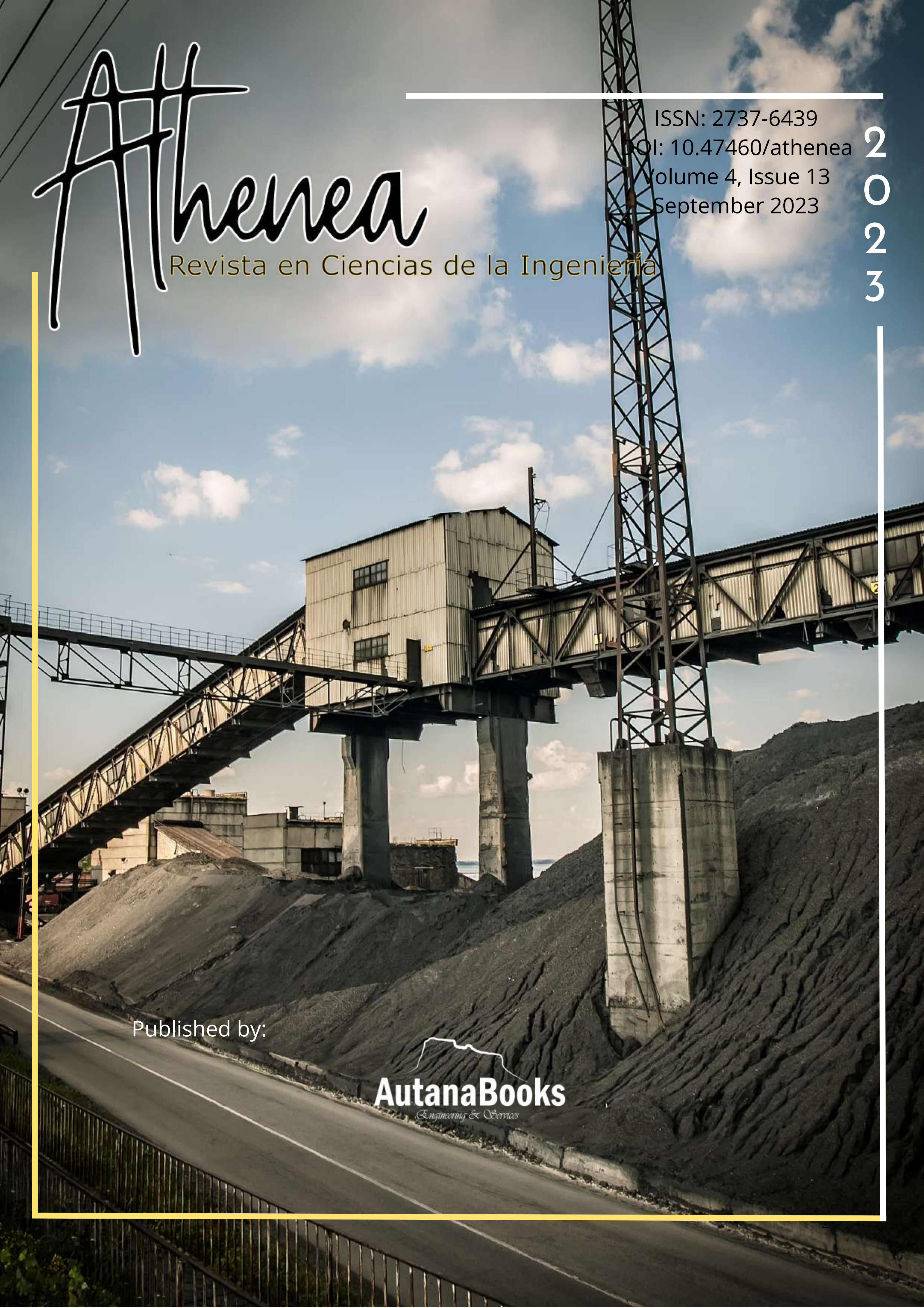
Athenea

Revista en Ciencias de la Ingeniería

ISSN: 2737-6439
DOI: 10.47460/athenea
Volume 4, Issue 13
September 2023

2023



Published by:
AutanaBooks
Engineering & Services

ATHENEA JOURNAL

JOURNAL IN ENGINEERING SCIENCES

Electronic Journal Edited By AutanaBooks.

Quarterly Periodicity

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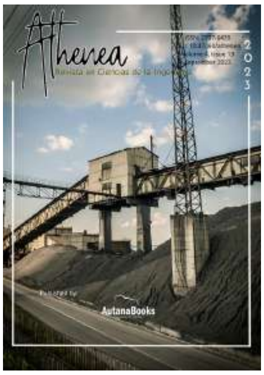

Our cover shows the contribution of engineering in the mining industry, being engineering also contributes to a wide diversity of industries, companies, and current technological developments.

Volume 4 // Issue 13 // March 2023
DOI:10.47460/athenea
ISSN: 2737-6439

Viewing the Journal:
https://athenea.autanabooks.com/index.php/revista

"by the grace of God"

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AutanaBooks, Quito, Ecuador

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JOURNAL IN ENGINEERING SCIENCES
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ACADEMIC COMMITTEE

Athenea Journal
Volume 4 // Issue 13 // September 2023
DOI:10.47460/athenea/v4i11
ISSN: 2737-6439

Content

Editorial

In today's era of technology and innovation, engineering has become the fundamental foundation of the industry. From advances in manufacturing to sustainable energy solutions, engineering plays a vital role in creating and improving the products, services, and processes that shape our world. In this context, engineering is the discipline that drives the constant transformation of the industry. Engineers design and develop critical infrastructure, efficient transportation systems, advanced machinery, and technological solutions that improve the quality of life of people and the competitiveness of companies. Engineering is present in every corner of the world, tackling complex challenges and finding ingenious solutions.

Innovation, which is essential for the industry, flourishes thanks to the creativity and knowledge of engineers. From process automation to the artificial intelligence revolution, technological advances are driving significant change in the way we produce and consume goods and services. The industry has become more efficient, sustainable, and adaptable thanks to inventive minds seeking innovative solutions. On the other hand, sustainability is another pillar of modern engineering. Engineers play a crucial role in finding environmentally responsible solutions that mitigate the industry's impact on our planet. They develop technologies and practices that reduce resource consumption, promote renewable energy, and minimize waste, helping to build a more sustainable and resilient future.

Furthermore, engineering is a discipline that encourages collaboration and diversity. Multidisciplinary teams of engineers work together to address complex problems from diverse perspectives, leading to more complete and effective solutions. Including diverse voices in engineering ensures that solutions adapt to the needs of an increasingly globalized society.

In this edition of our Athenea magazine, we will explore the impact of engineering on the industry, highlighting successful results, technological advances, and visions for the future. Engineering is more than a profession; It is a passion, a vocation, and a driving force that drives human advancement. In Athenea Journal, we highlight the multiple applications of engineering for the world.

Dr. Franyelit Suárez
Athenea Journal Publisher
Engineering Sciences

ISSN-E: 2737-6419

Athenea Journal,
Vol. 4, Issue 13, (pp. 7-16)

https://doi.org/10.47460/athenea.v4i13.60

Effects of thermoviscous flow and mechanical stresses on nitrogen desorption during iron transformation

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Received (3/06/2022), Accepted (27/08/2023)

Abstract. - The objective of this paper is a theoretical calculation of the mechanical stresses due to nitrogen pressure in an iron vacancy in the temperature range of 600 to 1100 °C and its effect on the swelling phenomenon associated with the high-temperature viscous flow. The method for quantification is theoretical and based on the analysis of experimental data reported in the literature. Two equations related to the variable were generated: swelling index with time and the stress due to nitrogen pressure. Both the variables are described in increasing ways and correlated significantly at the 99% confidence level. The equations include the value of stresses obtained from previous papers for ferrite (Feα) of 621, 2 Kgf/mm2 and for austenite (Feγ) of 727, 6 Kgf/mm2. The overall effect when opposing these values to the average sample cold compression strength of commercial samples, which varies with the corresponding degree of reduction, the final value of this parameter results in the range of 35.2 and 69.6 Kgf/mm2.

Keywords: Swelling, nitrogen, reduction, stresses.

Efectos del flujo termoviscoso y de las tensiones mecánicas en la desorción de nitrógeno durante la transformación del hierro

Resumen: El objetivo de este trabajo es realizar un cálculo teórico de los esfuerzos mecánicos debidos a la presión de nitrógeno en una vacante de hierro en el rango de temperatura de 600 a 1100 °C y su efecto sobre el fenómeno de hinchamiento asociado al flujo viscoso a alta temperatura. El método de cuantificación es teórico basado en el análisis de datos experimentales reportados en la literatura. Se generaron dos ecuaciones que relacionan la variable índice de hinchamiento con el tiempo y con el estrés por presión de nitrógeno, en ambas las variables se relacionan de manera creciente y se correlacionan de manera significativa al 99% de confianza. Las ecuaciones incluyen el valor de tensiones, obtenido de trabajos anteriores, para ferrita (Feα) de 621,2 Kgf/mm2 y para austenita (Feγ) de 727,6 Kgf/mm2. El efecto global resultante al oponer estos valores al promedio de resistencia a la compresión en frío de las muestras comerciales, que varía con el correspondiente grado de reducción, da como resultado el valor final de este parámetro en el rango de 35.2 y 69.6 Kgf/mm2.

Palabras clave: Hinchamiento, nitrógeno, reducción, esfuerzos.

I. INTRODUCTION

This investigation continues the swelling of iron oxides in metallization processes in the FeO/Fe phase transition [1]. In this theoretical work, a mechanism and a calculation method are defined to obtain the values of the pressure exerted by the absorption of nitrogen gas molecules. Consequently, the stresses generated by the desorption of three nitrogen gas molecules inside a point defect or vacancy of the crystal lattice need to be estimated in the presence of iron allotropic phases of ferritic (Feα) and austenitic (Feγ) iron at temperatures between 900 and 1100 °C, respectively, without quantifying thermoplastic effects on iron.

The objective is to calculate the stresses (pN2) and their relationship with the swelling phenomenon, incorporating the thermoplasticity characteristics of iron in the temperature range associated with the evolution from nascent iron to when the highest metallic iron content is obtained during the reduction process in the temperatures range 600 to 1100 °C. The following method was used for the purpose: (a) setting the temperature for the formation of iron; (b) calculations of the stress produced by nitrogen solubility in metallic iron described in the previous aimed temperature range [1], (c) fixing of temperature where iron acquires the thermoplastic property. Thus, apply the plasticity calculation method, determine the retention time at each reduction temperature, and associate the stress values with the swelling index (HI).

To quantify the values of the swelling index (HI) due to the expansion of dissolved nitrogen in a cluster of iron vacancies. It is (convenient) necessary to highlight that obtaining solid-state iron begins by reducing its minerals, oxides generally having fragile mechanical properties. The reduction progress starts with the increase in temperature and the presence of reducing agents; this process initiates metallic iron formation. The oxides and materials of known plastic properties at room and high temperatures present, and the viscous flow predominates; consequently, it is necessary to define these properties and relate them to the nascent iron. The thermoplastic property of iron will favor the participation of the abnormal swelling (HA) phenomenon if the stress produced by the pressure of nitrogen is greater than the yield stress and even more significant than the breaking stress. The value of the stresses previously obtained for Feα was 621.2 Kgf/mm2, and for Feγ, it was 727.6 Kgf/mm2. The criteria to incorporate and determine the start temperature of the thermoplastic effect of the metal is based on multiplying its melting temperature of the phases involved, FeO 1377ºC and 1535ºC for iron, by a specific proportionality factor, whose value varies depending on the source consulted.

II. DEVELOPMENT

A. Fixing the nascent iron Nano crystal particle's temperature

In the reduction process of hematite iron oxide, with the increase in temperature, the well-known transformation to magnetite, wustite, and metallic iron occurs; this begins with the formation of Nanocrystals. After exceeding the critical radius, these will generate the nuclei and growth of iron Feα and become crystals, and to reach the cubic crystalline structure centered on the body, it is necessary to group at least nine atoms, two per cell with an edge of 0.33 nm. Thus, it turns out that the nascent iron is formed by Nanocrystals, consistent with experimental results obtained in [2] when iron nucleation is formed on wustite reduced with hydrogen at 800 °C and from a spheroidal nucleus with a diameter of 3.6 nm. The further growth of a pyramidal body with a square base with sides 4-8 nm and a height of 1.2-1.8 nm, as shown in Image 1 below determines the temperature at which the Nanocrystals appear. For this assessment, the Chaudron triple point of the iron-oxygen equilibrium diagram was used; this is the temperature point at which the magnetite/wustite/iron phases coexist simultaneously and, according to [3], is 590°C. For calculation purposes, a reference temperature of 600 °C was assumed.

Fig. 1. Semi-reduced natural ore particle reduced with 100% hydrogen, showing wustite (light gray) and several metallic iron nuclei on the wustite surface.
Source: Author files.

B. Stress calculations in iron allotropic phases

Following the proposed calculation methodology to determine the pressure of three nitrogen molecules in the vacancy of the iron crystal lattice, without considering thermoplastic effects, used in [1], and starting from 600 °C, the stress values were obtained, as shown in Table 1. It also got the relationship with the value of resistance to rupture of the allotropic phases of iron at room temperature; the obtained values are 28 and 105 Kgf/mm2 for Feα and Feγ, respectively.

Table 1. Stress produced by nitrogen in a vacancy of metallic iron in the study temperature range.

Fe allotropic phase	Temperature (°C)	Stress (Kgf/mm^2)	Stress/Rupture Ratio
Feα	600	462. 4	16.5
Feα	700	515.5	18.4
Feα	800	568.2	20.3
Feα	900	621.2	22.2
Feγ	1000	673.9	6.4
Feγ	1100	727.6	6.9

These stresses, knowing that they exceed the breaking strength of the iron, will be indirectly related to the expansion of the solid or agglomerate through the increase in the radius of the vacancy due to the thermoplastic effect that occurred in the material, depending on the time of agglomerate retention at each of the indicated temperatures.

The Nanocrystals generated at 600 °C will become crystals as the reduction process progresses and the temperature increases since most industrial reduction processes are carried out under dynamic, not isothermal, conditions.

C. High and low-temperature limits and the iron thermoplastic effect

The mechanical properties of materials are affected by temperature, specifically in crystalline solids such as metals and their alloys. Thus, the resistance properties of metals decrease with the increase in temperature, in exchange with the rise in plasticity properties and depending on the temperatures, stresses, and deformation speed. This can be achieved by the metal adopting a behavior quasi-viscous. It behaves like a fluid, increasing its original dimensions and limiting its use at high temperatures. In the criteria to determine the limits between low and high temperature, the correction factor is disclosed in [4], p. 373, and [5], p. 450, which is Tlow 0.5 and Thigh > 0.5 Tf. In an issue, it is considered to highlight that, in ferrous materials, the viscous flow begins at 420-430 °C, p.p. 355 and 429, respectively. It would correspond to a factor of 0.39, while in [6], p. 363, an aspect of 0.33 or 0.5 is considered, and in [7], p. 5, the plastic deformation starts from T > 0.6 Tf.

Thus, at high temperatures, it is necessary to consider the viscous flow due to hot forming or slow creep (Creep), as in the present work where the vacancy cavity is subjected to nitrogen pressure. When deformed at high temperatures, the material's response presents a curve similar to plastic flow at low temperatures. However, according to [6], these results do not allow predicting the behavior at high temperatures. However, in the temperature range studied for the FeO/Fe transformation, at 600 °C for nascent iron, it corresponds to the factor 0.48 (8), and for higher temperatures, values of 0.39 can be considered to 0.33, which is in the high-temperature range for the effects of thermoplasticity, viscous behavior.

To quantify the plasticity of iron at temperatures above 420 °C, equation (1) was used [9].

$$l = lo\,[1 + \beta\, t^{\frac{1}{3}}]e^{kt} \qquad (1)$$

l = Length of the material according to the time elapsed at the set temperature.
lo = Length at the instant of applying the effort.
β = Slope of strain rate, known as transient flow.
t = Time.
k = Slope of strain rate, called viscous flow.

According to [10], the parameters lo, β, and k are constants that must be determined experimentally since they correspond to physical processes, being necessary to obtain them to generate the curve that represents the thermoplastic characteristics of the material. In this regard, in his experimental results, p. 336, values of β and k are collected for iron, lead, copper, tin, and mercury at different temperatures. From their analysis, the following conclusions were highlighted:

- β, in general, presents slight variation with the increase in temperature, with a tendency to decrease.

- βFe, at a temperature of 444 °C (factor 0.40), although it increases with effort, tends to a constant value of 0.0210. When compared with the values of βPb, it presents a value of 0.045 at 17 °C, low temperature for Pb, and 0.043 at 160 °C (Thigh), associating it with the main result of his work, [10], p. 332, where he expresses "it is to show that typical metals of widely different natures obey the same general flow law," it is assumed that βFe will be maintained at high temperatures, that is, above 444 °C, so βFe = 0 will be used,0.0210.

- The value of k increases with the increase in temperature. With the effort to determine the values that it acquires at temperatures higher than 444 °C, it is necessary to know one of the following characteristics of iron: (a) the curve of real deformation (ε) as a function of the residence time at the temperatures previously set from 600 °C, (b) the constants indicated above for the same thermal range, data not available in the literature. Based on [4] "at elevated temperature viscous creep is predominant," p. 372; and the proof of it concerning k, p. 362, where it can be interpreted as independent of temperature, being consistent with results of viscous creep in aluminum, where a graph taken from [11] is shown showing the invariance of the relationship: ε = f(t), for absolute temperatures: 424, 478 and 531, p. 376, with factors 0.45, 0.46 and 0.57 respectively, the value of kFe = 0.00033 will be assumed. In the real case that it was more significant, an increase in stretching would be obtained with an increase in volumetric expansion, thus maintaining the accepted value of k, and a lower swelling index would be obtained.

D. Fixing the sample soaking time temperature range of 600 °C - 1100 °C

The sample soaking time will depend on the heating rate used in the reduction processes, whose values do not vary appreciably between them, as shown in Table 2, which summarizes the results of the best-known commercial processes.

Table 2. Heating rate according to industrial reduction processes.

Process	Origin	Heating rate (°C/min)	Source
COREX	Experimental	3.3	[12] p. 16. Fig. 4.1.2.3.
HyL, Midrex	Oven design	3.8 – 5.0	[13] p.p. 87-91.
Blast furnace	Experimental	5.0	[14]

The 5 °C/min rate will be used, considering that by applying the relationship (1), the length obtained for the 3.8 rates and 5 °C/min, a variation of 0.76 % is generated, that is, produces little impact, and also allows to be consistent with the search for greater productivity. For an increase of 100 °C, with a rate of 5 °C/min., the residence time equals 20 min. To associate the heating rate with the residence time of the material at temperatures between 600 and 1100 °C, heating bands were defined. A 100 °C increase in temperature would allow them to be associated with the retention time, and It accumulates as the temperature rises since the reduction process is continuous. Table 3 shows the results of this approach.

Table 3. Sample heating ranges, average temperatures, and retention time.

Heating bands (°C)	Average temperature (°C)	Soaking time (min)	Heating bands (°C)	Average temperature (°C)	Soaking time (min)
550-650	600	20	850-950	900	80
650-750	700	40	950-1050	1000	100
750-850	800	60	1050-1150	1100	120

III. METHODOLOGY

The quantification method used is a theoretical approach, defined in the previous section, of a mechanism where the (a) physicochemical aspects of adsorption-desorption of nitrogen gas are associated, (b) crystalline structure of the material, (c) experimental data reported in the literature and (d) the ideal gas equation to facilitate algebraic calculations. For the study subjects, the phenomenon of abnormal swelling that can occur in the reduction of iron minerals in the solid state is included in the study, and through intentional sampling, six samples were fixed to relate the dependent variable (IH) with the reduction retention time and nitrogen pressure at a temperature of 600 to 1100°C.

Having defined the iron retention time at each average temperature, the expanded length is estimated by (1), considering the following values for the constants:

lo = initial length = vacancy radius of Fe crystal lattice: 0.124 nm.
β = 0.0210
k = 0.00033

IV. RESULTS

A.Swelling Index relation with iron thermoplasticity

The resulting values of the expanded length make it possible to obtain the volume change concerning the initial volume of the vacancy left by an iron atom (8.0 10-3 nm3) and thus the swelling index (IH%), which will be associated with temperature and time and may be modeled dynamically. Results are shown In Table 4.

Table 4. According to residence time and temperature, the iron swelling index is associated with nitrogen pressure.

Temperature (°C)	Retention time (min.)	Expanded length* (nm)	Expanded Volume x 10^{-3}(nm^3)	IH** (%)
600	20	0,132	9,634	20,4
700	40	0,135	10,306	28,8
800	60	0,137	10,771	34,6
900	80	0,139	11,250	40,6
1000	100	0,141	11,742	46,7
1100	120	0,142	11,994	49,9

* Calculated (1). ** Obtenidos a través de Norma ISO 4698 [15].

B. Swelling index (HI) mathematical relationship with retention time

The dispersion graph is obtained through the Excel software, Fig. 1, with the regression line, dotted, and its equation (2) that allows estimating one variable from the other in the considered range and thus its correlation. This determines the degree of dependence between these variables in direction and magnitude, represented by the Pearson index (r). From the above data, it is possible to obtain a clear mathematical expression from the curves presented in Figure 1 and shown in Equation 2 for the estimation of the volume increase of an iron Nano crystallite.

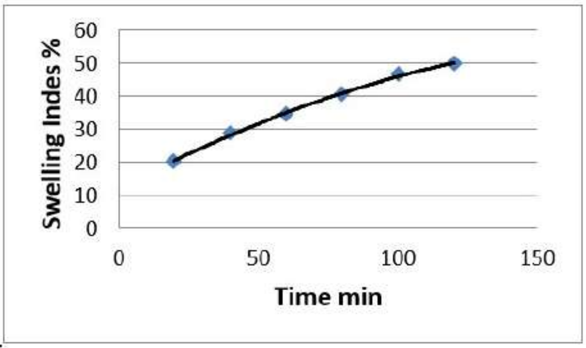

Fig.2. Retention/soaking time effect on the swelling index by iron induces thermoplasticity by partial pressure on N2 gas absorption desorption hysteresis.
Source: The author

$$IH\,(\%) = -0{,}0011\,t^2 + 0{,}451\,t + 11{,}98 \qquad R^2 = 0{,}998 \qquad (2)$$

C. Mathematical relation between the swelling index and stresses due to the nitrogen pressure

In Table 1, it is shown that the stress generated by the nitrogen pressure in an iron vacancy exceeds the value of its resistance to breakage in a minimum ratio of 6.4 and a maximum of 22.2 times because this pressure increases the volume of the cavity depending on whether the thermoplastic response of the iron produces its rupture and gas escape, recovering the elastic deformation but not the plastic one, thus, utilizing the expanded volume, Table 4, the pressure is quantified through the procedure developed in [1], the values are recorded in Table 5.

Table 5. The swelling index in iron is associated with the effort generated by the nitrogen pressure.

IH (%)	20,4	28,8	34,6	40,6	46,7	49,9
Stress (Kgf/mm^2)	130,4	135,9	143,4	150,1	156,1	164,8

From the values in Table 5, a mathematical equation can be obtained through Figure 3 described in equation 3.

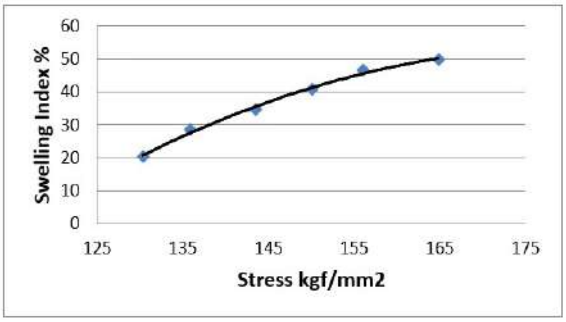

Fig. 3. Effect of the stress created by the nitrogen gas absorption on metallic iron on the final swelling index (percentage).
Source The author.

$$HI\ (\%) = -0{,}0126x^{*}\ 8kgf/mm2)^2 + 4{,}564^{*}\ (Kgf/mm2) - 360{,}46 \qquad (3)$$

At this stage, it is worth bearing in mind that the cold compression strength of manmade iron oxide agglomerates drops sharply with extended reduction time to 9 min; nevertheless, the compressive strength remained at the same level as that of 1 min. The reduction degree reached 11.11% at 1 min, corresponding to the magnetite phase, and finally increased to 32.45%rresponding to the wustite stage at 9 minutes. This effect is associated with the porosity increase and defect generation in the sample periphery, which causes strength loss [16]. The reduction step of hematite to magnetite causes the most extensive strength loss of 75.85% to approximately 200 Kgf/mm2, as shown in Fig. 4.

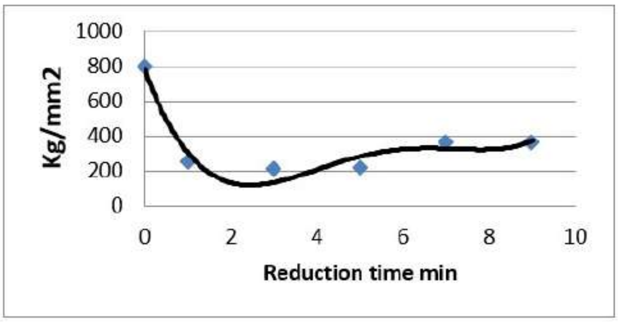

Fig. 4. Effect of reduction time on the compressive strength of iron aggregates in the transition from hematite to magnetite (16).
Edited by the author.

The effect shown in Fig. 4 can be represented mathematically by a polynomic equation shown in the polyphonic relationship in equation 4.

$$\textbf{Stress Kg/mm2} = 1.3583\ t4 - 30.464\ t3 + 234.82t2 - 681.12t + 777\quad R^2 = 0.9395\ (4)$$

With these two expression stress values are presented in Table 5, and considering that it is an opposite vector working against the compression force that maintains the solid condition of the reduced sample obtained by equation 3, the resulting stress value may be in the range of 69.6 and 35.2 Kgf/mm2.

The mathematical findings in this research pay the importance of the strength of liquid-bound granules, which depend on at least three forces: (1) interparticle friction; (2) capillary and surface tension forces, supposed to be thermo creep of viscous FeO/Fe material, in the liquid between the nanoparticles; (3) viscous forces in the liquid between the particles. The former two have been addressed and quantified in this paper [17], [18].

The high correlations obtained in the equations of Figures 2 and 3 allow the association of the values with an increasing sense and a strong dependence between the variables. As in the present case, consider the correlation index robust due to the low dispersion between the values obtained and the regression line. Since the Pearson index does not give a cause-effect relationship, it is convenient to carry out a significance test. The test was done by comparing the statistical value (tc) of Student, calculated using (4) [19], p. 118, with the double-tailed tabulated value and degree of freedom (n-2), in the relationships: IH versus f(time) and IH versus f(pN2), with the null hypothesis Ho of "there is no correlation between the variables. "

$$tc = \frac{|r| \times \sqrt{n-2}}{\sqrt{1-r^2}} \quad (5)$$

The significance test result allowed us to reject the null hypothesis and accept a significant correlation with a confidence level of 99%. The relationships, IH versus f (time) and IH versus f(pN2), of Fig. 2 and 3, are consistent with the physical phenomenon of the reduction process. The former process involves the thermoplastic characteristics of both phases, considered FeO and iron, the time-temperature rise, and the expansive effect of the nitrogen pressure, which allows the assumption to be valid for the stress values presented in Table 5. These values, which are lower when compared with those of Table 2, were obtained without quantifying the expansive effect due to the thermoplasticity of iron. The data in Table 4 was used to establish the HI with the temperature variation relationship and obtain its linear regression and correlation.

CONCLUSIONS

- This research has demonstrated and mathematically supported the triggering cause and effect of nitrogen's atomic absorption/molecular desorption in nascent iron nanoparticles during the wustite to iron reduction path.

- Including this effect reveals this gas as a hidden, and so far, disregarded, impurity, which triggers the abnormal swelling mechanism by inducing the internal mechanic stresses.

- The magnitude of the stresses generated by the nitrogen pressure in the iron crystal lattice and the mathematical relationship with the abnormal swelling index were determined. Considering the stresses act as a vector working against the compression force that maintains the solid condition of the reduced sample, it is possible to conclude that the value resulting from the stress is in the range of 69.6 and 35.2 Kg/mm2.

- From the laboratory and industrial analyzed data, a direct correlation was obtained between the partial pressure of nitrogen, the swelling index, and the reduction time.

- The obtained result indicates that the swelling index increases with the increase in the reduction temperature and that abnormal swelling, in the presence of Nitrogen gas, begins at 700 °C, reaching a maximum effect at 900ºC.

ACKNOWLEDGEMENTS

The author would like to thank the Universidad Nacional Experimental Politecnica "Antonio Jose de Sucre" UNEXPO for their support in this research, as well as to Mr. Luis Alberto Azócar for carrying out the mathematical calculations and valuable suggestions on the definition of the defined swelling model.

CONFLICTS OF INTEREST

The author declares no conflicts of interests

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https://doi.org/10.47460/athenea.v4i13.61

Supply chain in the food industry in the meat sector

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Received (3/06/2022), Accepted (27/08/2023)

Abstract. - The meat industry is one of the largest and most important today due to its high consumption, especially in meat from animals such as cows and the derivatives obtained from their processing. This is why it is of utmost importance to design a supply chain that ensures the flow of raw materials efficiently, safely, and humanely. This is how, in this document, the simulation of the beef slaughter and processing process is generated in the FlexSim software to obtain process performance dashboards. In addition, a cleaner production proposal has been included that contains wastewater treatment and the system's energy optimization. This will not only help reduce waste and the use of energy and water but is also intended to ensure the quality of the products and the conservation of the environment.

Keywords: Supply chain, food industry, simulation, meat sector.

Cadena de suministro de la industria alimentaria en el sector cárnico

Resumen: La industria cárnica es una de las más grandes e importantes de la actualidad, esto debido al alto consumo que se presenta, especialmente en carne de animales como la vaca y los derivados que se obtienen de su procesamiento. Es por esto por lo que es de suma importancia el diseño de una cadena de abastecimiento que asegure el flujo de materia prima de una forma eficiente, segura y humanitaria. Es así como en el presente documento se genera la simulación de proceso de sacrificio y procesado de carne de vaca en el software FlexSim para obtener tableros del rendimiento del proceso. Además, se ha incluido una propuesta de producción más limpia que contiene el tratamiento de agua residual y la optimización energética del sistema, esto no solo ayudará a reducir desperdicios, disminuir el uso de energía y agua, se pretende asegurar la calidad de los productos y la conservación del medio ambiente.

Palabras clave: Cadena de suministro, industria alimenticia, simulación, sector cárnico.

I. INTRODUCTION

The Food Industry is one of the most potential sectors in Ecuador, as it brings economic and social benefits to the country. This industry has grown exponentially, representing 6.6% of the Gross Domestic Product (GDP) and 42.8% of the income generated in the country. It represents 45% of manufacturing activity, creating five out of ten jobs in the country [1].

The food industry encompasses industrial activities focusing on the treatment, transformation, preparation, preservation, and packaging of food products [2]. For this reason, it is essential to direct efforts towards continuously improving processes to optimize production management in general, reduce energy consumption and greenhouse gas emissions, and optimize water use in this industry.

There is a broad diversification of sectors in the food industry, which includes the meat industry, the poultry industry, the dairy industry, the chocolate industry, the fishing industry, and the beverage industry. For this study, priority will be given to the meat industry, and points of improvement in the use of water and energy resources will be analyzed to obtain benefits for the company and reduce the negative impact on the environment [2].

The meat industry represents a significant part of the Ecuadorian economy. Currently, it ranks 20th among 47 industries nationally. In 2019, this industry contributed approximately $1,176.5 million. In addition, global demand for meat products is estimated to grow at an annual rate of 1.3% between 2007 and 2050 [3]. It is also important to note that around 220,000 metric tons of meat are processed annually in Ecuador. This previously mentioned industry has several meat sources for human consumption, which are cattle, pigs, and sheep, that strengthen this industry.

This project aims to collect data from the meat industry and analyze it to develop a simulation model. This model will enable the identification of the critical points within the supply chain concerning optimizing resources such as water and energy. In addition, simulations will be carried out in various scenarios to determine the best option in terms of improvement for this industry.

II. DEVELOPMENT

The supply chain is essential for the proper functioning of companies since it is not only responsible for the relationships between suppliers, manufacturers, and distribution centers until they reach the final customer since it associates all the activities of the flow to transform them into goods and services, from the inputs of raw materials to consumption to the final customer [4]. For this reason, communication between the parties involved is necessary to achieve a horizontal integration of the supply chain because the groups or individuals involved in this business may be affected by the fulfillment of the objectives of the organization. This includes employees, customers, suppliers, shareholders, environmental banks, and governments [5].

On the other hand, the study of logistics is essential for the realization of supply chain activities optimally, or called the green chain. For this, it must be considered that logistics refers to all the processes of planning, carrying out, and controlling, efficiently, the flow of raw material, inventory, finished products, services, and information involved. This is monitored from the point of origin to consumption, which includes movements of transfers for importing and exporting goods to meet customer needs. Therefore, the supply chain's comprehensive value proposition aims to optimize its total performance at all chain stages while separately comparing the resulting complete performance with each link [6].

Currently, the food industry is one of the most polluting, so there must be effective control of the supply chain to reduce the pollution they generate. In the particular case of the meat industry, it is responsible for producing, processing, and distributing all animal meat to distribution centers such as markets, warehouses, and department stores [7]. However, meat is a livestock product of more excellent value. It has proteins and amino acids, minerals, fats and fatty acids, vitamins and other bioactive components, and small amounts of carbohydrates. From the nutritional point of view, the importance of meat derives from its high-quality proteins, which contain all the essential amino acids, as well as its minerals and vitamins of high bioavailability [8]. The objective of optimizing the supply chain of the meat industry starts from the animal processing plants or slaughterhouses, where it benefits the species of animals that were declared, authorized, and registered for human consumption [9] and then involves the process to the other participants of the supply chain until reaching the final customer.

III. METHODOLOGY

This research work is based on a mixed approach, that is, a process of collection and analysis of qualitative and quantitative data from primary, secondary, and tertiary information sources obtained from electronic libraries such as Scielo and Dialnet, among which stand out Cleaner production procedure in the Obdulio Morales slaughterhouse in the province of Sancti Spiritus, Cuba; Guide to Clean Production in the meat processing sector and Benchmarking and Energy Saving and Efficiency Measures in the Meat Industry. This is to learn more about the meat supply chain and propose cleaner production initiatives. In addition to this, an interview was conducted with an operator who works in the area of the cattle slaughter process in the Camal Metropolitano of Quito, who provided information and data on the process, from the reception of the animals to the refrigeration stage and distribution of the meat. On the other hand, for developing the simulation model, the use of FlexSim software is proposed, which simulates the performance and behavior of the AS IS and TO BE model of the production process in the meat industry. Therefore, the different hypotheses propose that:

1. Automating the equipment significantly reduces Energy consumption during the slaughtering process.
2. Implementing a water collection system allows water recirculation throughout the production process, reducing water consumption.
3. Pollution from spills decreases when the actual waste of livestock is reused in other production processes, such as dog food.

IV. RESULTS

A. Production process

The meat industry's supply chain starts with input suppliers. At this stage, inputs may include standing animals, i.e., farmers who raise and sell them when they reach the right weight and age, vaccines, medicines, and even food. Then, the reception and marking of the animal are included in the processing stage. In this phase, the animals are received from the truck and taken to the pens, resting for 4 to 8 hours. Subsequently, they pass through a corridor in the washing the animal stage and are bathed. Then, the animal stage is slaughtered, where they enter the knockout box. Desensitization, bleeding, removal of legs and head, skinning, sternum cutting, leather removal, and cleaning of viscera are performed.

It then follows the post-mortem process, which analyzes the animal's relevant parts to evaluate the meat's quality. Then, the animal stage is divided, where a cut is made in half of the animal. At the end of this process, the inspection stage continues, in which a veterinarian reviews the animal to determine if it has any disease or stroke. In case of any illness, tumor, or blow in the meat, it is not intended for human consumption. It is confiscated and transported to a plant called digester, where it is incinerated.

Next, the cut meat goes through the washing process, where it is washed from side to side, and then continues to the quartering process, where cuts are made in the meat to divide it into quarter portions. Finally, it undergoes refrigeration while waiting to be distributed. Importantly, distribution must be done in refrigerated trucks to maintain meat quality. The meat is distributed to processing companies, which treat it to make sausages or other cuts. It is also distributed to specialized butchers that meet the needs of the business sector, restaurants, hotels, and finally to retail distributors, which can be stores or minimarkets that sell meat at retail. Next, the supply chain of the meat industry will be presented [8]:

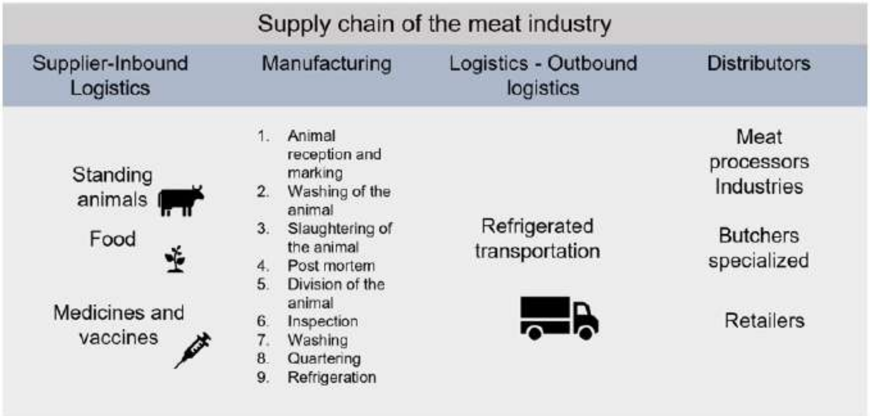

Fig. 1. Meat Industry Supply Chain
Source: Authors.

B. Flujo de materiales

Es necesario tomar en cuenta el proceso de producción para así conocer el flujo de materiales desde la cadena de suministro, de igual manera se considera los controles pertinentes para así lograr cumplir con los controles de calidad de la carne y las necesidades de los clientes.

1. Ganado (Recepción de materia prima).
2. Beneficio, desposte, refrigeración (tantos productos de carácter comestible y no comestible) [8].
3. Carne (Resultado).
4. Industrialización y procesamiento de cárnicos (Transporte – Distribución).

Table 1. Material flow.

Phases	Materials
Reception of raw materials	Animals, food and medicines
Slaughter - cutting	Blood, fat, viscera, flesh
Processing	Packaging, labels, condiments
Storage - distribution	Refrigerants, packaging, processed meat
Derivative products	Chopped seasonings and spices

Source: Authors.

C. Waste

The meat industry is characterized by the execution of the process in which some types of waste and scrap are obtained in the solid and liquid environment. This is why you should think about correctly managing these wastes since, if not, they damage the environment.

The waste includes meat by-products during the slaughter process. They are divided into blood, viscera, bones, and skin. These are organic wastes that, if not appropriately treated, become contaminants. Understanding these wastes, a percentage can be specified for the animals entering the process. For blood, you have approximately 12 liters, viscera is 10.8%, skin is 8.8%, and bones represent 20%.

D. Cycle time

The process in the plant begins with the arrival of the cows, which are placed in a coral for 4 to 8 hours to calm down after the trip. After this, they can move on to the washing phase, which takes about 8 minutes per beef. On the other hand, evisceration is the most important since the meat quality is endangered when the animal dies. It is necessary to process the animal quickly, that is, remove all the organs in at least 1 hour since the internal tissues begin a physiological process that causes the bacteria to migrate. There is a sanitary regulation on animal slaughter, where maximum times are established to execute the evisceration, and depending on the country, it can vary between 30 and 45 minutes. Removing the most significant amount of heat from the animal, in the long run, represents a substantial improvement in the quality of the carcass, with an adequate cold and pH curve [10]. According to the data collected in the interview, approximately 70 and 80 cattle are processed per hour.

E. Transport routes

The transport of meat products must be quality, and food safety is the main factor to be considered. The vehicle of raw material from the supplier to the producing company and the movement of this within the company and to the distribution centers must be considered. It is also necessary to have a cold chain to keep the products in good condition. This implies the optimal design of route packaging and ensures that no variations compromise the quality and state of the product.

F. Development of the simulation model

The software chosen for the simulation is FlexSim since it has a broad functionality and range of tools to make the simulation as close to reality. In addition, it has an excellent graphical interface that allows one to know the process in a precise and intuitive way, and, above all, it has a wide range of variables of machinery and operators that allow one to use control panels to know the development of the process, and also to carry out the simulation of the hypotheses raised to propose improvements of cleaner production in the meat industry.

G. Calibration and Validation

Generation of simulation model variables:

For the proposal of good, cleaner production practices, the variables of processing time were considered since the possibility of automating the process to reduce energy consumption could be evaluated. Likewise:

- Processing time: Machinery cycle times were defined to identify the number of kilowatts spent.
- Liters of water: The highest water waste during washing was identified.

H. Optimization and analysis of scenarios

As for the water system proposed for harvesting, the importance of water in the cow washing area was taken into account because it is in this process that most of the water is used. However, it is essential to note that this resource is used in all procedures carried out in the meat industry. In this way, considering the care of it, the system above was raised. A P&ID diagram was used to represent the essential elements for the collection system operation.

There is the presence of an expansion joint, which fulfills the objective of providing flexibility and thus achieving an expansion or contraction of the system if necessary. This is related to the water that passes through there regarding the needed amount. Similarly, a control valve next to the passage pipe is required when leaving the tank with a filter so that the amount and pressure the water returns to the initial source to restart the process can be regulated. Finally, a filter is used to separate the solids from the water and thus purify, as the solids extracted will be used as fertilizer and in the nutrition of the land.

I. Implications for industry in terms of cleaner production

In the results of the FlexSim simulation, the priority of cattle entry into the model was controlled by the date of arrival, the time it had been in line, and the level of urgency based on labels for the products. As well as the capacity of the pens before and after the meat process, which allowed us to define the number of resources that can enter the processing and the times in which they must intervene. Also, bottlenecks in the machinery during the slaughter process were determined, as well as water and energy waste.

The proposal for improvement in the meat industry consists of minimizing pollution from discharges, adopting energy-saving measures, and reducing water consumption since, during cattle washing, around 10.000 liters of water are used, with 1.500 liters per animal, and during slaughter for the separation of parts are used 2.400 liters, which are converted into wastewater; for this, the dry cleaning of animals and the recirculation of water, the use of water is significantly reduced. On the other hand, the most significant waste of energy in the meat industry occurs thanks to cold machines. For example, the average electricity consumption in Spain is 155 kWh / ton of channel, where 45% of this consumption occurs in complex generation plants and 10% in the conditioning of equipment; so, the strategies proposed in the table will help improve the energy consumption of meat companies.

Tabla 2. Variables asociadas a la propuesta de mejora.

Proposal to improve cleaner production		
Variable	**Objective**	**Strategy**
Processing time	Minimize pollution from spills.	Adapt the contact surfaces to have a more hygienic design that is easy to clean and inclines the evacuation of liquids.
		Implement the use of stun guns as the primary method of immobilizing cows.
		Install a double drainage system for the post-mortem process of the animal, and thus, the blood is directed to a storage tank and another for the discharge of cleaning wastewater.
	Energy saving	Replace low-efficiency motors with high-performance EFF1/EFF2
		Install motion sensors in low-traffic areas to avoid energy waste.
		Automate the use of pumping equipment in slaughtering and refrigeration processes.
Liters of water	Water saving	Install automated water use systems in the washing and cracking process
		Installation of water recirculation systems for washing the animal
		Perform dry cleaning of the animal before the washing process.

Source: The authors.

After the analysis carried out by simulation, the following results were reached:

By automating the process, mainly slaughtering, process cycle times were considerably reduced by reducing waste and unnecessary tasks or movements. With automation, energy consumption was significantly reduced since the machine is only on for the processing time, and the facilities are not constantly working.

Implementing a water repository system allows the water content to be stored and increased constantly. This water is processed and re-entered into the production process. As you can see, the water content reaches up to 15,000 liters at the end of a shift, of which around 6,000 liters can be treated, so it is a significant saving for the company to re-enter the water already used through a treatment system.

Concerning the waste found in the process, it can be seen to accumulate throughout the day. However, the control panel expresses it only when they are already collected at the end of the shift, reaching a final weight of 1 ton of waste. This waste produces dog food and fertilizer in fruit and vegetable cultivation processes. For this reason, the waste is much less since most of the parts of the cow are used.

CONCLUSIONS

First, it is essential to know the process that is being treated, which can only be achieved by researching academic and reliable sources to contrast data and understand how the way of doing the same activities has evolved. Similarly, interviewing a direct operator in this industry was of utmost importance to know the process firsthand and know the primary wastes that are presented.

It must be taken into account that when a cleaner production proposal is made, attention must be paid, and efforts must be focused on reducing the damage or impact that the chosen industry currently has. Considering this, proposing something that goes according to the leading cause will be easier. Care must be taken since the impact caused on the environment must be minimized, but without affecting the productivity and performance of organizations.

The use of control panels is of utmost importance in generating a process simulation model. This is because, in this way, you can know the circle's performance and identify bottlenecks and productive problems through data. This will be of utmost importance for realizing a proposal for improvement based on results.

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https://doi.org/10.47460/athenea.v4i13.62

Engineering and social responsibility: Challenges and opportunities in high education

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Received (11/06/2022), Accepted (16/08/2023)

Abstract. - This study focuses on analyzing university social responsibility in the training of engineers. Engineering students were surveyed and contrasted with social science students to relate higher education with social education. The research was a quantitative and descriptive approach using a non-experimental cross-sectional design. The sample comprised 1023 intentionally selected engineering and social science students. A specific validated scale was applied to assess students' perception of their social responsibility in the university context and ordinary life. The results indicated a medium level of social responsibility with a tendency to be low in the group of university students analyzed. In addition, it was observed that engineering careers should reinforce the social commitment of students.

Keywords: University social responsibility, engineering students, university careers.

Ingeniería y responsabilidad social: Retos y oportunidades en la educación superior

Resumen: Este estudio se enfoca en el análisis de la responsabilidad social universitaria en la formación de ingenieros. Para ello se analizaron estudiantes de ingeniería y se contrastó con estudiantes de ciencias sociales, esto con la finalidad de relacionar la educación universitaria con la educación social. La investigación tuvo un enfoque cuantitativo y descriptivo, utilizando un diseño no experimental de corte transversal. La muestra comprendió a 1023 estudiantes de ingeniería y ciencias sociales seleccionados de manera intencional. Se aplicó una escala validada específica para evaluar la percepción de los estudiantes en relación con su responsabilidad social en el contexto universitario y en la vida común. Los resultados indicaron un nivel medio de responsabilidad social con una tendencia a ser bajo en el grupo de estudiantes universitarios analizados. Además, se observó que las carreras de ingeniería deben reforzar el compromiso social de los estudiantes.

Palabras clave: Responsabilidad social universitaria, estudiantes de ingeniería, carreras universitarias.

I. INTRODUCTION

The fundamental objective of university social responsibility in engineering careers is training socially responsible engineers. This implies that, besides acquiring academic skills, students must develop attitudes toward the common good. Engineers must possess interpersonal skills, the ability to address challenges, and a deep understanding of reality. From the beginning of their university education, students are expected to assume the social responsibility of contributing to local development, an essential requirement in contemporary society[1]. This training is not exclusive to engineering but includes other professional areas, such as training in social sciences, where much emphasis is placed on this subject.

Incorporating social responsibility in the training of engineers is a significant challenge today. Some of the most prominent issues and challenges include[2]:

Lack of Curricular Integration: Social responsibility is treated in isolation or as optional rather than fully integrated into the curriculum in many engineering programs. This can lead to a perception that social responsibility is not essential to engineering training.

Lack of Clarity in Objectives: The objectives and goals of social responsibility in engineering education may not be clearly defined. Assessing whether students develop the necessary skills and values can be challenging without specific goals.

Exclusive Technical Focus: Often, the training of engineers focuses mainly on technical and scientific skills, leaving aside the social and ethical dimensions. This can lead to engineers lacking the necessary sensitivity to their actions' social and moral consequences.

Lack of Role Models: Students may lack examples of engineers who have significantly impacted social responsibility, making it difficult to identify with the concept and motivate them to engage in related activities.

Cultural Resistance: In some educational institutions and among some teachers, there may be resistance to including social responsibility in engineering training due to the perception that this could divert time and resources from technical aspects.

Poor Assessment and Measurement: Measuring progress in acquiring competencies in social responsibility can be challenging. The lack of practical assessment tools can make determining whether students are developing these skills difficult.

Resource Scarcity: Some institutions may lack the resources necessary to implement effective social responsibility programs in engineering education, such as trained staff, extracurricular activities, and community projects.

Superficial Motivation: Occasionally, students may engage in social responsibility activities by fulfilling an academic requirement rather than by genuine commitment, which reduces the actual impact of these activities.

Focus on Limited Social Problems: Sometimes, social responsibility in engineering training focuses on specific problems, such as environmental sustainability, leaving out other equally important aspects, such as social justice and human rights.

Challenges of Scale and Complexity: The social and environmental problems engineers face can be highly complex and large-scale. This can leave students feeling overwhelmed or insecure about how to address these challenges.

According to University Law No. 30220 [3], university social responsibility is an ethical and effective management tool that must have a significant impact on society, with the added value that future professionals are not only trained for the occupational market but also develop their skills for the common good, protecting the environment, attending to the welfare of the population and contributing to the generation of wealth, bases of an adequate, sustainable development within an administrative, legal framework [4].

Therefore, this work aims to analyze university social responsibility in the training of engineers. It is compared with students of social sciences, which, because it is a more humanistic career, could have a component in favor of social responsibility. In this way, it is intended to compare their socio-academic variables, evaluate the curricular contents, and explore the challenges of future professionals within their community.

II. ENGINEERING AND SOCIETY

Engineering careers have undergone a remarkable evolution over time, and today, they play an essential role in the development and advancement of society. This evolution and how engineering contributes to current progress is described below:

A. Evolution of Engineering Careers

Engineering has ancient roots, from the construction of the pyramids in Egypt to military engineering in ancient Rome. However, it was not considered a formalized discipline at the time. Later, the Industrial Revolution in the nineteenth century marked the beginning of modern engineering. Mechanical, civil, and electrical engineering, among others, began to develop as distinct disciplines. During the twentieth century, engineering diversified further with the creation of fields such as aerospace engineering, electronics, computer science, and biotechnology. Engineering continues to evolve today, with an increasing focus on technology, sustainability, and interdisciplinarity. This career has become essential in solving global problems, from the fight against climate change to developing advanced information technologies. In addition, the present engineers make crucial contributions to developing social improvements, such as contributions to medicine and civil life.

B. Current Contributions of Engineering Careers

Engineering drives the development of cutting-edge technologies in fields such as artificial intelligence, robotics, nanotechnology, and cybersecurity, transforming how we live and work. In addition, engineers are crucial in finding sustainable solutions to environmental and energy challenges. They work on renewable energy projects, green building design, and sustainable transport. Civil and transportation engineering are central to constructing and maintaining essential infrastructure, such as roads, bridges, and public transport systems. On the other hand, one of the most significant contributions is biomedical engineering and biotechnology, which are revolutionizing medicine and medical care contributing to the creation of advanced medical devices, gene therapies, and diagnostic systems. Another significant contribution is in computer engineering and telecommunications branches that have transformed how we communicate and access information, facilitating globalization and global connectivity. Engineering has also driven business innovation through product design, supply chain management, and process optimization.

Next, the cut meat goes through the washing process, where it is washed from side to side, and then continues to the quartering process, where cuts are made in the meat to divide it into quarter portions. Finally, it undergoes refrigeration while waiting to be distributed. Importantly, distribution must be done in refrigerated trucks to maintain meat quality. The meat is distributed to processing companies, which treat it to make sausages or other cuts. It is also distributed to specialized butchers that meet the needs of the business sector, restaurants, hotels, and finally to retail distributors, which can be stores or minimarkets that sell meat at retail. Next, the supply chain of the meat industry will be presented [8]:

C. Social responsibility and the university

The social responsibility of university students allows them to identify their commitment to the environment. The student has the challenge of committing himself personally and socially to the development of his community ethically and responsibly, seeking a country with better life opportunities for the entire population [5].

Concerning the challenges pursued by university social responsibility in future professionals is a long-term expectation; however, some challenges are prioritized and should serve as a guide for the student. First, the training of new researchers with the ability to identify the different problems within society; second, social participation, to strengthen the sense of democracy through the main mechanisms of public management by organizing themselves in guilds or associations that represent the true feelings of the population and, thirdly, professional performance with ethics, morals, and principles, the basis of every human being. These elements show that, by integrating research and social participation in professional practice, the person will be able to recognize their responsible commitment by making decisions in favor of the entire population. To achieve this goal, it is necessary to incorporate academic strategies that encourage social responsibility and motivate socially responsible behavior[8][9].

The research background indicates that few studies have focused on studying social responsibility in university students, comparing its socio-academic variables and the challenges for new professionals. Research has shown that men have shown more outstanding social commitment in some study groups than women [7]. Other studies[10] explain that university students in Peru have an average level of university social responsibility, indicating that they participate in the activities of commitment by obligation to pass certain subjects and not by conviction, and teachers must change strategies and mechanisms so that students can participate voluntarily. In addition, other research reveals that university students of engineering and social sciences are socially responsible students at a high level, [11] valuing aspects such as respect and collaboration between students and teachers, zero discrimination, comprehensive training, opportunity to participate in social projects and promotion of social sensitivity. However, in no case is it shown that there is a distinction between students of different careers. An essential characteristic in the samples analyzed in previous studies is that socially responsible students present positive attitudes such as empathy, tolerance, and respect for cultural values and the environment and are emotionally equitable with better social relationships [12][13].

These premises motivated me to formulate this work, which focused on the evaluation of social responsibility in engineering careers, as a focal axis because it is a career that concentrates historically on technical education and not on social aspects. To assess this work, a comparative analysis is made with students of social sciences jobs, who are traditionally more humanistic. Measuring the sense of social responsibility of university students includes the study of the commitment to others and the environment.

Students must understand their different realities and expand their capacities to serve others. In addition, the valuation of the personal discovery of values is one of the objectives of social responsibility to instill in students not only knowledge but also values of respect and recognition of the dignity of people. It also discusses the formation of social responsibility as the mechanism by which students transfer knowledge to society. Finally, the study of the approach of professional practice from social commitment is included, being one of the challenges of the social responsibility of the university to apply in practice the knowledge acquired in the professional field so that the student can continue to exercise and increase the ability to become a socially responsible person and committed to their environment[6][7].

III. METHODOLOGY

The research was descriptive-comparative, with a quantitative approach, using the non-experimental cross-sectional design [14]; data collected from May to July 2023 were considered. The sample was made up of 1023 university students from Peru. The participants who regularly attended classes were intentionally selected, took any subject that integrated university social responsibility activities, belonged to the areas of engineering and social sciences, and were students of any sex of all academic cycles. Only university students who did not wish to participate in the study were excluded.

The university social responsibility questionnaire (RSEU) validated by García and others [5]was applied. The test consists of 21 items, distributed in 4 dimensions, and a criterion item that the student must assess through the Likert scale that considers 1 to 5 points (1 = minimum agreement and 5 = maximum agreement). The instrument presents criteria of validity and reliability in its construct. The internal consistency indices to determine reliability were made through Cronbach's alpha coefficient, obtaining high scores (0.923). The construct validity through exploratory factor analysis indicates the existence of 3 factors that explain 56.45% of the variance. However, confirmatory factor analysis, with the maximum likelihood method, confirmed the reformulation of the initial structure of the scale to obtain a better measurement of the construct by pointing out the four dimensions and a criterion item. In addition, the reliability analysis of the scale was made to the local sample, using Cronbach's Alpha statistical test, obtaining an alpha of 0.88 considered high reliability [15].

The instrument was applied directly, individually, and face-to-face, considering the guidance García and others provided [5]. All procedures were carried out with due informed consent, committing to participate voluntarily by signing the respective document and with institutional rigors and permits.

The data were analyzed considering the normality distribution through the Kolmogorov-Smirnov test, finding that the data do not present a normal distribution ($p< 0.000$). Mean, skewness, kurtosis, and standard deviation were calculated. In addition, variance homogeneity tests were performed. Considering using nonparametric tests. The descriptive analysis of social responsibility in university students was carried out to determine the degree of social responsibility. In addition, the student's social responsibility was compared according to socio-academic variables such as sex, area, and cycle of studies. To reach the levels of social responsibility of the university according to socio-academic variables, contingency tables were used; in addition, the statistical test Chi-Square was used to determine the association of variables or check or reject the hypotheses of independence between the variables[16][17]. In addition, the JAMOVI 1.2.27 software was used to perform the statistical analysis [18].

IV. RESULTS

The analysis of the socio-academic variables presented by university students was made, finding the following information: 54% were men and 46% were women. According to the area of studies, 47.8% were students in the area of engineering and 52.2% in social sciences; in addition, the average age was 23 years with a standard deviation of 1.41 years in a range of 18 to 29 years, including to university students of all years and academic cycles. It was found that the level of social responsibility of the student and its dimensions is medium, with a tendency to be low (Table 1). The main difficulty students encounter is that there is no adequate training in social responsibility to apply it in society. Also, the student does not know many realities to commit to their environment, and the activities they perform as social responsibility are more helpful or social support.

Table 1. Level of Social Responsibility of the University and Dimensions of Study

MSW and dimensions	Level			*Total*
	High	*Middle*	*Low*	
Social responsibility of the university student	17%	56%	27%	100%
Commitment to others and the environment	23%	49%	28%	100%
Personal discovery of values	22%	60%	18%	100%
Social responsibility training	12%	57%	31%	100%
Approach to professional practice from social commitment	16%	51%	36%	100%

Regarding sex, it was obtained that men present, on average, a social responsibility of 42.2%, while women offer a social responsibility of 57.8%. Therefore, it was found that women tend to be more socially responsible, are more committed, discover their values, and consider their future professional practice from the social commitment concerning male students.

Table 2. Comparison of the social responsibility of the university and its dimensions of study according to area of study.

MSW and dimensions	Area of studies	
	Engineering	*Social sciences*
Social responsibility of the university student	40%	60%
Commitment to others and the environment	35%	65%
Personal discovery of values	45%	55%
Social responsibility training	37%	63%
Approach to professional practice from social commitment	41%	59%

When comparing the results according to the area of study of the university student, it was found that the students of social sciences develop more sense of social responsibility compared to the students of the engineering area—considering that the students of the different programs of social sciences by nature present more significant relationship and link with society, motivating the participation of these students in the other activities of Social Responsibility of the University.

From the comparison of the results according to the year of studies, it was found that students in the last years present a greater degree of social responsibility than the students of the first years of study, being the students of the previous years who, through their pre-professional practices find greater motivation to work responsibly for society.

Table 3 shows the results of the Chi-Square tests, which indicate that they are lower than the significance, rejecting the hypothesis of independence of the variables. In that sense, the socio-academic variables are significantly associated with the university's social responsibility. There is a high probability that to the extent that the university student studies a career in social sciences, is looking in the last years, and is a female student, the degree of social responsibility in the face of society's demands will increase.

Table 3. Chi-Square test between the social responsibility of the university and the socio-academic variables.

Chi-Square	***Test***	Area of studies	Year of studies	sex
Social responsibility of the university student	***p***	0.000	0.002	0.000
	Chi²	12,645^to	12,025^to	12,693^to
	Df	4	4	4

Note. p= p-value (0.05); Chi2= value of the statistic; Df= Degrees of freedom.

CONCLUSIONS

Once the study is completed, the following conclusions can be affirmed:

There is a significant social responsibility difference between engineering and social science students. Social science students tend to exhibit a higher social responsibility than their engineering counterparts. These findings highlight the importance of social science education for academic development and fostering greater awareness and engagement with social and community issues. It is necessary to include more significant activities of university social responsibility in the academic programs of the engineering area so that students can develop their social skills, improve social relationships, identify their values towards others, and think that engineering can solve various problems presented by communities and the environment.

Educational institutions could benefit from implementing awareness programs and developing social skills in engineering programs to promote greater social responsibility among students in this field. In this sense, interdisciplinary collaboration between engineering and social science students could effectively promote social responsibility in both groups, encouraging an exchange of perspectives and knowledge.

University students, in general, do not fully develop the competencies of university social responsibility due to the weakness in the content of the curricula, forcing the student to participate in social responsibility activities to pass the subjects and not because the competencies have been achieved within the training. Converting this professional value into fulfilling tasks and not acquiring social commitment as a person's value.

University students, in general, do not fully develop the competencies of university social responsibility due to the weakness in the content of the curricula, forcing the student to participate in social responsibility activities to pass the subjects and not because the competencies have been achieved within the training. Converting this professional value into fulfilling tasks and not acquiring social commitment as a person's value.

There is confusion when executing university social responsibility activities because it is considered that most of these activities should benefit the population, bringing social assistance to the most precarious areas of society. In that sense, the academic challenge must pursue an end according to the identification and planning to help solve societal problems. In this way, the new professional must be clear about social commitment as part of his management in the area he performs.

This study opens the door to future research to analyze better the variables that influence social responsibility, such as educational curriculum, academic culture, and personal values, to understand the reasons behind the observed differences. Finally, it is crucial to highlight that social responsibility is a fundamental skill and attitude for professionals in all fields. The findings of this study have important implications for the preparation of future engineers and social science professionals who wish to address societal challenges and contribute to the well-being of society. It is necessary to continue doing studies related to university social responsibility to understand how this variable behaves, considering expanding the sample to more universities, allowing to compare the results of this study to take measures, especially in the academic system, to empower students and that their pre-professional practices are based on the common good ethically and effectively.

The challenges demanded by social responsibility in students are part of training new researchers who can identify societal problems. In this way, social participation is presented as an opportunity to strengthen the sense of democracy through the main mechanisms of public management organizing in guilds or associations that represent the true feelings of the population. It is essential to perform professionally with ethics, morals, and principles, the basis of every human being to integrate research and social participation in their professional practice for decision-making and promote new developments committed to social, animal, and environmental life.

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https://doi.org/10.47460/athenea.v4i13.63

Physics education in the training of engineers for digitized industry

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Received (29/05/2022), Accepted (30/07/2023)

Abstract. - This paper addresses the synergy between engineering and physics education, highlighting how applying physics principles and concepts in engineering projects can significantly enrich STEM education. Innovative pedagogical approaches that foster a deeper understanding of physics by solving practical problems and integrating theory with practice are discussed, thus promoting more effective and meaningful learning in engineering. The main results show that, despite the inclusion of new technological strategies in the engineering career, it is not advisable to eliminate the teaching of physics in the engineering education curriculum and that, on the contrary, it is essential to reinforce these theories.

Keywords: STEM, engineering education, physical theories, physics education.

La enseñanza de la física en la formación de ingenieros para la industria digitalizada

Resumen: Este estudio se enfoca en el análisis de la responsabilidad social universitaria en la formación de ingenieros. Para ello se analizaron estudiantes de ingeniería y se contrastó con estudiantes de ciencias sociales, esto con la finalidad de relacionar la educación técnica con la educación social. La investigación tuvo un enfoque cuantitativo y descriptivo, utilizando un diseño no experimental de corte transversal. La muestra comprendió a 1023 estudiantes de ingeniería y ciencias sociales seleccionados de manera intencional. Se aplicó una escala validada específica para evaluar la percepción de los estudiantes en relación con su responsabilidad social en el contexto universitario y en la vida común. Los resultados indicaron un nivel medio de responsabilidad social con una tendencia a ser bajo en el grupo de estudiantes universitarios analizados. Además, se observó que las carreras de ingeniería deben reforzar el compromiso social de los estudiantes.

Palabras clave: STEM, educación en ingeniería, teorías físicas, enseñanza de la física.

I. INTRODUCTION

Physics, a fundamental element of science, has proven to be a crucial pillar in understanding and developing modern technology. As we move into the twenty-first century, the role of physics in engineering and technology has become even more prominent, driving significant advances in fields as diverse as renewable energy, quantum communication, and space exploration. According to data from the World Health Organization (WHO), in 2021, more than half of the world's population had access to the Internet. This achievement would not have been possible without the underlying physical foundations of data transmission over global fiber optic networks [1].

However, despite these advances, physics education faces persistent challenges worldwide. According to UNESCO's Global Education Monitoring Report [2], published in 2020, the lack of equitable access to quality education in science, including physics, remains a global concern [3]. The gap in science education is particularly pronounced in low-income countries, raising crucial questions about how to improve the pedagogy and accessibility of physics globally.

In this context, this paper examines the intersection between engineering and physics education, highlighting how the practical application of physical principles in engineering projects drives technological innovation and can significantly enrich the way physics is taught and learned. Through examples and innovative pedagogical approaches, we explore how integrating theory with practice in physics teaching can foster a deeper understanding of the discipline and inspire the next generation of engineers and scientists to tackle the most pressing global challenges. In this sense, the collaboration between engineering and physics education is an essential bridge to a technologically advanced future and a more informed and capable society.

In several Latin American countries, a worrying phenomenon has been observed in higher education, where attempts are made to eliminate physics from engineering careers. This trend, often motivated by the need to simplify curricula and accelerate the training of professionals in the STEM (Science, Technology, Engineering, and Mathematics) field, poses significant challenges for the quality and breadth of training of future engineers. One of the main risks lies in losing a solid foundation in physics, which is essential for understanding and applying the fundamental principles underpinning modern engineering and technology [4][5].

Removing physics from engineering careers can also negatively impact graduates' ability to solve complex problems and face multidisciplinary challenges in the real world. Physics provides the theoretical and conceptual tools needed to address a wide variety of problems in engineering, from the design of power systems to the development of advanced medical devices [6]. The omission of physics could result in incomplete training, limiting the versatility and adaptability of future engineers in the face of a constantly evolving job landscape.

In addition, the elimination of physics in engineering careers could undermine the ability of these countries to stay at the forefront of technological innovation and scientific research. Physics is the basis of numerous technical and scientific advances, and depriving students of this discipline could reduce their ability to contribute to global scientific and technological progress. Ultimately, education policymakers in Latin America must consider the long-term impacts of this trend and seek a balance between simplifying curricula and maintaining comprehensive engineering and STEM training.

II. STEM methodologies and the challenges in engineering training

STEM methodologies (Science, Technology, Engineering, and Mathematics) are pedagogical approaches that promote the interdisciplinary integration of these four disciplines in education [4][7]. These methodologies aim to foster critical thinking, problem-solving, and creativity in students, preparing them to tackle complex challenges in the real world. Here are some of the most relevant STEM methodologies:

Project-Based Learning (PBL): This methodology engages students in hands-on projects related to real-world problems. Students apply STEM concepts to solve concrete challenges, encouraging practical application of knowledge and teamwork [8].

Collaborative Learning: In STEM learning, collaboration between students is promoted. Working in teams allows students to share ideas, face challenges, and develop communication skills, all essential in engineering training.

Use of Technology: Modern technologies, such as simulations, modeling software, and specialized hardware, play a critical role in STEM teaching. These tools help students understand abstract concepts and gain practical skills.

Focus on Problem Solving: STEM methodologies focus on developing skills to identify and solve complex problems. Students learn to deal with ambiguous situations and to apply the scientific method to arrive at informed solutions.

Active Learning: Instead of traditional passive teaching, STEM learning actively engages students. They participate in experiments, discussions, and hands-on activities that foster more profound, meaningful learning.

However, the effective implementation of STEM methodologies in engineering training faces several challenges:

Resources and Equipment: STEM teaching often requires expensive equipment and advanced technology. Not all schools have access to these resources, which creates inequalities in STEM education.

A. Teacher training

Educators must be trained to implement STEM methodologies effectively. Continuous teacher training is essential to keep up with trends and best practices [6] [9]. Training educators in effectively implementing STEM methodologies is critical to ensuring students get a quality education in these disciplines. For this, teachers must develop and strengthen the following activities:

Updated Knowledge: Continuous training allows educators to keep up with advances in Science, Technology, Engineering, and Mathematics. Since these fields constantly evolve, teachers must know about the latest research, technologies, and pedagogical approaches. This allows them to offer students up-to-date and relevant information.

Specific Teaching Skills: STEM methodologies often require particular teaching approaches, such as project-based learning, problem-solving, and hands-on teaching. Educators must acquire and hone these skills to effectively guide students through enriching STEM learning experiences.

Adaptability: Continuous training helps teachers adapt to changing student needs and preferences. Teaching methods that worked in the past may not be the most effective today. The training allows them to adjust their pedagogical approaches to better address the changing challenges and demands of the classroom.

Curricular Integration: STEM teaching often involves the integration of multiple disciplines into the curriculum. Educators must connect science, technology, engineering, and math concepts coherently and meaningfully. This may require interdisciplinary collaboration and a solid understanding of how these disciplines relate.

Technology Tools: In the digital age, educators should also be familiar with the technological tools and resources available to improve STEM teaching. This includes simulation software, virtual labs, online learning platforms, and other educational technologies that can enrich the learning experience.

Practical Assessment: Ongoing training also addresses assessing students in STEM contexts. Teachers must learn to effectively determine understanding, practical skills, and problem-solving using methods beyond traditional tests. This involves creating authentic assessments and interpreting the results to improve teaching.

B.Encourage Diversity

Engineering training should be inclusive and diverse [2]. Overcoming gender biases and promoting the participation of underrepresented groups in STEM are significant challenges. Indeed, engineering training must be inclusive and diverse to reflect the global reality and ensure everyone has equal STEM opportunities. This includes the following:

Gender Equality: Historically, STEM careers have been dominated by men. Overcoming gender bias is an essential challenge. This implies eliminating gender stereotypes and prejudices in education and society. In addition, it is crucial to encourage girls' interest in STEM from an early age and provide female role models in these disciplines. Promoting an inclusive and discrimination-free learning environment is critical to encouraging women's participation in engineering and other STEM areas.

Racial and Ethnic Equity: Racial and ethnic diversity in engineering education is equally important. Many ethnic and racial groups are underrepresented in STEM. Promoting inclusion and equity in access to STEM education is crucial to address this issue. This may include implementing inclusive admissions policies and developing specific support programs for students from underrepresented groups.

Economic Accessibility: Another challenge to diversity in STEM is affordability. STEM careers often require significant educational investments, such as college tuition and expensive study materials. To overcome this obstacle, it is crucial to offer scholarship opportunities and financial support to students from all economic backgrounds.

Cultural Adequacy: Cultural diversity must also be addressed. STEM training programs must be culturally appropriate and sensitive to attract and retain students from diverse cultural backgrounds. This may involve adapting curricula and including diverse perspectives and examples in educational content.

Mentoring and Support: Mentoring is crucial in promoting diversity in STEM. Establishing mentoring programs that connect students from underrepresented groups with STEM professionals can provide role models, guidance, and emotional support that help overcome barriers.

C. Community Engagement

Collaboration with local communities and the involvement of educational institutions in STEM outreach initiatives are essential [10] [8]. This includes organizing workshops, events, and activities to engage the community and foster interest in STEM from an early age. Collaboration with local communities and the involvement of educational institutions in STEM outreach initiatives play a crucial role in promoting interest in science, technology, engineering, and mathematics from an early age [11]. This includes the following elements:

Educational Workshops: Hosting STEM workshops in local schools and elsewhere in the community can effectively bring students closer to these disciplines. These workshops can include hands-on activities, experiments, and engaging and challenging projects. Educators and STEM professionals may be invited to deliver these workshops to inspire young people.

Special Events: Hosting special STEM events, such as science fairs, technology expos, and robotics competitions, creates opportunities for students to showcase their projects and discover the potential of STEM careers. These events also encourage interaction between students, educators, and professionals, which can be very motivating.

After-School Programs: In schools or community centers, after-school STEM programs provide students additional space to explore their interests in these disciplines. These programs can include science clubs, robotics teams, programming classes, and more. They facilitate deeper learning and allow students to apply what they have learned in a practical context.

Talks and Conferences: Inviting STEM experts to give talks and lectures in schools or the community is another effective strategy. These talks can expose students to various areas of STEM and show them how these disciplines are related to everyday life and professional careers.

Mentoring: Establishing mentoring programs that connect students with professionals and college students in STEM gives young people role models and personalized guidance. Mentors can share their experiences, offer advice, and help students set educational and career goals.

Collaboration with Companies and Organizations: Educational institutions can collaborate with local businesses and organizations to organize STEM events and activities. This may include company visits, internships, joint projects, and sponsorship of educational activities. This collaboration can help students understand how STEM concepts are applied in the real world.

D. Effective Assessment

Measuring success in STEM education goes beyond grades. The assessment should assess deep understanding, practical application, and problem-solving skills [9]. Review in STEM should go beyond traditional qualifications and focus on deep knowledge, practical application, and problem-solving skills, as these are the critical aspects of preparing students for successful careers in science, technology, engineering, and mathematics. In addition, practical assessment in STEM should reflect these disciplines' collaborative and helpful nature.

IV. RESULTS

The analysis of the socio-academic variables presented by university students was made, finding the following information: 54% were men and 46% were women. According to the area of studies, 47.8% were students in the area of engineering and 52.2% in social sciences; in addition, the average age was 23 years with a standard deviation of 1.41 years in a range of 18 to 29 years, including to university students of all years and academic cycles. It was found that the level of social responsibility of the student and its dimensions is medium, with a tendency to be low (Table 1). The main difficulty students encounter is that there is no adequate training in social responsibility to apply it in society. Also, the student does not know many realities to commit to their environment, and the activities they perform as social responsibility are more helpful or social support.

Deep Understanding: Assessment in STEM should assess the depth of students' understanding rather than simply measuring their ability to memorize information. This means that tests and assessments should be designed to assess students' ability to explain concepts in their own words, connect ideas, and apply knowledge in different contexts.

Practical Application: One of the main goals of STEM education is to prepare students to apply their knowledge in real-world situations. Therefore, assessments should include practical problems and scenarios that require students to use their theoretical understanding to solve concrete situations. This can consist of projects, simulations, experiments, and case studies.

Problem-Solving: Problem-solving skills are essential in STEM. Assessment should measure students' ability to identify problems, develop strategies to address them, analyze data, and arrive at informed solutions. Questions and concerns in evaluations should be challenging and encourage critical and creative thinking.

Teamwork: In many STEM disciplines, collaboration is critical. Therefore, assessments may include teamwork components where students must collaborate on projects or solve problems. This assesses individual skills and students' ability to work effectively in groups.

Results Presentation: Effectively communicating findings and results is essential to STEM. Assessments may require students to present their findings clearly and concisely through written reports, oral presentations, or digital media. This assesses your ability to communicate scientific and technical information effectively.

Formative Assessment: Besides summative assessments (which measure learning at the end of a period), formative assessment is critical in STEM. This involves continuous feedback during the learning process. Educators can use regular feedback and formative assessments to help students identify areas for improvement and adjust their study approaches.

Learning Portfolios: Instead of relying solely on standard exams and tests, students can compile learning portfolios that include projects, assignments, reports, and reflections throughout their STEM education. This provides a holistic view of your progress and achievements.

Authentic Assessment: Authentic assessments involve the application of knowledge and skills in situations that mimic those in the real world. This may include solving problems based on real scenarios or creating practical solutions to current STEM challenges.

Overcoming these challenges in engineering education through properly implementing STEM methodologies is essential to prepare future professionals to face the constantly evolving technological and scientific challenges.

III. METHODOLOGY

In this work, a content analysis of publications from 2020 to the present has been carried out, which involves the necessary aspects of training students in engineering careers. It is intended to know if the incorporation of STEM methodologies influences the professional quality of the future engineer. In this sense, Table 1 shows the principal internationally recognized authors and their contributions to STEM methodologies for vocational training.

Table 1. Principal authors and their contributions to STEM methodologies.

Author(s)	Featured Publication	Main Focus
Linda Darling-Hammond[12]	"Preparing Teachers for a Changing World: What Teachers Should Learn and Be Able to Do"	It advocates teacher training that includes STEM teaching as an essential competency for modern education.
Mitchel Resnick[13]	"Lifelong Kindergarten: Cultivating Creativity through Projects, Passion, Peers, and Play"	It highlights the importance of creativity and play in STEM education, especially in inspiring young students.
John Hattie[14]	"Visible Learning: A Synthesis of Over 800 Meta-Analyses Relating to Achievement"	It examines the effectiveness of various pedagogical strategies on student achievement, including STEM-related ones.
Eric Mazur [15]	"Peer Instruction: A User's Manual"	It proposes active teaching methods like peer instruction to improve STEM comprehension.
Pamela McCauley-Bush [16]	"Ergonomics: Foundational Principles, Applications, and Technologies"	It advocates the inclusion of ergonomics and usability in the training of engineers, highlighting its relevance in STEM.

Note. p= p-value (0.05); Chi2= value of the statistic; Df= Degrees of freedom.

For the classification of these documents, the following criteria were taken into consideration:

Inclusion Criteria:

- Thematic Relevance: The articles had to deal with the importance of incorporating STEM methodologies in the training of engineers.
- Publication in Recognized Scientific Journals and Conferences: Inclusion of articles published in peer-reviewed scientific journals and renowned academic conferences.
- Publication Date: Articles published in the last five years.
- Geographic Focus: International studies were included.
- Type of Research: Qualitative and quantitative research, systematic reviews, meta-analyses, and case studies, among others, were considered, provided that they included aspects of this research.
- Educational Focus: Articles had to somehow address engineering education or engineering programs. Either from the levels of education such as undergraduate, graduate, or technical education.

Exclusion Criteria:

- Thematic Irrelevance: Articles that do not focus on the importance of STEM methodologies in engineering training were excluded.
- Non-Scientific Sources: Non-academic sources, such as unverifiable websites, personal blogs, or non-peer-reviewed sources, were excluded.
- Language: Articles that were not in Spanish or English were excluded.
- Old Publication Date: Works published outside five years were excluded.
- Duplicates: Duplicates or similar articles were avoided in the literature review.
- Lack of Access: Non-open access works were excluded.

IV. RESULTS

The results of the literature review on the teaching of physics in the training of engineers are presented with an overview of the results found:

Physics represents a fundamental basis in the training of engineers. The review showed how understanding physical principles is essential to success in engineering and how this discipline provides the theoretical foundation needed to tackle complex problems.

The different teaching methodologies used in training engineers in physics include traditional approaches, such as lectures and laboratories, and more innovative techniques, such as project-based learning or simulation teaching.

Identifying the challenges and obstacles engineering programs face when teaching physics is essential. This includes a lack of resources, a student understanding gap, or the need to improve pedagogy. It is observed that engineering schools tend to have high academic demands and little empathy between teachers and students.

The review provided an insight into the effectiveness of specific pedagogical strategies used in teaching physics to engineers; in this sense, the primary methods used in engineering training are simulations and experimental practices, project-based learning, case studies, and online resources.

Evaluating how teaching physics influences student performance and success in engineering programs is essential. Table 2 shows the contributions of physics in engineering and its participation in the training of engineers.

Table 2. Contributions of physics in engineering.

Aspects of Physics	Contribution in Engineering
Mechanics	It supports the design and analysis of structures, machines, vehicles, and mechanical systems. It helps to understand the movement, force, and tensions in objects and methods.
Thermodynamics	Essential in engineering power systems, such as engines, power plants, and oiling systems. It is also applied in industrial processes and heating and cooling systems.
Electromagnetism	It is based on electronics and electrical engineering, from circuit design to generating and transmitting electrical energy.
Optics	It is used in the design of imaging systems, such as cameras and microscopes, and technologies, such as fiber optics and optical sensing devices.
Waves and Sound	They are applied in telecommunications, acoustics, and the design of communication devices, such as antennas and speakers. It is also used in sonar and ultrasound technologies.
Materials and Properties	It helps select suitable materials for engineering applications, considering strength, conductivity, and durability properties.
Fluid dynamics	Essential in fluid systems engineering, from piping system planning to aerodynamics in the aerospace and automotive industry.

Research on new methodologies, technologies, or pedagogical approaches in physics education for engineers makes it possible to identify and report on these innovations and their potential impact. This shows that the contribution of physics helps train engineers to develop new technologies and innovations (Table 3).

Table 3. Engineering developments that include contributions from physics.

Engineering Innovation	Contribution of Physics
Lasers	Quantum physics is fundamental to understanding and developing lasers. These devices are used in various applications, from optical communication to medicine and manufacturing.
Positron Emission Tomography (PET)	This medical diagnostic technique relies on physical principles, such as positron emission and gamma radiation detection, to create three-dimensional images of the inside of the body.
Nanotechnology	Nanotechnology draws on principles of quantum physics and statistical mechanics to manipulate and design materials at the nanometer level, which has applications in electronics, medicine, and advanced materials.
Advanced Sensors	Sensors used in cars, airplanes, and medical devices, among others, are often based on physics concepts, such as measuring pressure, temperature, and light.
Magnetic Resonance Imaging (MRI)	MRI is a medical diagnostic technique that takes advantage of principles from the physics of nuclear magnetic resonance to obtain detailed images of soft tissues in the body.

Research on new methodologies, technologies, or pedagogical approaches in physics education for engineers makes it possible to identify and report on these innovations and their potential impact. This shows that the contribution of physics helps train engineers to develop new technologies and innovations (Table 4).

Table 4. Present and future trends for physics education.

Current Trends in Physics Education	Future Trends in Physics Education
Interdisciplinary Approach	Quantum Education
Active Learning	AI and Physics Integration
Educational Technology	Applied Quantum Physics
Focus on fundamental concepts.	Renewable Energy Education
Personalization of Learning	Global Project-Based Learning
Distance Education	Space Exploration and Physics
Inclusion of Experimental Methods	Nanotechnology and Physics
Formative Assessment	Focus on Quantum Technology
Focus on Problem-Solving Skills	Education in Sustainability and Climate Change
Inclusive and Diverse Education	Advanced Materials Physics
Focus on Communication Skills	Physics and Advanced Robotics
Sustainability and Renewable Energy	Data Science and Physics Education
	Development of New Materials

The review also identified areas where further research is needed. Table 5 shows the main areas where new research and development is required for engineering physics.

Table 5. Research areas for engineering.

Areas of Contribution to the Teaching of Physics for Engineers	
Development of New Educational Resources	Creation of simulations, virtual labs, and high-quality online content to improve the accessibility and interactivity of learning.
Interdisciplinary Approach	Integration of physics with other engineering disciplines and applied sciences to prepare engineers for multidisciplinary projects.
Personalization of Learning	Adaptation of teaching to the individual needs of students through technology and continuous feedback.
Practical Approach and Projects	Promotion of practical problem-solving and real engineering-related projects for a meaningful application of physics.
Advanced Educational Technology	Integration of advanced technological tools, such as virtual or augmented reality, to improve the understanding of complex physical concepts.

Other areas that could be of interest in the engineering areas and that focus on areas essential in current professional training and necessary for new professionals in the digitalized industry are presented in table 6. It is important to highlight that as progress technology and social characteristics are transformed, new areas may emerge that adapt to the realities of the moment and adapt to the demands of the professional of the future.

Table 6. Other areas of interest for the training of engineers.

Other areas of interest for the training of engineers	
Effective Formative Assessment	Development of assessment methods that provide helpful feedback and enable students to correct mistakes and improve their understanding.
Promoting Diversity and Inclusion	Implement strategies to attract and retain diverse students and eliminate gender bias in physics education.
Development of Communication Skills	It helps students communicate physical concepts and experiment results effectively for engineering success and interdisciplinary collaboration.
Quantum Education and Quantum Technology	Inclusion of quantum concepts in physics teaching to prepare engineers for growth in the field of quantum technology.
Teaching Emerging Issues	Preparation of engineers to address emerging issues such as sustainability, climate change, and cybersecurity through applied physics.
Continuous Teacher Training	They offer professional development programs for teachers to keep up with the latest trends and best practices in physics education.
Research in Physics Education	Conducting research in physics pedagogy to identify practical, evidence-based approaches to teaching physics to engineers.

CONCLUSIONS

1. A strong background in physics remains essential for engineers, as it provides a fundamental theoretical and conceptual foundation for understanding and addressing complex problems in various engineering fields.
2. Physics plays a crucial role in the digitized industry by supporting the development of advanced technologies, such as electronics, programming, artificial intelligence, and quantum technology.
3. Engineers with a background in physics can work on multidisciplinary projects, combining their knowledge of physics with digital and technological skills to tackle complex challenges.
4. Engineers with a background in physics are well known for their ability to innovate and problem-solve, making them valuable assets in the digital industry, where creativity and problem-solving are constantly required.
5. Understanding physical principles is essential to address sustainability and social responsibility issues in the digital industry, such as energy efficiency and data management.
6. Professionals in the digital industry must commit to continuing education to keep up with ever-evolving technological and scientific advances, including understanding the underlying physical principles.

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$$(x+a)^n = \sum_{k=0}^{n} \binom{n}{k} x^k a^{n-k}$$

$$(1+x)^n = 1 + \frac{nx}{1!} + \frac{n(n-1)x^2}{2!} + \cdots$$

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