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MATHEMATICAL MODELING OF NICKEL ORES PRE-REDUCTION SIMULATIONS IN LABORATORY ROTARY KILN ''LINDER"

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ABSTRACT

In the context of this paper are presented the results of the research dependence of mineralogical and metallurgical parameters determining the degree of pre-reduction of nickel ores, during simulation laboratory furnace "Linder", according to the planning and the analysis of experiments with orthogonal plans of the first order 2^k with more factors. Such plans are referred to experimentation so as to reflect the dependence according to the equations in exponential form, for each parameter separately, graphic interpretation "3D" and "2D" in MATLAB package. Such planning can be applied in the process of increasing research of pre-reduction degree of nickel ores used in New Smelter of Ferronickel Drenas, in laboratory rotary kiln (Kavadarc). This research presents a methodology relatively new in this field, in order to study the relationship between technological parameters and composition of the ore, with the possibility of increasing the pre-reduction degree of the ores in Smelters, creating the opportunity of gaining a number greater than scientific arguments.

KEYWORDS: Furnace, Simulation, Pre-Reduction Degree, Humidity etc

INTRODUCTION

In New Smelter of Ferronickel in Drenas are used some types of ores from different places of Kosovo, Albania, Indonesia, Philippines, Turkey, Macedonia and ores from Turkey where their chemical and mineralogical composition changes.

In New Smelter of Ferronickel in Drenas the pre-reduction degree of nickel ores is low and as a result we have a problem in the process of obtaining nickel. In order to determine the factors that affect the pre-reduction degree's increase of Smelter's nickel ores, we have realized simulations of industrial cases for some temperatures in rotary kiln laboratory "Linder" in Macedonia.

At first, the charges were prepared in the laboratory of New Smelter of Ferronickel, Drenas(pic.1 and the determination of pre-reduction degree and its increasing factors in FeNi laboratory, Kavadarc in Macedonia, totally 12 experiments in rotary-kiln laboratory "Linder"(pic.2 and obtained results were verified by mathematical modeling).

Design of Experiments Model

The experiment's planning according to orthogonal plans by first order 2^k,applied for investigating relationships between mineralogical and metallurgical parameters in order to achieve the increase of pre-reduction degree of nickel ores in Smelter. Therefore, this case presents a good opportunity to build mathematical models that expresses such dependencies for working conditions(Makar.M,1990). Therefore, based on the relationship between input and output parameters of the research laboratory, the connection between them is done according to the expression (1):

$(C_{fix}, R_i)=f(T,w,q)$ (1)

T-temperature process

w-ore humidity(%)

q-quantity of coal (%)

C_{fix}-fixed carbon (%)

Ri- before-reduction degree of nickel ores

Function (1) can be transformed into the expression (2):

$$R=C\prod_{i=1}^{k} f_i^{p_i} \quad (2)$$

Which is composed by R(T,w,q),where the set of unknowns C and p_i can be made by statistical processing of the results, wether in this case are developed the total of N''proofs.

Starting from the IV principle of work process equipment (Zivkovic, S.iVerkljan, D.2002), our research is based on three parameters or variables: temperature "T", nickel ore humidity "w" , the amount of coal "q".

Then the number of tests will be:

$$N=2^k+n_o \quad (3)$$

Where:

k-number of parameters k = 3

n_o - evidence number in the center of the plan of the experiment, $n_o = 4$

$$N = 2^3 +4 = 12$$

One such composition of experimentation points associate with a certain number of tests at the focal point of experimentation plan (Pfaff, How Salopek, B, 2004).

Therefore, an easy supervision of the research results in the realization of the simulation process in order to increase the pre-reduction degree, ranging from measuring the temperature "T" of the process, the humidity of the ore, coal quantity "Q", we add the matrix of experimentation planning, where we preliminarily encode variables (C_{fix}, Ri),through the values (-1,0,+1).

Coding or real value transformation is done according to the expression: $x_i = 1 + 2\frac{\ln f_i - \ln f_{i\max}}{\ln f_{i\max} - \ln f_{i\min}}$

Where:

f_i - average

f_{min} - minimum value

f_{max} - maximum value

when $f_i = f_{imax}$, then the value of the code will be $x_i = +1$, when $f_i = f_{imin}$ then coded value will be $x_i = -1$. Research planning matrix is presented for real-coded values and parameters obtained from the experiments in Table 1.

Are Presented

Encoded Parameters

-1 - The value of the lower limit

0 - average

+1 - The value of the upper

Real Parameters

Temperature

Humidity

The amount of auxiliary material

Parameters Obtained from Experiments

R_i- before-reduction degree

C_{fix}-fixed carbon

Table 1: Experiment Matrix Planning $2^k + n_o$

Nr	Encoded Parameters				Real Parameters			Parameters Obtained from Experiments	
	X0	X1	X2	X3	T	w	q	Ri %	Cfix
1	1	-1	-1	-1	800.00	22	8	68	1.11
2	1	0	0	0	850.00	27	10	73	1.35
3	1	1	-1	-1	900.00	22	8	77.05	2
4	1	-1	1	-1	800.00	32	8	65	1
5	1	0	0	0	850.00	27	10	73	1.35
6	1	1	1	-1	900.00	32	8	74.18	1.49
7	1	0	0	0	850.00	27	10	73	1.35
8	1	-1	-1	1	800.00	22	12	70	2
9	1	1	-1	1	900.00	22	12	75.08	2.4
10	1	0	0	0	850.00	27	10	73	1.43
11	1	-1	1	1	800.00	32	12	69	1
12	1	1	1	1	900.00	32	12	75.08	1.62

Methods and Equipment

Determination of mineralogical parameters is done in the laboratory of Ferronickel Smelter, Drenas.

Picture 1: Laboratory Furnace for Removing Humidity of Nickel Ore in New Smelter of Ferronickel, Drenas

For the experiment's realization research have been analyses 12charges formed by three types of ores, pieces of baked material and for ancillary material we have used the Kosovo lignite and stone coal from Indonesia. While analytical parameters are obtained in laboratory rotating apparatus called 'Linder "in the laboratory of FeNi Kavadarc, Macedonia.

Picture 2: Laboratory Rotary-Kiln Linder in FeNi Kavadarc

Mathematical Analysis of the Processing Results

Mathematical analysis of the results of research should be done in order to build mathematical models, which express the nature of the interaction between technological parameters and work technique during the rotary furnace process of pre-reduction. In this case such mathematical models will be built on the surface of regression in linear form (Wackerly, DD 1996)

$$y=b_o+\sum_{i=1}^{n=3} b_i x_i \tag{5}$$

where:

b_i-coefficients with unknowns

xi-unknowns, then, its alignment included factors such as: temperature "T",humidity"w", and the amount of ancillary material "q". The interaction of mentioned parameters with those regression surface is as follows: x_1 = T, x_2 = w, x_3 = q; in this case the regression surface:

$$y=b_o+ b_1x_1+ b_2x_2+ b_3x_3 \tag{6}$$

Should be transformed into logarithmic function:

$$\ln R=\ln C+ p_1\ln T+ p_2\ln w+ p_3\ln q \tag{7}$$

Variables that constitute the logarithmic function (7) are:

$y=\ln R$ $x_1=\ln T$ $x_2=\ln w$ $x_3=\ln q$

While the coefficients of the unknowns are replaced by the transformation equations:

$b_0 =\ln C$ $p_1=b_1$ $p_2=b_2$ $p_3=b_3$

Under these conditions, the expression of surface regression takes the form of an exponential function:

$$R=C\,T^{p_1} w^{p_2} q^{p_3} \tag{8}$$

C-constant

p_1, p_2, p_3 - exponents

According to expression (3) and the values of variable x_i matrix formed the plan of the experiment in the form $2^k + n_o$, where k = 3. Based on the properties of orthogonal which must meet matrices, enable regression equation coefficients "b_i" are defined according to the expression:

$$b_i = \frac{1}{N}\sum_{n=1}^{N} x_{iu} y_u \tag{9}$$

where:

N-number of tests

x_{iu}-known parameters values

y_u-values of the parameters obtained

Coefficients of the regression surface (mathematical model) based on the conditions laid down, as well as the initial condition equation transformation is done according to the expression:

$$p_i = \frac{2b_i}{\ln\left(\frac{f_{imax}}{f_{imin}}\right)}$$

$$p_o = \left|\sum_{n=1}^{3} b_i\right|_{i=0,1,2,3} - \left|\sum_{n=1}^{3} p_i \ln(f_{imax})\right|_{i=1,2,3} \tag{10}$$

In this case we get correlations between the parameters where their determination may be made by the equation (2);in that case we get correlations between input parameters and the parameters obtained from experiments.

The estimation of the parameters obtained from the experiments is usually done according to the criterion F,compared with dispersion zero point:

$$F = \frac{s_i^2}{S_E^2} > F_t^* \tag{11}$$

Dispersion of the values of the model parameters is assigned according to the report

$$S_i^2 = \frac{s_i^2}{f_i} \tag{12}$$

F-values of known parameters

F^*_t-table values for given condition

f_{LF}=1and f_E=3) F^*_t=10.13

s^2_i - dispersion correlation parameters

S^2_E-dispersion of results in zero point

F_i – degree of freedom

While the sum of the squares is calculated:

$$Sb_i = b_i \sum_{n=1}^{p} x_{iu} y_u = N_i b_i^2 \tag{13}$$

Where i=0,1,2,3 in our case we have:

i=0 N=12

i=1,2,3 N=8

In this case degrees of freedom "fi" must be ensure,while the dispersion is calculated according to the expression:

$$S_E^2 = \frac{S_E}{f_E} \tag{14}$$

Where;

S_E – sum of the squares

F_E- degree of freedom

Dispersion in zero point, in this case, is calculated according to the expression (Montgomery,D.C Runger,G.C 1994)

$$S_E^2 = \sum_{u=1}^{4} y_{ou}^2 - \frac{1}{n_o}\left(\sum_{u=1}^{4} y_{ou}\right)^2 \tag{15}$$

And the degrees of freedom in this case are calculated according to the expression $F_E = n_o-1$. Where the significance level "α" and $F_l > F_t^*$, parameters "b_i" are estimated otherwise these parameters should be excluded from the mathematical model. Any mathematical model, which describes a work process of systems or presenting phenomena, must determine a confidence interval criterion "F" significance level "α".

$$F_l < F_t^* \tag{16}$$

As the focal point lies in the same plane in which the experiment is repeated n_o times, then the computed value of F_i criteria needed to determine the confidence interval of mathematical model expressed in the following equation:

$$F_{l_{LF}} = \frac{S_M^2}{S_E^2} \tag{17}$$

The change of the distribution of values y_i experiment and calculated $\hat{y}_i$:

$$S_M^2 = \frac{1}{f_R - f_E}\left\{\sum_{u=1}^{12}(y_u - \hat{y})^2 - \left(\sum_{u=1}^{4} y_{ou}^2 - \frac{1}{n_o}\left(\sum_{u=1}^{4} y_{ou}\right)^2\right)\right\} \tag{18}$$

And the distribution of measurement results with mid-level calculated to the according expression:

$$S_M^2 = \frac{1}{f_E}\left\{\sum_{u=1}^{4} y_{ou}^2 - \frac{1}{n_0}\left(\sum_{n=1}^{12} y_{0u}^2\right)^2\right\} \tag{19}$$

So tabular value criterion, F "chosen in advance by the relevant tables with lower degrees of freedom, where our case is $F_t^* = 9.01$

$$f_{LE}=f_R-f_E \quad (20)$$

$$f_E=n_0-1$$

The procedure of execution of regressive and dispersive analysis, and finding addiction is done by analyzing the input parameters by which are set the output parameters, carried out during the phase of setting the pre-reduction degree. In this case we can build correlation reports of these parameters with each other, one by one. According to the equation (2) we can propound the equations of dependence of output parameters, such as:pre-reduction degree R_i, fixed carbon C_{fix} and the input parameters; the amount of humidity, temperature T and the amount of ancillary material, lignite q, the percentage of humidity 27(%).

Interpretation and Graphical Presentation

3D and 2D Graphical interpretation of dependence of mineralogical parameters(input) and metallurgical(output),is realized in MATLAB separately for each case.

Pre-Reduction Degree

$$R_i = 0.2218 \cdot T^{0.874} \cdot w^{-0.065} \cdot q^{0.046} \quad (21)$$

Fixed Carbon(Cfix)

$$C_{fix} = 1.85 \cdot 10^{-11} \cdot T^{3.994} \cdot w^{-0.838} \cdot q^{0.386} \quad (22)$$

Here are the graphical interpretations(fig.1,fig.2) of obtained correlations for the percentage of the mixture of charges humidity 27(%).

3D graphical presentation; Case: $R_i = 0.179 T^{0.874} q^{0.046}$; $w = 27[\%]$

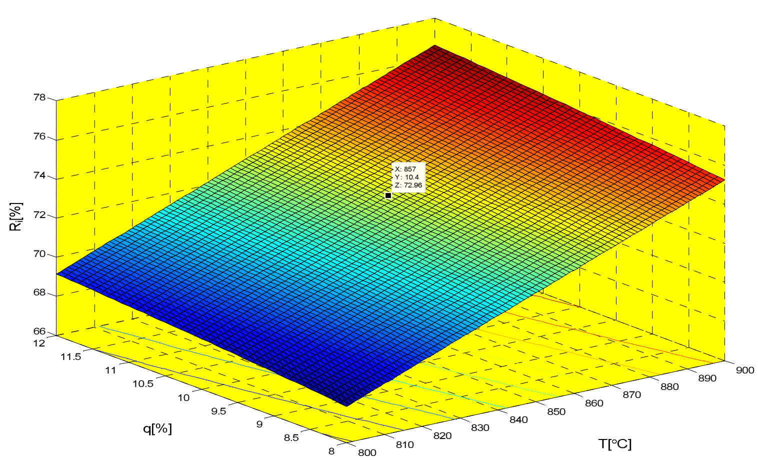

Figure 1: Regression Surface for Dependence of Pre-Reduction Degree of Nickel Ores from Temperature and the Amount of Ancillary Material (Kosovo Lignite and the Stone Coal Indonesia)

Case; $C_{fix} = 1.16\exp(-11) T^{3.994} \cdot q^{0.386}$; $w = 27[\%]$

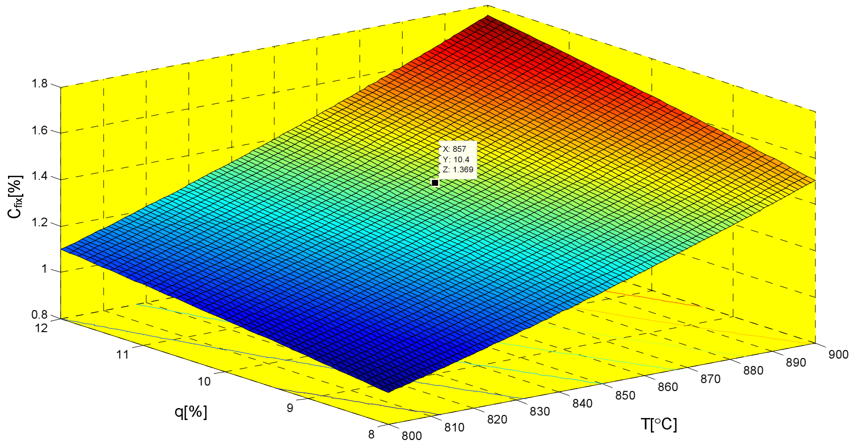

Figure 2: Regression Surface for Dependence of C_{fix} from the Amount of Ancillary Material and Temperature

Here we presented two-dimensional graphics; fig 3-dependence of percentage Ri from temperature and the ancillary material for humidity level 22(%).Fig.4.Percentage's dependency of pre-reductio degree(Ri) from temperatures and ancillary material for humidity level 22%.Fig5. Percentage's dependency of pre-reduction degree(Ri) from temperatures and ancillary material for humidity level 27%.Fig.6. Percentage's dependency of before-reduction degree(Ri) from temperatures and ancillary material for humidity level 27%.Fig.7. Percentage's dependency of pre-reduction degree(Ri) from temperatures and ancillary material for humidity level 32%.Fig.8. Percentage's dependency of before-reduction degree(Ri) from temperatures and ancillary material for humidity level 32%.

Two-dimensional graphical presentation

Case: $R_i = 0.181 T^{0.874} q^{0.046}; \; w = 22[\%]$

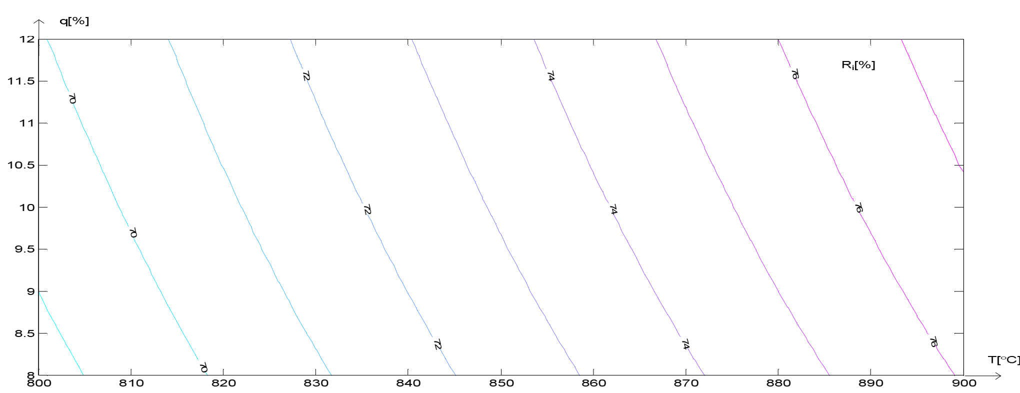

Figure 3: Percentage's Dependency of Pre-Reduction Degree (Ri) from Temperatures and Ancillary Material for Humidity Level 22%

Case: $C_{fix} = 1.38\exp(-11) \cdot T^{3.994} \cdot q^{0.386}; \; w = 22[\%]$

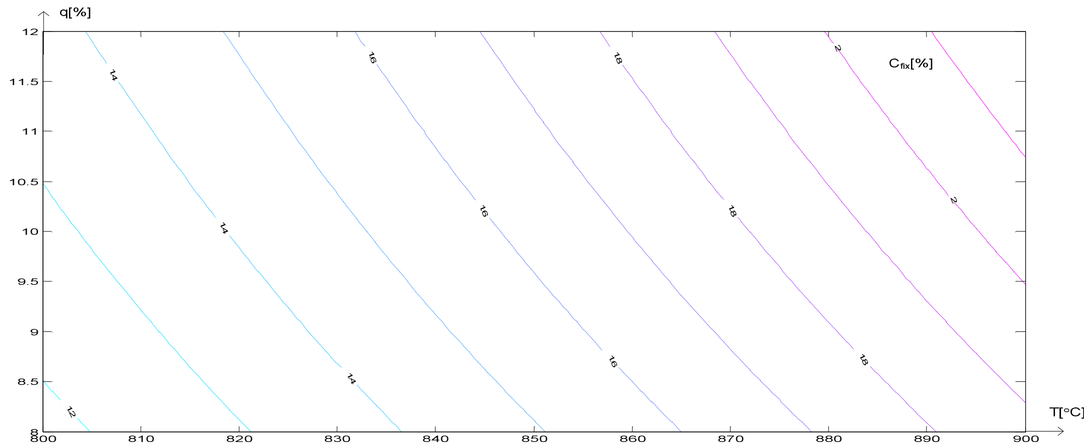

Figure 4: Percentage's Dependency of Pre-Reduction Degree (Ri) from Temperatures and Ancillary Material for Humidity Level 22%

Case; $R_i = 0.179T^{0.874}q^{0.046}$; $w = 27[\%]$

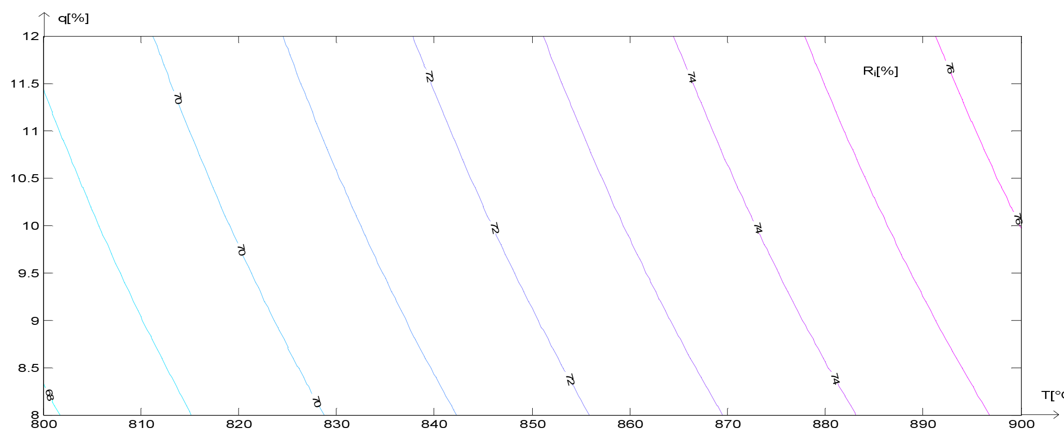

Figure 5: Percentage's Dependency of Pre-Reduction Degree (Ri) from Temperatures and Ancillary Material for Humidity Level 27%

Case: $C_{fix} = 1.16\exp(-11)T^{3.994} \cdot q^{0.386}$; $w = 27[\%]$

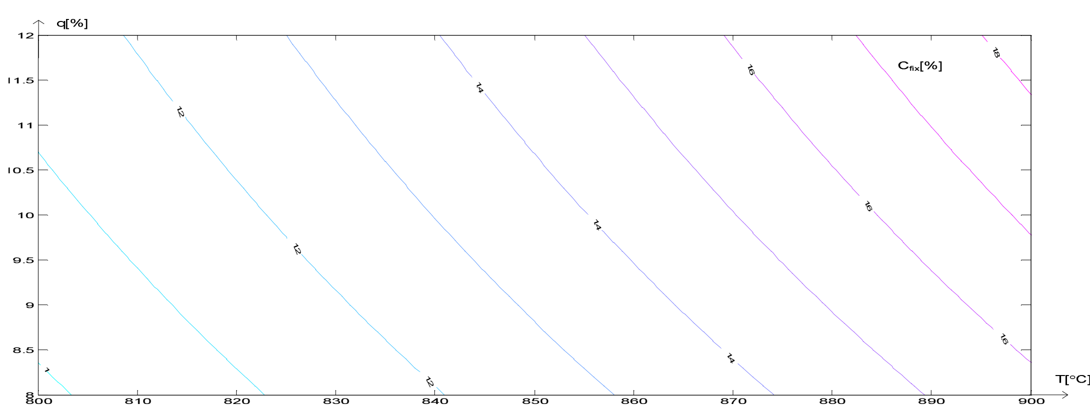

Figure 6: Percentage's Dependency of Pre-Reduction Degree (Ri) from Temperatures and Ancillary Material for Humidity Level 27%

Case: $R_i = 0.177T^{0.874}q^{0.046}$; $w = 32[\%]$

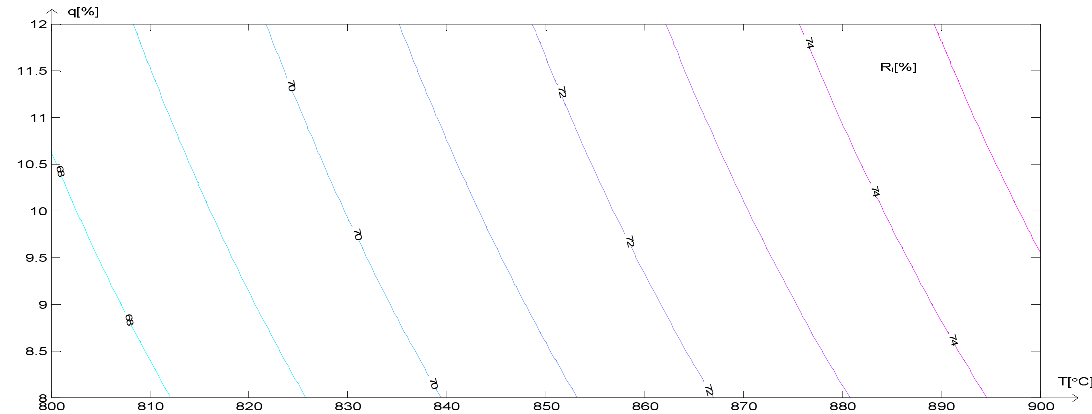

Figure 7: Percentage's Dependency of Pre-Reduction Degree (Ri) from Temperatures and Ancillary Material for Humidity Level 32%

Case; $C_{fix} = 1.01\exp(-11)\cdot T^{3.994}\cdot q^{0.386}$; $w = 32[\%]$

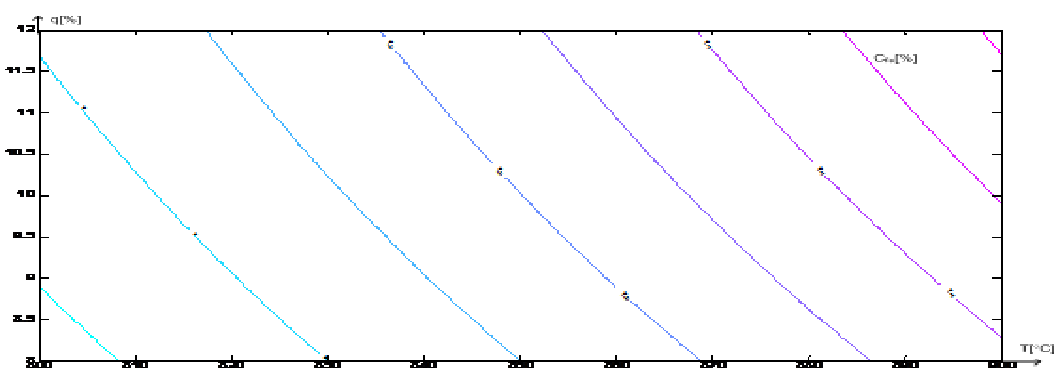

Figure 10: Percentage's Dependency of Pre-Reduction Degree (Ri) from Temperatures and Ancillary Material for Humidity Level 32%

CONCLUSIONS

In this case, regression and dispersive analysis of the experiment by orthogonal plans by first order "2^k" with many factors, we can conclude that the obtained values of metallurgic parameters according to correlations are more favorable than those obtained by industrial process, if we count the simulations realized in laboratory rotating furnace "Linder" in FeNi lab, Kavadarc.

With the help of laboratory simulations of nickel ores pre-reduction in laboratory rotary-kiln Linder, we have achieved satisfying results of the degree growth of pre-reduction 40% higher in the case of our experiments compared to those industrial (***Experimental Research on pre-reduction of Nickel silicate ore in New Ferronickel Factory in Drenas*** ,WSEAS-2011)

If we increase the amount of dry ores ,we're not only going to have changes in the metallurgical process and pre-reduction increasing degree, we're also going to have economic profit because the fuel for drying the ores will be cheaper than the electric energy that is needed in the process of obtaining the baked material. Analysis of the results obtained from research experiments realized between mineralogical(input) and metallurgical parameters(obtained from results) in tha case of increase degree of pre-reduction nickel ores realization after humidity reduction.

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