Revista de metalurgia

Some influences of the chemical composition upon the viscosity of synthetic slags used in continuous steel casting[(•)]

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Abstract The continuous cast semifinished products quality is in a major part influenced by the lubrication process from the mould, which is influenced at its turn by slag viscosity, resulted from the melting of the lubrication powders. In the paper it is analysed the chemical composition influence on slag viscosity. The research targeted establishing some correlations between the dynamic viscosity and the chemical composition of the slag. For the chemical composition it was chosen as variable factors (representative components) the contents of CaO, MgO, Al_2O_3, SiO_2 (the last two expressed through Al_2O_3/SiO_2 ratio). The experiments for viscosity were performed on slags at temperatures of 1350 °C. Processing the data was performed in MATLAB laboratories, obtaining four (4) multiple correlations. The results are presented both in an analytical form and in a graphical form. The use of the obtained relations allows determining slag viscosity with a mathematical error, and using graphical correlations allows establishing the variation area (the limits) of viscosity to the representative components.

Keywords Steel. Continuous casting. Lubrication. Slags. Viscosity. Chemical composition.

Algunas influencias de la composición química sobre la viscosidad de las escorias sintéticas usadas en la colada continua del acero

Resumen La calidad de productos semiacabados de la colada continua está influenciada, en gran parte, por el proceso de lubricación de la matriz que, a su vez, está influenciado por la viscosidad de escoria que resulta de la colada de polvos de fundición. Este trabajo analiza la influencia de composición química sobre la viscosidad de la escoria. La investigación ha tenido como meta establecer unas correlaciones entre la viscosidad dinámica y la composición química de la escoria. Para la composición química se han escogido como factores variables (componentes representativos) el contenido de CaO, MgO, Al_2O_3, SiO_2 (los dos últimos expresados por la razón Al_2O_3/SiO_2). Los ensayos sobre la viscosidad se han realizado sobre escoria a temperaturas de 1.350 °C. Él análisis de los datos se ha efectuado en los laboratorios MATLAB y se han obtenido cuatro correlaciones múltiples. Los resultados se presentan tanto en forma analítica como grafica. La utilización de las relaciones obtenidas permite determinar la viscosidad de las escorias con un error matemático y la utilización de las correlaciones graficas permite establecer el área de variación (los limites) de la viscosidad, para los componentes representativos.

Palabras clave Acero. Colada contínua. Lubricación. Escorias. Viscosidad. Composición química.

1. INTRODUCTION

The efficiency of steel continuous casting is determinate in addition to technological factors by the using of the slag powdery mixtures for steel protection in crystalliser tanks of the continuous casting devices.

The mixtures have the following functions [1-4]:

- ensure the lubrication between the walls of the crystalliser tank and the solidified steel crust.
- retain a part of the non-metallic inclusions, which decant at the interface metal-slag.

(•) Trabajo recibido el día 4 de agosto de 2003 y aceptado en su forma final el día 28 de enero de 2005.
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- improve heat transfer from the surface of the half-finished product to the crystalliser tank walls.
- ensure thermal insulation of the liquid steel surface and protect it against excessive cooling.
- ensure high quality of the surface of the half-finished product cast with high speed.

These functions can be ensured by a proper choosing of the materials compounding the lubricating flux, with certain physical and chemical properties. The main properties of lubricating flux are[1-3]:

- melting range and melting rate.
- viscosity.
- crystallising temperature and vitrification temperature.

Melting range of synthetic flux is recommended to be greater, because in this way slag film seeped between crust and crystalliser tank remain liquid and ensure a better lubrication[3-5].

Lubrication efficiency depends on slag viscosity, which is mainly influenced by chemical composition and temperature. As long as slag remains liquid its yielding properties are determinate by the viscosity curve[5].

The research was directed towards determining slag viscosity at a given temperature and for different chemical compositions. There were chosen as representative components CaO, MgO, Al_2O_3, and SiO_2, having in view the quaternary system of CaO – MgO – Al_2O_3 – SiO_2, a representative system for this quality of slag.

The performed research had in view to obtain correlations between the dynamic viscosity of slag and its chemical composition, defined by the representative components.

2. SIMULATION IN MATLAB AREA. DESCRIPTION AND RESULTS

The main types of slag mixtures belong to ternary systems: $SiO_2 – Al_2O_3 – CaO$, $SiO_2 – Al_2O_3 – FeO$, $SiO_2 – Al_2O_3 – Na_2O$ [3-5]. This paper presents the results obtained processing the experimental dates related to slag dynamic viscosity (η) - function on chemical composition. It was studied slags from the system SiO_2 - Al_2O_3 - CaO - MgO for which there were determinate chemical composition and viscosity at 1350 °C. In table I the main chemical composition of the studied slags are presented. Also, in table I, the experimentally and the theoretically mean values of the dynamic viscosity are presented.

During the experiments we used original recipes for lubricating. To produce the powders we used different materials, including industrial wastes, in the following percentage[4 y 5]:

- thermal power station dust concentrate: 15...20 %.
- termoplast cellular concrete wastes: 12...16 %.
- furnace slag: 24...28 %.
- raw fluorine: 5...6 %.
- graphite (powders): 20...23 %.
- limestone: 6...10 %.
- soda: 5...6 %.
- dolomite: 3...4 %.

Industrial research has been performed to obtain a number of 8 charges, cast in bloom form (240×270 mm) at a 4 wire equipment (experimental wires) and has been compared with one standard wire which use standard lubricating powders (scorialit type C163-79/H). In table II the main characteristics of the studied powders are presented. Also the main chemical composition, the proportion and the variation limits are

Table I. The experimental and the theoretically mean values

Tabla I. Valores medios, experimentales y teóricos

Nº.	CaO [%]	MgO [%]	Al_2O_3/SiO_2 [-]	$\eta_{experimental}$ [poise]	$\eta_{teoretically}$ [poise]	Error [-]
1.	37.21	0	0.21	1517.26	-2.26	
2.	33.02	0	0.25	9.9	8.52	0.38
3.	40.11	0	0.33	10.33	11.38	-1.05
4.	43.52	0	0.52	9.2	8.47	0.72
5.	42.54	0	1.02	14.37	13.38	1.02
6.	38.83	5.02	1.03	9.33	12.23	-2.9
7.	40.06	5.08	0.33	9.5	7.02	2.48
8.	47.51	4.94	0.22	3.75	3.41	0.34
9.	40.25	10.03	1.02	4.45	4.27	-0.02
10.	35.63	10.05	0.53	3.52	5.06	-1.54
11.	37.09	9.97	0.33	6.03	5.29	0.71
12.	40.83	10.05	0.25	4.57	4.78	-0.21
13.	39.75	9.96	0.21	6.86	7.85	-0.99
14.	34.16	15.04	1.03	3.34	1.89	1.45
15.	38.16	15.06	0.512	2.19	2.92	0.73
16.	35.02	14.93	0.33	3.85	3.58	0.27
17.	40.66	14.98	0.25	4.17	4.65	0.48

Table II. Chemical composition and main characteristics and the area of percentual variation of the components in the uses lubricating powders

Tabla II. Composición química, proporción, características principales y área de variación de los componentes en la utilización de los polvos de fundición

				Variation area. [%]
Chemical components			SiO_2	24.62-27.64
			CaO	20.30-24.88
			MgO	1.40-1.70
			Al_2O_3	8.30-12.20
			Fe_2O_3	4.71-6.42
			CaF_2	5.77-9.58
			P_2O_5	0.10-0.14
			Na_2O	4.31-4.75
			K_2O	0.35-0.42
			TiO_2	0.16-0.20
			MnO	0.51-0.57
Properties	main characteristics	specific weight		0.7-0.9 g/cm^3
		softening point temperature		1150-1210 ºC
		melting temperature		1240-1285 ºC
		lubricating temperature		1300-1350 ºC
	granulometric analyses	screen size. [mm]		0.5
				0.125
				0.06
		screenings. [%]		all > 0.5
				2.0-10.0
				10.0-30.0

presented. The experimented powders have been good behaviour, similar with the standard powder. To obtain the desirable viscosity the composition of the powder production recipes is modified.

The values processing were made using MATLAB calculation program. Mathematical simulation allows determining the medium values of the basic components of the slag, in order to obtain a necessary value for the viscosity. Therefore, we suggest a mathematical interpretation of the influences of the main components over the viscosity, through the triple correlations theory in the MATLAB area. For independent variables the CaO, MgO, and the Al2O3/SiO2 ratio are considered, and the viscosity is the dependent parameter. We searched for a method of molding the dependent variables depending on the independent variables x, y, z:

$$u = c_1 \cdot x^2 + c_2 \cdot y^2 + c_3 \cdot z^2 + c_4 \cdot x \cdot y + c_5 \cdot y \cdot z + c_6 \cdot z \cdot x + c_7 \cdot x + c_8 \cdot y + c_9 \cdot z + c_{10} \quad (1)$$

Next, there are shown the results of the multidimensional processing of experimental data. Using this calculation program we determinate a correlation of the following form:

$$\eta = 0.0097 \cdot (CaO)^2 + 0.04493 \cdot (MgO)^2 + 11.37 \cdot (Al_2O)/(SiO_2)^2 + 0.074 \cdot (CaO) \cdot (MgO) - 0.6481 \cdot (MgO) \cdot (Al_2O_3)/(SiO_2) - 0.0966 \cdot (Al_2O_3)/(SiO_2) \cdot (CaO) - 1.705 \cdot (CaO) - 3.942 \cdot (MgO) - 4.798 \cdot (Al_2O_3)/(SiO_2) + 65.51 \quad (2)$$

The correlation coefficient has the value R = 0.8794 (R ≈ 0.88) and the deviation from the regression surface is S = 3.44.

This surface in the four-dimensional space admits a saddle point of coordinates:

$$(CaO)_s = 44.97\ \%; \quad (MgO)_s = 12.22\ \%; \quad (Al_2O_3)/(SiO_2)_s = 0.75$$

to which the corresponding value of viscosity is $\eta_s = 1.29$.

The existence of a saddle point inside the technological domain has a particular importance as it ensures stability to the process in the vicinity of this point, stability which can be either preferable of avoidable.

The behaviour of this hyper surface in the vicinity of the stationary point (when this point belongs to the technological domain) or in the vicinity of the point where the three independent variables have their respective mean value, or in a point where the dependent function reaches its extreme value in the technological domain (but not being a saddle point) can be rendered only as a table, namely, assigning values to the independent variables on spheres which are concentrically to the point under study.

As this surface cannot be represented in the three-dimensional space, we resorted to replacing successively one independent variable by its mean value. Thus, we obtained the following equations:

$$\eta_{CaO\ med} = 0.0449\cdot(MgO)^2 + 11.37\cdot(Al_2O_3)/(SiO_2)^2 + 0.6481\cdot(MgO)\cdot(Al_2O_3)/(SiO_2) - 1.047\cdot(MgO) - 8.573\cdot(Al_2O_3)/(SiO_2) + 13.68 \quad (3)$$

$$\eta_{MgO\ med} = 11.37\cdot(Al_2O_3)/(SiO_2)^2 + 0.0097\cdot(CaO)^2 - 0.0966\cdot(Al_2O_3)/(SiO_2)\cdot(CaO) - 9.313\cdot(Al_2O_3)/(SiO_2) - 0.0966\cdot(Al_2O_3)/(SiO_2)\cdot(CaO) - 9.313\cdot(Al_2O_3)/(SiO_2) - 1.189\cdot(CaO) + 40.23 \quad (4)$$

$$\eta_{Al_2O_3/SiO_2\ med} = 0.0097\cdot(CaO)^2 + 0.04493\cdot(MgO)^2 + 0.074\cdot(CaO)\cdot(MgO) - 1.752\cdot(CaO) - 4.255\cdot(MgO) + 65.85 \quad (5)$$

These surfaces, belonging to the three-dimensional space can be reproduced and therefore interpreted by technological engineers. These surfaces are represented in figures 1, 3 and 5. In order to have as accurate a quantitative analysis as possible we showed in figures 2, 4 and 6 the corresponding level lines, which lead to the following conclusions:

- in case CaO = CaO_{med}, η is maximum for low values of MgO and minimum for MgO ≈ 15 % and Al_2O_3/SiO_2 ≈ 0.8 %;
- in case MgO = MgO_{med}, η is maximum for CaO ≈ 25 % and minimum for CaO ≈ 45 %;
- in case Al_2O_3/SiO_2 = Al_2O_3/SiO_{2med}, η is maximum for CaO ≈ 25 % and MgO minimum and, respectively, takes minimum values for CaO ≈ 50 % and MgO ≈ 15 %.

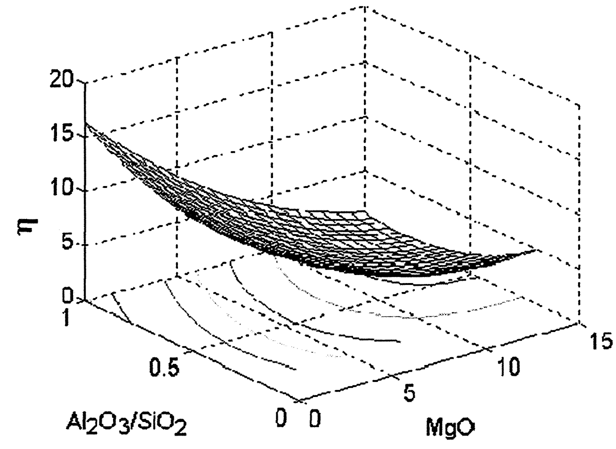

Figure 1. Surface $\eta = f(CaO_{med}, MgO, Al_2O_3/SiO_2)$.

Figura 1. La superficie $\eta = f(CaO_{med}, MgO, Al_2O_3/SiO_2)$.

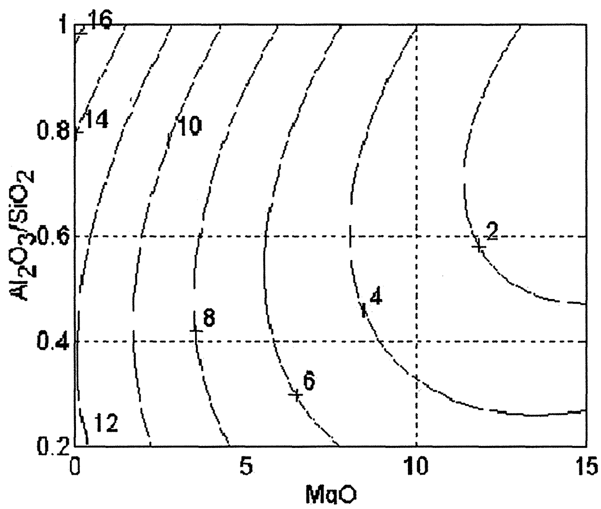

Figure 2. The correlation level lines $\eta = f(CaO_{med}, MgO, Al_2O_3/SiO_2)$.

Figura 2. Líneas de nivel de la correlación $\eta = f(CaO_{med}, MgO, Al_2O_3/SiO_2)$.

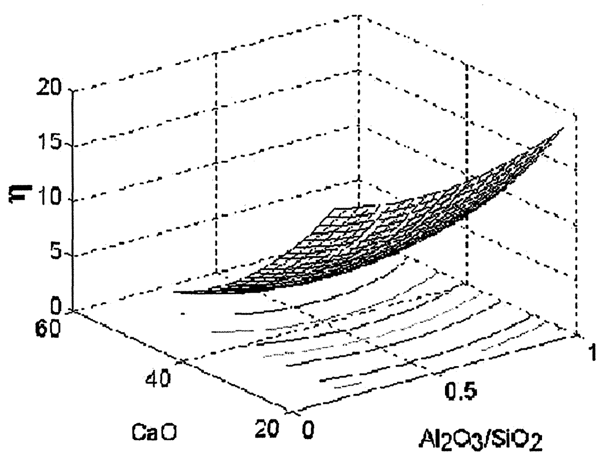

Figure 3. Surface $\eta = f(CaO, MgO_{med}, Al_2O_3/SiO_2)$.

Figura 3. La superficie $\eta = f(CaO, MgO_{med}, Al_2O_3/SiO_2)$.

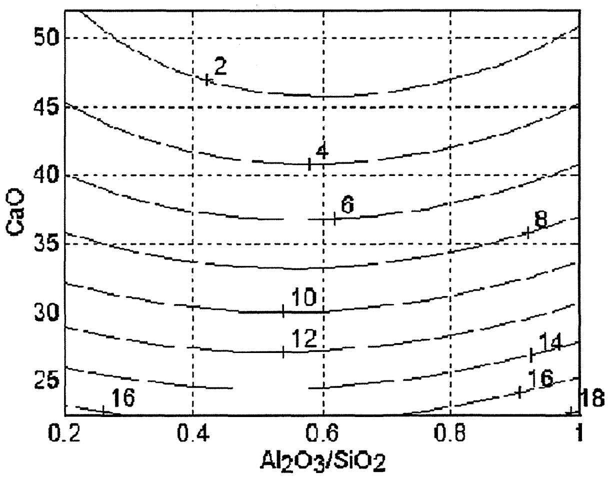

Figure 4. Surface $\eta = f\ (CaO, MgO_{med}, Al_2O_3/SiO_2)$.

Figura 4. La superficie $\eta = f\ (CaO, MgO_{med}, Al_2O_3/SiO_2)$.

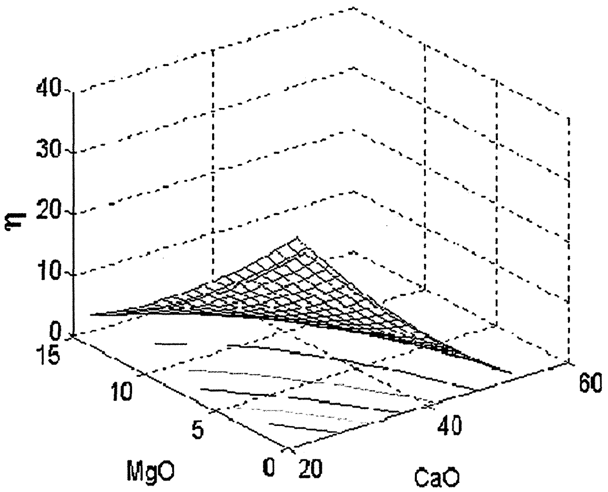

Figure 5. Surface $\eta = f\ (CaO, MgO, Al_2O_3/SiO_{2\ med})$.

Figura 5. La superficie $\eta = f\ (CaO, MgO, Al_2O_3/SiO_{2\ med})$.

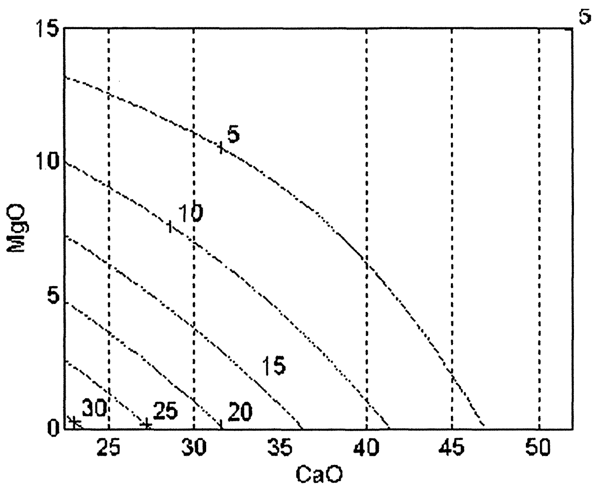

Figure 6. The correlation level lines $\eta = f\ (CaO, MgO, Al_2O_3/SiO_{2\ med})$.

Figura 6. Líneas de nivel de la correlación $\eta = f\ (CaO, MgO, Al_2O_3/SiO_{2\ med})$.

Knowing these level curves allows the correlation of the values of the two independent variables so that we can obtain a viscosity within the required limits.

If in equation (2), instead of assigning the mean value to an independent variable, we assign it two values, namely the mean value to which we add, respectively deduct one third of the mean square deviation of this variable, we obtain in the space a domain limited by these surfaces, as well as by the technological limitations of the other two independent variables. In this way we obtained the figures 7, 8 and 9, corresponding to them, the level lines of the two extreme surfaces, shown in figures 10, 11 and 12.

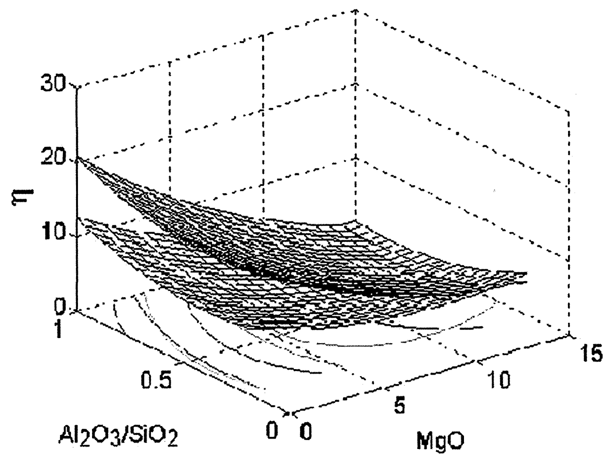

Figure 7. Grade volume representation for CaO within $CaO_{med} \cdot 0.9$ and $CaO_{med} \cdot 1.1$.

Figura 7. Representación de la clase del volumen para CaO en $CaO_{med} \cdot 0.9$ y $CaO_{med} \cdot 1.1$.

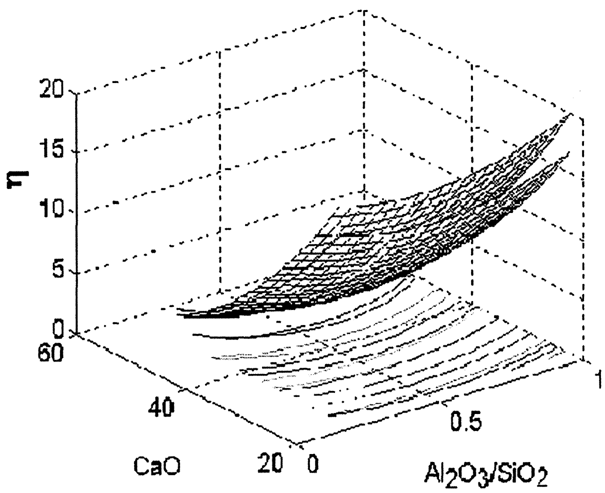

Figure 8. Grade volume representation for MgO within $MgO_{med} \cdot 0.9$ and $MgO_{med} \cdot 1.1$.

Figura 8. Representación de la clase del volumen para MgO en $MgO_{med} \cdot 0.9$ y $MgO_{med} \cdot 1.1$.

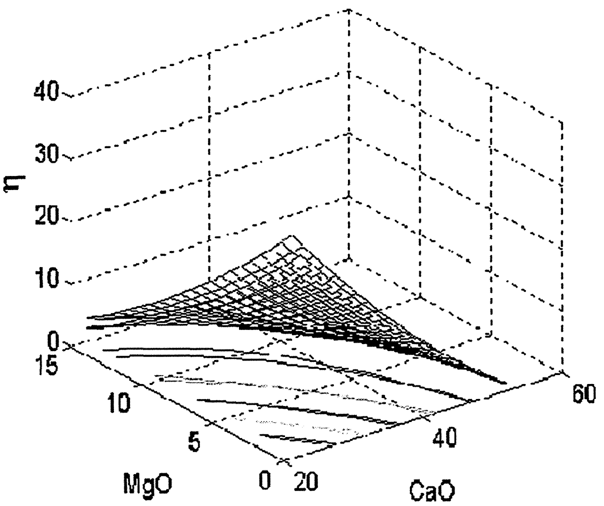

Figure 9. Grade volume representation for Al_2O_3/SiO_2 within $Al_2O_3/SiO_{2\ med}{\cdot}0.9$ and $Al_2O_3/SiO_{2\ med}{\cdot}1.1$.

Figura 9. Representación de clase del volumen para Al_2O_3/SiO_2 en $Al_2O_3/SiO_{2med}{\cdot}0.9$ y $Al_2O_3/SiO_{2med}{\cdot}1.1$.

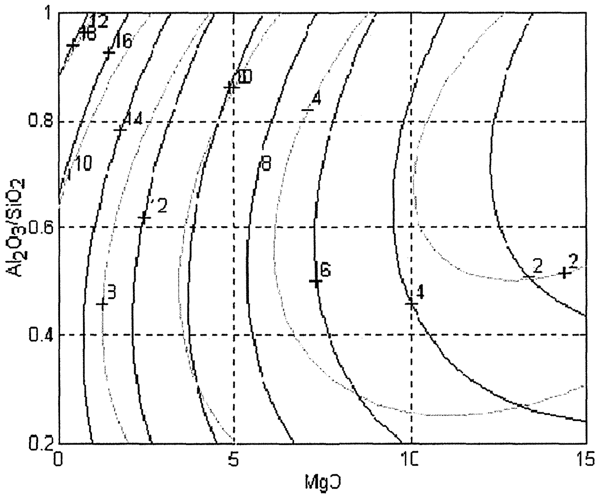

Figure 10. The level lines for variation volume for Al_2O_3/SiO_2 and MgO.

Figura 10. Líneas de nivel para la variación del volumen para Al_2O_3/SiO_2 y MgO.

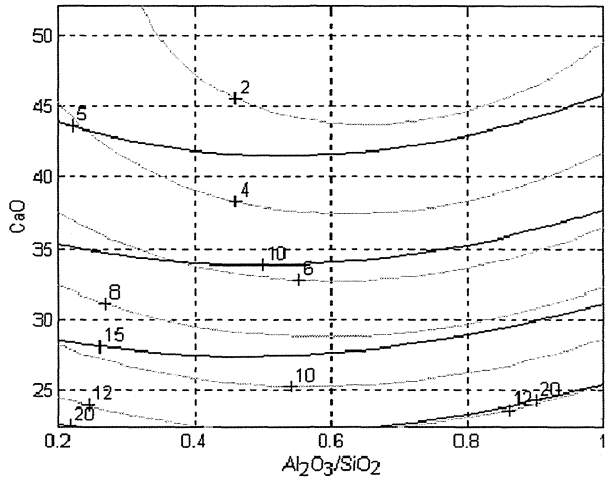

Figure 11. The level lines for variation volume for CaO and Al_2O_3/SiO_2.

Figura 11. Líneas de nivel para la variación del volumen para CaO y Al_2O_3/SiO_2.

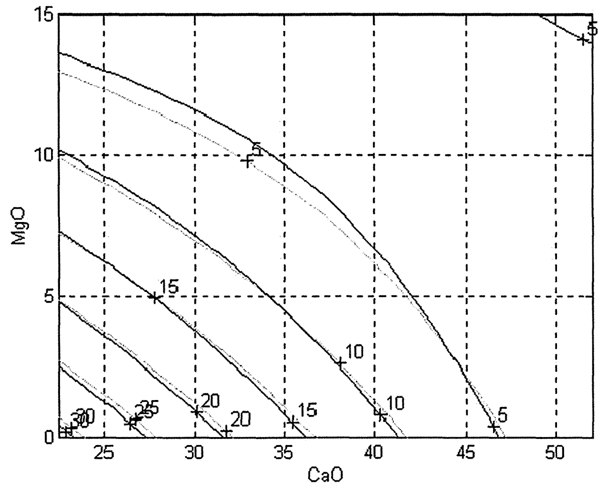

Figure 12. The level lines for variation volume for MgO and CaO.

Figura 12. Líneas de nivel para la variación del volumen para MgO y CaO.

Knowing these volumes allows technological engineers to correlate more loosely the three independent variables in order to obtain a clear-cut zone, leading to a constant viscosity, of desired value.

3. CONCLUSIONS

Having in view the influence of other factors (such as temperature, type and size of complex anions) upon the viscosity, the researches will continue, including firstly the temperature factor into the equation. The researches were performed as part of a grant (research contract) from the National Plan for the Romanian Research Development.

The researches we carried out have lead to the following conclusions:

- the viscosity of the slag resulting from melting the lubricating powder is influenced by its chemical composition.
- using the MATLAB calculation programs we determined correlations between viscosity and chemical composition indices. expressed both graphically and analytically.

- knowing the double and triple correlations is really helpful in practice. as it allows us to determine variation boundaries for the indices of slag chemical composition. in view of obtaining the desired values of viscosity[4].
- the usage of these programs can also be extended to the study of other slag characteristics.

We consider that it would be interesting and useful for practice knowledge of these triple correlations between viscosity and the powder constituents which would allow a safer adjustment of the recipe constitution. The usage of this theory and the mathematical interpretation in MATLAB area, can also be extended to the study of influences other components of the slags, and can be presented other level curves and regression surfaces from the continuous casting practice and engineering technological interpretation. This is the opinion of the Romanian technologists.

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