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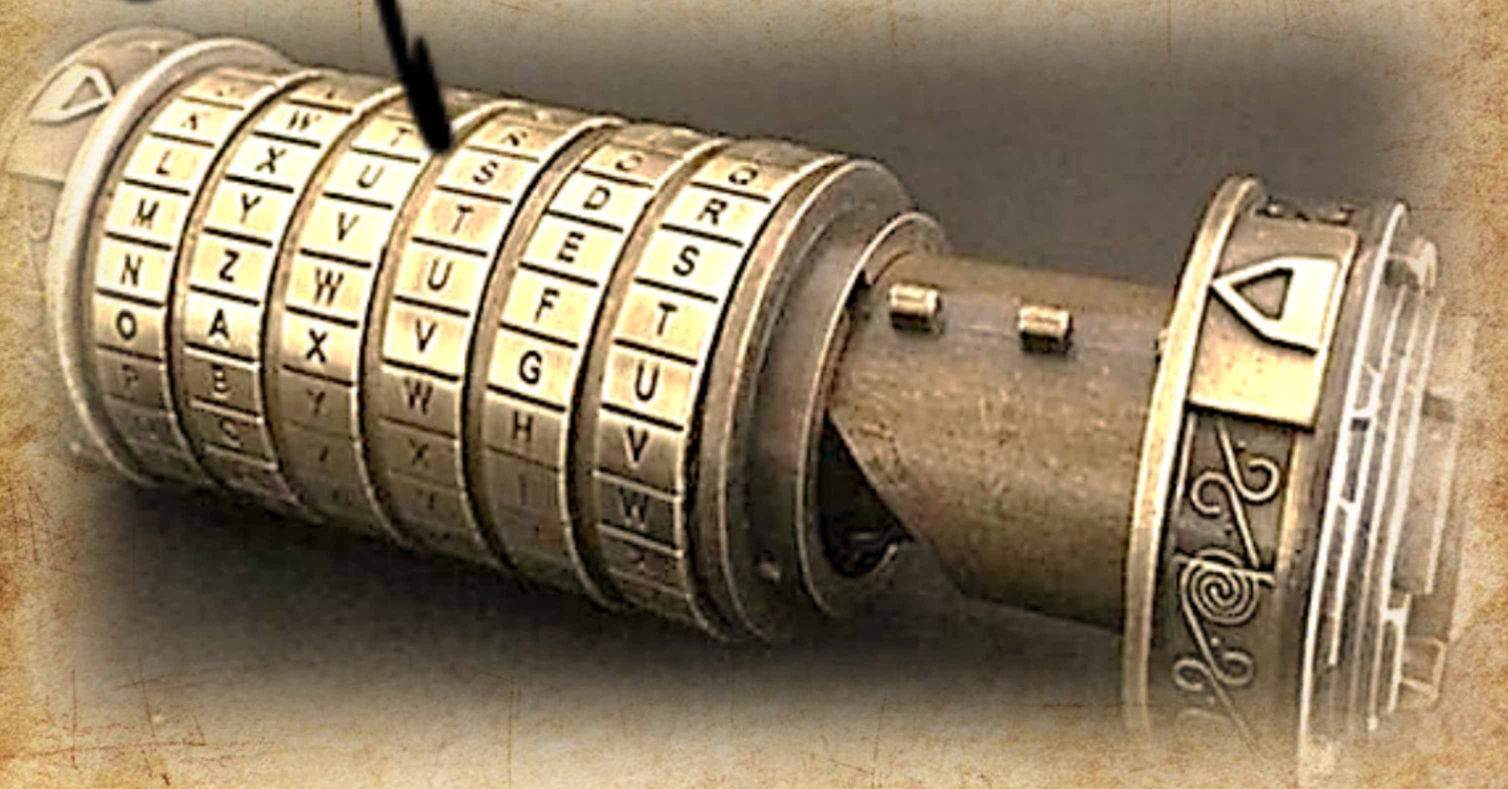

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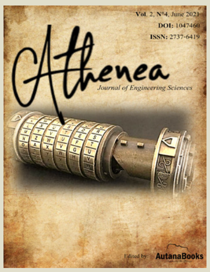

Our cover

The cryptex

The cryptex is a cylindrical device used to keep a message, considered secret. It consists of a capsule composed of a set of wheels with letters or symbols that form an access code. Inside it is a vinegar test tube, which will break if the cryptex is forced to open or if it receives a strong blow, damaging the message inside.

References

[1]Tecnología CES, «Criptex (desarrollo lógico),» 2015. [Online]. Available: https://tecnologiasces.webnode.es/tecno3/criptex-desarrollo-logico/. [Last Access: 2021].

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CONTENTS

EDITORIAL

Advances in science can cause controversy as to their use, both in the natural sciences, such as physics, as well as in applied sciences such as engineering. As new avenues of knowledge open up, scientific debates inevitably arise. For example, the universe itself is an accumulation of questions that keep the life of physics in constant renewal, but it is engineering, with its numerous contributions and solutions, that allows us to delve into the mysteries of the cosmos.

Engineering is increasingly useful in all branches of knowledge, it began as a set of inventions necessary to achieve devices and machines that facilitate the work of other professions. But it has become a gigantic potential in itself, which can both offer solutions and lead to new technologies.

Thus, engineering is a powerful resource for human development, for exploration on land, sea, air and space. Engineering is a perfect blend of science and competencies that support technological, technical, development and innovation structures.

Athenea, a journal focused on engineering sciences, publishes in its fifth issue some research results in the area of engineering, which contribute significantly to the development of new technologies.

Dr. Franyelit Suárez

General editor.

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Structural equation models - PLS in engineering sciences: a brief guide for researchers through a case applied to the industry

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Abstract: Modeling using structural equations, is a second generation statistical data analysis technique, it has been positioned as the methodological options most used by researchers in various fields of science. The best known method is the covariance-based approach, but it presents some limitations for its application in certain cases. Another alternative method is based on the variance structure, through the analysis of partial least squares, which is an appropriate option when the research involves the use of latent variables (for example, composite indicators) prepared by the researcher, and where it is necessary to explain and predict complex models. This article presents a brief summary of the structural equation modeling technique, with an example on the relationship of constructs, sustainability and competitiveness in iron mining, and is intended to be a brief guide for future researchers in the engineering sciences.

Keywords: Competitiveness, Structural equations, Iron mining, Sustainability.

Modelos de ecuaciones estructurales - PLS en ciencias de la ingeniería: una breve guía para investigadores a través de un caso aplicado a la industria

Resumen: El modelado mediante ecuaciones estructurales, es una técnica de análisis de datos estadísticos de segunda generación, se ha posicionado como la opción metodológica más utilizada por investigadores en diversos campos de la ciencia. El método más conocido es el basado en la covarianza, pero presenta algunas limitaciones para su aplicación en determinados casos. Otro método alternativo se basa en la estructura de varianza, mediante el análisis de mínimos cuadrados parciales, que es una opción adecuada cuando la investigación implica el uso de variables latentes (por ejemplo, indicadores compuestos) elaboradas por el investigador, y donde es necesario explicar y predecir modelos complejos. Este artículo presenta un breve resumen de la técnica de modelado de ecuaciones estructurales, con un ejemplo sobre la relación de constructos, sostenibilidad y competitividad en la minería del hierro, y pretende ser una breve guía para futuros investigadores en las ciencias de la ingeniería.

Palabras Clave: Competitividad, Ecuaciones estructurales, Minería de hierro, Sostenibilidad.

I.INTRODUCTION

Latent variables or constructs are present in everyday life more than we realize, although we use them daily, examples of which are: happiness, intelligence, poverty, etc. Also at the level of engineering disciplines, constructs are present, examples of which are sustainability, environmental performance, competitiveness, corporate social responsibility, quality of service, capacity for innovation, among others, which need to be measured and evaluated for the problem diagnosis and decision making.

The structural equation model (Structural Equation Modeling, SEM) is a multivariate method that allows simultaneously evaluating the dependency relationships between observable and unobservable variables (constructs). With this technique, research models are carried out through the transformation of theoretical concepts into unobservable variables and the transformation of empirical concepts into indicators, both are related through the hypothesis expressed graphically by path diagrams. The SEM method can be applied using two alternatives: SEM based on the structure of covariance (BC) or SEM based on the structure of variance, through partial least squares analysis (PLS).

The origin of the BC SEM dates back to 1973, when Karl Jöreskog introduced a maximum likelihood algorithm for estimating models of covariance structures [1]. The Swedish professor Herman Wold, criticized the dependence of the distribution assumptions, which affects the validity of the empirical results, and proposed an alternative approach, Partial Least Squares (PLS), and in 1977 he developed the algorithm NIPALS (Nonlinear Iterative Partial Least Squares) [2]. The BC SEM is based on the assumption of normality of the variables and uses a maximum likelihood estimate, requires a generally large sample and is focused on the "reproduction" of the structure of relationships between variables.

This article is based on the PLS SEM, which has advantages for its application. This modeling method is more flexible by not requiring rigorous parametric assumptions. PLS SEM does not assume normality and is estimated by recursive least squares, it is applicable with small samples and is focused on prediction. The mathematical and statistical procedures underlying the PLS SEM are rigorous and robust [2].

PLS SEM is the iterative combination of principal component analysis, path analysis, and Ordinary Least Squares (OLS) regression. The principal component analysis links the observable variables with the constructs, the path analysis allows the construction of the structure of the system of variables and the OLS regression allows the estimation of the parameters. It is important to highlight that PLS SEM can be used for both explanatory (confirmatory) and predictive (exploratory) research [1], [3].

In engineering sciences, relatively few researchers have also begun to successfully exploit the potential of PLS SEM to obtain relevant results in their analyzes. In this article, after proposing the theoretical definitions and the procedure, to illustrate the application of the PLS SEM, a case of an multidisciplinary nature of mining, industrial and environmental engineering is developed, on the relationship of the constructs Sustainability and Competitiveness in the iron mining industry, demonstrating the high applicability of this novel technique for the development of models in the field of engineering.

II.THEORETICAL ASPECTS

The general model of structural equations consists of a measurement model, also called an external model, and a structural model or internal model. The measurement model specifies the relationships between the observable variables and the latent variables that underlie them. On the contrary, the structural model specifies the relationships between the latent variables, which in turn consist of exogenous variables or constructs (η) and endogenous variables or constructs (ξ). In Figure 1, a schematic of the general model of a PLS SEM is presented. In the context of PLS SEM, you can work with two types of measurement models: (1) the reflective model; and (2) the training model.

The measurement model is governed by two equations; one that measures the relationships between endogenous latent variables and their observable variables.

$$y = \Lambda_y \eta + \varepsilon \qquad (1)$$

Where:

y is the vector of p observable variables (px1)

Λy is the matrix of coefficients that show the relationships between the latent and observed variables (pxm). Also called the charge matrix (λ).

ε is the error vector (px1).

The second equation of the measurement model is the one that governs the relationships between the exogenous latent variables and their observable variables:

$$x = \Lambda_x \xi + \delta \qquad (2)$$

Where:

x is the vector of p observable variables (qx1)

Λx is the matrix of coefficients that show the relationships between the latent and observed variables (qxm). Also called a matrix of weights (π).

δ is the error vector (qx1).

The structural model is defined by the equation:

$$\eta = \beta\eta + \tau\xi + \zeta \qquad (3)$$

Where:

η represents the vector of endogenous latent random variables of dimension mx1.

ξ represents the vector of exogenous latent random variables of dimension nx1.

β represents the matrix of coefficients that govern the relationships between the endogenous variables mxm.

Γ represents the matrix of coefficients that govern the exogenous relationships and each of the endogenous ones, or in other words, the effects of ξ on η . Its dimension is mxn.

ζ represents the vector of disturbances or errors.

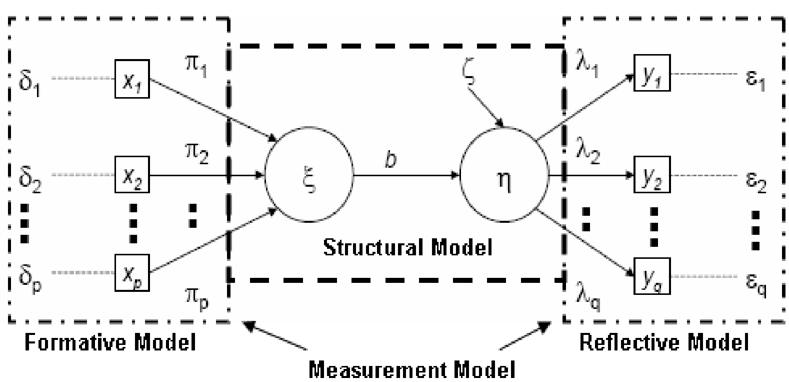

Fig. 1. General model schematic of a PLS SEM
Source: Adapted from Cepeda and Roldán [4]

III.PROCEDURE TO APPLY PLS SEM

The procedure to apply PLS SEM is illustrated in Figure 2, there are six steps:

1. Specify the measurement and structural models.
2. Collect and examine the data.

3. Estimate the PLS parameters.
4. Evaluate the results of the measurement and structural models.
5. Re-specify the model.
6. Interpret the results and draw conclusions.

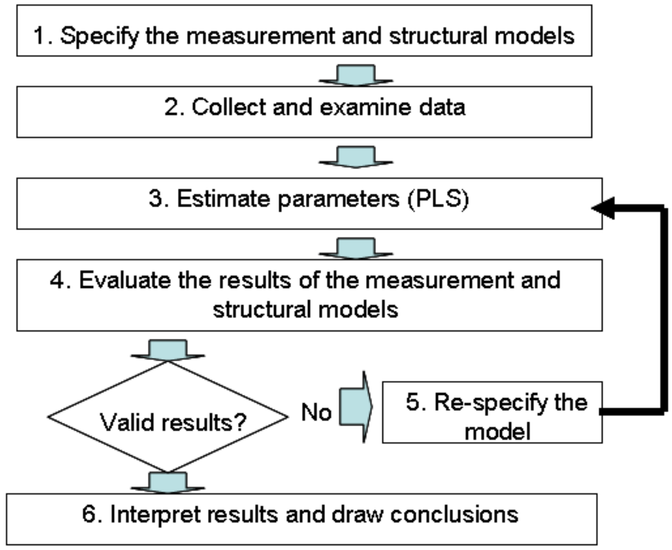

Fig. 2. cheme of the procedure to apply the PLS SEM.

A. Specify the measurement and structural models.

The researcher applies the theoretical knowledge of the studied phenomena to the formulation of mathematical expressions related to the relationships between latent variables, and their relationships with their indicators or observable variables.

B. Collect and examine data.

The data collection and examination stage is very important in the SEM application and can avoid delay, especially when careful examination of the data manages to rid the data of outliers and identify missing data. The first step in dealing with outliers is to identify them, standard statistical software packages offer a multitude of statistical tools, which allow you to identify outliers. In general, each PLS SEM software offers ways to handle the missing data, the most common are: substituting the mean of the valid values of that indicator or eliminating the cases that include missing values.

C. Estimate parameters (PLS).

Once specified, the structural and measurement parameters of a PLS SEM model are estimated by the software (in our case the SmartPLS) iteratively using simple Ordinary Least Squares (OLS) and multiple regressions. In a much summarized way it would be the following sequence of iterations:

1. In the first iteration of PLS, you get an initial value for η(adding the values y1 ..., yq).
2. Estimation of the regression weights π1 ..., πp (regression of the value of η with x1 ..., xp).
3. Estimates of π1 ..., πp in linear combination with x1 ..., xp resulting in an initial value for ξ .
4. Estimates of the charges λ1 ..., λ q by a series of simple regressions of y1 ..., yq on ξ.
5. The estimated charges λ1 ..., λ q, in linear combination with y1 ..., yq, obtain a new estimate of the value of η .

This procedure continues until the difference between consecutive iterations is extremely small, according to the criterion selected by the researcher [4].

D. Evaluate the results of the measurement and structural models.

To evaluate the results, it is necessary to verify and validate the goodness of fit of the models. There is no global fit coefficient available in PLS SEM and not all measures are appropriate to assess all types of fit [5]. The validation of the SEM model through the PLS statistical tool requires a series of parameters that are estimated in two stages: the measurement model and the structural model [6], [7].

Validation of the Measurement Model. This is done with respect to the validity and reliability attributes of the model. This implies verifying: i) individual item reliability, ii) internal consistency, iii) convergent validity, and iv) discriminant validity [7], [8].

Item Reliability. The criterion for an item to be considered in the composition of the variables is that it must load at least 0.5 in the factor [9]. In this sense, it is considered that the individual reliability of the item is assessed by examining the loads (λ) or simple correlations. Another more demanding criterion to accept an indicator is that it has a load equal to or greater than 0.707 (λ^2, 50% of the variance is explained) [4].

Internal Consistency (Construct Reliability). The reliability of a construct makes it possible to check the internal consistency of all the indicators when measuring the concept, that is, it is evaluated how rigorously the observable variables are measuring the same latent variable (Roldán, 2004). Construct reliability can be verified using composite reliability and Cronbach's alpha. Composite reliability is a preferred alternative to Cronbach's alpha as a test of convergent validity in a reflective model; Cronbach's alpha may overestimate or underestimate the reliability of the scale. In a model suitable for exploratory purposes, the composite reliabilities should be equal to or greater than .6 [10], [11]; equal to or greater than .70 for a suitable model for confirmation purposes [12]; and equal to or greater than .80 is considered good for confirmatory research [13]. The compound reliability measure (ICC) is given by the following mathematical expression:

$$ICC = \frac{(\sum \lambda_i)^2}{(\sum \lambda_i)^2 + \sum_i var(\varepsilon_i)} \qquad (4)$$

donde λi = carga estandarizada del indicador i, λi = error de medida del indicador i, y var(ε i) = 1 – λ^2i [14].

Convergent Validation. It determines if the different items destined to measure a concept or construct really measure the same thing, then the adjustment of these items will be significant and they will be highly correlated [6]. The assessment of convergent validity is carried out by means of the measure developed by Fornell and Larcker (1981) called the mean extracted variance (Average Variance Extracted: AVE) [4]. AVE measures the amount of variance that a construct obtains from its indicators in relation to the amount of variance due to the measurement error, its formula being the following:

$$AVE = \frac{(\sum \lambda_i^2)}{(\sum \lambda_i^2) + \sum_i var(\varepsilon_i)} \qquad (5)$$

Where, λi = standardized load of indicator i, λ i = measurement error of indicator i, and var (ε i) = 1 - ε^2i [14].

This statistic can be interpreted as a measure of construct reliability and as a measure of the evaluation of discriminant validity [15]. The mean extracted variance is recommended to be greater than 0.50, which establishes that more than 50% of the variance of the construct is due to its indicators [14].

Discriminant validity. It indicates to what extent a given construct is different from others in a research model [6]. Therefore, establishing discriminant validity implies that a construct is unique and captures phenomena not represented by other constructs in the model [1]. For there to be discriminant validity in a construct, there must be weak correlations between it and other latent variables that measure different phenomena [7].

Traditionally, researchers have relied on two measures of discriminant validity: the Fornell-Larcker discriminant validity criterion and crossloads. According to the Fornell-Larcker criterion, for any latent variable, the square root of the AVE must be greater than its correlation with any other latent variable. In a good model, the indicators load well in their expected factors and the cross loads with other factors that they should not measure should be low, as a general rule it is understood that the expected loads should be greater than .7 (some use .6) and cross loads must be below .3 (some use .4) [5].

Validation of the Structural Model. In this phase, it must be verified whether the amount of variance of the endogenous variable is explained by the constructs that predict it. The appropriate model fit criteria are summarized in the following aspects:

R-square
R-squared change and the f-squared effect of exogenous factors
Structural path coefficients
Predictive relevance (q-square)
Multicollinearity

The R-square, also called the coefficient of determination, is the measure of the overall effect size for the structural model, it indicates the% of the variance in the variable that is explained by the model. The explained variance of the endogenous variables (R^2) should be greater than or equal to 0.1 [16].

To assess the validity of the structural model, changes in R^2 can also be explored to determine whether the influence of a particular latent variable on a dependent construct has a substantive impact [10]. The importance of the effect f^2 can be calculated with the following expression:

$$f^2 = \frac{R^2_{included} - R^2_{excluded}}{1 - R^2_{included}} \quad (6)$$

where R^2included and R^2excluded represent the R^2 provided by the dependent latent variable when the predictor variable is used or omitted in the structural equation respectively [10]. The f^2 levels of 0.02, 0.15 and 0.35 are respectively a small, medium or large effect.

The structural path coefficients (loads) vary from 0 to 1, for standardized data. These loads must be significant. The significance level is determined from the Student t value derived from the resampling or bootstrapping process, which is a non-parametric technique (there are no initial parameters; it is tested if the paths between variables are feasible) [17].

The predictive relevance check is performed using a procedure called “blindfolding”, to determine the Q^2 coefficients. This procedure omits part of the data when estimating a dependent latent variable from other independent latent variables, and then attempts to estimate those data using the previously estimated parameters. The process is repeated until each omitted data has been estimated.

The Q^2 (Stone-Geisser validated redundancy measures), predicts the punctual indicators in the endogenous reflexive measurement models and the constructs (the Q^2 does not apply to the endogenous formative constructs). This criterion refers to the fact that the model must have the ability to predict reflective indicators of endogenous latent variables [18].

For its calculation of Q^2, an omission distance "D" is taken that is not a divisor of the sample size. "D" corresponds to the number of cases omitted in the sample that must be estimated. Generally in existing PLS software packages, the default distance is between 5-10.

A good model demonstrates predictive relevance when Q^2 is greater than zero [10]. For values close to .02 it represents a "small" relevance size, .15 represents a "medium" relevance size and .35 represents a "high" relevance size [19]. The Stone-Geisser Q^2 measurement is based on the following parameters:

$$Q^2 = 1 - \frac{SSE}{SSO} \quad (7)$$

Where:
SSE = sum of squares of prediction error
SSO = sum of squares of observations

Multicollinearity is a problem in the reflective or formative models, as well as the structural model, for the same reason that it is in the OLS regression models. To evaluate multicollinearity, it is performed through the variance inflation factor coefficients (VIF) and / or the tolerance is equal to 1.0 minus R^2. In a well-fitted model, the structural VIF coefficients should not exceed 4.0 (some use the more lenient criterion of 5.0), and tolerance <.20 indicates possible multicollinearity [1]. This is equivalent to saying that $R^2 > .80$ suggests a possible multicollinearity problem [5].

E. Re-specify the model.

On rare occasions, the proposed model is the one that best fits initially in the first run, so it is very common to re-specify it, which consists of adding or removing parameters from the model. These modifications must respond to theoretical justifications, and not to desirable empirical justifications.

F. Interpret results and draw conclusions.

As a last step, the simple regression coefficients between the scores of the components of ξ and η are analyzed, where the results and statistical significance of the relationships between latent variables that make up the hypotheses are analyzed, in order to check whether they were accepted or not in the study.

IV.Case Study: Evaluation Of The Effect Of Sustainability Dimensions On Competitiveness In Iron Mining

A.Measurement and structural models.

To study the effect of the dimensions of sustainability on competitiveness in iron mining, the dimensions specified in the model proposed by the ICMM ("International Council on Mining and Metals") and the GRI ("Global Reporting Initiative"). This model establishes three dimensions for sustainability in economic, environmental and social terms. The economic dimension refers to the impacts of the organization on the economic conditions of its stakeholders and on economic systems at the local, national and global levels. The environmental dimension refers to the impact of the organization on natural systems, including land, air, water, and ecosystems. The Environmental Category covers impacts related to energy, water, emissions and waste. The social dimension refers to the impacts that the organization has on the social systems in which it operates [20]. In Figure 3, the indicators and dimensions of the sustainability and competitiveness of iron mining are illustrated, the variables that were commonly reported by mining companies in their sustainability reports were selected as indicators.

To define the competitiveness construct of iron mining, the variables used by prominent authors in the area of business competitiveness and mining competitiveness were taken.

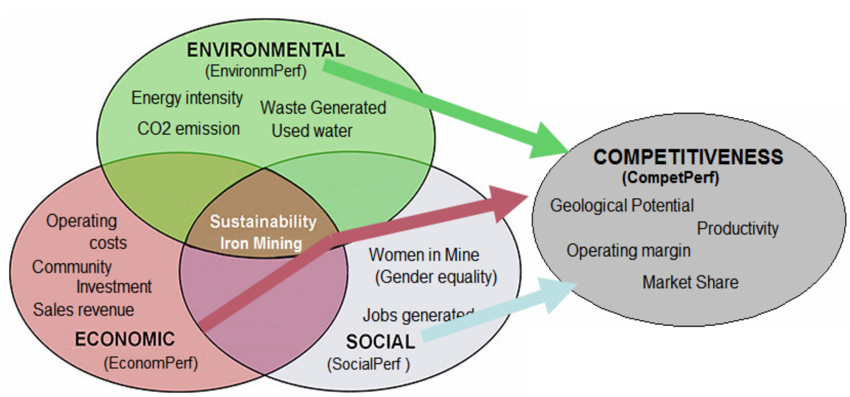

Fig. 3. Scheme of indicators of the dimensions of sustainability and competitiveness of iron mining.

Table 1 shows the variables and their units. Figure 4 shows the diagram of the measurement and structural models. The hypotheses were as follows:

- H1: EconomPerf has a positive and significant effect on CompetPerf.

- H2: EnvironmPerf has a positive and significant effect on CompetPerf.
- H3: SocialPerf has a positive and significant effect on CompetPerf.

Table 1. Description of the observable variables

	Description	Dimension	United
JouleEI	Energy intensity	Environment	Gjoules/Tm produc
WIM	Women in Mina	Social	% of total Employees
PTF	Productivity	Competitiveness	Tm / Inputs
GP	Geological Potential	Competitiveness	% Fe, Reserves and Mine Weighted Useful Life
CO2	CO2 emission	Environment	Kg./Ton produc
OM	Operating margin	Competitiveness	EBIT/Revenues
GMW	Waste Generated	Environment	Tm Waste / Tm MENA
CI	Community Investment	Economic	% Profit before tax, depreciation and amortization
OC	Operating costs	Economic	Costs Supplies and Serv.
RS	Sales revenue	Economic	Income / Tm sold
Employ	Jobs generated	Social	Employee/KTm
WaterW	Used water	Environment	M3 water / Tm produc
SH	Market Share	Competitiveness	Tm Sold / Global Tm

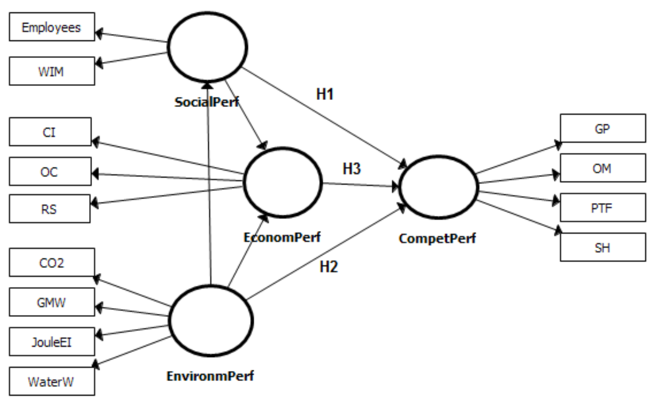

Fig. 4. Diagram of the measurement and structural models

B.Data collected from the indicators.

For data collection, annual data were taken from the reports of eight mining companies, national and international organizations. The mining companies were Assmang (South Africa), CAP (Chile), IOC (Canada), Kumba (South Africa), LKAB (Sweden), Rio Tinto (Australia), Vale (Brazil) and Ferrexpo (Ukraine). These companies represented approximately 45% of the world market for 2019. Table 2 presents the descriptive statistics of the data collected.

Table 2. Descriptive statistics of the data of the observable variables

	Mean	Min	Max	D. estánd	Asymmetry	Kurtosis
JouleEI	0.64	0.20	1.77	0.45	1.458	1.013
WIM	17.11	7.30	29.00	6.77	0.008	-1.075
PTF	0.02	0.01	0.04	0.01	0.15	-0.562
GP	10.34	1.30	50.79	14.05	2.104	3.171
CO2	43.03	15.60	80.16	17.46	0.198	-1.094
OM	0.30	-0.07	0.60	0.16	-0.321	-0.646
GMW	3.55	0.78	9.98	2.30	0.664	-0.027
CI	0.04	0.00	0.35	0.07	3.214	11.395
OC	47.05	24.06	85.36	16.95	0.505	-0.83
RS	81.85	40.63	143.50	23.72	0.465	-0.466
Employees	0.24	0.03	0.88	0.25	1.904	2.371
WaterW	0.82	0.25	1.64	0.40	1.012	-0.406
SH	5.81	0.56	21.82	7.81	1.233	-0.374

C.Estimated PLS parameters of the models.

For PLS calculations, SmartPLS version 3.2.7 software was used. In Figure 5, the model is presented with the values of the loads of the measurement model, the path coefficients of the structural model and the composite reliability values of the latent variables.

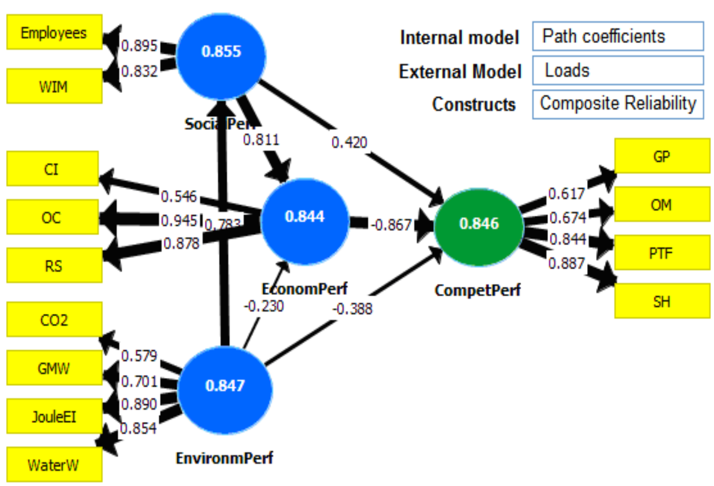

Fig. 5. Models with the estimated parameters: Loads, Coefficients and composite reliability indices.

D.Evaluation of the results

Validity of the Measurement Model. The individual reliability of each of the items is assessed by examining the loads (λ), as can be seen in Figure 5, all the loads are greater than 0.5, which satisfies the criterion of the minimum required load value λ> 0.5. Table 3 shows the statistical significance of all loads (λ), it is observed that they are significant; therefore all items are accepted as valid.

Internal Consistency and Convergent Validity. Table 4 shows the results of the composite reliability index and the mean extracted variance (AVE) for each latent variable. The measurement model is considered to have internal consistency and convergent validity, since the composite reliabilities are greater than .80 and the AVEs are greater than 0.5.

Table 3. Statistical significance of the loads of the observable variables

Loads (Standardized λ)	Statistics t	P Values
CI <- EconomPerf	5.056	0.000
CO2 <- EnvironmPerf	5.748	0.000
Employees <- SocialPerf	19.316	0.000
GMW <- EnvironmPerf	4.161	0.000
GP <- CompetPerf	4.611	0.000
JouleEl <- EnvironmPerf	26.370	0.000
OC <- EconomPerf	60.485	0.000
OM <- CompetPerf	7.137	0.000
PTF <- CompetPerf	30.127	0.000
RS <- EconomPerf	19.277	0.000
SH <- CompetPerf	19.428	0.000
WIM <- SocialPerf	7.834	0.000
WaterW <- EnvironmPerf	8.941	0.000

Table 4. Internal consistency and convergent validity

	Composite reliability	AVE
CompetPerf	0.846	0.583
EconomPerf	0.844	0.654
EnvironmPerf	0.847	0.587
SocialPerf	0.855	0.747

Discriminant validity. There are different criteria for determining the discriminant validity, among which are the analysis of the extracted variance (AVE) and the cross loads. Table 5 shows the correlation matrix between constructs, where the diagonal shows that the square root of the extracted variance is greater than the shared variance between constructs, therefore, according to the Fornell-Larcker criterion, can affirm that there is discriminant validity. In Appendix A1, the cross-load matrix is presented, which also confirms the discriminant validity of the measurement model.

Table 5. Discriminant validity (Fornell-Larcker criterion).

Constructs	CompetPerf	EconomPerf	EnvironmPerf	SocialPerf
CompetPerf	0.764			
EconomPerf	-0.759	0.809		
EnvironmPerf	-0.410	0.405	0.766	
SocialPerf	-0.430	0.631	0.763	0.864

Validity of the Structural Model. For the evaluation of the structural model, the collinearity coefficients, the magnitude and statistical significance of the path coefficients, the effect sizes f^2 and the predictive relevance Q^2 were verified.

The R² values <0.8 and tolerance> 0.2, shown in Table 6, indicate the absence of multicollinearity, this is also corroborated with the VIF values shown in Appendix A2, by satisfying the criterion of VIF <4.0.

Table 6. Reliability and construct validity

	R^2	Tolerance
CompetPerf	0.636	0.3869
EconomPerf	0.419	0.581
EnvironmPerf		
SocialPerf	0.613	0.395

Table 7 shows the standardized path coefficients, the t statistics and the corresponding statistical significance, it is observed that the coefficients are significant.

Table 7. Path coefficients (standardized regression coefficients)

	Path coefficient (Standardized β)	Statistics t	P Values
EconomPerf -> CompetPerf	-0.867	10.144	0.000
EnvironmPerf -> CompetPerf	-0.388	2.547	0.011
SocialPerf -> CompetPerf	0.420	2.240	0.026

In Table 8, the values of f² are presented, which measure the change in R² when a certain exogenous construct is omitted from the model. As can be seen, the EconomPerf has a large effect with the CompetPerf; however, the EnvironmPerf has a medium effect with the CompetPerf, and the SocialPerf has a small effect with the CompetPerf.

Table 8. F square

Constructs	Compet Perf	Econom Perf	Environm Perf	Social Perf
CompetPerf				
EconomPerf	1.202			
EnvironmPerf	0.154	0.035		1.585
SocialPerf	0.131	0.438		

In Table 9, the Q squared values are presented. According to the criterion of Cohen (1988), affirming that the model has a high degree of predictive relevance with respect to the endogenous CompetPerf and SocialPerf factors. In the case of EconomPerf, it presents a medium degree of predictive relevance.

Table 9. Q squared

	SSO	SSE	Q² (=1-SSE/SSO)
CompetPerf	192.0	132.8	0.308
EconomPerf	144.0	110.6	0.232
SocialPerf	96.0	55.3	0.424

E.Interpret results and draw conclusions.

The results of the path coefficients in Table 7 indicate that EconomPerf -> CompetPerf and EnvironmPerf -> CompetPerf, even when they have statistical significance, have signs contrary to those postulated in hypotheses H1 and H2, which indicates that these hypotheses are rejected. On the other hand, the path SocialPerf -> CompetPerf, corresponding to hypothesis H3, has statistical significance and a positive sign, therefore this hypothesis is accepted (see Table 10).

Table 10. Summary of results

Hypotheses	Independent variable	Results
H1	EconomPerf has a positive and significant effect on the CompetPerf	Rejected
H2	EnvironmPerf has a positive and significant effect on the CompetPerf.	Rejected
H3	SocialPerf has a positive and significant effect on the CompetPerf	Accepted

The results obtained reveal that the economic sustainability and environmental sustainability dimensions of iron mining have a negative influence on competitiveness. This result, far from being a conflict of interest between latent variables, represents the effect of the observable variables. In the case of the environmental dimension, the emission of CO_2, the waste generated, the use of water and the use of energy results in a negative effect on competitiveness. In the case of the economic dimension, the operating costs involved in the acquisition of goods and services in the localities, generating indirect jobs for the mining activity, and the community investment, if it increases, benefits the community, but in turn affects the profitability by being expenditures.

It is then a reality, in which the mining companies must give responsible treatment to the socio-environmental systems affected by the operations, and where necessarily part of the income and benefits generated will necessarily have to be allocated to their remediation.

V.CONCLUSIONS

The following conclusions emerge from the research carried out:

1.It has been shown that the PLS SEM is a technique that facilitates the development of research models from theoretical concepts and latent variables, with a limited number of observations.

2.With the present case of a multidisciplinary nature of mining, industrial, environmental engineering and statistical science, applied to the mining industry, where indicators prepared from objective data of the observed reality were used, we can affirm that the PLS SEM technique, constitutes an excellent support tool for research in the field of engineering sciences.

3.The ability to model the relationships between latent variables in a flexible way and not subject to rigorous parametric assumptions of the PLS SEM, allows us to forecast for this recent technique many applications in the field of engineering sciences.

4.Finally, as future research work, there are possible applications of the PLS SEM to the study of important aspects of the industry such as: productivity, efficiency, innovation, quality, corporate social responsibility, operation of industrial plants, organizational climate, ergonomics, industrial safety, among others.

APPENDIX

A1. Cross Factor Loads.

	Compet Perf	Econom Perf	Environm Perf	Social Perf
SH	0.887	-0.565	-0.389	-0.394
PTF	0.844	-0.803	-0.401	-0.407
OM	0.674	-0.410	-0.071	-0.044
GP	0.617	-0.387	-0.345	-0.465
OC	-0.798	0.945	0.399	0.596
RS	-0.597	0.878	0.483	0.631
CI	-0.368	0.546	-0.054	0.199
JouleEI	-0.401	0.562	0.890	0.821
WaterW	-0.294	0.260	0.854	0.559
GMW	-0.217	0.105	0.701	0.601
CO2	-0.358	0.106	0.579	0.202
Employees	-0.394	0.486	0.843	0.895
WIM	-0.347	0.623	0.475	0.832

A2. VIF values of the structural model

Constructs	CompetPerf	EconomPerf	EnvironmPerf	SocialPerf
CompetPerf				
EconomPerf	1.720			
EnvironmPerf	2.677	2.585		1.000
SocialPerf	3.718	2.585		

REFERENCES

[1]J. Hair, G. Hult, C. Ringle and M. Sarstedt. A Primer on Partial Least Square Structural Equation Modeling (PLS-SEM). California: United States. Sage, 2017.
[2]H. Wold. Model Construction and Evaluation when Theoretical Knowledge Is Scarce: An Example of the Use of Partial Least Squares. Genève. Faculté des Sciences Économiques et Sociales, Université de Genève. 1979.
[3]J. Henseler, G. Hubona & P. Ray. "Using PLS path modeling new technology research: updated guidelines". Industrial Management & Data Systems, 116(1), 2-20. 2016.
[4]G. Cepeda and Roldán J. "Aplicando en la Práctica la Técnica PLS en la Administración de Empresas". Congreso de la ACEDE, Murcia, España, 2004.
[5]D. Garson. Partial Least Squares. Regresión and Structural Equation Models. USA. Statistical Associates Publishing: 2016.
[6]D. Barclay, C. Higgins & R. Thompson. "The Partial Least Squares (PLS) Approach to Causal Modeling: Personal Computer Adoption and Use as an Illustration". Technology Studies. Special Issue on Research Methodology. (2:2), pp. 285-309. 1995
[7]J. Medina, N. Pedraza & M. Guerrero. "Modelado de Ecuaciones Estructurales. Un Enfoque de Partial Least Square Aplicado en las Ciencias Sociales y Administrativas". XIV Congreso Internacional de la Academia de Ciencias Administrativas A.C. (ACACIA). EGADE – ITESM. Monterrey, México, 2010.
[8]J. Medina & J. Chaparro. "The Impact of the Human Element in the Information Systems Quality for Decision Making and User Satisfaction". Journal of Computer Information Systems. (48:2), pp. 44-52. 2008.
[9]D. Leidner, S. Carlsson, J. Elam & M. Corrales. "Mexican and Swedish Managers' Perceptions of the Impact

of EIS on Organizational Intelligence, Decisión Making, and Structure". Decision Science. (30:3), pp. 633-658. 1999.
[10]W. Chin. "The partial least squares approach for structural equation modeling". Chapter Ten, pp. 295-336 in Modern methods for business research. Edited by Macoulides, G. A., New Jersey: Lawrence Erlbaum Associates, 1998.
[11]M. Höck & C. Ringle M. "Strategic networks in the software industry: An empirical analysis of the value continuum". IFSAM VIIIth World Congress, Berlin 2006.
[12]J. Henseler, Ch. Ringle & M. Sarstedt. Handbook of partial least squares: Concepts, methods and applications in marketing and related fields. Berlin: Springer, 2012.
[13]S. Daskalakis & J. Mantas. "Evaluating the impact of a service-oriented framework for healthcare interoperability". Studies in Health Technology and Informatics. pp. 285-290. 2008.
[14]C. Fornell & D. Larcker: "Evaluating Structural Equation Models with Unobservable Variables and Measurement Error", Journal of Marketing Research, vol. 18, pp. 39-50. Februay 1981.
[15]C. Fornell. A Second Generation of Multivariate Analysis: An Overview. Vol. 1. New York, U.S.A. Praeger Publishers: 1982.
[16]R. Falk and N. Miller. A Primer for Soft Modeling. Ohio: The University of Akron. 1992.
[17]M. Martínez. Aplicación de la técnica PLS-SEM en la gestión del conocimiento: un enfoque técnico práctico. Revista Iberoamericana para Investigación y el Desarrollo Educativo. Vol. 8, Núm. 16. 2018.
[18]S. Geisser. "A predictive approach to the random effects model". Biometrika, Vol. 61(1), pp. 101-107. 1974.
[19]J. Cohen. Statistical power analysis for the behavioral sciences. Mahwah, NJ: Lawrence Erlbaum, 1988.
[20]GRI (2013). G4 Sustainability Reporting Guidelines. Global Reporting Initiative. Available: www.globalreporting.org

CURRICULUM SUMMARY

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Adaptive control systems for solar collectors

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Abstract: En este trabajo se presentan las estrategias de control del flujo de aceite mediante la técnica de Control Predictivo basado en Modelo, para el mecanismo de control del campo de colectores solares cilindros parabólicos. Se analiza el comportamiento dinámico del sistema con el uso del modelo matemático, una técnica de control self-tunning y controlador predictivo basado en modelo para el control de plantas tipo ACUREX.

Keywords: Automation, Modernization, ControlLogix, Supervisory System, Mimic Panel

Sistemas de control adaptativo para colectores solares

Resumen: En este trabajo se presentan las estrategias de control del flujo de aceite mediante la técnica de Control Predictivo basado en Modelo, para el mecanismo de control del campo de colectores solares cilindros parabólicos. Se analiza el comportamiento dinámico del sistema con el uso del modelo matemático, una técnica de control self-tunning y controlador predictivo basado en modelo para el control de plantas tipo ACUREX.

Palabras Clave: Autómata, Modernización, ControlLogix, Sistema Supervisorio, Panel Mímico.

I.INTRODUCTION

The use of clean energy on the planet is increasingly necessary, research in this area is becoming more frequent and important to better preserve our environment and natural resources.

There are currently a growing number of solar plants generating electricity or heat energy that can be used for human consumption or industrial processes. One of the experimental solar plants in Spain is the one in Almeria. Some control strategies have been tested in the last 30 years, seeking better performance and control of the temperature of the oil that this system uses in its operation, the energy of solar radiation is absorbed and transported by a thermal fluid for later use.

It is of interest new alternatives and criteria that allow the continuous improvement of this type of plant. This work intends to contribute with criteria on the use of the Model-Based Predictive Control technique that can serve as a basis with criteria for further developments.

II. DEVELOPMENT

A. Simulator in Simulink of the ACUREX type Collector Field

Process Model

Considering the basic operation of the collector field and the more detailed description of Arahal [1], the following is a brief explanation of the development of the model, as well as the variables necessary for the control employing the simulator.

Taking into account the principle of conservation of energy to the metal pipe and considering the thermal phenomenon of the oil-absorbing energy, a mathematical model has been developed [1] with which the initial estimation of the temperature of the fluid (f) and the metal (m) of the pipe is allowed.

$$\rho_m c_m A_m \frac{\partial T_m}{\partial t} = I\eta_o D - H_1 G(T_m - T_a) - LH_t(T_m - T_f\Big) \quad (1)$$

$$\rho_f c_f A_f \frac{\partial T_f}{\partial t} + \rho_f c_f \dot{V} \frac{\partial T_f}{\partial x} = LH_t(T_m - T_f) \quad (2)$$

Table 1. Variables used in equations (1) and (2)

Symbol	Description	Units
t	Time	S
x	Length	m
ρ	Oil Density	kgm^{-3}
c	Specific Heat	$JK^{-1}kg^{-1}$
A	Cross-sectional area	m^2
T	Outlet temperature	$K, °C$
I	Solar radiation	$W\ m^{-2}$
H_1	Global coefficient of thermal loss	$W\ m^{-2}C^{-1}$

D	Reflective surface width	m
H_t	Metal-fluid heat transfer coefficient	$W\ m^{-2}\ C^{-1}$
G	Manifold opening	m
L	Linear tube length	m
$\dot{V}$	Oil flow	$m^2\ s^{-1}$
η_0	Geometric efficiency	-
T_a	Room temperature	$K, °C$

As the system is composed of several collectors connected in series, some of them may be inactive for maintenance reasons, therefore equations (1) and (2) will be taken into account for the control only for the active areas of the field, considering the number of active and non-active collectors. Table 2 details the parameters used in the mathematical model.

Process Simulator in Simulink-Matlab

The Simulink simulator was originally developed in C language and then adapted with the use of MEX files.

Two stages are considered for the simulation. The first one calculates the fluid and metal temperature considering (1) and (2), a stationary regime is assumed. The second stage considers the energy transported in the fluid.

Two models are used for this simulation. The distributed model of the collector field was obtained by using the energy conservation principle. In addition, parameter adjustment models are used, which have been achieved through the adjustment of polynomial functions as a function of temperature by the method of least squares.

To simulate the system, data feedback is used, taking into account the handling of 39 variables that are updated as the process is simulated. Real data measured on September 16, 1991, are also considered. The simulation day is considered from 8:50 a.m. and its duration time is 6 hours and 36 minutes, the sampling time is 39 seconds [2].

B.Adaptive Control

This type of control ensures that the automatic control system adapts to varying circumstances of behavior in the dynamics of a system and its disturbances.

A useful definition would be that Adaptive Control is a special type of nonlinear control in which the process state can be separated into two-time scales that evolve at different speeds. The slow scale corresponds to the parameter changes and therefore to the speed with which the controller parameters are modified, and the fast scale corresponds to the dynamics of the ordinary feedback loop [3].

We appreciate in Figure 1 a basic scheme of adaptive control. There is a negative feedback loop, a controller acts, and another loop where the performance is evaluated, the error is compared with the desired performance, and with the help of an adaptive mechanism, the controller parameters are adjusted, and sometimes it acts directly on the control signal. There may also be a third loop with the task of monitoring the performance of the previous two loops.

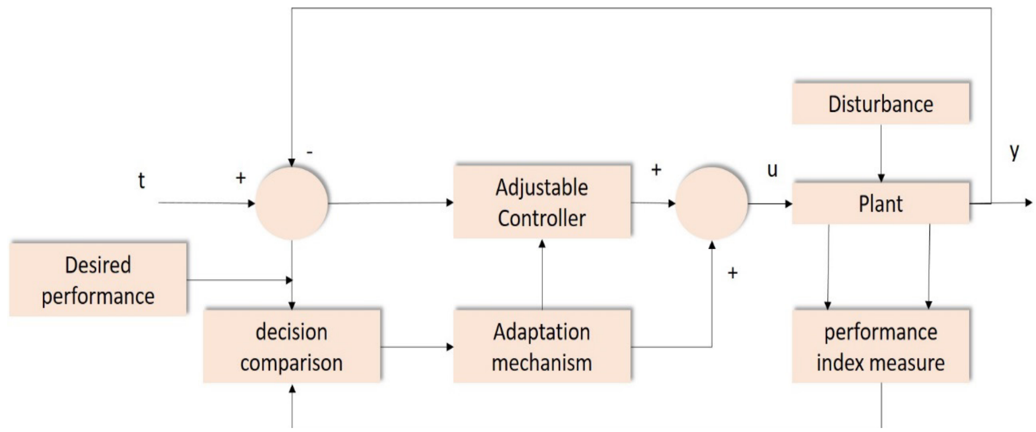

Fig 1. Basic configuration of a adaptive control.

III.METHODOLOGY

In this work and to find alternative solutions, the predictive controller has been implemented in three situations that could be useful or as a basis for future developments.

The mathematical combination of the Prefeed Block and Plant has been carried out, and the predictive controller has been designed with this model.

The second case is the simulation of the system with MPC and the use of an identifier to estimate a fixed model of the Prefeed and Plant blocks and use it in the control.

The third case corresponds to the previous identifier placed online in the simulation that will allow estimating the parameters of the model as it evolves and thus adjusts the controller, this being a case of adaptive control to some degree.

Considering the mathematical model, the predictive controller has been implemented in the simulator. Figure 2 shows the scheme used in Simulink for the control. The replacement of the PI controller block is observed. Some functions have been created in Matlab and used to adapt them to the simulator functions.

The blocks are fed externally to individualize the main parameters such as IRR, T_in, T_AMB, T_REF. The function that obtains the corrected radiation is placed immediately to the Irradiation to feed the blocks, this function used to belong to the pre-fed block.

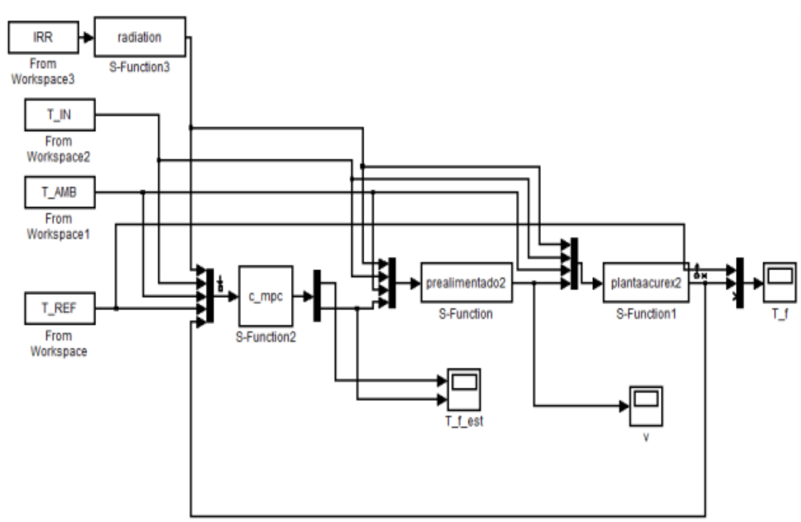

Figure 2. MPC simulator (mathematical model and fixed estimate)

IV.RESULTS

A.MPC with Mathematics Model

The data used in the simulations are obtained from the simulator file SA910916.lst, which provides the values of Irradiance and Corrected Radiation, these parameters are presented in Figure 3, it is observed that the corrected radiation manages to improve the irregular behavior of the direct radiation. Although it is not fully exploited, at least it contributes to a more stable value for the simulation.

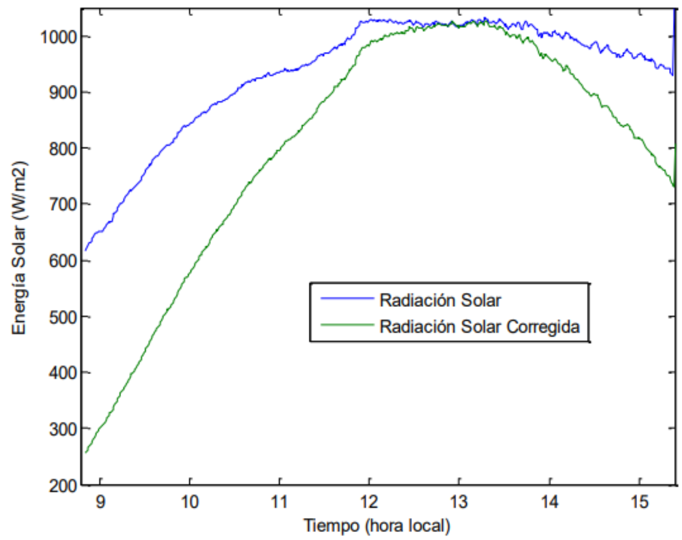

Fig 3. Solar Radiation and Corrected Radiation

Figure 4 shows the system reference, the inlet temperature, and the outlet temperature of the oil. The green line shows an irregular behavior of the temperature, which is provided by the controller using the mathematical model. The output in the red line although it adequately follows the reference, presents an oscillatory behavior throughout the time in a +-4 °C band. It is observed that the settling time is acceptable, taking approximately 12 minutes to reach the aforementioned band.

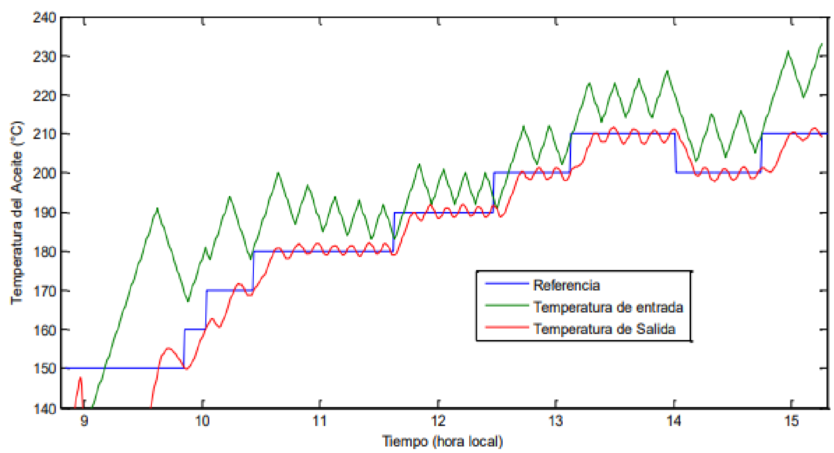

Fig 4. System inlet and outlet temperature (mathematical model)

B.MPC With Estimated Fixed Model

Figure 5 shows the system reference, the inlet temperature, and the outlet temperature of the oil when the fixed estimated model was used with the MPC controller. The green line shows an irregular behavior, lower than the previous case. The output in the red line adequately follows the reference until it exceeds 190° where the behavior generates an offset that increases and deteriorates the output behavior. It is observed that the oscillatory behavior has been reduced. This generated offset would need some integral action to improve its performance in case this method is used in future controls.

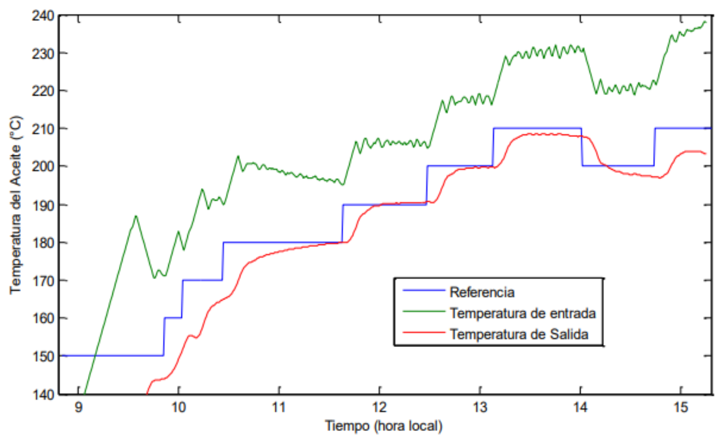

Fig 5. System inlet and outlet temperature (MPC fixed model)

V.CONCLUSIONS

-As it has been observed the use of predictive control is a technique that adapts to a variety of models allowing the solution of a large number of control problems. In this case, it did so although the power source is not adjustable and intermittent, still managed to solve such systems. Hence the growth of its expectation in the industrial field.

- The use of the simulator allows to conclude in a better way the applied techniques and compare them based on the fact that the radiation conditions for the plant are not reproducible from one day to the other, the simulator allows through its design to implement new control techniques being a very useful academic.

- As observed, the change in the operating point generates variation in the model, the simulator data does not allow comparison with other operations at different operating points, it would be useful to have more data on changes in the reference point to conclude how the system varies and the true reason for the offset generated in the responses.

REFERENCES

[1]Arahal, M. R., Berenguel, M. & Camacho, E. F., 1997. Nonlinear neural model-based predictive control of a solar plant. In Proc. European Control Conf. ECC'97. Brussels, Belgium, Volumen TH-E I2, p. paper 264.

[2]Arahal, M. R., Berenguel, M. & Camacho, E. F., 1998a. Comparison of RBF algorithms for output temperature prediction of a solar plant.. In Proc. CONTROLO'98, 9-11 September.

[3]Arahal, M. R., Berenguel, M. & Camacho, E. F., 1998b. Neural identification applied to predictive control of solar plant. Control Engineering Practice, Volumen 6, pp. pp. 333-344.

[4]Aström, K. J. & Wittenmark, B., 1989. Adaptative Control. Aström, K. J. & Wittermark, B., 1984. Computed controlles Systems, Theory and Design. Englewood Cliffs, NJ: Prentice Hall.

[5]Barão, M., 2000. Dynamic and no-linear control of a solar collector field. Thesis (in Portuguese). Universidade Técnica de Lisboa, Instituto Superior Técnico.

[6]Barão, M., Lemos, J. M. & Silva, R. N., 2002. Reduced complexity adaptative nonlinear control of a distribuited collector solar field. J. of Process Control, Volumen 12(1), pp. pp. 131-141.

[7]Berenguel, M., Arahal, M. R. & Camacho, E. F., 1998. Modeling free responses of a solar plant for predictive control. Control Engineering Practice, Volumen 6, pp. pp. 1257-1266.

[8]Berenguel, M., Camacho, E. F. & Rubio, F. R., 1994. Simulation software package for the Acurex field.. Departamento de Ingeniería y Automática.

[9]Berenguel, M., Camacho, E. F. & Rubio, F. R., 1997. Advanced Control of Solar Plants. Londres: Springer-Verlag.

CURRICULUM SUMMARY

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Impact of engineering on medicine: a literature review

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Abstract: This paper presents an analysis of the evolution of engineering and its current impact on health and medicine. The bibliographic documentation is analyzed and the most relevant aspects that highlight engineering and its contribution to new clinical developments are shown. The results show that medicine has an evolutionary need to adapt to new technological developments and that engineering plays a fundamental role in the advancement of medical, health, and scientific processes in general.

Keywords: Engineering, technology, medical advances, health developments.

Impacto de la ingeniería en la medicina: una revisión bibliográfica

Resumen: En este trabajo se presenta un análisis de la evolución de la ingeniería, y su actual repercusión en la salud y la medicina. Se analiza la documentación bibliográfica y se muestran los aspectos más relevantes que destacan a la ingeniería y su aporte en los nuevos desarrollos clínicos. Los resultados muestran que la medicina tiene una necesidad evolutiva, que debe acoplarse a los nuevos desarrollos tecnológicos, y que la ingeniería juega un papel fundamental en el avance de los procesos médicos, de salud y científicos en general.

Palabras Clave: Ingeniería, tecnología, avances médicos, desarrollos en la salud

I.INTRODUCTION

The new medical challenges include the application of traditional medical knowledge and its linkage with new technological trends. The contribution of engineering in medical processes [1], [2] has meant greater efficiency in clinical diagnosis and turn the discovery of new ways to address the most complex health problems.

Engineering advances have made it possible to address different professional areas, contributing significantly to the solution of problems and the improvement of processes. New technologies are not only a solution tool for present situations but also for the prognosis of future situations, both to know their origins and to face their possible variants over time.

In the 20th century, medicine had an important advance in society, politics, and science [3] And here it should be mentioned the significant professional trajectory of the scientist Jacinto Convit [4], who developed the vaccine against leprosy and the dignification of the sick. It is also worth mentioning the development of insulin in 1922 [5], the first vaccine for whooping cough [6], there was also a high level of scientific development in several vaccines [7], the development of medical equipment [8], and a different medical vision that motivates engineering to actively participate in clinical solutions.

Engineering, on the other hand, experienced in the 20th century a high scientific growth, with the development of software and artificial intelligence techniques, opened a new panorama for engineering, as well as a new contribution for all professional branches. Engineering began to get involved in different professions, to provide innovative, optimal, and scientific-technological solutions.

This paper reviews the contributions of engineering in medicine, especially in times of pandemics, where the need for fast and efficient solutions grows spontaneously. Thus, a systematic review of the scientific results and technical contributions of engineering is carried out.

This work consists of four sections, the first one has described the premises of the research, the second one shows the theoretical aspects developed, then the methodological foundations are exposed and finally, the results and conclusions are described.

II.THEORETICAL FUNDAMENTALS

Some of the most outstanding scientific advances, where engineering was used, are detailed below. The list of contributions could be extremely long, but only some of the most outstanding contributions that have an impact on the current world health situation have been considered. To this end, the microscope is evaluated as an indispensable piece of equipment in medicine that has gone through several eras, improving each time with technology. Then recent developments in times of pandemics, which favor improvements in health and the preservation of life, are evaluated.

A.Microscope history

The microscope was invented in 1590 [9] and meant an important advance for medicine. Its creator was Zacharias Janssen who was a manufacturer by profession, that is, the first signs of engineering. Later on, other inventors perfected this equipment and managed to improve the quality of image detection.

The evolution of engineering also allowed the microscope to make significant progress, and in turn, its use in medicine became indispensable for the detection of important clinical situations. Today it is even possible to conceive the virtual microscope[9], [10], which allows the analysis of samples remotely without the need to depend on schedules. This equipment can analyze static or dynamic samples.

Engineering and its big data processing, image processing, information processing, calculation have been timely to contribute to the development of medical equipment that favors medical studies.

B.Artificial respirators

Mechanical ventilators are a scientific development that has been evolving since 1543 [11]. It has had an important development throughout history and has been able to attend innumerable medical situations related to respiratory processes.

Today, with the COVID-19 pandemic, the need for mechanical ventilators has been extended throughout the planet. Engineering has played an important role in the design, development, and improvement of medical ventilatory equipment. Various pieces of equipment have been proposed as an alternative to clinical situations in intensive care units [12].

Understanding the respiratory system is fundamental to the development of equipment that offers more efficient and optimal processes.

The respiratory system can be divided into two sections: conduction airway and gas exchange units [13].

A.Airway conduction.

Its main function is to condition and direct the air before it reaches the alveoli. It therefore warms and humidifies the air and filters out foreign particles.

There is an upper airway: nose, pharynx, and larynx; and a lower airway: trachea and bronchi.

The bronchial tree branches into bronchioles and terminal bronchioles (the smallest part of the airway before reaching the alveoli). This is called the conduction airway or dead space.

B.Gas exchange units.

The area of the lung that depends on the terminal bronchiole is called the acinus or pulmonary respiratory unit. It gives rise, and in this order, to: respiratory bronchioles, alveolar ducts, alveolar sacs and alveoli. It is in the alveoli, that gas exchange takes place.

In the wall of the alveoli a phospholipid called surfactant or surfactant is produced whose function is to protect the alveoli from collapse during expiration.

C.Blood supply.

The lung is an organ with a double blood supply: on the one hand, it receives blood from the minor circuit through the pulmonary arteries (venous blood); and on the other hand, from the major circuit through the bronchial arteries (arterial blood).

III.METHODOLOGY

In this work, a set of scientific papers was analyzed and the most relevant aspects of engineering and its participation in medical developments were taken into account. The review process followed the scheme shown in Figure 1.

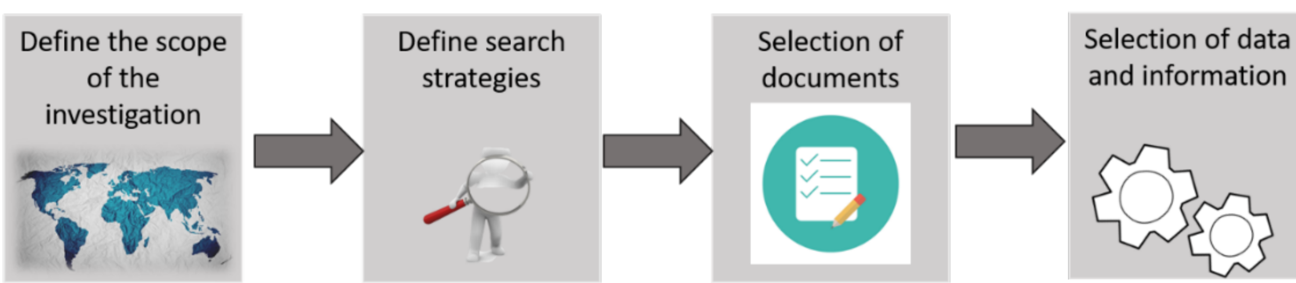

Fig. 1. Information selection process.

A.Exclusion criteria

For the selection of the academic papers, those that did not correspond to engineering advances and that only dealt with medical aspects were excluded. In addition, all papers that did not make a significant contribution to this research were excluded.

B.Inclusion criterio.

For the inclusion of scientific material in this work, we considered those that contained relevant information on the subject, as well as those with recent dates. In addition, priority was given to papers published in leading databases such as Scopus, with a high impact factor.

Engineering and its inventions have been overshadowed by other scientific branches, which could not have stood out in science without the support of inventors and engineers who supported the discoveries. At present, engineering stands out as a tool allied to many professional branches.

IV.RESULTS

Once the review process has been completed, the following results can be described:

1.Engineering is born as the result of inventions and creative processes to contribute to social needs and contribute to all sciences.

2.The development of engineering has allowed a technological advance in societies, not only in the development of computational equipment but also in the contribution in all professional branches, in the design of equipment and machines that provide solutions to an infinite number of problems. We can mention portable equipment for DNA detection, mechanical respirators, X-ray equipment, robotic mechanisms for laparoscopy, among many others that have improved medical care.

3.Medicine faces a global health problem that can only be overcome or attenuated with the support of engineering, taking into account medical equipment for the evaluation of samples, data processing, information selection, and all those mechanisms that help in-hospital clinical assistance.

4.The development of new technologies could be a path to health improvements in future societies.

V.CONCLUSIONS

At the end of this bibliographic review, the following conclusions can be drawn:

1.Medicine is a science that, in addition to caring for the health, is responsible for attending to the problems caused by diseases, thus it has the task of preserving and restoring health, and this is only possible with technological tools that contribute to the improvement of processes, the efficient detection of variables, the processing of data and information, and the management of medical situations.

2.Engineering must be at the service of all professions, to offer efficient, useful, practical, and optimal solutions that facilitate scientific work and provide improvements to people.

3.The alliance of engineering and medicine can mean an important technological advance for societies, which will result in better medical care, better detection of health problems, better follow-up of problems, more efficient methods, and, consequently, more options for improvement and better quality of life for people.

REFERENCES

[1]T. Flaherty, M. Tamaddon y C. Liu, «Micro-Computed Tomography Analysis of Subchondral Bone Regeneration Using
Osteochondral Scaffolds in an Ovine Condyle Model,» Appl. Sci., vol. 11, nº 3, p. 891, 2021.
[2]Y.-C. Chan, C.-Y. Li, C.-W. Lai, M.-W. Wu, H.-J. Tseng y C.-C. Chang, «Synthesis and Application in Cell Imaging of Acridone
Derivatives,» Appl. Sci., vol. 10, nº 23, p. 8708, 2020.
[3]J. López y M. Lugones, «Avances de la medicina en el siglo XX,» Rev Cubana Med Gen Integr, vol. 18, nº 4, pp. .245-247, 2002.
[4]Jacinto Convit, «wikipedia,» 13 05 2021. [En línea]. Available: https://es.wikipedia.org/wiki/Jacinto_Convit. [Último acceso: 24 05 2021].
[5]G. Sánchez, «Historia de la medicina,» Gaceta médica boliviana, pp. 74-78, 2007.
[6]M. Campinsa, D. Moreno-Pérez, A. G.-d. Miguel, F. González-Romo, F. A.Moraga-Llop, J. Arístegui-Fernández,
A. Goncé-Mellgrene, J. M.Bayas y L. Salleras-Sanmartía, «Whooping cough in Spain. Current epidemiology, prevention
and control strategies. Recommendations by the Pertussis Working Group,» Enfermedades Infecciosas y Microbiología Clínica, vol. 31, nº 4, pp. 240-253, 2013.
[7]Clinic Cloud, «Avances de la medicina,» 13 04 2021. [En línea].

Available: https://clinic-cloud.com/blog/avances-tecnologicos-en-la-medicina-desde-el-siglo-xx/#:~:text=1922%20La%20insulina%20se%20usa,Primera%20vacuna%20para%20la%20tuberculosis.. [Último acceso: 24 05 2021].
[8]Anthropology and Practice, «Equipamiento Médico: Desarrollo e Historia de los Equipos Médicos,» 2020. [En línea]. Available: https://anthropologyandpractice.com/antropologia-medica/equipamiento-medico-desarrollo-e-historia-de-los-equipos-medicos/. [Último acceso: 2021].
[9] Wikipedia, «Microscopio,» 22 05 2021. [En línea]. Available: https://es.wikipedia.org/wiki/Microscopio#:~:text=El%20microscopio%20fue%20inventado%20por%20Zacharias%20Janssen%20en%201590.&text=Fue%20el%20primero%20en%20estudiar,bacterias%2C%20espermatozoides%20y%20gl%C3%B3bulos%20rojos.. [Último acceso: 24 05 2021].
[10]wikipedia, «Microscopía virtual,» 13 05 2020. [En línea]. Available: https://es.wikipedia.org/wiki/Microscop%C3%ADa_virtual. [Último acceso: 24 05 2021].
[11]Scrib, «Historia del Ventilador Mecánico,» [En línea]. Available: https://es.scribd.com/document/474956549/historia-del-ventilador. [Último acceso: 2021].
[12]J. Diarte, «Tipos de respiradores mecánicos y modos de ventilación convencionales para uso no invasivo,» Manuales SECUR, vol. 1, nº 1, pp. 35-57, 2009.
[13]Á. Armes, M. R. Mosegue y M. Galloway, «Ventilación mecánica: conocimientos básicos,» 2014. [En línea]. Available: https://www.elpracticante.galeon.com/. [Último acceso: 2021].

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Analysis of electromagnetic fields in transmission line configurations associated with the electrical system

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Abstract: This work presents an analysis of the electromagnetic fields generated by the different configurations of transmission lines associated with the Venezuelan electrical system, with voltages 230, 400 and 765 kilo Volts, and the transmission towers that will be built at the Manuel Piar Hydroelectric Plant. - Tocoma. The theoretical aspects and technical foundations for the evaluation of the magnetic field in transmission lines are analyzed. The work was carried out at the CORPOELEC company in Venezuela. The criteria and technical regulations were observed to verify respect for the levels allowed by national and international standards, to which a person may be exposed. The results show the location areas of the transmission lines and their corresponding electromagnetic analysis.

Keywords: Electromagnetic fields, transmission lines, transmission towers.

Análisis de los campos electromagnéticos en las configuraciones de líneas de transmisión asociadas al sistema eléctrico

Resumen: En este trabajo se presenta un análisis de los campos electromagnéticos generados por las diferentes configuraciones de líneas de transmisión asociados al sistema eléctrico venezolano, de tensiones 230, 400 y 765 kilo Voltios, y las torres de transmisión que se construirán en la Central Hidroeléctrica Manuel Piar- Tocoma. Se analizan los aspectos teóricos y los fundamentos técnicos para la evaluación del campo magnético en las líneas de transmisión. El trabajo se realizó en la empresa CORPOELEC en Venezuela. Se observaron los criterios y normativas técnicas, para constatar el respeto por los niveles permitidos por las normas nacionales e internacionales, a los cuales puede estar expuesta una persona. Los resultados muestran las zonas de ubicación de las líneas de transmisión y su correspondiente análisis electromagnético.

Palabras Clave: Campos Electromagnéticos, Líneas de transmisión, torres de transmisión.

I.INTRODUCTION

In Venezuela, most of the electricity is generated in hydroelectric power plants, which are responsible for transforming the potential energy of the river in the reservoir, the kinetic energy produced by the movement of water through the gates, and the mechanical energy produced by the movement of the rotor, into electrical energy. It is transported through transmission lines, with voltage levels of 230, 400, and 765 kiloVolts (kV).

During this process, large amounts of current and voltages are transported, which generate high intensity magnetic and electric fields respectively, which through the ANSI C37-32-1996, NEMA SG-6-1995, COVENIN 2238:2000 standards, and the national safety code for electrical power supply and communications facilities [2-5], have defined the minimum levels to which a person can be exposed without running risks.

This work presents a study of the electromagnetic fields generated by the different configurations of CORPOELEC transmission lines, using a simple methodology that will allow us to calculate the magnetic or electric field of any desired configuration and to see the levels to which people are exposed under those lines.

For this purpose, the electrical characteristics of the line will be analyzed, such as voltage, current, apparent power, magnetic permeability, electrical permittivity, angular frequency, yielding the results of the field levels produced by the conductors, the distribution in the environment of the field lines, and finally a comparison between the different transmission lines and their location by zones.

The Manuel Piar (Tocoma) hydroelectric power plant is located on the Caroní River, upstream from the mouth of the Claro river, between the municipalities of Angostura and Piar, approximately 18 km downstream from the Simón Bolívar (Gurí) hydroelectric power plant in the state of Bolívar, Venezuela.

The Tocoma development will form, together with the Gurí, Macagua, and Caruachi hydroelectric plants, the lower Caroní hydroelectric system. The outstanding energy characteristics of the project are predetermined by the regulated discharge of the Guri Project, which will contribute together with the other hydroelectric plants, contributing 2,160 MW to the national interconnected system.

The hydroelectric power plant is made up of several concrete structures, being a Power House integrated into the Intake structure and Assembly Building, with ten (10) Kaplan-type turbine units and a total installed capacity of 2,160 MW. 160 MW, a Lateral Services Building, an Operations and Control Building, left, right and intermediate transition dams, a spillway with nine (9) radial gates and eighteen (18) bottom ducts, a rockfill dam with a concrete screen on he left bank and an earth and rockfill dam with clay core on the right bank.

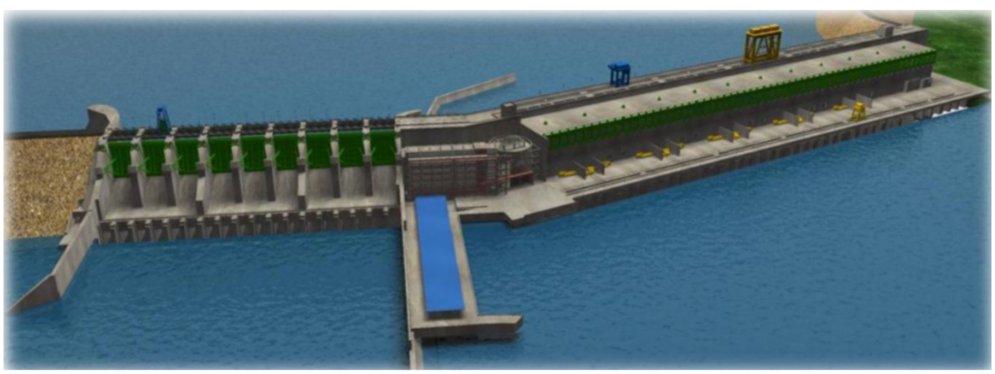

Fig.1. Future three-dimensional model of the Manuel Piar-Tocoma hydroelectric power plant.

Five (5) towers with two conductors per phase and two guard cables will be used, with horizontal arrangement of the phases, A50/CAR type towers facing Tocoma S/E, as shown in Figure 2.

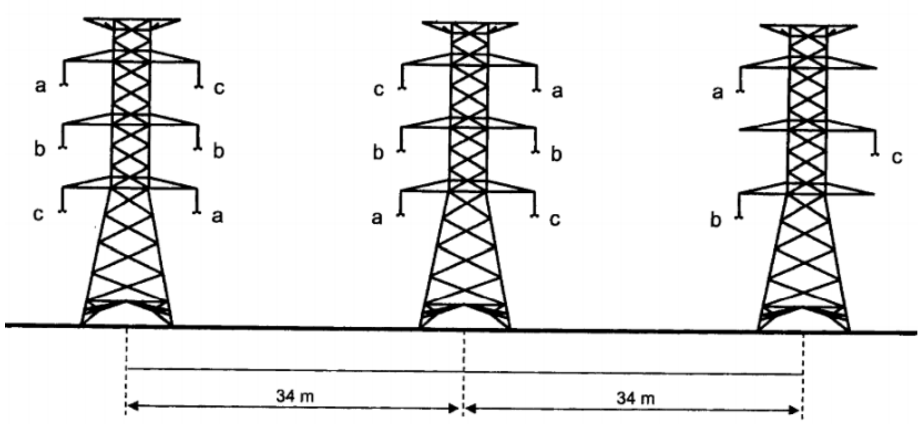

Fig. 2. Recommended tower spacing distance and phase arrangement. Lines between the plant and the Tocoma substation at 400kV.

In that path, transmission lines generate electric and magnetic fields at an industrial frequency of 60 Hz. These play an important role in the design and operation of transmission lines. The study of electric fields in these structures is important in terms of current induction in conductive materials in general, such as vehicles, the transmission tower itself, electrocutions caused by spark discharges, interference with pacemakers, and electric arcs [1]. While magnetic fields, due to the inductive effect on parallel lines and interference with computer screen operation [2].

II.DEVELOPMENT

The objective of this work is to analyze the Electromagnetic Fields generated by the different configurations of transmission lines most used in the Venezuelan National Electric System with special attention to the Manuel Piar Tocoma Hydroelectric Power Plant.

Electricity and magnetism are two different aspects of the same physical phenomenon, called electromagnetism [8], [9]. This theory unifies the electric and magnetic phenomena in one, whose foundations are due to Faraday, but was formulated in a more general form by Maxwell. The formulation consists of four-vector differential equations, known as Maxwell's equations, which relate the electric field, the magnetic field, and their respective material sources: electric charge density, electric current, electric displacement, and displacement current [8].

James Clerk Maxwell [12], based on Faraday's work but modifying some concepts and interpretations, mathematically structures the electromagnetic theory and introduces the displacement current. He proves directly that the fields fulfill a wave equation where the phase velocity coincides with the speed of light. The electromagnetic character of light was demonstrated by Hertz, with his experiments on the propagation of electromagnetic waves in 1887, and by Zeeman in 1896 when he showed that there were charges capable of moving with sufficient acceleration to radiate within the visible spectrum.

The now called Maxwell's equations demonstrated that electric fields and magnetic fields were manifestations of a single electromagnetic field. The motion of an electric charge produces a magnetic field, the variation of a magnetic field produces an electric field, and the accelerated motion of electric charges generates electromagnetic waves.

Nikola Tesla [13] is best known for his many revolutionary inventions in the field of electromagnetism, developed in the late 19th and early 20th centuries. Tesla's patents and theoretical work formed the basis of modern alternating current (AC) electrical power systems, including the polyphase electrical distribution system and the AC motor, which contributed so much to the birth of the Second Industrial Revolution.

Since Nikola Tesla [13] discovered alternating current and the way to produce it in alternators, an immense technological activity has been carried out to bring electricity to all inhabited places in the world, so that, along with the construction of large and varied power plants, sophisticated transmission networks and distribution systems have been built. Most of the electricity generated worldwide comes from the first three types of power plants: thermal, hydroelectric, and wind.

The transportation networks of the generated electric energy are made through transmission lines as a first phase. However, these entail several problems, among the most important, the environmental impacts and their effect on people's health, the latter has been of great concern and has been the subject of study for decades, however many studies conclude that "there is still no relationship between the presence of electric and magnetic fields with cancer or other diseases affecting human beings", according to the book Electromagnetic Fields and Human Health, by John E. Moulder, professor of oncology at the University of California, Berkeley, USA. Moulder, professor of radiation oncology at the Medical College of Wisconsin, USA, contains the most frequently asked questions and answers on the subject, as well as a bibliography of research studies on power lines and health around the world.

The study of electromagnetic fields in transmission lines is nowadays a subject of great interest for the world, countries like Lebanon have made detailed studies on the numerical calculation of these fields using the multipole expansion theory, as they did:

Some research [9] developed a detailed analysis of the magnetic fields emitted by 220 kV transmission lines in Lebanon. An overview of the latest developments in transmission line designs is made, including recent configurations and different conductor locations to help reduce the emitted magnetic field and making a basic review of the equations governing the magnetic field to be used later. There is also a worldwide investigation done by various studies discussing the health impact of ultra-high voltage lines. Concluding with analysis, using software that makes use of the Finite Element Method to estimate the magnetic field of transmission lines [10].

Some authors [11] present a model of electric and magnetic fields in transmission systems, which operates through a partial differential equation. This research has been conducted by analyzing the electromagnetic fields radiating around transmission lines, which uses line transposition in case of long distributions. The six (6) types of 500 kV transposed transmission line configurations with double circuits will be considered.

III.METHODOLOGY

The different transmission line configurations associated with the Venezuelan National Electric System will be analyzed. The technical data of each configuration to be studied will be used to generate the magnetic and electric field graphs.

First, the analysis will be performed on two 400 kV transmission lines, the first one is an A50/CAR type tower, with two ALUMOWELD 7#6 guard wires, a circuit with three phases, together with two conductors per phase (2 x 1024.5 MCM). And the other is an A/55/TT/222 tower, two conductors per phase, double circuit, using the same types of conductors. These models are the ones that will be used in the Manuel Piar hydroelectric power plant, three towers A/55/TT/222, or double circuit, will be used to connect each output of the transformers to a circuit, but the last tower will use an equivalent delta distribution, connecting with five transmission towers A/50/CAR before reaching the S/E Tocoma.

A.Data collection techniques and instruments.

Then, the fields generated by the 765, 400 and 230 kV transmission line configurations will be studied.

To carry out this research, the following tools were used for data collection:

•Google Chrome, the internet browser used for the research, which allowed obtaining the international standards that indicate the maximum level of electromagnetic fields to which a person can be exposed.

•CORPOELEC's Intranet, which allowed obtaining the electrical data of each transmission line configuration of the company used in the Venezuelan National Electric System.

•CVG EDELCA's plans and manuals, which includes the transmission line models, along with the measurements of the towers, guard cables, conductors and insulators, which allowed the creation of the physical model.

•MATLAB, the program in which the plots of the electromagnetic fields generated in the transmission line configurations were made.

•ANSYS, the program in which the results obtained by the MATLAB software were validated.

IV.RESULTS

The advantages offered by computers in numerical calculations have allowed the development of programs with a high degree of accuracy, in this case, MATLAB will be used, which through the exposed methodology will proceed through an algorithm to simulate the electromagnetic fields generated by the different configurations of transmission lines associated with the Venezuelan electrical system.

The maximum level of the electric and magnetic field to which a person can be exposed is 4.16 kV/m and 83. 3 A/m, respectively, generally in the transmission lines there are high levels near the conductors, however, the field decreases the farther away it is from the source, that is why two types of results are analyzed, the first is a graphical view of the fields generated in the conductors, then a two-dimensional graph of the field levels to the transverse distance to the lines, which shows the exposure to the fields of people of an average height of 1.75 meters, which are located just below the lines.

The National Electric System is made up of 18 public and private electric companies. The private companies are Electricidad de Caracas and its subsidiaries. The companies CADAFE, EDELCA, E. de C., and ENELVEN, signatories of the Interconnection Contract, supply 95.4% of the electric energy consumed in the country, and these, in turn, represent in OPSIS the total value of the aforementioned electric companies. The remaining percentage comes from the Self-supplied Sector (Petróleos de Venezuela, independent producers, and industries with their generation). Figure 3, highlights part of the national interconnected system.

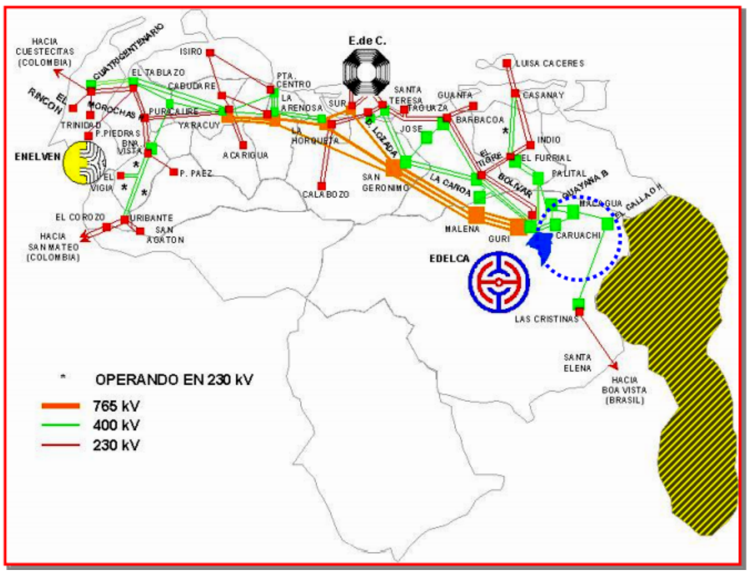

Fig. 3. National electric system, Venezuela.

At 765kV voltage levels, the highest levels of electromagnetic fields are produced, because it is the line that transmits the highest voltage and current, therefore, magnitudes of high electric and magnetic fields compared to the others. The following table shows the location and lines current of each of the configurations for this voltage level.

The current level is the same in each of the lines, although in each sub conductor 1695.75 Amperes are handled because they are horizontal towers of four conductors per phase, this means that the level of electromagnetic fields is the same in each area where the 765 kV lines are located, however in some areas, different heights are producing different levels of the field on the ground, this is because the higher the height of the conductors to the ground, the lower the effect will be. The graphical results generated in the line configurations of these zones are located in section A-3.

For transmission, 400kV is usually used as the output of hydroelectric power plants such as Macagua, Caruachi, Tocoma, and some lines of Guri. In this case, there is a greater variety of line configurations, horizontal with two conductors per phase, a double circuit with two and four conductors per phase, and 77 different current levels generating magnetic fields of various magnitudes (Table 2).

Table 1. Location and current levels of 765 kV transmission lines.

Líneas		Nivel de Corriente (Ampere)	Alturas de los conductores	
Barra Inicial	Barra Final		Mínima	Máxima
Gurí	Malena	6783	15	43.70
Malena	San Gerónimo	6783	15	43.70
San Gerónimo	Horqueta	6783	15	43.70
San Gerónimo	Sur	6783	13.2	43.00
San Gerónimo	Arenosa	6783	15	43.70
Arenosa	Yaracuy	6783	13.2	43.00
Horqueta	Arenosa	6783	13.2	43.00
Horqueta	Sur	6783	13.2	43.00

In many areas the same 400 kV line configurations are repeated, based on this, there are fourteen different types, which present a great variety of electromagnetic fields, both in distribution and magnitude, having cases where there are very low levels, such as the case of Tablazo-Cuatricentenario line 2, as well as others where there are large magnitudes such as the Gurí-Palital lines. The graphic results generated in the line configurations of these zones are located in section A-4.

Table 2. Location and current levels of the main 400 kV transmission lines.

Líneas		Nivel de Corriente (Ampere)	Alturas de los conductores	
Barra Inicial	Barra Final		Mínima	Máxima
Gurí	Tigre L1	3127.5	8	16.74
Gurí	Tigre L2	3062.5	8	22.50
Gurí	Canoa	3062.5	8	27.00
Canoa	Tigre	3062.5	8	27.00
Tigre	San Gerónimo L1	3127.5	8	16.74
Tigre	San Gerónimo L2	3062.5	8	22.50
San Gerónimo	Santa Teresa L1	3127.5	8	16.74
San Gerónimo	Santa Teresa L2	3062.5	8	22.50
Tigre	Barbacoa II	3062.5	8	27.00
José	Barbacoa II	3062.5	8	26.00
San Gerónimo	José	3062.5	8	26.00
Gurí	Guayana B L2 y L3	6125.0	7.6	26

In 230kV lines, there are lower voltage and current levels, generating consequently lower electric and magnetic fields, however, an important factor concerning other configurations is the number of sub conductors per phase.

In this case, it is one conductor per phase, this is relevant because the double circuit towers, which present greater distribution of fields in the zones, present lower levels of electric and magnetic fields, because the equipotential lines are reduced.

In the delta configuration, there is a lower magnitude and field distribution in the zone where they are located.

IV.CONCLUSIONS

If there are areas where the electromagnetic field level is higher than allowed by the standards, it is recommended to use field mitigation methods. In a study done [23] a theoretical and experimental study was made of the mitigation of the magnetic fields generated in a model of high voltage lines employing a passive loop or closed loop, of non-energized conductors, to which a current is induced in the opposite direction to that of the lines, generating a field opposite to the original one, reducing the total field.

It is advisable to perform these simulations in the MATLAB program because ANSYS requires machines with a high graphic processor and the designed algorithms yield very accurate results, concerning the program used to validate.

It is recommended to continue this research to study electromagnetic fields in substations, produced during electrical faults such as single-phase, two-phase, and three-phase, where there are high levels of short circuit current generating very high field magnitudes, which could cause interference with measuring equipment and exceed the minimum level of electromagnetism to which a person can be exposed.

REFERENCES

[1]EPRI AC Transmission Line Reference Book- 200 kV and Above, Third Edition. 2005
[2]"Interruptores de desconexión de aire de alto voltaje estándar nacional estadounidense Interruptores interruptores, interruptores de iniciación de fallas, interruptores de puesta a tierra, soportes de bus y accesorios Rangos de voltaje de control: programas de clasificaciones preferidas, pautas y especificaciones de construcción", en ANSI C37.32-1996 , vol., núm., págs. i-36, 1996, doi: 10.1109 / IEEESTD.1996.95627.
[3]NEMA SG-6-1995, Nema sg 6 1995 tablas 32 1114 ilustración determina [Online], Available: https://www.coursehero.com/file/p5ngkj3/NEMA-SG-6-1995-Tables-32-1-114-Illustration-Determine-the-electrical/
[4]COVENIN 2238:2000. Radiaciones No Ionizantes. [Online], Available: http://www.sencamer.gob.ve/sencamer/normas/2238-00.pdf
[5]Codigo Nacional de Seguridad en Instalaciones de Suministro de Energia Electrica y de Comuninaciones, CODELETECTRA, Codigo de Seguridad Electrica. Espacios libres mínimos para partes activas.
[6]ESP OIL Engineering Consultants, WorkShop International, "Diseno de subestaciones eléctricas", dictado por M.Sc Manuel Briceno, 2006
[7]F.Gonzalez-Longatt, Líneas De Transmisión. [Online], Available: https://fglongatt.org/OLD/Archivos/LT_1.html
[8]R. López Valverde. Historia del electromagnetismo. Ediciones IES, Pablo Picasso, 2001.
[9]P. Muné, M. Hernández-Wolpez, A. Cruz-García y RJ Jardim. (2015). "Sobre la penetración y atrapamiento del flujo magnético en superconductores Bi-2223". Rev. Cubana de Física. Vol. 32, no. 1 pp 53
[10]C. Furió y J. Guisasola. (2001). "La enseñanza del concepto de campo eléctrico basada en un modelo de aprendizaje como investigación orientada". Rev. Enseñanza De Las Ciencias, 19 (2), pp.319-334
[11]D. Vásquez Gonzales. (2017) "Aplicación del método cadena crítica para la mejora en construcción de cimentaciones de torres autosoportadas – caso línea de transmisión 66kV, en Sayán, Lima" Tesis de grado. Universidad César vallejo. Perú.
[12]J. Maxwell (1864). "Una teoría dinámica del campo electromagnético". Rev. Sociedad de la realeza. Vol 155.
[13]D. Strebkov. (2014) "Perspectivas de uso de tecnologías de nicola tesla en ingeniería de energía actualizada". Rev.Light & Engineering. vol. 22 Edición 2, pp 4-14.

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Effect of the reaction of ammonia gas on the swelling of metallic iron and its oxides during nitriding processes

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Abstract: In order to study the relationship and effect of nitrogen gas in the reducing gases used in the reducibility tests of iron oxides, under isothermal conditions, a test scheme was executed using ammonia gas, such that its decomposition of the gas in the reactor produced a mixture of H2 and N2 gases. Furthermore, the addition of 6% NH3 in a 28% H2 and 68% N2 gas stream was planned to obtain a gas composition of 70% N2 and 30% H2. This would allow comparing the reducibility curves between both conditions, assuming that the possible difference between both conditions to compare the volume changes of the reduced samples. The difference to be studied will be based on the estimation and comparison of the rate of formation of metallic iron in the stages of reduction of Hematite / Magnetite / Wustite (FeO), as well as the effects of nitrogen absorbed by the fresh metallic iron produced, or present. in iron catalysts to produce ammonia, from the reducing gas mixture, on the volume change of the samples. Likewise, the catastrophic volume changes caused by nitrogen are compared by comparing sources of this gas in solid carbonaceous reducers.

Keywords: Gaseous Reduction, Direct Reduced Iron, isothermal tests.

Efecto de la reacción de gas de amoniaco sobre el hinchamiento de hierro metálico y sus óxidos durante procesos de nitruración

Resumen: Con el objeto de estudiar la relación y efecto del gas nitrógeno en los gases reductores utilizados en los ensayos de reductibilidad de óxidos de hierro, en condiciones isotérmicas, se ejecutó un esquema de ensayos utilizando gas amoniaco, tal que su descomposición en el reactor produjera una mezcla de gases de H2 y N2. Además, se planifico la adición de 6% de NH3 en una corriente de gas 28% H2 y 68% N2 para obtener una composición de gas de 70% N2 y 30% H2. Esto permitiría comparar las curvas de reductibilidad entre ambas condiciones, asumiendo que la posible diferencia entre ambas condiciones a comparar los cambios de volumen de las muestras reducidas. La diferencia a estudiar se basará en la estimación y comparación de la velocidad de formación de hierro metálico en las etapas de reducción de hematita/magnetita/wustita (FeO), así como los efectos del nitrógeno absorbido por el hierro metálico fresco producido, o presente en catalizadores de hierro para producir amoniaco, a partir de la mezcla de gas reductor, sobre el cambio de volumen de las muestras. Así mismo se comparan los cambios catastróficos de volumen causados por el nitrógeno comparando fuentes de este gas en reductores carbonosos sólidos.

Palabras Clave: Campos Electromagnéticos, Líneas de transmisión, torres de transmisión. Reducción gaseosa, Hierro de reducción directa, ensayos isotérmicos.

I.INTRODUCTION

To study the relationship and effect of nitrogen gas in the reducing gases used in the iron oxide reducibility tests, under isothermal conditions, a test scheme was executed using ammonia gas, such that the decomposition of the gas in the reactor would produce a gas of 15% H2 and 25% N2. In addition, the addition of 6% NH3 in an H2 and N2 gas stream was planned to obtain a gas composition of 70% N2 and 30% H2 at a gas flow rate of 2 liters/minute. The comparative study will be based on the estimation and comparison of the rate of metallic iron formation in the hematite/magnetite/wustite (FeO) reduction stages, as well as the effects of the nitrogen absorbed by the metallic iron, to that produced in parallel during the reduction process, on the volume change of the samples. The volume changes caused by nitrogen are also compared by comparing sources of this gas in solid carbonaceous reductants.

II.REDUCTIBILITY TESTS

The reducibility tests were carried out in a stainless steel reactor [1], using samples of hematitic iron ore with a porosity of 3% and an iron content of 69.05 % in weight with measures of a cube of dimensions 3x3x3 mm per side. On the other hand, the gases used were mixed to obtain compositions of 30% H2 and 70 % N2, and 28% H2 and 68% N2, and 6% NH3, with this last mixture when decomposed, the first composition would be obtained, but the adsorption and activation reactions of the hydrogen gas would be obviated to react with the oxygen in the reaction front for reduction, and generate H2O, and of the nitrogen to be absorbed by the metallic iron, since all the gaseous species are assumed as "nascent", that is in the form of H+2 ions, N=2 and metallic Fe formed from Fe=3 ions with 4 tetrahedral vacancies passing to Fe=2 and metallic Fe, releasing 4 vacancies and the associated energy of between 1.98 and 2.52 Ev/Vacancy [2] Between 100 and 140 °C, while Dam [1] estimated this value at 1.28 Ev/Vacancy calculated at 25 °C. For the estimation of the chemical composition of the reduced oxide, it is estimated using the method deduced by Dam and Jeffes [3].

III.RESULTS

The reducibility curves of the cubic samples used under 100% NH3 conditions and with the 6% NH3 mixtures in 30%H2/70% N2 gas mixtures are shown in Figures 1 and 2. In this figure, it can be seen that the reducibility of the same mineral is faster with ammonia gas than with the 30% Hydrogen and 70% Nitrogen mixture, which is associated with the reduction of the activation step of the hydrogen molecule on the surface of the oxide to adsorb before chemically reacting with oxygen and then desorbing, since the adsorption of the NH3 molecule on the oxide surface, it decomposes into H=2 ions ready to react with O/2 ions accelerating the reduction reaction. Both curves fitted by least-squares have R-squared correlation coefficients of 0.99 and 0.98 respectively.

$$\% R = 0{,}1629t^2 + 6{,}8198t - 0{,}2283 \qquad (NH3,\ 850\ ^{\circ}C) \tag{1}$$

$$\% R = -0{,}1494t^2 + 6{,}105t - 2{,}9935 \qquad (30\%H2/70\%N2,\ 900\ ^{\circ}C) \tag{2}$$

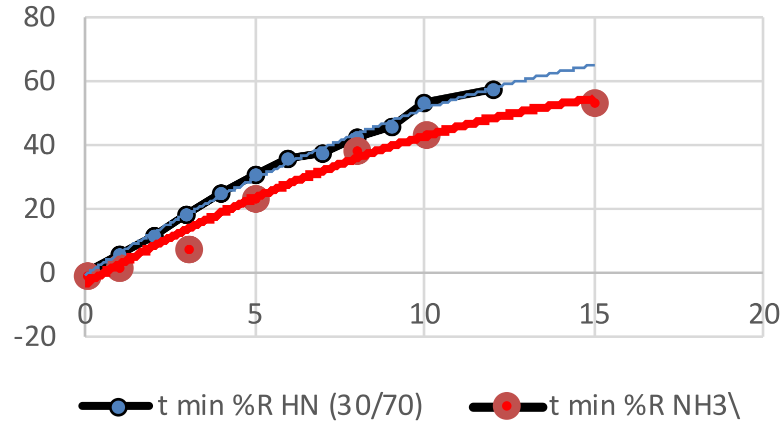

Fig. 1. Reduction curve %Reduction (y-axis) versus time (x-axis, minutes). [1], upper curve Eq. 2, lower curve Eq. (1).

The determination of the formation of the chemical composition of the reduced product, regarding the evolution of iron formation, the model deduced by Dam and Jeffes [3] was used, obtaining the results shown in Figure 2. In this figure, it can be seen that the formation of metallic iron starts earlier than in an atmosphere of 30% H2 and 70% Nitrogen, which corresponds to higher reducibility as shown in Figure I, in both curves a correlation coefficient R square of 0.99 was obtained for both mathematical expressions, as shown below.

$$\%Fe\ met = 0{,}3678t^2 - 0{,}8423t \qquad (NH3,\ 850\ {\sim}C) \tag{3}$$

$$\%\ Fe\ met = 0{,}3101t^2 - 1{,}0057t - 0{,}2189 \quad (30\%H2/70\%N2,\ 900\ {\sim}C) \tag{4}$$

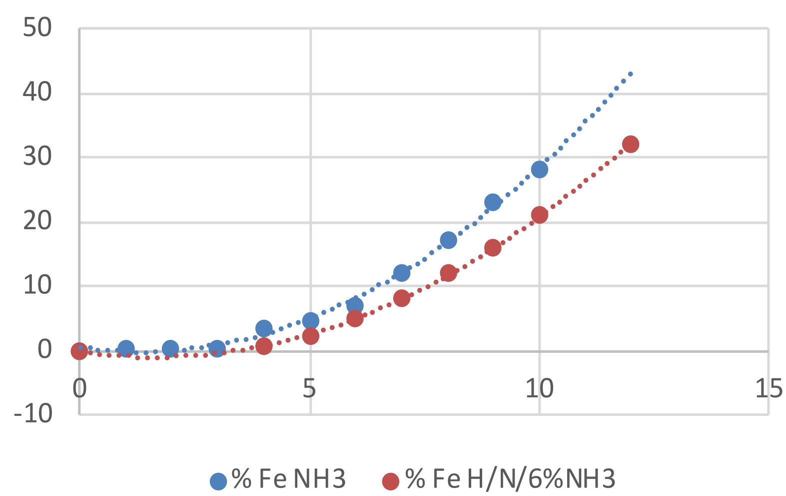

Fig. 2. Metallic iron formation (% Fe met, y-axis) versus reduction time (t min, x-axis, min). [1].

When the metallic iron formation values are expressed as metallization rate (dFe met/dt), Figure 3 is obtained, in which it can be observed that the rate of formation of this metallic iron in the early stages of the reduction process from the transformation of the magnetite/wustite (FeO) phases to form metallic Fe.

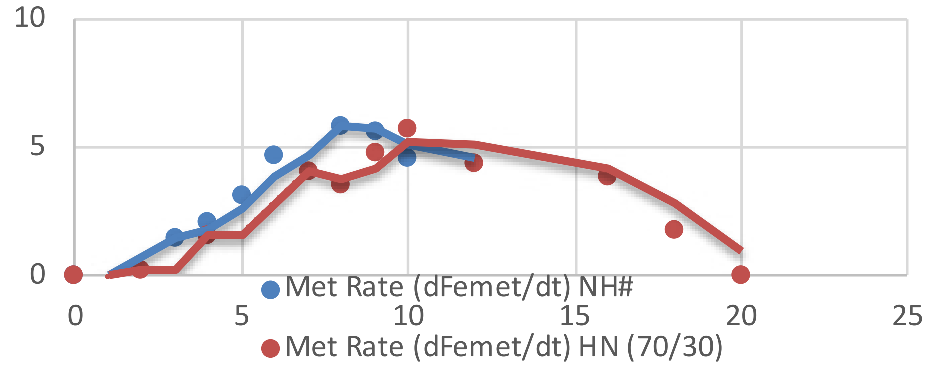

Fig. 3. Metallic Fe formation rate (y-axis) and reduction time (x-axis, min). (Source. Author's own) [1].

This expression of this rapidity, with an intermediate value between these gaseous mixtures and others with higher reducing power and temperatures, is generated by an energy release mechanism to dissociate the NH3 molecules and provide the energy necessary to form the activated hydrogen and nitrogen molecules on the surface of the solid. This energy is obtained from the release of a cluster of vacancies associated with Fe+3 ions passing to Fe+2 and subsequently to metallic Fe. For the schematic representation of the reduction reaction involving the energy per vacancy between 1.28 eV [1] and between 1.98 and 2.25 eV [2] and the crystalline effects of the species involved, this can be seen in Figure V [2,4].

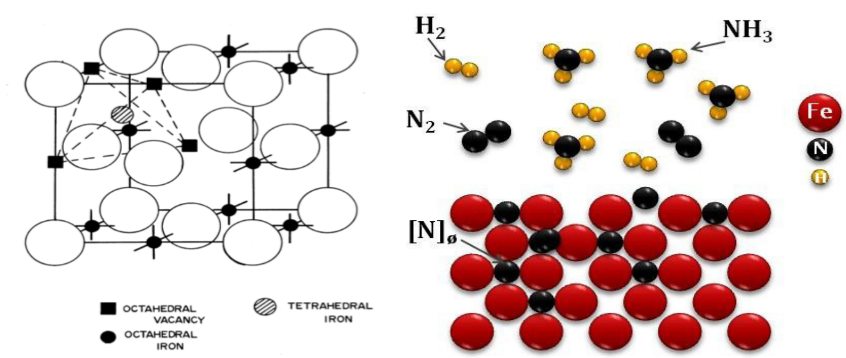

Fig. 4. Schematic of the interaction of NH3 molecules on the reaction surface of the oxide to be reduced and the vacancies and defects of iron oxides [2,4].

IV.EFFECT OF REDUCING GASES ON VOLUME CHANGE

The effect of gases and especially nitrogen gas on the volume changes of iron oxides during reduction has been reported by Dam [1] referred by El Geassy [5], in this paper, we present the analysis of the data reported by Dam as the average maximum values of the volume change values of the samples subjected to reduction with mixtures of 30% H2 and 70% N2. These values are compared with the values of dissolved nitrogen in iron, represented in the unstable Fe-N phase diagram, whose values are presented in Table 1. In Table I, the two values are represented for the temperature 900 degrees Celsius, since it is at this temperature that the allotropic change of alpha to gamma iron occurs and the measured volume change of experiments expressed in 1/10000, in favor of plotting on visible scales.

Table 1. Variations of % N dissolved in iron and volume of the samples (Author's source) [1].

T °C	700	800	850	900 Fe α	900 Fe γ	950	1000
% [N]	0,0025	0,0033	0,0040	0,0053	0,0063	0,0256	0,0025
ΔVol % x 10E-4	0,0025	0,0028	0,0032	0,0034	0,0075	0,0060	0,0044

The graphical representation of these values shows a very clear and noticeable trend correlation. It should be noted that the values of the percentage change in volume are divided by 1000 for graphical representation purposes

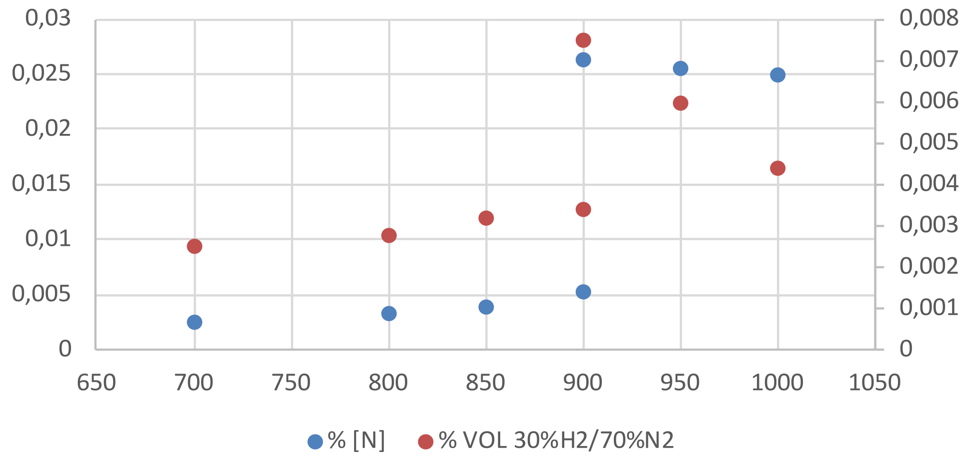

Fig. 5. Relationship between reduction temperature (x-axis) and Nitrogen content (% y, left) and volume increase (%/10000) (y-axis, right) (Author's source).

Since the absorption of nitrogen in iron causes distortions in the crystalline structure of both allotropic forms of iron considered in the temperature range studied and since the FeN stability diagram indicates that, upon cooling the samples, the desorption of nitrogen in the molecular form will occur, the system must supply necessary and equivalent activation energy of between 51 to 58 Kcal/mol. This energy is equivalent to the binding energy of the FeN nitride [10] and whose effect has not been considered as mechanical stress involved in the volume changes considered.

A.Origin of the nitrogen element of solid reductants.

Since, in this comparative study, nitrogen has been mentioned as a component in a gaseous mixture, it is pertinent to review the origin of this element in other materials, such as solid carbonaceous reductants like coal, coke, and petroleum coke, under the condition of not competing with other sources of oxygen, that is, that the reduction process is not carried out in air atmospheres.

The nitrogen content in the coals is in the form of compounds of the H=N=C type so that the nitrogen content, although low to exert an appreciable effect on the studied phenomenon of abnormal swelling of the volume of the oxides present, must break the respective bonds to subsequently participate in the reduction reactions that include activation and adsorption states and then be absorbed into the iron produced. Therefore, it is to be expected that this effect will not occur. As a reference and to evidence this opinion, a comparison of reduction works carried out in India with local coals is made [6,7]. The reported values of the volume changes of the iron oxides used are compared with those of the experiences with NH3 gas reduction and 30% H2=70% N2 mixtures, as mentioned above. The comparison is presented graphically in Figure VI, where it can be seen that the compared values of the reduction experiments with Indian coals are very similar to the values reported for normal swelling, that is, up to the range of 30%.

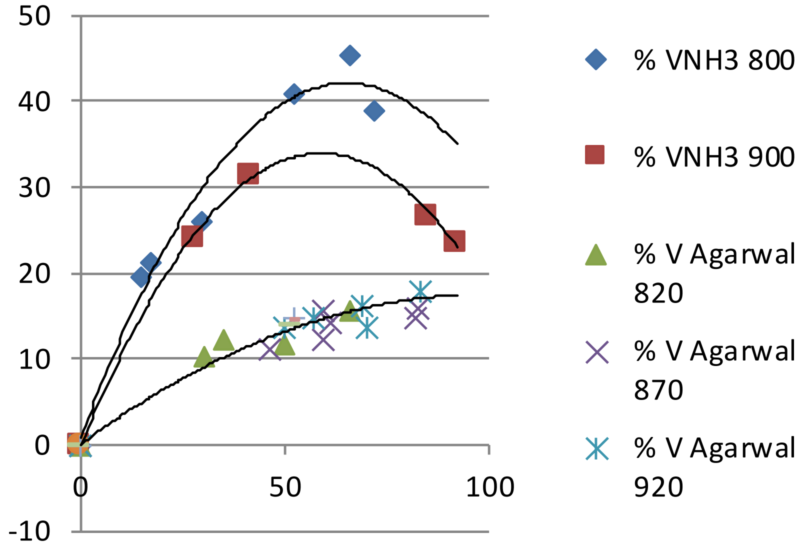

Fig. 6. Comparison of swelling values of iron oxides reduced with NH3 and carbon (ΔVol %, y-axis) as a function of the percentage of Reduction (%R, x-axis) at different temperatures in the range of 800 to 920 °C. (Source: Authors)

The curves in Figure 6 are mathematically represented as

$$\textbf{ΔVol (\%)} = -0{,}0098\ \%R^2 + 1{,}2676\ \%R + 0{,}8953 \qquad (R^2 = 0{,}973) \qquad (5)$$

$$\textbf{ΔVol (\%)} = -0{,}0017\ \%R^2 + 0{,}3489\ \%R + 0{,}0873 \qquad (R^2 = 0{,}9698) \qquad (6)$$

The differences are basically seen in the coefficients of the quadratic expression, in a ratio of 5 to 1 or greater.

B. Nitrogen absorption during the reduction process.

Nitrogen absorption has been widely studied in the nitriding processes of steels, at 600 °C, contents of 0.1% in weight have been reported [11} and reporting a volume increase of between 10 and 20% [12]. Other authors have reported contents of 0.0015% at 900 °C, and 1 atmosphere of pressure [12). In the field of catalysis, nitrogen contents in catalysts of between 0.1 % to 0.5 % per gram of catalyst have been reported [13]. In the field of direct reduction of iron oxides, nitrogen contents of 0.005 to 0.01 % in weight have been reported in reduced minerals in gaseous mixtures with 55 and 66 % in weight nitrogen by volume [13]. For his part, Dam [1] reports the results of analyses for the remaining nitrogen content in samples reduced from 50 ppm (0.005 % in weight) in samples with abnormal swelling greater than 40% according to Figure V, using Micro-Kjendal techniques and vacuum melting technique for nitrogen determinations. These results are consistent with the curve in Figure VII, and whose mathematical expression is presented in Equation 7 as

$$\%[N] = -5E\text{-}05\ \%R^2 + 0{,}0048\ \%R - 0{,}0989 \qquad (R^2 = 0{,}9454) \qquad (7)$$

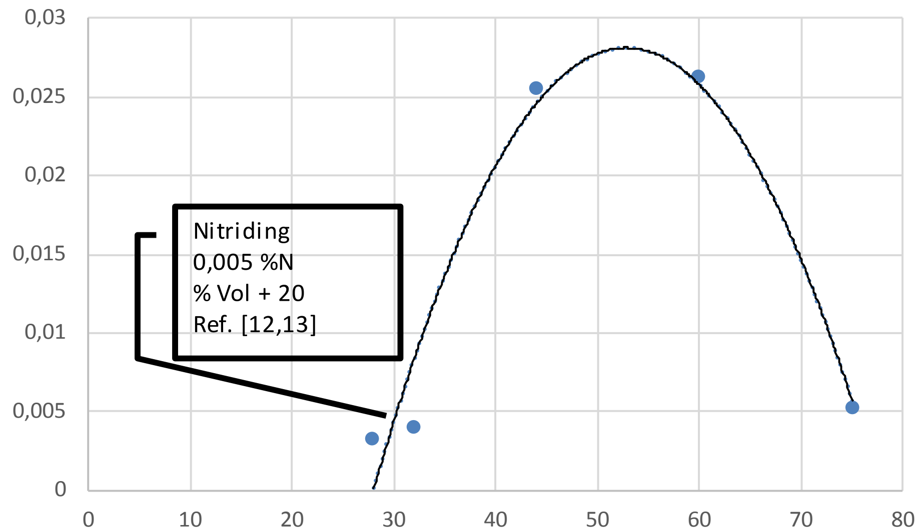

Fig. 7. Effect of dissolved nitrogen content (%) in iron (y-axis) on volume increase (%) (x-axis) during iron oxide reduction.(Source: Authors).

When applying the values of nitrogen content in iron by nitriding processes and nitrogen content in the samples reduced to room temperature, these values coincide with those estimated in the curve in Fig. 7. Note the similar trend of the curves shown in Fig. 6 and 7.

V.CONCLUSIONS

Comparison of the results of this paper leads to the following conclusions

1.The relationship between the mechanism of the swelling phenomenon of iron oxides with the mechanism of nitrogen absorption in fresh nascent iron even during the early stage of the reduction from magnetite to wustite was established.

2.It is shown that both during nitrogen absorption in the range of 900 °C and by allotropic change of ferrite (alpha iron) to austenite phase (gamma iron) in weight percent absorbed causes volumetric expansion during nitriding.

3.By characteristics of the isothermal test, and during the cooling of the samples occurs the desorption of molecular gaseous nitrogen inside the reduced samples by the effect of thermodynamic equilibrium according to the Fe-N equilibrium diagram.

4.The effect of stresses caused by the desorption of nitrogen in the form of molecular gas is unstudied in the picture of mechanical stresses associated with the swelling mechanism of iron oxides.

5.There is a clear similarity in the trends of nitrogen adsorption and volume change curves.

REFERENCES

[1]O. Dam G. “The Influence of Nitrogen on the Swelling Mechanism of Iron Oxides During Reduction”. Univ. of London. PhD Thesis 1983.

[2]J. Bogde. “Thermoelectric Power Measurements in Wustite. Univ. of Michigan”. 1976.

[3]O. Dam G. y J. Jeffes. “Model for the Assessment of Chemical Composition of reduced iron ores from single measurements. Ironmaking and Steelmaking”. Vol. 14, N`5. 1987

[4]M. Yang. “Nitriding-Fundamentals, modelling and process optimization”. Tesis PhD. Worcester Polytech Institute. 2012

[5]EL Kasabgy. T and W-K. LU. “The Influence of Calcia and Magnesia in Wustite on the Kinetics of Metallization and Iron Whisker Formation”. Metallurgical 1980 American Society for Metals and the Metallurgical Society of AIME Volume 11b, pp. 410-414. 1980.

[6]"Srikar Potnuru Studies nn the Physical Properties and Reduction Swelling Behavior of Fired Haematite Iton ore Pellets". MSc Thesis. Department of Metallurgical and Materials Engineering National Institute Of Technology, Rourkela May 2012
[7]R. Agarwal, S. Hembram. "To Study the Reduction and Swelling Behavior Iron Ore Pellets". BSc. Department of Metallurgical and Materials Engineering National Institute Of Technology, Rourkela May 2013
[8]C. Seaton., J. Foster. and J. Velasco. "Structural Changes Occurring during Reduction of Hematite and Magnetite Pellets Containing Coal Char". Transactions ISIJ, Vol. 23, 1983, pp.
[10]C. Bozco. "Interaction of Nitrogen with Iron Surfaces". Journal of Catalysis 49. pp16-41. 1977.
[11]L. Darken y R. Gurry. "Physical Chemistry of Metals". Mc Graw hIll . 1953.
[12]H. Weirdt and Z. Zwell, Trans. AIME. 229. 142. 1969
[13]J. Schulten. Trans. Soc. Faraday. 53, 1363, 1957.
[14]E. Barret y C. Wood. Bureau of Mines R-I 3229. 1934


$H(t)|\psi(t)\rangle = i\hbar\frac{d}{dt}|\psi(t)\rangle$
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