost production. This data should be analyzed quarterly to evaluate progress and make adjustments as needed.

Program implementation and follow-up:
Once the plan is developed, it is crucial to continuously monitor its implementation to ensure that objectives are met. This may include regular inspections of recycling points, waste audits, and periodic meetings with staff to discuss potential improvements. The success of the program will be measured in terms of waste reduction, savings in disposal costs, and the production of quality compost that can be reused in the estate's agricultural operations.

Timeline for Developing a Recycling and Composting Plan
Below is a proposed detailed timeline for the development and implementation of a recycling and composting plan on the estate, with specific timeframes for each stage.

Month 1: Evaluation and Planning
- Evaluate generated waste: Conduct an initial assessment of the types and quantities of waste generated on the farm, classifying them as recyclable and compostable.
- Set objectives: Define clear and measurable goals, such as reducing landfill waste by 50% and composting at least 25% of the generated organic waste.

Month 2: Plan Design and Training
- Develop the recycling and composting plan: Include clear procedures for waste separation, container placement, and waste transport routes to processing facilities.
- Train staff: Provide practical workshops on how to properly separate and manage waste, using demonstrations with the equipment and containers that will be implemented.

Month 3: Equipment Acquisition and Program Implementation
- Acquire necessary equipment: Purchase recycling bins, composters, and other equipment. If possible, consider reusable bins or those made from recycled materials.
- Initiate program implementation: Place containers in strategic locations on the farm and begin waste separation at the source.

Month 4: Initial Monitoring
- Monitor and evaluate the program: Conduct an internal audit to ensure staff is complying with the plan and evaluate the amount of waste recycled and composted against established goals.

Subsequent Months: Evaluation and Continuous Improvement
- **Continue monitoring:** Review performance indicators monthly, such as tons of waste processed and cost savings in disposal.
- Promote the program: Strengthen staff commitment through educational campaigns and encourage farm visitors to participate in the recycling and composting program.

Tips for Effective Implementation:
- **Assign specific roles**: Designate employees responsible for overseeing waste separation and coordinating logistics with waste management providers.
- **Use incentives:** Implement a recognition system for employees who stand out in their commitment to recycling and composting.
- **Engage the community:** Collaborate with local recycling and composting companies and promote public-private partnerships to ensure the program's sustainability.

3.4. Improving Water Management in a Mango Plantation in Los Ríos Province, Ecuador
Los Ríos Province, one of Ecuador's main mango-producing regions, faces significant water management challenges due to climatic variability, including recurrent droughts and floods. Improving water management in mango plantations is essential not only for the sustainability of production but also for adapting to climate change in the region.

Recommended Practices for Improving Water Management:
1. **Efficient Irrigation:**
   - Drip irrigation system: This system delivers water directly to the roots of the trees, significantly reducing evaporation and ensuring optimal water use during drought periods.
   - **Irrigation automation:** Use humidity sensors and weather stations to automate irrigation based on specific crop needs and climatic conditions.
2. **Rainwater Harvesting and Storage:**
   - Build reservoirs or implement rainwater harvesting systems on the farm to capture this resource during the rainy season and use it in dry periods.
3. **Graywater Reuse:**
   - Install graywater treatment systems from farm facilities to reuse it for crop irrigation or other agricultural activities. This method reduces potable water use for irrigation, maximizing water efficiency.
4. **Fertilizer and Pesticide Management:**
   - Apply fertilizers and pesticides efficiently to minimize the risk of runoff and ensure that these substances are used in appropriate quantities and at the right time to reduce environmental impact.
5. **Water Source Contamination:**

- Implement soil conservation measures, such as the construction of terraces and contour ditches, to prevent erosion and protect nearby water bodies. Planting vegetative barriers along the banks of rivers and streams will also contribute to the protection of the resource.

Benefits of Efficient Water Management:

- **Cost Reduction:** The implementation of efficient irrigation systems and rainwater harvesting decreases the use of potable water, thus reducing operational costs.
- **Increased Productivity:** A constant water supply during drought periods improves both the quality and quantity of mango production.
- **Long-Term Sustainability:** Protecting water sources and reusing water resources enhances the farm's resilience to climate change, ensuring the long-term viability of the business.
- **Regulatory Compliance:** Implementing good water management practices ensures compliance with both local and international environmental regulations.

Monitoring and Evaluation of the Water Management Program:
Continuous monitoring of the implemented improvements is key. The use of humidity sensors, measuring the volume of recycled water, and analyzing crop productivity will help assess the success of the measures. Periodic adjustments to irrigation techniques and water reuse will ensure that optimal water balance is maintained in the plantation.

4. Discussion

One of the key findings of this study is that the majority of workers on the mango-producing estate lack knowledge about environmental management, which aligns with previous research conducted in other agricultural contexts in Ecuador [14]. The lack of training in environmental management not only limits the adoption of sustainable practices but also hinders compliance with current environmental regulations. This deficiency is especially concerning in a sector where sustainability is increasingly demanded by consumers and international regulations [9].

Another relevant finding is that the estate lacks a formally implemented Environmental Management System (EMS). This situation reflects a common pattern in small and medium-sized agricultural operations in Ecuador, as documented in previous studies [23]. The absence of an EMS hinders the organization’s ability to identify, manage, and mitigate the environmental impacts generated by its operations, such as inefficient resource use and poor waste management [5], [8].

Regarding specific challenges related to water and waste management, similar issues to those reported in fruit farms in other Latin American countries were identified. When not properly managed, these areas tend to generate significant environmental impacts, such as contamination of water sources and soil degradation. The implementation of an EMS could address these problems by providing a clear framework for the efficient management of these resources [16], [17].

Finally, the hypothesis that implementing an EMS based on the ISO 14001:2015 standard would improve the estate's environmental performance was supported by the results obtained. Existing literature shows that agricultural organizations adopting this standard not only improve their environmental performance but also enhance their competitiveness in international markets and ensure regulatory compliance [10], [20].

The findings of this study not only partially validate the proposed hypotheses but also highlight the urgent need to strengthen environmental management capabilities within the agricultural sector. This study can serve as a basis for future research on the actual impacts of implementing EMSs in the region.

5. Conclusions

Based on the analysis of the results obtained, the following key conclusions can be drawn regarding the proposed implementation of an Environmental Management System (EMS) based on the ISO 14001:2015 standard on the mango-producing estate:

Lack of an EMS: The estate currently lacks a formal environmental management system, which has led to inadequate management of critical resources such as fertilizers, pesticides, and waste. This deficiency increases the environmental risks associated with its operations and reduces its ability to comply with current regulations.

Deficiencies in training: Most workers on the estate lack the necessary knowledge about the benefits and importance of implementing an EMS. This lack of training is a significant barrier to adopting sustainable practices and improving environmental performance.

Potential benefits of implementing an EMS: The proposal for an EMS based on ISO 14001:2015 will enable the estate to achieve its medium-term environmental certification goals, with benefits such as reducing operational costs, ensuring regulatory compliance, and improving its public image.

Relevance of the Study for the Agricultural Sector:
This study not only has implications for the estate analyzed, but it can also serve as a model for other agricultural operations seeking to improve their environmental

performance. The adoption of Environmental Management Systems (EMS) in the agricultural sector will significantly contribute to reducing the country's ecological footprint.

Future Research:
Future studies should be conducted to measure the actual impacts of EMS implementation, using performance indicators such as the reduction in agrochemical use and the improvement of water and soil quality. These studies will help validate the long-term benefits of these systems in similar contexts.

The implementation of an EMS on the studied estate is not only feasible but also necessary to ensure the sustainability of its operations in the long term and to improve its competitiveness in demanding markets.

6.- Author Contributions.

1. Conceptualization: José Estiven Pincay Moran; Jordán Francisco Ramírez Salcan, Francisco Javier Duque-Aldaz.
2. Data Curation: José Estiven Pincay Moran; Jordán Francisco Ramírez Salcan; William Villamagua Castillo.
3. Formal analysis: José Estiven Pincay Moran; Jordán Francisco Ramírez Salcan; William Villamagua Castillo.
4. Acquisition of funds: N/A.
5. Investigation: William Villamagua Castillo; Armando Fabrizzio López Vargas.
6. Methodology: William Villamagua Castillo; Ricardo Sánchez Casanova.
7. Project Administration: William Villamagua Castillo; Francisco Javier Duque-Aldaz.
8. Resources: N/A.
9. Software: N/A.
10. Supervision: William Villamagua Castillo; Armando López Vargas.
11. Validation: Francisco Javier Duque-Aldaz; Ricardo Sánchez Casanova.
12. Visualization: José Estiven Pincay Moran; Jordán Francisco Ramírez Salcan; William Villamagua Castillo.
13. Writing - original draft: José Estiven Pincay Moran; Jordán Francisco Ramírez Salcan, William Villamagua Castillo.
14. Writing - proofreading and editing: Armando Fabrizzio López Vargas; Francisco Javier Duque-Aldaz; Ricardo Sánchez Casanova.

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Thermo-hydraulic design of a helical coil heat exchanger for ethanol cooling

Diseño térmico-hidráulico de un intercambiador de calor de serpentín para el enfriamiento de etanol

Amaury Pérez Sánchez [1] * ; Heily Victoria González [2] ; Arlenis Cristina Alfaro Martínez [3] ; Elizabeth Ranero González [4] ; Eddy Javier Pérez Sánchez [5]

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* Author for correspondence.

Abstract.
The helical coil configuration is very effective for heat exchangers because they can accommodate a large heat transfer area in a small space, resulting in high heat transfer coefficients. This paper deals with the thermo-hydraulic design of a helical coil heat exchanger to cool an ethanol stream coming from the top of a rectification column, by using a classical, well-known calculation methodology. Several parameters were determined such as the overall heat transfer coefficient (65.88 $W/m^2.K$); the spiral total surface area (10.75 m^2); the actual number of turns of coil (91) and the height of cylinder (4.12 m). The values of the pressure drop were 290,344 Pa and 0.097 Pa respectively, which are below the limits set by the heat exchange process. The pumping power required for the chilled water (coil-side fluid) stream was 375.21 W, while the pumping power required for the ethanol stream can be considered negligible.

Keywords.
Helical coil heat exchanger, pressure drop, pumping power, spiral surface area, Actual turns of helical coil.

Resumen.
La configuración de serpentín helicoidal es muy efectiva para intercambiadores de calor debido a que pueden acomodar un área de transferencia de calor elevada en un pequeño espacio, resultando en altos coeficientes de transferencia de calor. Este artículo trata acerca del diseño térmico-hidráulico de un intercambiador de calor de serpentín para enfriar una corriente de etanol proveniente del tope de una columna de rectificación, mediante el empleo de una metodología de cálculo clásica bien conocida. Varios parámetros fueron determinados tales como el coeficiente global de transferencia de calor (65,88 W/m2.K), el área superficial total de la espiral (10,75 m2); el número real de vueltas del serpentín (91) y la altura del cilindro (4,12 m). Los valores de la caída de presión fueron de 290 344 Pa y 0,097 Pa, respectivamente, los cuales están por debajo de los límites fijados por el proceso de intercambio de calor. La potencia de bombeo requerida para la corriente de agua fría (fluido que circula por el serpentín) fue de 375,21 W, mientras que la potencia de bombeo requerida para la corriente de etanol puede considerarse despreciable.

Palabras clave.
Intercambiador de calor de serpentín, caída de presión, potencia de bombeo, área superficial de la espiral, vueltas reales del serpentín.

1. Introduction.

Nowadays, due to the increase in energy saving demand in many engineering fields of the modern industry such as heating, ventilation, air conditioning and waste heat recovery, heat exchangers that are more efficient, and have smaller sizes and lower costs are desired, while heat transfer enhancement have been introduced to improve its overall thermo-hydraulic performance [1].

Heat exchangers are widely used in mechanical devices which exchange heat from one type of fluid to another. They are mainly used in heat transfer applications, such as power plants, refrigeration, electronics, air conditioning, chemical and petrochemical processes, automobile devices, and so on [2]. Heat exchangers can improve industrial production efficiency and ensure equipment safety [3], and come in a variety of shapes and sizes, depending on the application: shell and tube, double pipe, spiral or straight, plate type, finned type, helical, among others [2].

Due to their compact structure and high heat transfer coefficient, the helical coil tube heat exchanger (HCHX) has been extensively studied as one of the passive heat transfer enhancements [3].

An HCHX consists of a helical coil fabricated out of a metal pipe that is fitted in the annular portion of two concentric cylinders, as shown in Figure 1. The fluids flow inside the coil and the annulus with heat transfer taking place across the coil wall. The dimensions of both cylinders are determined by the velocity of the fluid in the annulus needed to meet heat-transfer requirements.

[1] University of Camagüey; Faculty of Applied Sciences; amaury.perez84@gmail.com ; https://orcid.org/0000-0002-0819-6760 , Camagüey, Cuba.
[2] University of Camagüey; Faculty of Applied Sciences; heily.victoria@reduc.edu.cu ; https://orcid.org/0009-0007-9319-6506 , Camagüey, Cuba.
[3] Center of Genetic Engineering and Biotechnology of Camagüey; arlenis.alfaro@cigb.edu.cu ; https://orcid.org/0000-0003-2975-6867 , Camagüey, Cuba.
[4] University of Camagüey; Faculty of Applied Sciences; eliza.eddy2202@gmail.com ; https://orcid.org/0000-0001-9755-0276 , Camagüey, Cuba.
[5] Company of Automotive Services S.A.; Commercial Department; eddyjavierpsanchez@gmail.com ; https://orcid.org/0000-0003-4481-1262 , Ciego de Ávila, Cuba.

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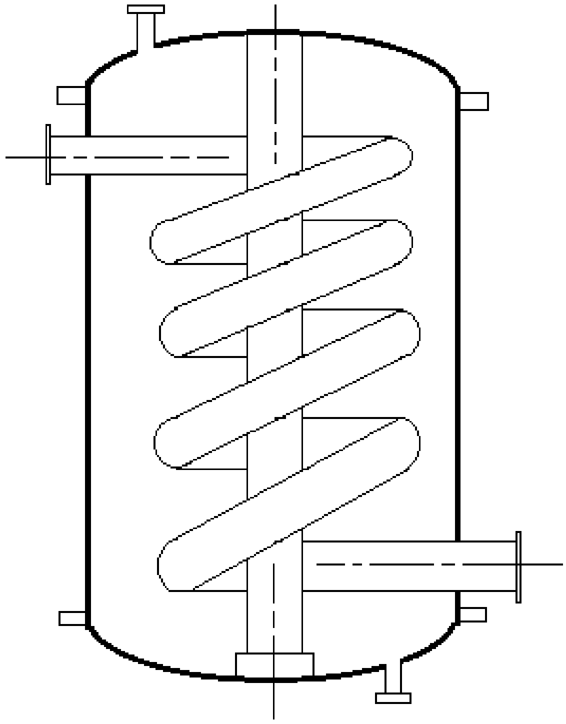

Fig. 1. A helical coil heat exchanger.

Helically coiled exchangers offer certain advantages over the typical heat transfer equipment. Among them it can be mentioned higher film coefficients and heat transfer rate through the tube wall from one fluid to the other, as well as more effective use of available pressure drop, which result in efficient and less-expensive designs. True counter-current flow fully utilizes available logarithmic mean temperature difference, while helical geometry permits handling high temperatures and extreme temperature differentials without highly induced stresses or costly expansion joints. High-pressure capability and the ability to fully clean the service-fluid flow area also add to the exchanger's advantages.

When fluid flows through a helically coiled tube, the curvature of the coil induces centrifugal force [4], which in turn can produce a longitudinal secondary flow in the helically coiled tube, resulting in higher heat transfer efficiency than the value obtained from the straight tubes [3], that is, the centrifugal force induced due to the curvature of the tube results in the secondary flow known as Dean Vortex superimposed on the primary flow which enhances the heat transfer [5]. Fluid flow in a helical tube is characterized by the Dean number, which is a measure of the geometric average of inertial and centrifugal forces to the viscous force ratio, and thus is a measure of a magnitude of the secondary flow [4]. In addition, the coil pitch would influence flow torsion, while depending on the Dean number, the secondary flow pattern within a coiled tube can strongly enhance its heat transfer rate [6].
Helically coiled tubes are useful for various industrial processes such as combustion systems, heat exchangers, solar collectors, and distillation processes because of their simple and effective means of enhancement in heat and mass transfer [7], as well as because they can accommodate a large heat transfer area in compact space, with high heat transfer coefficient [5]. In general they can be used as coolers, heaters, condensers or evaporators [5].

HCHX are broadly used in heating and cooling applications such as heat recovery system, food industries, nuclear power plant, chemical processing, solar water heater, and refrigeration and air-conditioning units because of their simple and effective means of enhancement in heat and mass transfer The HCHX showed increase in the heat transfer rate, effectiveness and overall heat transfer coefficient over the straight tube heat exchanger on all mass flow rates and operating conditions [7].

The merit of the HCHX is that its tube can contact the fluid flowing in the shell side directly, resulting in good heat transfer performance. Therefore, using helical coils in heat exchangers is an effective way for heat transfer enhancement in industries and households [8], although the pressure drop is increased across the heat exchanger, frequently for the coil-side fluid.

In the design of HCHXs, heat transfer performance and pressure loss are significant indicators to consider. It is important to reduce the pressure loss in the helical tube and enhance the heat transfer performance between the shell and tube sides to improve the thermo-hydraulic performance of the helical coil heat exchanger. However, there are many influencing factors on both indices, such as the size of the helical tube, coil pitch, coil diameter, the position of the inlet and outlet streams, and the flow direction, etc. [8]. Heat transfer on HCHX depends largely on the coil size, tube size, mass flow rate, type of thermal fluids and number of turns [7].

Several authors have carried out the design and performance analysis of HCHX. In this sense, [2] numerically investigated the heat transfer performance of a helical heat exchanger using various water-based nanofluids and considering multiple head-ribbed geometries with different coil revolutions. The numerical results were validated against experimental correlations and a published numerical study, thus obtaining as a result that the helical heat exchanger with 2 head ribbed and 30 coil revolutions is the most effective among all the cases and is selected for the nanofluid study. Furthermore, the heat transfer rate could be enhanced by 20%–80% utilizing 2 rib head geometry and by 17%–66% using 30 coil revolutions. Likewise, [8] employed the Computational Fluid Dynamics (CFD) software, ANSYS FLUENT to predict the thermo-hydraulic performance of an HCHX, including the overall heat transfer coefficient and Fanning friction factor. Using different sizes of the HCHX, comparing the CFD results with experimental data or correlations available in the literature revealed that both results on thermo-hydraulic performance agreed well. Then the Taguchi method was used coupled with grey relational analysis to optimize the HCHX design with the improvement of thermo-hydraulic performance. Among the selected three factors in the optimization process, it was found that the coil pitch and coil diameter were the two most important factors in influencing the thermo-hydraulic performance of HCHXs, while the outer diameter of the helical tube had little impact. Similarly, [1] carried out a three-dimensional study of a shell and helically corrugated coiled tube heat exchanger considering exergy loss, where various design parameters and operating conditions such as corrugation depth, corrugation pitch, the number of rounds, and inlet fluid flow rate on the coil and shell sides, were numerically investigated to examine the heat exchanger hydrothermal performance.

Taguchi analysis was also used to analyze the hydrothermal parameters by considering the interaction effects of them. The results obtained in this study showed that increasing the inlet fluid flow rate on the coil side, corrugation depth and the number of rounds increases both heat transfer and pressure drop, while the most effective parameter that influence on the thermal and hydrodynamic performance of the heat exchanger is the fluid flow rate on the coil side. Also, [3] performed an intelligent optimization scheme on the whole shell and helically coiled tube heat exchanger, where a genetic algorithm was used to automatically determine the coiled pitch, coiled diameter, tube diameter, and flow parameters, in order to maximize the heat transfer rate per thermal surface area by combining the optimization design, structural design, meshing, and numerical calculation. At the same time, the optimization results with and without the pressure drop constraint were compared. The field synergy principle (FSP) was used to explain the cause of the improved performance of the heat exchanger, while the theory of entropy production minimization was employed to evaluate the overall thermal performance. In another study, [5] carried out the analytical and experimental analysis of heat transfer for a finned tube coil heat exchanger immersed in a thermal storage tank, where this tank is equipped with three helical-shaped heating coils and cylindrical-shaped stratification device.

Calculations of thermal power of water coil were made, and correlations of heat transfer coefficients in curved tubes were applied. In order to verify the analytical calculations, the experimental studies of heat transfer characteristic for coil heat exchanger were also performed. Other authors [9] designed HCHX with two different shell configurations, that is, with and without a central core, while both configurations has a copper helical coil. The design was done by using CATIA V5 R2015, and the performance of both the configurations were analyzed and compared by means of Fluid flow (Fluent) in ANSYS for CFD simulations. Saydam [10] designed, fabricated, and experimentally analyzed a prototype phase change material (PCM) heat exchanger with a helical coil tube for its thermal storage performance under different operational conditions. Paraffin wax was used as PCM and an ethylene glycol-water mixture was used as heat transfer fluid (HTF).

Different HTF inlet temperatures, flow directions, and flow rates were tested to find out the effects of these parameters on the performance, including charging and discharging time, of the thermal storage unit. In the work carried out by [11] a supercritical heat exchanger of helical coil type was first designed and then evaluated under real operational conditions. Three heat transfer correlations available from the literature were employed for the design of the heat exchanger. These heat transfer correlations were derived for different working fluids and conditions than the tested organic Rankine cycles. Therefore, to account for the uncertainties of the heat transfer correlations the heat exchanger was oversized by 20%. Finally, performance evaluation of the constructed heat exchanger was performed at supercritical working conditions (laboratory conditions) by examining the influence of several different parameters. [6] proposed a computational fluid dynamics (CFD) methodology to investigate the effects of different Dean (De) number and pitch size on the thermal-hydraulic characteristics in a helically coil-tube heat exchanger with high-temperature helium (He) flowing in the shell side and low-temperature water in the coiled tube.

Three values of De number and four sizes of pitch are considered herein. Based on the simulation results, the complicated phenomena occurred within a helically coiled-tube heat exchanger can be reasonably captured, including the flow acceleration and separation in the shell side, the turbulent wake around the rear of a coiled tube, the secondary flow within the tube, and the developing flow and heat transfer behaviors from the entrance region, etc. [12] performed an experimental investigation of the natural convection heat transfer from helical coiled tubes in water. The outside Nusselt number was correlated to the Rayleigh number using different characteristic lengths, and the relationship obtained was based on a power law equation. The constants in the equation were presented for each of the different characteristic lengths used. The best correlation was using the total height of the coil as the characteristic length.

The developed models were then used to develop a prediction model to predict the outlet temperature of a fluid flowing through a helically coiled heat exchanger, given the inlet temperature, bath temperature, coil dimensions, and fluid flow rate. [13] designed and modeled several unique tube configurations to examine the thermal and hydraulic

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performance of a helical tube heat exchanger both experimentally and numerically. For cold and hot side tube designs, the numerical investigation is completed using three-dimensional modeling, and the findings are confirmed using experimental data with Reynolds numbers ranging from 16,000 to 25,000. The findings showed that, as compared to the uniform tube distribution, the novel tube arrangements have a greater overall heat transfer coefficient, and the performance of heat transfer is dramatically improved, although variations in pressure drop and pumping power are only a little affected.

Other authors presented and successfully implemented a simple mathematical methodology to model the shell and coil heat exchanger [4]; analyzed the performance of a helical coil heat exchanger operating at subcritical and supercritical conditions [14]; introduced an experimental study of horizontal shell and coil heat exchangers in order to determine the effect of coil torsion on heat transfer and pressure drop of shell and coil heat exchangers [15] and determined the convective heat transfer coefficient in both helical and straight tubular heat exchangers under turbulent flow conditions [16].

In certain chemical processing plant it's desired to cool down a stream of ethanol coming from the top of a rectification column, and for that a vertical helical coil heat exchanger was selected as the preferred equipment due to space limitations and the need of achieving a high heat transfer rate. In this context, the present work deals with the design of a helical coil heat exchanger using a well-known, classical calculation methodology, where several parameters are determined such as the actual number of coil turns, calculated spiral total tube length, height of cylinder, spiral total surface area, the pressure drop of both fluids and the pumping power required.

2. Materials and methods.
2.1. Problem definition.

It's desired to cool 750 kg/h of an ethanol stream from 90 ºC to 30 ºC using chilled water at 2 ºC as the cooling medium.
The following data are available for the coil, core tube and shell (Figure 2):

- Shell inner diameter (D_i): 0.46 m.
- Core tube outer diameter (D_K): 0.34 m.
- Average spiral diameter (D_H): 0.40 m.
- Tube outer diameter (d_o): 0.030 m.
- Tube inner diameter (d_i): 0.025 m.

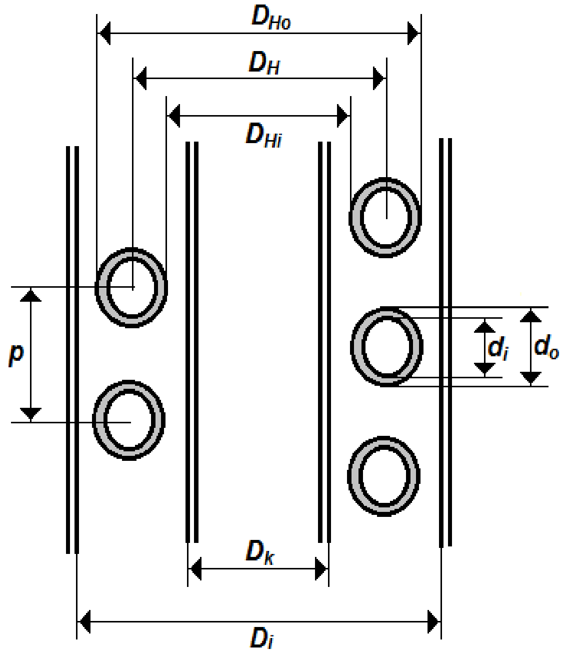

Fig. 2. Geometric parameters of the helical coil heat exchanger.

The outlet temperature of the chilled water should not be higher than 10 ºC, while the fouling factors for the water and ethanol are 0.000176 and 0.000352 K.m^2/W, respectively [17]. The chilled water will be located inside the coil, while the ethanol will flow inside the shell, and both fluids will circulate at countercurrent flow inside the designed helical coil heat exchanger (Figure 2). The coil material is 316 stainless-steel thus having a thermal conductivity of 16.3 W/m.K [18] and the tube pitch, which is the spacing between consecutive coil turns (measured from center to center) (p) can be taken as $1.5 \cdot d_o$. The pressure drop of the shell-side and coil-side fluids must not exceed 0.5 Pa and 300,000 Pa, respectively. Design a suitable helical coil heat exchanger for this heat transfer service.

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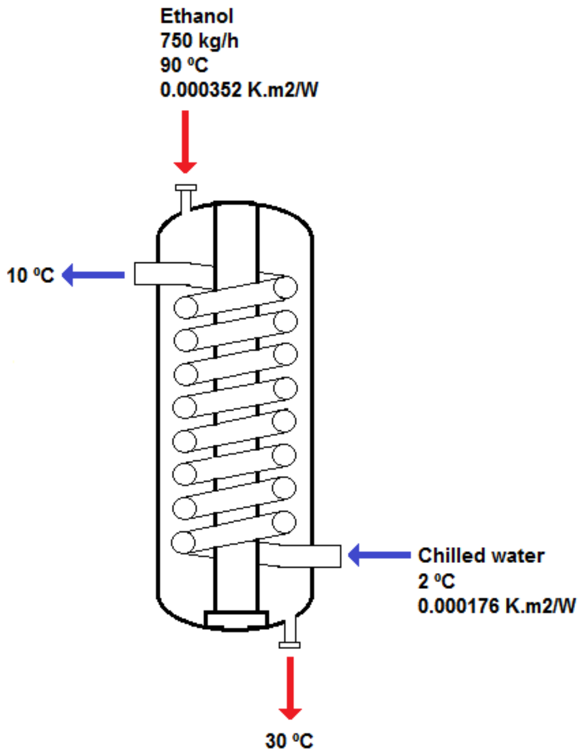

Fig. 3. Schematic view of the proposed helical coil heat exchanger.

2.2. Design methodology.
The equations and correlations reported by [4] [19] [20] were employed to design the helical coil heat exchanger, where several important design parameters are determined such as the overall heat transfer coefficient, the required heat exchange area, the spiral total tube length, the actual number of turns of helical coil, the height of cylinder, as well as the calculated pressure drops and the required pumping power for both fluids.

2.3. Thermal design of the helical coil heat exchanger.

Step 1. Initial data required:

- Mass flowrate of shell-side fluid (m_{shell}).
- Inlet temperature of hot fluid (T_1).
- Outlet temperature of hot fluid (T_2).
- Inlet temperature of cold fluid (t_1).
- Outlet temperature of cold fluid (t_2).
- Fouling factor of hot fluid (R_h).
- Fouling factor of cold fluid (R_c).
- Maximum allowable pressure drop for coil-side fluid ($\Delta P_{coil(A)}$).
- Maximum allowable pressure drop for shell-side fluid ($\Delta P_{shell(A)}$).
- Thermal conductivity of coil material (k_W).
- Shell inner diameter (D_i): 0.46 m.
- Core tube outer diameter (D_K): 0.34 m.
- Average spiral diameter (D_H): 0.40 m.
- Tube outer diameter (d_o): 0.030 m.
- Tube inner diameter (d_i): 0.025 m.
- Tube pitch (p).

Step 2. Average temperature of both fluids:

- Ethanol:

$$\bar{T} = \frac{T_1 + T_2}{2} \quad (1)$$

- Chilled water:

$$\bar{t} = \frac{t_1 + t_2}{2} \quad (2)$$

Step 3. Physical properties of both fluids at the average temperatures determined in the previous step:
The physical properties showed on Table 1 must be determined for both fluids:

Table 1. Physical properties of both fluids.

Physical property	Hot fluid	Cold fluid	Units
Density	ρ_h	ρ_c	kg/m^3
Viscosity	μ_h	μ_c	Pa.s
Heat capacity	Cp_h	Cp_c	kJ/kg.K
Thermal conductivity	k_h	k_c	W/m.K

Source: Own elaboration.

Step 4. Heat load (Q):
Taking the data for the hot fluid (ethanol):

$$Q = \frac{m_{shell} \cdot Cp_h \cdot (T_1 - T_2)}{3{,}600} \quad (3)$$

Step 5. Required mass flowrate of chilled water (m_c):

$$m_{coil} = \frac{Q}{Cp_c \cdot (t_2 - t_1)} \cdot 3{,}600 \quad (4)$$

Step 6. Cross-sectional area of coil (A_{coil}):

$$A_{coil} = \frac{\pi \cdot d_i^2}{4} \quad (5)$$

Step 7. Volumetric flowrate of coil-side fluid (q_{coil}):

$$q_{coil} = \frac{\frac{m_{coil}}{\rho_c}}{3,600} \quad (6)$$

Step 8. Velocity of coil-side fluid (v_{coil}):

$$v_{coil} = \frac{q_{coil}}{A_{coil}} \quad (7)$$

Step 9. Reynolds number of coil-side fluid (Re_{coil}):

$$\mathrm{Re}_{coil} = \frac{d_i \cdot v_{coil} \cdot \rho_c}{\mu_c} \quad (8)$$

Step 10. Prandtl number of the coil-side fluid (Pr_{coil}):

$$\mathrm{Pr}_{coil} = \frac{Cp_c \cdot \mu_c}{k_c} \cdot 1,000 \quad (9)$$

Step 11. Nusselt number of the coil-side fluid (Nu_{coil}):

- For $\mathrm{Re}_{coil} > 8,000$

$$Nu_{coil} = 0.023 \cdot \mathrm{Re}_{coil}^{0.8} \cdot \mathrm{Pr}_{coil}^{0.33} \quad (10)$$

Step 12. Coil-side heat transfer coefficient (α_{coil}):

$$\alpha_{coil} = \frac{Nu_{coil} \cdot k_c}{d_i} \quad (11)$$

Step 13. Heat transfer coefficient inside coiled tube based on inside diameter [$\alpha_{coil(SP)}$]:

$$\alpha_{coil(SP)} = \alpha_{coil} \cdot \left(1 + 3.5 \cdot \frac{d_i}{D_H}\right) \quad (12)$$

Step 14. Heat transfer coefficient inside coiled tube based on the outside diameter of the coil [$\alpha_{coil(SPa)}$]:

$$\alpha_{coil(SPa)} = \alpha_{coil(SP)} \cdot \frac{d_i}{d_o} \quad (13)$$

Step 15. Outer spiral diameter (D_{Ho}):

$$D_{Ho} = D_i - d_o \quad (14)$$

Step 16. Inner spiral diameter (D_{Hi}):

$$D_{Hi} = D_k + d_o \quad (15)$$

Step 17. Shell-side flow cross-section (A_{shell}):

$$A_{shell} = \frac{\pi}{4} \cdot \left[\left(D_i^2 - D_K^2\right) - \left(D_{Ho}^2 - D_{Hi}^2\right)\right] \quad (16)$$

Step 18. Volumetric flowrate of shell-side fluid (q_{shell}):

$$q_{shell} = \frac{\frac{m_{shell}}{\rho_h}}{3,600} \quad (17)$$

Step 19. Flow velocity of the shell-side fluid (v_{shell}):

$$v_{shell} = \frac{q_{shell}}{A_{shell}} \quad (18)$$

Step 20. Reynolds number of shell-side fluid (Re_{shell}):

$$\mathrm{Re}_{shell} = \frac{d_o \cdot v_{shell} \cdot \rho_h}{\mu_h} \quad (19)$$

Step 21. Prandtl number of the shell-side fluid (Pr_{shell}):

$$\mathrm{Pr}_{shell} = \frac{Cp_h \cdot \mu_h}{k_h} \cdot 1,000 \quad (20)$$

Step 22. Nusselt number of the shell-side fluid (Nu_{shell}):

$$Nu_{shell} = 0.196 \cdot \mathrm{Re}_{shell}^{0.6} \cdot \mathrm{Pr}_{shell}^{0.33} \quad (21)$$

Step 23. Heat transfer coefficient of shell-side fluid (α_{shell}):

$$\alpha_{shell} = \frac{Nu_{shell} \cdot k_h}{d_o} \quad (22)$$

Step 24. Coil wall thickness (s_W):

$$s_W = \frac{d_0 - d_i}{2} \quad (23)$$

Step 25. Overall heat transfer coefficient (U):

$$U = \frac{1}{\frac{1}{\alpha_{coil(SPa)}} + \frac{1}{\alpha_{shell}} + \frac{s_W}{k_W} + R_h + R_c} \quad (24)$$

Step 26. Logarithmic Mean Temperature Difference ($LMTD$):

- For countercurrent flow:

$$LMTD = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln \frac{(T_1 - t_2)}{(T_2 - t_1)}} \quad (25)$$

Step 27. Effective mean temperature difference (ΔT):

$$\Delta T = LMTD \cdot F_t \quad (26)$$

Where F_t is the temperature correction factor = 0.99 [20].
Step 28. Spiral total surface area (A):

$$A = \frac{Q}{U \cdot \Delta T} \cdot 1{,}000 \tag{27}$$

Step 29. Spiral total tube length (L):

$$L = n \cdot \sqrt{(D_H \cdot \pi)^2 + p^2} \tag{28}$$

Step 30. Theoretical number of turns of helical coil (N):

$$N = \frac{A}{\pi \cdot d_o \cdot \frac{L}{n}} \tag{29}$$

Step 31. Actual number of turns of coil (N rounded to the next highest integer) (n):
Step 32. Calculated spiral total tube length (L'):

$$L' = L \cdot n \tag{30}$$

Step 33. Height of cylinder (H):

$$H = n \cdot p + d_o \tag{31}$$

2.4. Pressure drop.

Step 34. Factor E :

$$E = D_H \cdot \left[1 + \left(\frac{p}{\pi \cdot D_H} \right)^2 \right] \tag{32}$$

Step 35. Friction factor for flow inside the coil (f):

$$f = \left[\frac{0.3164}{\mathrm{Re}_{coil}^{0.25}} + 0.03 \cdot \left(\frac{d_i}{E} \right)^{1/2} \right] \cdot \left(\frac{\mu_w}{\mu} \right)^{0.27} \tag{33}$$

Where $\left(\mu_w / \mu \right)^{0.27}$ = 1 as suggested by [4]

Step 36. Drag coefficient on coil surface (C_D):

$$C_D = \frac{0.3164}{\mathrm{Re}_{shell}^{0.25}} \cdot \left[1 + 0.095 \cdot \left(\frac{d_o}{D_H} \right)^{1/2} \cdot \mathrm{Re}_{shell}^{0.25} \right] \tag{34}$$

Step 37. Pressure drop for the coil side fluid (ΔP_{coil}):

$$\Delta P_{coil} = f \cdot \frac{L'}{d_i} \cdot \frac{v_{coil}^2 \cdot \rho_c}{2} \tag{35}$$

Step 38. Volume available for the flow of fluid in the annulus (V_{shell}):

$$V_{shell} = \frac{\pi}{4} \cdot \left(D_i^2 - D_K^2 \right) \cdot p \cdot n - \frac{\pi}{4} \cdot d_o^2 \cdot L' \tag{36}$$

Step 39. Shell side equivalent diameter (D_e):

$$D_e = \frac{4 \cdot V_{shell}}{\pi \cdot d_o \cdot L'} \tag{37}$$

Step 40. Pressure drop for the shell side fluid (ΔP_{shell}):

$$\Delta P_{shell} = C_D \cdot \frac{H}{D_e} \cdot \frac{v_{shell}^2 \cdot \rho_h}{2} \tag{38}$$

2.5. Pumping power.

Step 41. Pumping power required for the coil side fluid (P_{coil}):

$$P_{coil} = \frac{\Delta P_{coil} \cdot \frac{m_{coil}}{3{,}600}}{\eta_p \cdot \rho_c} \tag{39}$$

Where m_{coil} is given in kg/h and η_p = 0.8 [21].
Step 42. Pumping power required for the shell side fluid (P_{shell}):

$$P_{shell} = \frac{\Delta P_{shell} \cdot \frac{m_{shell}}{3{,}600}}{\eta_p \cdot \rho_h} \tag{40}$$

Where m_{shell} is given in kg/h and η_p = 0.8 [21].

3. Results.

3.1. Design parameters of the helical coil heat exchanger.

Table 2 shows the initial data required to design the helical coil heat exchanger, which are included in Step 1.

Table 2. Initial data required to design the helical coil heat exchanger.

Parameter	Symbol	Value	Unit
Mass flowrate of shell-side fluid	m_{shell}	750	kg/h
Inlet temperature of hot fluid	T_1	90	ºC
Outlet temperature of hot fluid	T_2	30	ºC
Inlet temperature of cold fluid	t_1	2	ºC
Outlet temperature of cold fluid	t_2	10	ºC
Fouling factor of hot fluid	R_h	0.000352	K.m²/W
Fouling factor of cold fluid	R_c	0.000176	K.m²/W
Maximum allowable pressure	$\Delta P_{coil(A)}$	300,000	Pa

drop for coil-side fluid			
Maximum allowable pressure drop for shell-side fluid	$\Delta P_{shell(A)}$	0.5	Pa
Thermal conductivity of coil material[1]	k_W	16.3	W/m.K
Shell inner diameter	D_i	0.46	m
Core tube outer diameter	D_K	0.34	m
Average spiral diameter	D_H	0.40	m
Tube outer diameter	d_o	0.030	m
Tube inner diameter	d_i	0.025	m
Tube pitch[2]	p	0.045	m

[1]As reported by [22].
[2]Taken as $1.5 \cdot d_o$

Source: Own elaboration.

Step 2. Average temperature of both fluids.

- Ethanol: $\overline{T}$ = 60 ºC
- Chilled wáter: $\overline{t}$ = 6 ºC

Step 3. Physical properties of both fluids at the average temperatures calculated in the previous step.

Table 3 presents the physical properties of both fluids at the average temperatures calculated in the previous step, as reported by [18].

Table 3. Physical property of both fluids.

Physical property	Ethanol	Chilled water	Unit
Density	753.22	999.94	kg/m^3
Viscosity	0.000584	0.001445	Pa.s
Heat capacity	2.781	4.203	kJ/kg.K
Thermal conductivity	0.159	0.572	W/m.K

Source: Own elaboration.

Table 4 exhibits the results of the parameters included in steps 4 to 33.

Table 4. Results of the parameters included in steps 4 to 33.

Step	Parameter	Symbol	Value	Unit
4	Heat load	Q	34.76	kW
5	Required mass flowrate of chilled water	m_{coil}	3,721.63	kg/h
6	Cross-sectional area of coil	A_{coil}	0.00049	m^2
7	Volumetric flowrate of chilled water	q_{coil}	0.0010	m^3/s
8	Velocity of chilled water	v_{coil}	2.04	m/s
9	Reynolds number of chilled water	Re_{coil}	35,292	-
10	Prandtl number of the chilled water	Pr_{coil}	10.62	-
11	Nusselt number of the chilled water[1]	Nu_{coil}	217.93	-
12	Coil-side heat transfer coefficient	α_{coil}	4,986.24	W/m^2.K
13	Heat transfer coefficient inside coiled tube based on inside diameter	$\alpha_{coil(SP)}$	6,076.98	W/m^2.K
14	Heat transfer coefficient inside coiled tube based on the outside diameter of the coil	$\alpha_{coil(SPa)}$	5,064.15	W/m^2.K
15	Outer spiral diameter	D_{Ho}	0.43	m
16	Inner spiral diameter	D_{Hi}	0.37	m
17	Shell-side flow cross-section	A_{shell}	0.0377	m^2
18	Volumetric flowrate of ethanol	q_{shell}	0.0003	m^3/s
19	Flow velocity of the ethanol	v_{shell}	0.008	m/s
20	Reynolds number of ethanol	Re_{shell}	309.54	-
21	Prandtl number of ethanol	Pr_{shell}	10.21	-

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22	Nusselt number of ethanol	Nu_{shell}	13.15	-
23	Heat transfer coefficient of ethanol	α_{shell}	69.70	$W/m^2.K$
24	Coil wall thickness	s_W	0.0025	m
25	Overall heat transfer coefficient	U	65.88	$W/m^2.K$
26	Logarithmic Mean Temperature Difference	$LMTD$	49.57	ºC
27	Effective mean temperature difference	ΔT	49.07	ºC
28	Spiral total surface area	A	10.75	m^2
29	Spiral total tube length	L	1.257n	-
30	Theoretical number of turns of helical coil	N	90.78	-
31	Actual number of turns of helical coil	n	91	-
32	Calculated spiral total tube length	L'	114.38	m
33	Height of cylinder	H	4.12	m

[1]Equation (10) is valid to use to determine the Nusselt number of chilled water since $Re_{coil} > 8,000$.
Source: Own elaboration.

3.2. Pressure drop.

Pressure drop increases as fluid flow velocity through the heat exchanger is increased, as does the convection heat transfer coefficient; a good design is therefore always a compromise of sufficiently heat transfer characteristics with acceptable pressure drop.

Table 5 displays the results of the parameters included in steps 34-40, valid to determine the pressure drop of both streams.

Table 5. Results of the parameters calculated in steps 34-40.

Step	Parameter	Symbol	Value	Unit
34	Factor E	E	0.40	m
35	Friction factor for flow inside the coil	f	0.0305	-
36	Drag coefficient on coil surface	C_D	0.0836	-
37	Pressure drop for the chilled water	ΔP_{coil}	290,344	Pa
38	Volume available for the flow of fluid in the annulus	V_{shell}	0.228	m^3
39	Shell side equivalent diameter	D_e	0.085	m
40	Pressure drop for the ethanol	ΔP_{shell}	0.097	Pa

Source: Own elaboration.

3.3. Pumping power.

Table 6 presents the results of the pumping power required for both fluids.

Table 6. Pumping power required for both fluids.

Step	Parameter	Symbol	Value	Unit
41	Pumping power required for the chilled water	P_{coil}	375.21	W
42	Pumping power required for the ethanol	P_{shell}	0.000034	W

Source: Own elaboration.

4. Discussion.

4.1. Design parameters of the helical coil heat exchanger.

According to the results of Table 4, the heat load had a value of 34.76 kW, while about 3,721.63 kg/h (1.03 kg/s) of chilled water will be necessary to meet the required heat exchange duty. The Reynolds number of chilled water was 35,292, which is 114 times above the Reynolds number of ethanol (309.54). This is due to the relatively high value of the shell-side flow cross-section (0.0377) and the small value of the volumetric flowrate of ethanol (0.0003 m^3/s), which in turn decreases the value of the flow velocity of ethanol (0.008 m/s), thus decreasing the Reynolds number of ethanol (Re_{shell}). The smaller value of the ethanol density (753.22 kg/m^3), as compared to the density of chilled water (999.94 kg/m^3), also affects the small value obtained for Re_{shell}. It's worth stating that the mass flowrate of chilled water is about five times higher than the mass flowrate of ethanol, which therefore influences in the large difference obtained for the Reynolds number of both streams.

The Nusselt number of the chilled water (217.93) is about 17 times higher than the Nusselt number for ethanol (13.15).

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This is mainly due to the small value of the Reynolds number obtained for ethanol as compared to the Reynolds number of chilled water. This also influences in that the heat transfer coefficient for the chilled water (5,064.15 W/m^2.K) is about 73 times higher than the heat transfer coefficient for ethanol (69.70 W/m^2.K), although the correlations used to determine these heat transfer coefficients for both fluids are relatively different with each other. Moreover, the values obtained of the Prandtl number for both fluids are almost the same (10.62 for chilled water and 10.21 for ethanol), thus this parameter doesn't affect the calculated values of the heat transfer coefficient for both fluids.

The overall heat transfer coefficient (U) had a value of 65.88 W/m^2.K, which can be classified as low mainly due to the small value obtained of the heat transfer coefficient for the ethanol stream. The rather small value obtained for U influences in the relatively high values obtained for the spiral total surface area (10.75 m^2), the theoretical number of turns of helical coil (90.78) and the height of cylinder (4.12 m). Finally, the calculated spiral total tube length was 114.38 m, while 91 turns of helical coil will be needed for the designed heat exchanger.

In a previous study [23] carried out, a helical coil heat exchanger was designed to cool an acetone stream, where a similar methodology that the one used in this work was applied. In this paper, the acetone mass flowrate is 300 kg/h, while about 1,287 kg/h of chilled water at an inlet temperature of 2 ºC were needed to accomplish the heat transfer duty of cooling the acetone from 70 ºC to 30 ºC. It was obtained a heat transfer coefficient for the chilled water of 1,684.30 kcal/h.m^2.ºC (1,958.84 W/m^2.K) which is about 68 times higher than the heat transfer coefficient for acetone (28.73 W/m^2.K). Also, the Reynolds number of the chilled water (the coil-side fluid) was 11,211, which is 17 times higher than the Reynolds number of acetone (the shell-side fluid). Likewise, the value obtained for the overall heat transfer coefficient was 23.88 kcal/h.m^2.ºC (27.77 W/m^2.K) which can be considered low.

Finally, it was required a heat transfer area of 6.60 m^2, an actual number of turns of helical coil of 53 and a cylinder height of 2.58 m. In general terms, the values of the parameters overall heat transfer coefficient, heat transfer area, actual number of turns of helical coil and cylinder height are higher in the present study as compared to that obtained in [23] due fundamentally to the higher mass flowrate handled for the hot stream. The results found in [23] agree and ratify the results obtained in this study regarding the values of the heat transfer coefficients and the Reynolds numbers for both streams, as well as the validity of the calculated design parameters.

4.2. Pressure drop.

As shown in Table 5, the pressure drop for the coil-side fluid (chilled water) had a value of 290,344 Pa, while the value of this parameter for the shell-side fluid (ethanol) was 0.097 Pa. Both values are below the limits established by the process (300,000 Pa and 0.5 Pa for water and ethanol, respectively). The high value obtained of the pressure drop for the coil-side fluid is due to the small value of the tube inner diameter (0.025 m), as well as the relatively high values of the calculated spiral total tube length (114.38 m), the velocity of chilled water (2.04 m/s) and the density of this fluid (999.94 kg/m^3).

Similarly, the low value of pressure drop obtained for the shell-side fluid is owed mainly to the very low values of the ethanol velocity (0.008 m/s) and the drag coefficient on coil surface (0.0836), as well as to the relatively high value of the shell side equivalent diameter (0.085 m). The same results were obtained in [23], that is, a higher pressure drop was obtained for the coil-side fluid (chilled water: 16,188 Pa) as compared to the pressure drop of the shell-side fluid (acetone: 0.2 Pa). This also agrees with the findings of [4], which reported that the pressure drop at the shell side is significantly smaller than that at the coil side.

Likewise, it can be observed that the higher value obtained for the pressure drop corresponds to the coil-side fluid since it has the highest value of the Reynolds number, which agrees with the reported by [13] and [24]. Also, in [4] it was determined that the pressure drop of both the shell-side and coil-side fluids increase with the increment of the mass flow rate.

4.3. Pumping power.

Regarding the values of Table 6, it will be necessary 375.21 W of pumping power for the chilled water, while the required pumping power for the ethanol can be considered negligible. This is owed mainly to the very small value of the calculated pressure drop obtained for this fluid.

5. Conclusions.

The thermo-hydraulic design of a helical coil heat exchanger was carried out in order to cool an ethanol stream coming from the top of a rectification column and by using a classical, well-known calculation methodology. Several design parameters were determined such as the overall heat transfer coefficient (65.88 W/m^2.K), the spiral total surface area (10.75 m^2), the spiral total tube length (114.38 m), the actual number of turns of helical coil (91) and the height of cylinder (4.12 m). The pressure drop of the coil-side fluid (chilled water) and the shell-side fluid (ethanol) were 290,344 Pa and 0.097 Pa, respectively, which are below the limits established by the heat exchange process for both streams. The pumping power required for the chilled water had a value of 375.21 W, while the pumping power for the ethanol stream can be neglected due to its very low value.

6.- Author Contributions.

1. Conceptualization: Amaury Pérez Sánchez.
2. Data curation: Yerelis Pons García, Elizabeth Ranero González.
3. Formal analysis: Amaury Pérez Sánchez, Daynel Basulto Pita, Eddy Javier Pérez Sánchez.
4. Acquisition of funds: Not applicable.
5. Research: Amaury Pérez Sánchez, Yerelis Pons García, Eddy Javier Pérez Sánchez. 6.
6. Methodology: Amaury Pérez Sánchez, Daynel Basulto Pita, Elizabeth Ranero González.
7. Project administration: Not applicable.
8. Resources: Not applicable.
9. Software: Not applicable.
10. Supervision: Amaury Pérez Sánchez.
11. Validation: Amaury Pérez Sánchez .
12. Writing - original draft: Eddy Javier Pérez Sánchez, Elizabeth Ranero González.
13. Writing - revision and editing: Amaury Pérez Sánchez, Yerelis Pons García.

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Nomenclature.

A	Spiral total surface area	m^2
A_{coil}	Cross-sectional area of coil	m^2
A_{shell}	Shell-side flow cross-section	m^2
C_D	Drag coefficient on coil surface	-
Cp	Heat capacity	kJ/kg.K
d_i	Tube inner diameter	m
d_o	Tube outer diameter	m
D_e	Shell side equivalent diameter	m
D_H	Average spiral diameter	m

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D_{Hi}	Inner spiral diameter	m
D_{Ho}	Outer spiral diameter	m
D_i	Shell inner diameter	m
D_K	Core tube outer diameter	m
E	Factor	m
f	Friction factor for flow inside the coil	-
F_t	Temperature correction factor	-
H	Height of cylinder	m
k	Thermal conductivity	W/m.K
k_W	Thermal conductivity of coil material	W/m.K
L	Spiral total tube length	m
L'	Calculated spiral total tube length	m
$LMTD$	Logarithmic Mean Temperature Difference	°C
m	Mass flowrate	kg/h
n	Actual number of turns of coil	-
N	Theoretical number of turns of helical coil	-
Nu	Nusselt number	-
p	Tube pitch	m
P	Pumping power	W
$\Pr$	Prandtl number	-
ΔP_{coil}	Pressure drop	Pa
$\Delta P_{(A)}$	Maximum allowable pressure drop	Pa
q	Volumetric flowrate	m^3/s
Q	Heat load	kW
R	Fouling factor	$K.m^2/W$
Re	Reynolds number	-
s_W	Coil wall thickness	m
t	Temperature of cold fluid	°C
$\bar{t}$	Average tempereature of cold fluid	°C
T	Temperature of hot fluid	°C
$\bar{T}$	Average temperature of hot fluid	°C
ΔT	Effective mean temperature difference	°C
U	Overall heat transfer coefficient	$W/m^2.K$
v	Velocity	m/s
V_{shell}	Volume available for the flow of fluid in the annulus	m^3

Greek symbols

α	Heat transfer coefficient	$W/m^2.K$
$\alpha_{coil(SP)}$	Heat transfer coefficient inside coiled tube based on inside diameter	$W/m^2.K$
$\alpha_{coil(SPa)}$	Heat transfer coefficient inside coiled tube based on the outside diameter of the coil	$W/m^2.K$
ρ	Density	kg/m^3
μ	Viscosity	Pa.s
η_p	Isentropic efficiency of the pump	-

Subscripts

1	Inlet
2	Outlet
c	Cold
coil	Coil-side fluid
h	Hot
shell	Shell-side fluid

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Implementation of gastrodiplomacy as a strategic axis of tourism development and contribution to the cultural dissemination of Ecuador

Implementación de la Gastrodiplomacia como eje estratégico de desarrollo turístico y aporte en la difusión cultural de Ecuador

María Belem Delgado Gómez[1]& Diana Delgado Campuzano[2]*

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* Author for correspondence.

* Author for correspondence.

Abstract.
Gastrodiplomacy refers to the strategies executed by a nation to spread gastronomic culture abroad, to make the culture known through the flavors of the territory through gastronomy. In Ecuador, the implementation of gastrodiplomacy symbolizes a viable alternative to be carried out as a strategic axis with a view to tourism development and contribution to the cultural dissemination of the diversity of Ecuadorian products and gastronomy. The purpose of this study was to propose the application of gastrodiplomacy as an implementation strategy by the national authority as a pillar of tourism development in Ecuador. The research methodology applied in the present study is of an exploratory nature with a qualitative approach given that the literature survey corresponding to gastrodiplomacy and its impact on the cultural diffusion of a country is used as a method; and the use of the Delphi method to validate the proposed strategies by experts in the field. The results of this research reflect the viability of implementing Gastrodiplomacy as a strategic axis of tourism development by the competent entities due to the high impact on the international cultural diffusion of Ecuador; given that success cases in countries in Asia and America have been studied, which is applicable in our country. In conclusion, the representative gastronomic diversity of our country that characterizes us for having four marked regions: Coast, Sierra, Amazon and Galapagos shows multiculturalism even in our products and gastronomy valued internationally.

Keywords:
Gastrodiplomacy - Strategic Axis - Development - Tourism - Dissemination - Cultural.

Resumen.
La gastrodiplomacia se refiere a las estrategias ejecutadas por una nación para difundir la cultura gastronómica en el exterior, dar a conocer la cultura mediante los sabores propios del territorio a través de la gastronomía. En Ecuador la implementación de la gastrodiplomacia simboliza una alternativa viable para llevarse a cabo en calidad de eje estratégico con miras al desarrollo turístico y aporte en la difusión cultural de la diversidad de productos y gastronomía ecuatoriana. El propósito del presente estudio fue plantear la aplicación de la gastrodiplomacia como una estrategia de implementación por parte de la autoridad nacional como pilar del desarrollo turístico en el Ecuador. La metodología de la investigación aplicada en el presente estudio es de carácter exploratorio con enfoque cualitativo dado que se emplea como método el levantamiento de literatura correspondientes a la gastrodiplomacia y su impacto en la difusión cultural de un país; y la utilización del método Delphi para validar las estrategias propuestas por parte de expertos de la rama. Los resultados de la presente investigación reflejan la viabilidad de implementar la Gastrodiplomacia como eje estratégico de desarrollo turístico por parte de los entes competentes debido al alto impacto en la difusión cultural a nivel internacional del Ecuador; dado que se ha estudiado los casos de éxito en países de Asia y América, que resulta aplicable en nuestro país. En conclusión, la diversidad gastronómica representativa de nuestro país que nos caracteriza por ser tener cuatro regiones marcadas: Costa, Sierra, Amazonía y Galápagos muestra la multiculturalidad inclusive en nuestros productos y gastronomía valorada a nivel internacional.

Palabras clave:
Gastrodiplomacia - Eje Estratégico - Desarrollo - Turístico - Difusión - Cultural.

1. Introduction

Gastrodiplomacy refers to the promotion of a country's culinary culture in order to share its essence, peculiarities, techniques, ingredients, and unique characteristics with people from other nations. Its development and recognition generate tourism activities with a cultural and gastronomic focus [1].

The term gastrodiplomacy does not appear in the dictionary of the Royal Spanish Academy (RAE), but etymologically it comes from the combination of two words: gastronomy and diplomacy, which together are understood as the art of preparing good food and its influence on politics and international relations [2].

Rockover [3] points out that gastrodiplomacy is an increasingly popular strategy for public diplomacy and has an impact on a country's brand. Furthermore, it fosters global awareness of different cultures through national brand promotion and international relations within the framework of inter-country engagement.

[1] Instituto Superior Tecnológico Escuela de los Chefs de Guayaquil; mbelemdelgado@gmail.com ; https://orcid.org/0009-0006-4224-6414 , Guayaquil; Ecuador.
[2] Universidad Estatal de Milagro; ddelgadoc@unemi.edu.ec ; https://orcid.org/0000-0001-7165-1255 , Milagro; Ecuador.

Economic, social, cultural, and political factors (political will) are fundamental in the implementation and empowerment of gastrodiplomacy by a government. As gastronomy is part of a country's cultural appeal, it must be linked to tourism development and the image projected both domestically and internationally.

According to Ecuador's 2023 Tourism Plan [4], the strategic pillars for tourism in Ecuador are quality destinations, connectivity, tourism security, marketing and promotion, and investment promotion, with a transversal focus on tourism competitiveness, accessibility, sustainability, inclusion, and innovation. It also proposes territorial coordination, collaborative governance based on information and communication technologies, as well as a regulatory framework and incentives.

The importance of gastrodiplomacy lies in establishing it as a strategy that transcends through a country's culinary culture and its international recognition. It contributes to the empowerment and pride of local culture, and on the other hand, generates appreciation for diversity, enriching the interculturality that has characterized humanity throughout history. Therefore, the goal of this research is to be useful to the national entity responsible for tourism activities, particularly with the involvement of the Central Government through the country's Embassies and Consulates in other nations.

Some authors, such as Moral (p. 1), define it as "the use of native food to project a specific national image abroad, establishing itself as an effective form of cultural diplomacy through which countries aim to gain reputation and influence in foreign societies" [5].

The global influence of gastronomy in introducing a new culture and proving its authenticity through products and the tasting of representative dishes from a specific territory is widely recognized. Regarding its origins, "... it was first embraced by Thailand, which has served as an example for other countries around the world to begin adopting measures to promote their culture through the flavors of their cuisine" [6].

In 2002, Thailand launched the "Global Thai" project, which made it one of the pioneering countries to use terminology and showcase its culture through its gastronomy [3]. This experience demonstrates that it is a tangible manifestation that allows crossing borders and promoting the adaptation of a people's typical and representative cuisine abroad.

In 2009, South Korea launched the "Korean Cuisine for the World" campaign, aiming to increase the number of South Korean restaurants abroad and promote its Hansik (traditional Korean cuisine), known for its fermentation techniques that allow many dishes to be consumed over long periods. This demonstrated that Korean food is as rich in flavors as it is in nutrients. The initiative included a program to improve training in Korean gastronomy at top culinary schools worldwide, scholarships for students of Korean cuisine, as well as a food truck that toured various countries to promote and offer tastings of their food [7].

Another example is Taiwan, which held international food fairs in major capital cities and airports around the world to promote its culinary culture [7]. Similarly, Japan, a country recognized worldwide for its sushi excellence, sent native chefs to teach sushi-making techniques in New York and London, where Japanese culinary schools have also opened, thus spreading its culture through teaching and learning [7].

Regionally, since 2008, Peru has integrated gastrodiplomacy into its cultural diplomacy strategy using two key tools: the Foreign Policy Plan for Culture, with clear objectives related to gastronomy, and the use of its country brand to promote Peru as a culturally attractive destination with a strong gastronomic offering [8]. Peru's success is based on three elements: the high value of its biodiversity, the cultural contribution and influence of migration processes, and its positioning as a center of food domestication and Incan cultural influence [9].

Moreover, chefs have influenced and led a shift in mindset within civil society, with the chef emerging as an agent of change. The discourse and promotion led by chefs have transcended and motivated the population to take ownership of their local gastronomy.

Ecuador's Ministry of Tourism [4], through the National Tourism Plan 2030, currently proposes that the strategic pillars of quality destinations, connectivity, tourism security, marketing and promotion, innovation, and investment promotion be supported by territorial coordination alongside collaborative governance, as well as strategic tourism data provided by big data. The regulatory framework also facilitates the regulation and categorization of tourism establishments, whose management is directed toward accessibility, sustainability, and inclusion [10].

The impetus for this research is based on the rich cultural and gastronomic heritage of Ecuador, which stems from its diverse climates, geography, and cultures. Therefore, developing a proposal leveraging this strength, which represents our cultural and natural diversity, is viable [11]. The application of gastrodiplomacy as an implementation strategy by the national authorities, as a pillar of tourism development, is both significant and coherent with the Constitution of the Republic of Ecuador [12], which is considered plurinational and multicultural (p.1, p.3).

This contributes to the national and international recognition of the gastronomic fusion resulting from migratory waves and local influences on cuisine as a cultural attraction of Ecuadorians.

According to statistical data from the National Financial Corporation [13], it is reported that "the Accommodation and Food Services sector totaled approximately $1,347.30 million in 2022, equivalent to a contribution to GDP of..." 1.90%" (p. 4). Therefore, it is entirely feasible for the food and beverage sector, focusing on local dishes, to be enhanced through policies from the national government aimed at the governing body of national tourism activities.

The purpose of this study has been to propose the implementation of gastrodiplomacy as a strategic initiative by the national authority, as a pillar of tourism development in Ecuador, as well as the synergy with the private business sector and academia. To this end, three specific objectives have been established: I) To identify theories and applications of gastrodiplomacy by other countries, II) To study the approaches to gastrodiplomacy in Ecuador, and III) To validate with experts in tourism and gastronomy the strategies of gastrodiplomacy to be implemented by the national authority as a pillar of tourism development in Ecuador, together with the private sector and academia.

2. Materials and Methods Applied

The research is exploratory, descriptive, and qualitative, as the method employed involves the review of literature through the analysis of publications, texts, documents, and records from other countries that have implemented gastrodiplomacy as foreign policy and a tourism promotion tool; as well as the application of the Delphi method, which builds consensus on execution strategies considered viable by tourism and gastronomy experts [14].

The first method, literature review, involves searching for academic publications related to gastrodiplomacy in Ecuador. For this purpose, studies and publications have been analyzed that encompass the positive high impact of gastronomic promotion, highlighting initiatives from Asian countries (Thailand, South Korea, Taiwan, Japan) as well as from Latin America, specifically Peru.

Additionally, tourism plans at the national level, tourism and cultural heritage magazines from Spain and Latin America, master's theses, and websites from international organizations such as UNWTO have been studied, spanning from 2001 to the present date.

Table No. 1
Studies related to Gastrodiplomacy internationally and in Ecuador.

No.	Tema	Autor Y Año
1	Thailand's gastro-diplomacy Like the cuisine, like the country	Diario The Economist, 2001.
2	Food as communication: Gastro diplomacy in South Korea.	Pham, M., 2013.
3	Turkey's soft power and cultural diplomacy: Historical and regional analysis factors.	Turbay, M., y Jaramillo M., 2013.
4	Gastronomy and Diplomacy: The Perfect International Relationship	Trejo, J.A., y Jiménez, M., 2013.
5	Soft power and cultural diplomacy, a re-emerging dynamic in international relations.	Jaramillo, M., 2015.
6	Gastrodiplomacy as a Foreign Policy Tool. Case study: Peru	Díaz Acevedo, M., 2016.
7	The II World Forum on Gastronomy Tourism emphasizes the relevance of culture and local communities.	ONU Turismo, 2016.
8	Gastrodiplomacy: Legitimization and credibility of culture through gastronomy.	Dávila Vallejo, D., 2017.
9	Strengthening the country image through the use of gastrodiplomacy in Chile's external projection, based on the Peruvian case.	Merino, C., 2018.
10	Traditional gastronomy as a tourist attraction in the city of Puebla, Mexico.	Acle-Mena, R. S., Santos-Díaz, J. Y., & Herrera-López, B., 2020.
11	Gastrodiplomacy: an opportunity for Latin America.	Mc Cubbin, R., 2021.
12	A conceptual and literary approach to gastrodiplomacy gastrodiplomacy as a destination brand driver.	González, S.M., 2021.
13	Gastrodiplomacy: a comparative study between Thailand and Peru.	Vega Gavilanes, 2023.

The The Economist newspaper highlighted in 2001 that the Thai government introduced Thai food to thousands of new palates around the world through approximately 5,500 restaurants, and would persuade more people to visit Thailand; this initiative could subtly help deepen relationships with other countries [15].

In 2013, Pham emphasized non-verbal communication through gastronomy and its impact on promoting a country's products and dishes, as well as the influence of a government's political will to showcase its culture [16].

The projection of emerging powers is a phenomenon that demonstrates the willingness of some states to reclaim political spaces from the past or to gain visibility they have never reached, according to Turbay and Jaramillo, 2013. Amid this discussion, there are other nations with different ambitions, as their reach is not global [17].

In the same year, Trejo and Jiménez discussed the influence that gastronomy holds within International Relations. This influence is explained using two theories of International Relations: Public Diplomacy and Social Constructivism [18]. For Jaramillo (2015), it is clear the extent and possibilities achievable through Turkey's soft power and cultural diplomacy, as well as the cultural lessons for Colombia, considering it a reemerging dynamic in international relations [19].

At the 2nd World Forum on Gastronomic Tourism, organized by the UNWTO, Basque Culinary Center, and Promperú, held in Lima, Peru in 2016, gastronomic tourism was emphasized as a tool for promoting destinations, closely linked with cultural diversity and biodiversity, recognized as fundamental tourist attractions. The preservation of both tangible and intangible heritage was conceived as a parallel process. Another value emphasized was the importance of gastronomy in bridging different cultures and facilitating interculturality, a process referred to as 'gastrodiplomacy' [20].

Researcher Díaz Acevedo, in 2016, noted that since 2008, Peru has integrated gastrodiplomacy into its cultural diplomacy strategy through two tools: its Foreign Cultural Policy Plan and the use of its country brand to promote Peru as an attractive destination due to its vast gastronomic offering [8].

In 2017, Dávila Vallejo, in his research "Gastrodiplomacy: Legitimacy and Credibility of Culture through Gastronomy," highlighted the key elements of evaluation and adaptability, cultural linkage as a mechanism of differentiation, emphasizing the authentic characteristics of the territory, and standardizing the offering to present a clear and defined product to consumers [20].

Merino (2018) proposed in his publication "The Improvement of Peru's International Projection through Gastrodiplomacy, and the Review of the Chilean Case for Replication" that Chile should develop policies to strengthen its national image through gastrodiplomacy, using the Peruvian experience as a guide. Peru's experience has been instrumental in improving its international projection [21].

Acle-Mena et al., in 2020, supported the idea that traditional gastronomy is a catalyst for tourism activity in the city of Puebla, Mexico. They suggested that to enhance its impact, the sector should improve aspects related to customer service and entertainment to achieve a better visitor experience [22].

In 2021, McCubbin, in the proposal "Gastrodiplomacy: An Opportunity for Latin America," identified that the successful models of Asian countries provide insight into how to achieve, through state policies that transcend governments and political parties, a national or regional strategy around gastrodiplomacy. This can result in international recognition, as well as economic investment and gastronomic tourism [23].

Silvia González, in 2021, described the different conceptual terms used in gastronomy, explaining gastrodiplomacy as an art for promoting a region or destination abroad and as a tool for cultural diplomacy [24].

Vega Gavilanes [25] added that there is the potential for a territory to promote a country's brand through food as an international attraction. His proposal involved a comparative study between Thailand and Peru, two countries that have excelled in gastrodiplomacy in Asia and Latin America. Both countries use diplomacy similarly, including historical background, program development, events, and media, though there are certain differences in these strategies.

While Thailand has an advantage due to its food's global popularity and longer use of gastrodiplomacy, Peru has managed to position itself as one of the most popular in Latin America.

In Ecuador, recognition from specialized gastronomic websites like Taste Atlas places encebollado as the second best soup in the world [26], and has ranked pan de yuca as the fifth best bread roll in the world [27].

Now, the second method involves applying the Delphi method to six experts in tourism and gastronomy, allowing the consensus of proposed strategies for implementing gastrodiplomacy as a strategic axis for tourism development and cultural diffusion in Ecuador. See Table No. 2.

The Delphi method consists of validating subjective information provided by experts on problematic situations, ranging from identifying topics to developing analysis tools and collecting information. It is widely recognized for its usefulness in the social sciences, respecting its peculiarities [28]. The importance of this application also lies in application of evaluating the results with quantitative analytical tools.

Firstly, from public sector leaders in tourism, as they are familiar with the public policies applied and feasible for promoting gastronomic tourism, as well as what exists or is similar to gastrodiplomacy within the national territory.

Secondly, the representativeness of the private sector (mainly hospitality and restaurants) influences the availability, interest, and commitment of this group to determine the feasibility of implementing and supporting gastrodiplomacy.

Thirdly, the participation of academia, whose pillars are teaching, research, and engagement with society, creates the vision of common benefit for the feasibility of applying this proposal.

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Considering that this technique validates decision-making based on the knowledge and expertise of professionals in the field of study, so that they evaluate and support the research conducted [29].

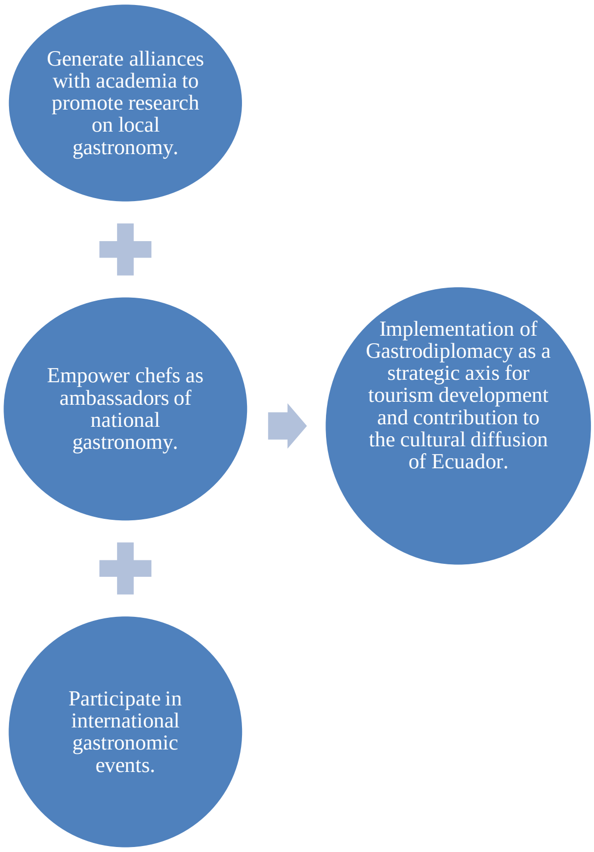
The experts who have been part of the strategy analysis in the Delphi matrix contribute to tourism-gastronomy development from non-governmental organizations (NGOs), academia, the private sector, and the public sector: Planeterra Foundation (1); Independent Tourism and Gastronomy Consultant (2); Escuela de los Chefs de Guayaquil, Higher Technological Institute (3); Pontifical Catholic University of Ecuador, Ibarra Campus (4); Insular Zonal Directorate of the Ministry of Tourism of Ecuador (5); and Hotel Palace (6). See Table No. 2.

Table No. 2.
Delphi Matrix Analysis: Implementation of Gastrodiplomacy as a Strategic Axis of Tourism in Ecuador.

Implementación de la Gastrodiplomacia como eje estratégico del turismo en Ecuador.								
No.	**Estrategias**	**Prom.**	**Expertos**					
			1	**2**	**3**	**4**	**5**	**6**
1	Political decision and inclusion in the Tourism Plan 2030	7,33	9	10	10	6	10	8
2	Agreements with the Ministry of Tourism and the Ministry of Foreign Affairs on dissemination policies	6,83	8	3	9	5	7	9
3	Positioning the importance of local gastronomy in civil society	8,00	10	4	10	7	7	10
4	Creation of gastronomic routes for the appreciation of national culture	8,50	10	4	10	9	8	10
5	**Empowering chefs as ambassadors of national gastronomy.**	**8,67**	**10**	**10**	**10**	**4**	**8**	**10**
6	Professionalize local gastronomy.	8,50	10	10	10	2	9	10
7	Agree with the national media to promote local gastronomy.	6,83	9	6	9	3	7	7
8	**Generate alliances with academia to promote research on local gastronomy.**	**9,00**	**9**	**8**	**10**	**10**	**8**	**9**
9	**Participation in international gastronomic events**	**9,33**	**8**	**10**	**10**	**8**	**10**	**10**
10	Economic boost for innovative cuisine (signature cuisine, application of techniques).	6,50	10	6	10	1	9	3

For this reason, the three strategies are reflected, which will consequently enable the achievement of the objective of this study: Implementation of Gastrodiplomacy as a strategic axis for tourism development and contribution to the cultural diffusion of Ecuador. See Image No. 1.

Fig. 1.
Strategies that enable the implementation of gastrodiplomacy as a strategic axis of tourism in Ecuador.



Based on the Delphi Matrix Analysis regarding the implementation of gastrodiplomacy as a strategic axis of tourism in Ecuador, the validation by the six chosen experts is evident, specifically for the three strategies with the highest averages:

Participation in international gastronomic events, Generating alliances with academia to promote research on local gastronomy, and Empowering chefs as ambassadors of national gastronomy.

The strategies that enable the implementation of gastrodiplomacy as a strategic axis of tourism in Ecuador, outlined in Image No. 1, were derived from the application of the Delphi Matrix on the implementation of gastrodiplomacy as a strategic axis of tourism in Ecuador.

3.- Analysis and Interpretation.

The analysis and interpretation of data are carried out based on the literary review of international relations, experiences from other countries regarding cultural and gastronomic diffusion, and country branding, as well as their significant positive impact on tourism. The Delphi method analysis by experts in the fields of tourism and gastronomy helps validate the strategies that will enable the achievement of the objective of this study, weighted and finalized according to the highest

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averages and lowest standard deviations marked in Table No. 2.

Literature Review: The data obtained from the literature review clarify that the closest related topic to this research in Ecuador is linked to the National Tourism Plan 2030, led by the Ministry of Tourism and developed in collaboration with key stakeholders in the industry. This plan, based on tourist demand and supply, aims to strengthen the country's tourism competitiveness through the creation of a favorable environment, policies for travel and tourism, infrastructure, and the valuation of natural and cultural resources. Gastronomy, an essential part of the cultural attraction of populations, showcases the essence of products and culinary preparations based on popular traditions.

The fourth axis, "Promotion and Marketing," of the National Tourism Plan 2030 focuses on reaching the tourist profile through digital media (social networks, platforms, etc.) that these groups use. However, the focus on gastronomic diffusion is not visibly established in the Tourism Plan 2023, which is an undeniable strength of the country that should be leveraged with a sustainable and responsible approach. There are thesis works proposing gastrodiplomacy in Ecuador, but as of now, there is no published information regarding a foreign or tourism policy focused on gastronomic diffusion.

Delphi Method: From the application of the Delphi Matrix method, unanimous consensus is reflected by the six experts who validate the proposed strategies for implementing gastrodiplomacy as a strategic axis of tourism in Ecuador; representing academia, the public sector, and the private sector related to gastronomy and tourism.

From the analysis, the validation is evidenced specifically for the three strategies with the highest averages, which stand out as follows:

Participation in international gastronomic events (average of 9.33),
Generating alliances with academia to promote research on local gastronomy (average of 9.00), and
Empowering chefs as ambassadors of national gastronomy (average of 8.67).
Participation in international gastronomic events aims to strengthen the experience of internationalization and diffusion of the country's most representative dishes, accompanied by their respective storytelling that strengthens and explains their origins, history, and applications.

Generating alliances with academia to promote research on local gastronomy considers the importance of tourism and gastronomy programs (graduate profiles, subjects, bibliographies), reviving higher education networks with a gastronomic focus to strengthen national identity and integrate the community (the general public).

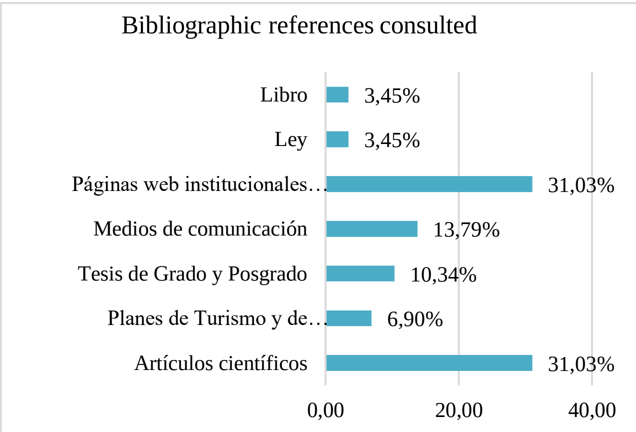
Empowering chefs as ambassadors of national gastronomy through participation and encouragement from the private sector, academia, and the public sector, leading processes to raise visibility and consolidate the role of the chef regarding the preservation of iconic and representative preparations of the region.

For this reason, the three strategies are reflected, which will consequently allow for the accomplishment of the objective of this study: Implementation of Gastrodiplomacy as a strategic axis of tourism development and contribution to the cultural diffusion of Ecuador.

In Table 1, publications related to gastrodiplomacy are presented, along with the influence on foreign policy, international relations, communication through gastronomy and the flavors of nations, as well as the strengthening of the country brand through its application both internationally and within Ecuador.

Within the country, it is evident that there is no information on the application by the relevant organizations. However, proposals have been reflected in the form of undergraduate thesis projects, scientific publications, media articles, and tourism plans. See Fig. 2.

Fig. 2.
References consulted regarding Gastrodiplomacy.



For the development of this research, twenty-nine bibliographic references have been consulted: 9 articles from scientific journals (31.03%), 9 institutional and business websites (31.03%), 4 national and international media outlets (13.79%), 3 degree and master's theses (10.34%), 2 tourism and marketing plans (6.90%), 1 law (3.45%), and 1 book (3.45%). This represents a total of twenty-nine sources.

4. Discussion

Ecuador is characterized by its mega-diversity in both natural (flora and fauna) and cultural (ethnic) aspects, making it a destination with great potential for gastronomic development, offering cultural appeal and representing the territory.

Reconsidering the application of Gastrodiplomacy in Ecuador raises questions about the reality in the national territory: What strategies have other countries implemented? What is Ecuador's strategy regarding Gastrodiplomacy? Has it been identified as a policy by the Central Government, the Ministry of Foreign Affairs, and the Ministry of Tourism? Who are the key actors for the cultural diffusion of Ecuadorian gastronomy?

According to the objectives set forth in this study, information was gathered to identify the successful cases of Thailand, South Korea, Taiwan, Japan, and Peru. However, there is no information from Ecuador regarding its application by the Central Government or the relevant ministries.

On the other hand, the Ministry of Tourism's gastronomic diffusion is reflected through participation in major international fairs such as FITUR in Spain, ITB Berlin in Germany, and WTM Latam in Brazil. However, gastrodiplomacy goes beyond just this; it lies in the large-scale cultural diffusion of gastronomy to the general population (people) of other nations.

Thus, this study is of high impact for the country, as tourism as an economic activity influences the dynamism of the economy on a large scale. Therefore, the literature review and validation of strategies by experts clearly show that its implementation is feasible as a strategy for the national authority to adopt as a pillar of tourism development in Ecuador.

If the proposed gastrodiplomacy is applied, it will create a positive image of the country despite the current social and economic reality and will also attract tourists eager to experience the nature and culture (including gastronomy) that our country offers. This will be possible as long as gastrodiplomacy is adopted as a strategic axis of national tourism development and is considered a public policy for the benefit of the population.

The limitations of the findings relate to the scope and impact on the Central Government and political will. The execution is viable by uniting the efforts of non-governmental organizations, the private sector, and academia, in promoting our products and gastronomy, which are valued internationally. Therefore, it is essential to consider this.

It is important to note that the three key actors for the viability of this proposal are coordination, commitment, and synergy between the public sector, the private sector, and academia.

5. Conclusions

In conclusion, the gastronomic diversity of our country is characterized by four distinct regions: the Coast, Highlands, Amazon, and Galápagos, each showcasing multiculturalism, reflected even in our internationally valued products and gastronomy. Therefore, the diffusion of our gastronomy is a key strategy that will help make Ecuador better known and recognized internationally.

The immediate recommendation is the implementation of this research with an inclusive approach involving all sectors of society that can influence the State, whose results will effectively contribute to the country's tourism and, consequently, economic development.

For the execution of the proposed strategies, there must be commitment from the public, private, and academic sectors to ensure the success and empowerment of this research proposal.

From the public sector, this involves the Central Government and agreements through the Ministry of Tourism, provincial and municipal offices, and Ecuadorian Embassies and Consulates abroad, to foster spaces for cultural discussion and gastrodiplomacy, with strategic partners and non-profit organizations to position Ecuadorian gastronomy internationally.

From academia, through educational services, empower gastronomic professionals to understand the significance of national culinary foundations, recognizing their origin, history, and current consumption.

From the private sector, the focus is on the professionalization of the gastronomy field and its promotion both nationally and internationally, ensuring high-quality national cuisine that also fosters the tourism experience within the country.

The reflections generated by this study represent an opportunity based on the implementation of Gastrodiplomacy as a strategic axis of tourism development and contribution to the cultural diffusion of Ecuador. The objectives outlined make it clear that with the combined contributions from academia (through professionalization and training), the private sector (creating quality, sustainable, and responsible offerings), non-governmental organizations (with continuous contributions to less developed communities), and the public sector (setting guidelines at national, provincial, and municipal levels), the execution is indeed possible.

6.- Author Contributions.

1. Conceptualization: María Belem Delgado Gómez and Diana Valeria Delgado Campuzano.
2. Data curation: María Belem Delgado Gómez and Diana Valeria Delgado Campuzano.

3. Formal analysis: María Belem Delgado Gómez and Diana Valeria Delgado Campuzano.
4. Acquisition of funds: María Belem Delgado Gómez and Diana Valeria Delgado Campuzano.
5. Research: Maria Belem Delgado Gomez and Diana Valeria Delgado Campuzano.
6. Methodology: María Belem Delgado Gómez and Diana Valeria Delgado Campuzano.
7. Project administration: María Belem Delgado Gómez and Diana Valeria Delgado Campuzano.
8. Resources: María Belem Delgado Gómez and Diana Valeria Delgado Campuzano.
9. Software: María Belem Delgado Gómez and Diana Valeria Delgado Campuzano.
10. Supervision: María Belem Delgado Gómez and Diana Valeria Delgado Campuzano.
11. Validation: (María Belem Delgado Gómez and Diana Valeria Delgado Campuzano.
12. Visualization: María Belem Delgado Gómez and Diana Valeria Delgado Campuzano.
13. Writing - original draft: María Belem Delgado Gómez and Diana Valeria Delgado Campuzano.
14. Writing - proofreading and editing: María Belem Delgado Gómez and Diana Valeria Delgado Campuzano.

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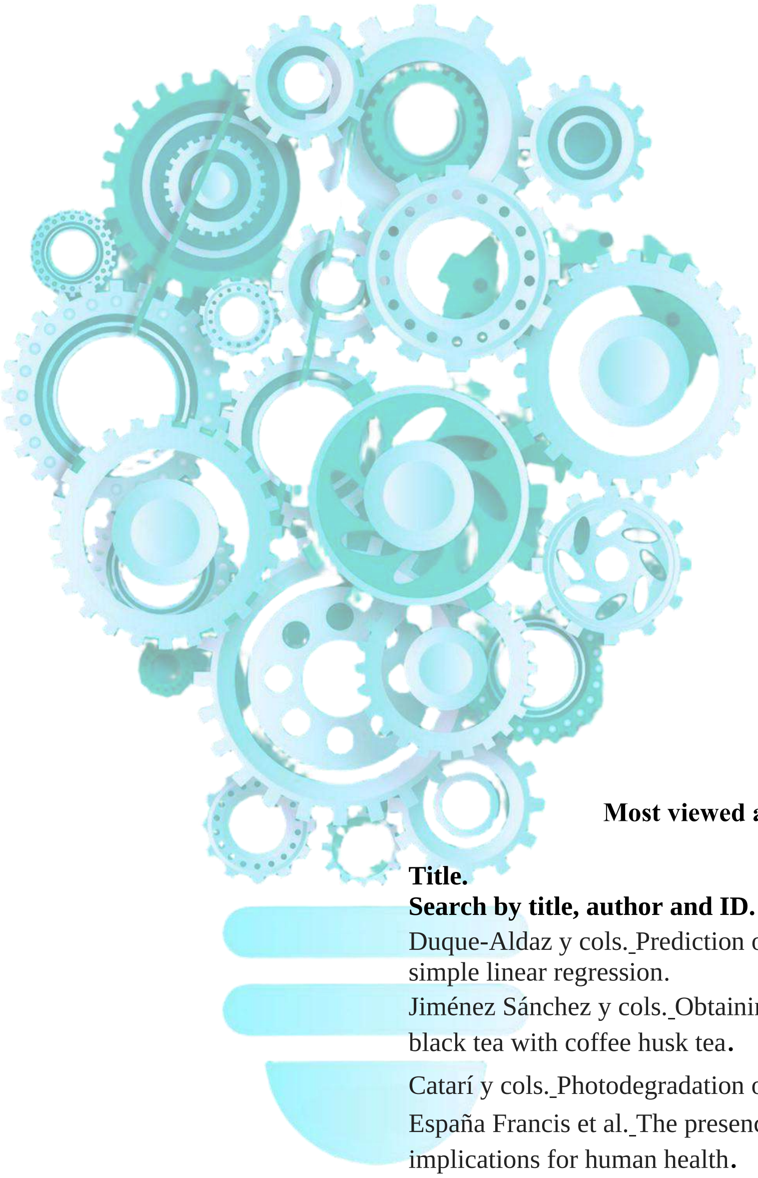

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Principal Contact
Francisco Javier Duque-Aldaz
University of Guayaquil
Phone +593 98 564 1201 WhatsApp
Phone +593 99 576 0762 Telegram
francisco.duquea@ug.edu.ec
inquide@ug.edu.ec

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