RESEARCHES ON THE QUALITY OF LUBRICATING POWDERS USED IN STEEL CONTINUOUS CASTING

T. Hepuţ , Ş. Maksay, E. Ardelean, A. Socalici, M. Ardelean
Universitatea "POLITEHNICA" Timişoara

INTRODUCTION

Continuous casting is the modern way of casting steel, fact proved by its wide spreading of late. The surface quality of the continuous cast products is influenced not only by the technological factors, but also by the characteristics of the casting powders.

The casting powders used in steel continuous casting have a complex role, as they need to:

- prevent steel reoxidizing on continuous casting ;
- capture and retain the non-metallic inclusions from the liquid steel;
- ensure thermal insulation and thermal transfer;
- ensure the lubrication between the solidified steel crust and the wall of the mould.

In order to meet these requirements the continuous casting powders must be analyzed in terms of: fusibility, viscosity, superficial and inter-phase strain, the capacity of inclusion absorption. These properties, in their turn, are to a large extent determined by the chemical and mineralogical structure, the grain size distribution, the physical and chemical humidity of the powder, respectively of the slag resulting from the melting of the casting powder.

1. STUDIES ON THE INFLUENCE OF SLAG CHEMICAL COMPOSITION ON VISCOSITY

The main factors influencing the viscosity of metallurgical slags and which can be acted upon in current practice are temperature and chemical composition.

Temperature has to rank within certain technological limits. In most cases, viscosity is corrected by means of chemical composition.

The existent oxides from the lubricating powder, respectively the slag resulting from their melting, have a different influence upon its viscosity.

This paper analyzes the influence of chemical composition of the slag resulting from the melting of the powder upon its viscosity.

1.1. The Influence Of Aluminum Oxide

An analysis of the ternary diagram $CaO-SiO_2-Al_2O_3$ - figure 1 (a diagram that is representative for the slags resulting from the melting of the lubricating powder), will lead to the conclusion that on introducing the aluminum oxide into the slags, there results an increase in its viscosity as Al_2O_3 is a "lattice-generator".

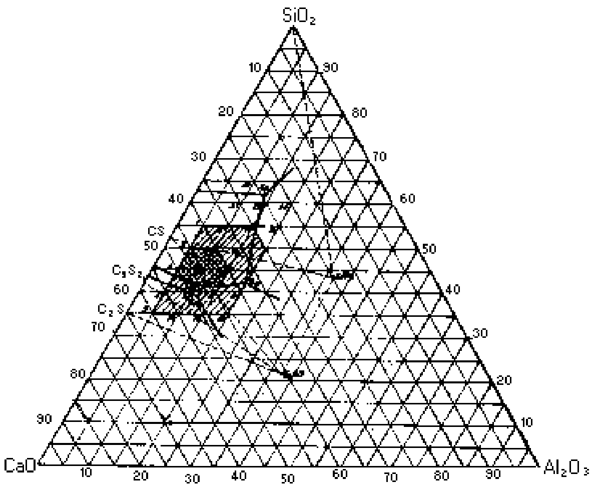

Figure 1. The ternary diagram $CaO – SiO_2 – Al_2O_3$.

In order to establish the correlation equations between viscosity and the contents in Al_2O_3 from slags for different temperatures, we processed several data in EXCEL for simple correlations and MATLAB for multiple correlations, which allowed the determination of certain correlations shown both graphically and analytically in figures 2,3,4 and 5.

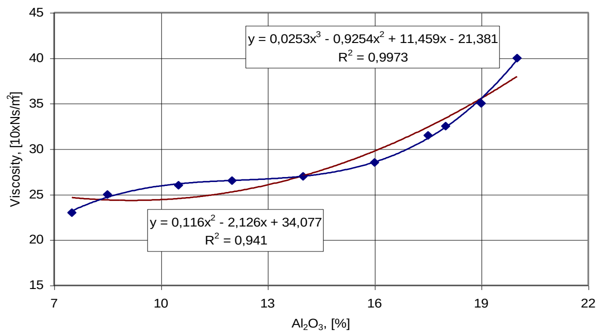

Figure 2. The variation of casting slag viscosity on continuous casting, with respect to the content in Al_2O_3 at a temperature of 1300°C.

The analysis of the results given in figures 2,3,4, confirms the existence of clear correlations between the contents in Al_2O_3 and viscosity, which is also proved by the value of coefficient R.

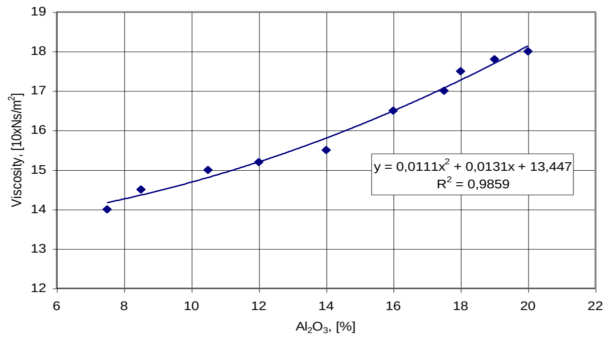

Figure 3. The variation of casting slag viscosity on continuous casting, with respect to the content in Al_2O_3 at a temperature of 1350°C.

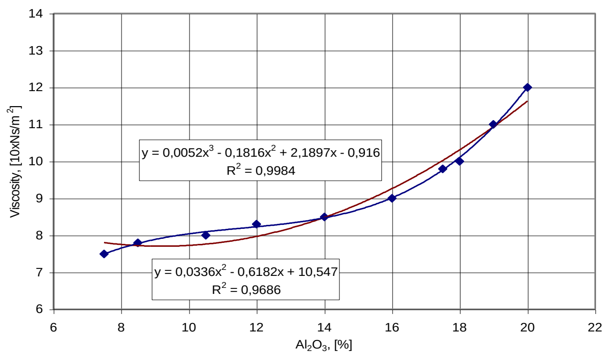

Figure 4. The variation of casting slag viscosity on continuous casting, with respect to the content in Al_2O_3 at a temperature of 1400°C.

Thus, at a temperature of 1300°C, the correlation clearly corresponds, from the analytical point of view, to a polynomial regression of 3rd degree, the increase being higher when the contents in Al_2O_3 is higher, unlike the case of the other two temperatures. For this case we consider that the influence of temperature on viscosity is higher than for the temperatures of 1350°C and 1450°C (which is confirmed in the reference literature by the diagram of slag viscosity variation with respect to temperature).

The multiple correlation allows the optimal choice of temperature and Al_2O_3 values, meant to lead to a certain range of viscosity (figure 5). We showed on the horizontal the sub-domains of viscosity variation (the boundaries between the levels).

By analyzing the correlation equation and, more obviously, the variation diagram of viscosity, one can notice that, for this characteristic, the low values are obtained when temperatures are high and the aluminum content is low.

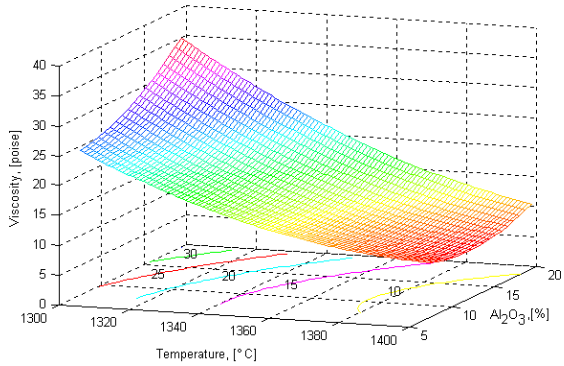

Figure 5. Continuous casting slag viscosity with respect to temperature and content in Al_2O_3.

Using this diagram one can choose the variation limits for temperature and the contents in Al_2O_3 in view of reaching the desired values for viscosity.

1.2. The Influence of Calcium, Silicon And Magnesium Oxides

As metallurgical slags are complex, the system representing the real slag (the current practice slag) includes at least seven oxide components and it is but natural to study the influence of these oxides (CaO, SiO_2, MgO) upon viscosity.

The data were processed in EXCEL and MATLAB, the influence of the silicon dioxide being determined in both correlations by the ratio Al_2O_3/SiO_2.

The correlations between viscosity and the contents in Calcium oxide from the slag, for different values of the ratio Al_2O_3/SiO_2 and the different contents in Magnesium oxide are given in figures 6,7,8 and 9.

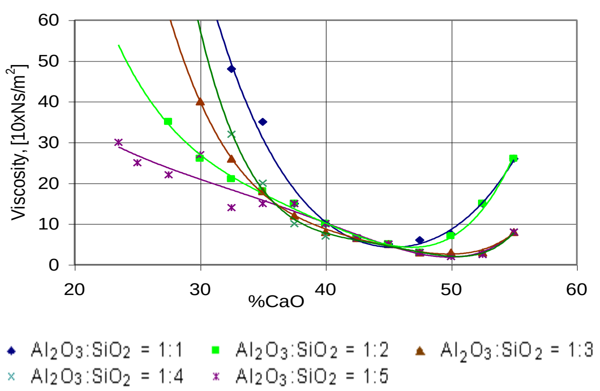

Figure 6. The influence of ratio Al_2O_3/SiO_2 on viscosity at 0%MgO.

Analyzing the correlations we obtained, one can say that, mathematically, they are representative, if we take into consideration coefficient R.

One can also notice that as the slag content in MgO increases, the values of viscosity decrease and they range within closer and closer limits.

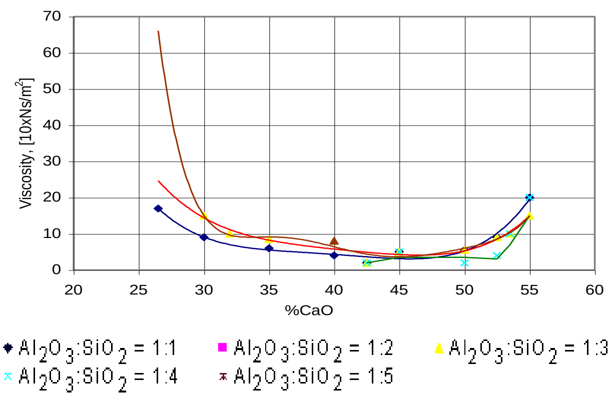

Figure 7. The influence of ratio Al_2O_3/SiO_2 on viscosity at 5%MgO.

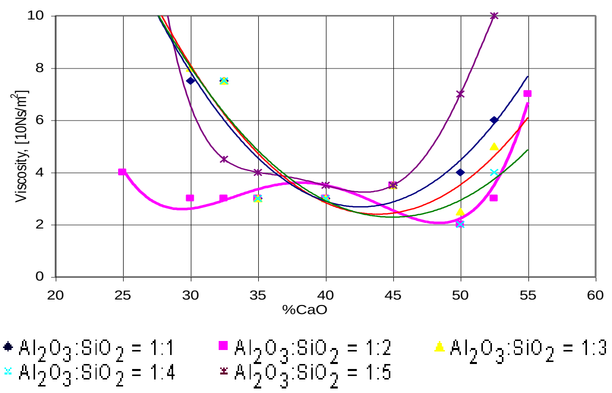

Figure 8. The influence of ratio Al_2O_3/SiO_2 on viscosity at 10%MgO.

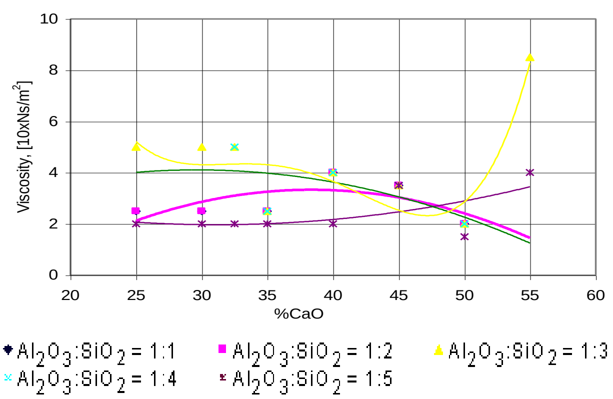

Figure 9. The influence of ratio Al_2O_3/SiO_2 on viscosity at 15%MgO.

Adding Magnesium oxide to the slag within certain limits (5 ... 8%) is also profitable as it ensures stability to silicon meltings, the composition varying within large limits without any significant modification of viscosity.

As to the influence of calcium oxide, one can notice that minimum values of viscosity are to be obtained for contents ranging around 45 %, contents that correspond to the formation of Calcium ortho-silicate in real slags.

We further introduce the results of multi-dimensional processing of the experimental data. Aiming at this, we looked for a way of modeling of the dependent variable u with respect to the independent variables x, y, z, of the form :

$$u = c1 \cdot x^2 + c2 \cdot y^2 + c3 \cdot z^2 + c4 \cdot x \cdot y + c5 \cdot y \cdot z + c6 \cdot z \cdot x + c7 \cdot x + c8 \cdot y + c9 \cdot z + c10 \qquad (1)$$

The optimal modeling form under question is given by the equation:

$$\eta = 0{,}009701 \cdot CaO^2 + 0{,}04493 \cdot MgO^2 + 11{,}37 \cdot Al_2O_3/SiO_2^{\,2} + 0{,}07406 \cdot CaO \cdot MgO - 0{,}6481 \cdot MgO \cdot Al_2O_3/SiO_2 - 0{,}09657 \cdot Al_2O_3/SiO_2 \cdot CaO - 1{,}705 \cdot CaO - 3{,}942 \cdot MgO - 4{,}798 \cdot Al_2O_3/SiO_2 + 65{,}51 \qquad (2)$$

where the correlation coefficient has the value ***r* = 0,8794** and the deviation from the regression surface is ***s* = 3,438**.

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

$CaO_s = 44{,}97$

$MgO_s = 12{,}22$

$Al_2O_3/SiO_{2\,s} = 0{,}7503$

to which the corresponding value of viscosity is $\eta_s = 1{,}296$.

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 behavior 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 concentrical 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:

$$\eta_{CaOmed}=0,04493\cdot MgO^2+11,37\cdot Al_2O_3/SiO_2^2-0,6481\cdot MgO\cdot Al_2O_3/SiO_2-1,047\cdot MgO-8,573\cdot Al_2O_3/SiO_2+13,68 \quad (3)$$

$$\eta_{MgOmed}=11,37\cdot Al_2O_3/SiO_2^2+0,009701\cdot CaO^2-0,09657\cdot Al_2O_3/SiO_2\cdot CaO-9,313\cdot Al_2O_3/SiO_2-1,189\cdot CaO+40,23 \quad (4)$$

$$\eta_{Al2O3/SiO2\ med}=0,009701\cdot CaO^2+0,04493\cdot MgO^2+0,07406\cdot CaO\cdot MgO-1,752\cdot CaO-4,255\cdot MgO++65,85 \quad (5)$$

These surfaces, belonging to the three-dimensional space can be reproduced and therefore interpreted by technological engineers. These surfaces are represented in figures 10, 12 and 14. In order to have as accurate a quantitative analysis as possible we showed in figures 11, 13 and 15 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 $Al_2O_3/SiO_2 \approx 0,8\%$;
- in case $MgO = MgO_{med}$, η is maximum for CaO ≈ 25% and minimum for CaO ≈ 45%;
- in case $Al_2O_3/SiO_2 = Al_2O_3/SiO_{2\ med}$, η is maximum for CaO ≈ 25% and MgO minimum and, respectively, takes minimum values for CaO ≈ 50% and MgO ≈ 15%.

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.

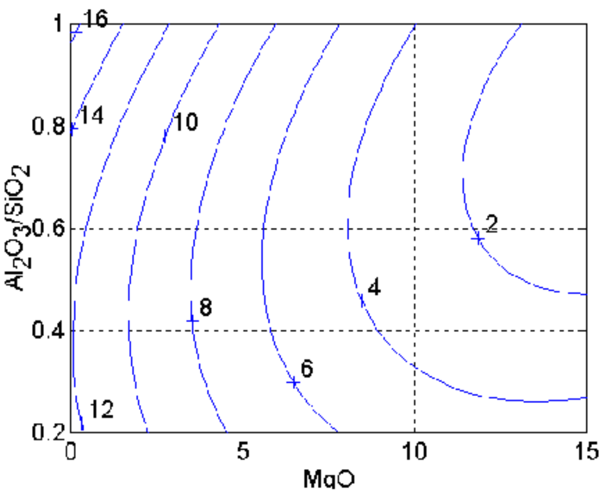

Figure 10. The correlation level lines η = f (CaO_{med}, MgO, Al_2O_3/SiO_2).

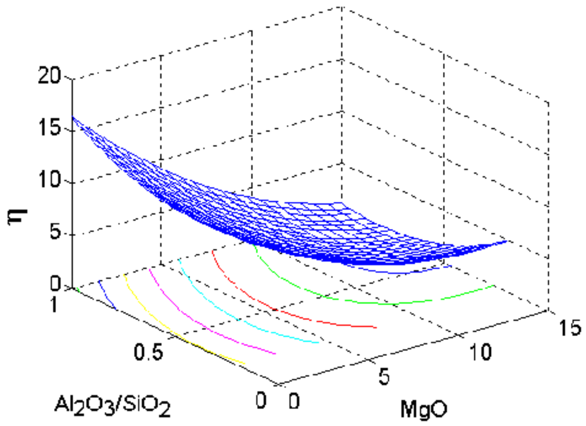

Figure 11. Surface η = f (CaO_{med}, MgO, Al_2O_3/SiO_2).

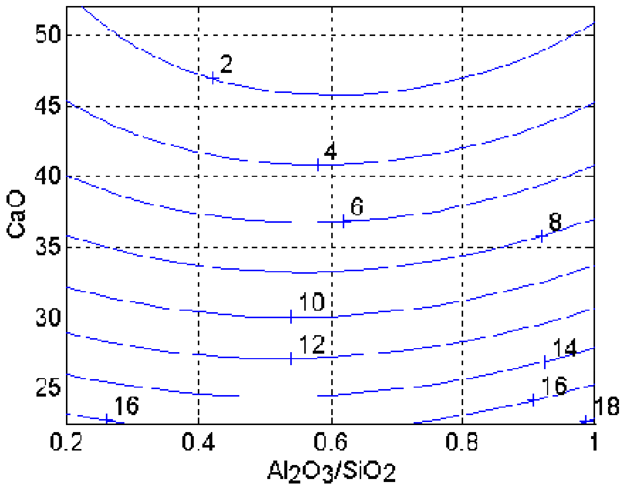

Figure 12. The correlation level lines η = f (CaO, MgO_{med}, Al_2O_3/SiO_2).

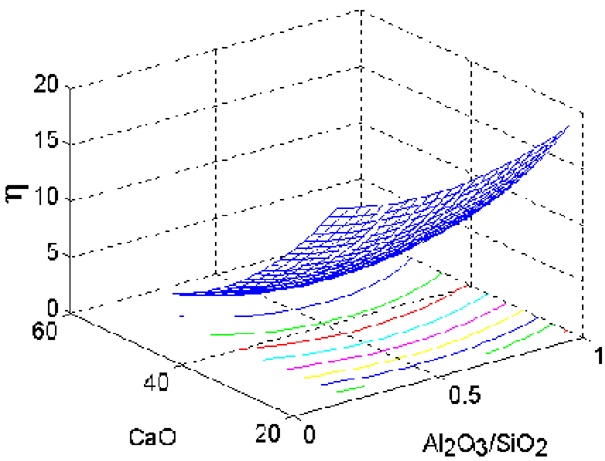

Figure 13. Surface η = f (CaO, MgO_{med}, Al_2O_3/SiO_2).

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 16, 17, 18 and, corresponding to them, the level lines of the two extreme surfaces, shown in fig. 19,20 and 21.

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.

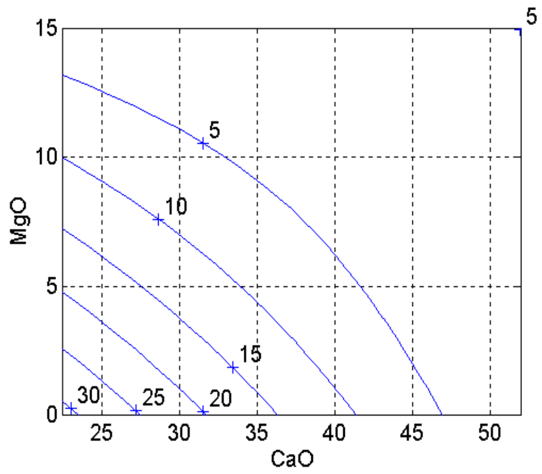

Figure 14. The correlation level lines $\eta = f(CaO, MgO, Al_2O_3/SiO_{2\ med})$.

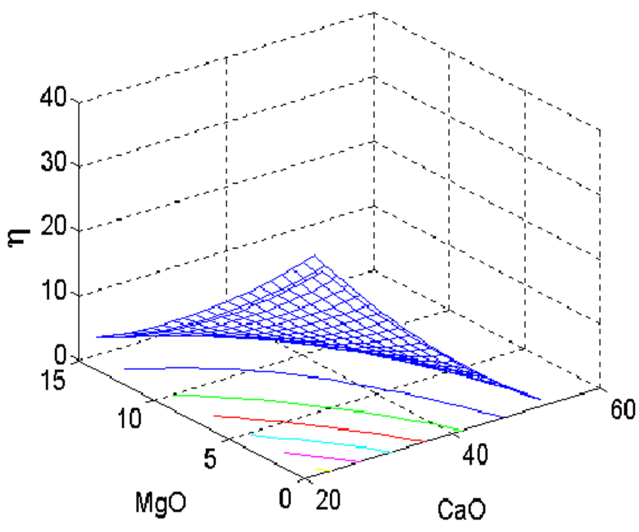

Figure 15. Surface $\eta=f(CaO, MgO, Al_2O_3/SiO_{2\ med})$.

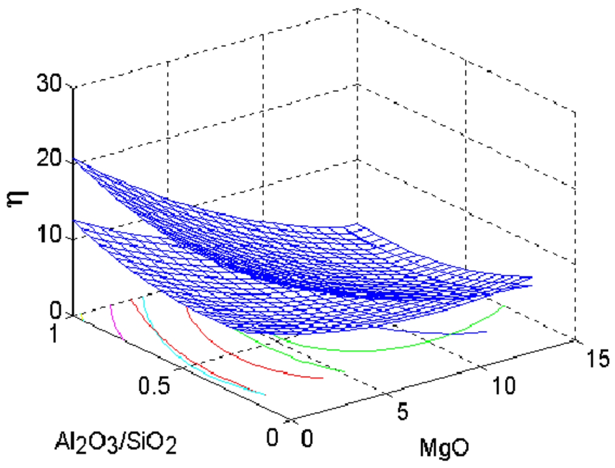

Figure 16. Representation of grade volume for CaO within $CaO_{med}\cdot 0.9$ and $CaO_{med}\cdot 1.1$.

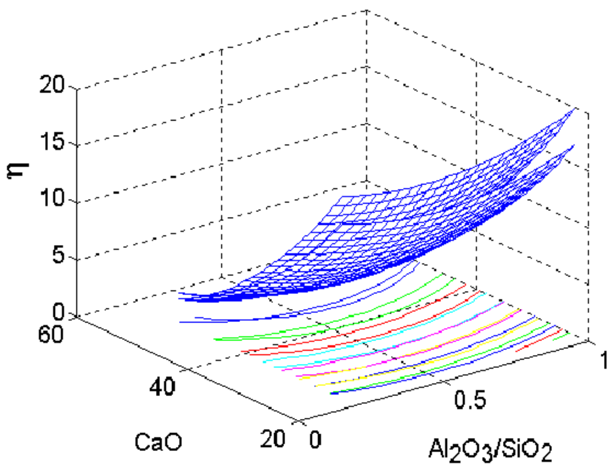

Figure 17. Representation of grade volume for MgO within $MgO_{med}\cdot 0,9$ and $MgO_{med}\cdot 1,1$.

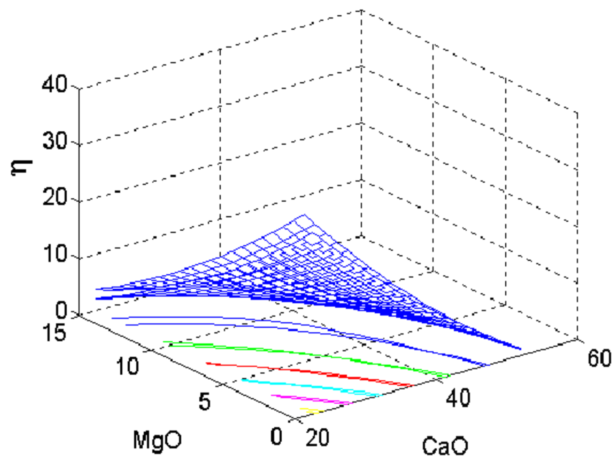

Figure 18. Representation of grade volume for Al_2O_3/SiO_2 within $Al_2O_3/SiO_{2\ med}\cdot 0.7$ and $Al_2O_3/SiO_{2\ med}\cdot 1,3$.

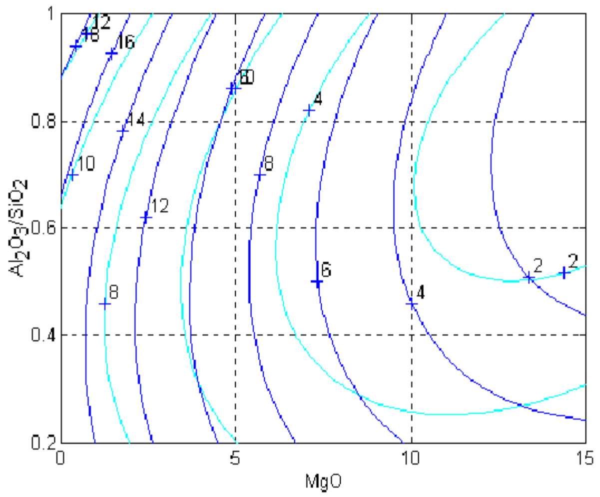

Figure 19. The level lines for variation volume for Al_2O_3/SiO_2 and MgO.

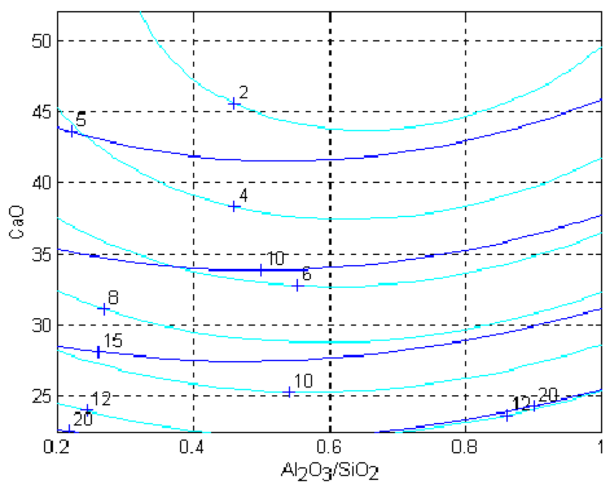

Figure 20. The level lines for variation volume for CaO and Al_2O_3/SiO_2.

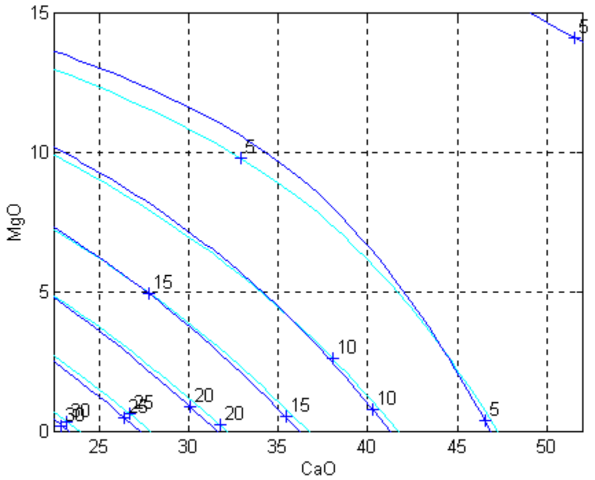

Figure 21. The level lines for variation volume for MgO and CaO.

2. CONCLUSIONS

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 EXCEL and 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;
- the usage of these programs can also be extended to the study of other slag characteristics.

References

1. Luca, A. Consideraţii teoretice asupra prafurilor pentru turnarea continuă a oţelurilor, în revista Metalurgia, nr.5/1979.

2. Kunio, K., ş.a. Proprietăţile fizice şi chimice ale prafurilor pentru turnarea continuă, Nippon Steel Technical Report, nr.34/1987.

3. Dragomir, I. Teoria proceselor siderurgice, Editura Didactică şi Pedagogică, Bucureşti, 1985.

4. *** Prospect Mannesmann.