Evaluation of Correlations for Viscosity of Blast Furnace Type Of Slags as a Function of Composition and Optical Basicity

V. Seshadri [1], C. A. Silva [2],
I. A. Silva [2], F.L, von Krüger[2]

1) Department of Met. Engg., Federal University of Minas Gerais, Belo Horizonte, Brazil
Ph. 55-31-. 238- 1810 Fax : 55- 31- 238- 1815
2) Department of Met. Engg., Federal University of Ouro Preto, Minas Gerais, Brazil
Ph. 55-31- 559-1530 Fax 55-31- 551- 1825

1 - Introduction

It is well known that slag viscosity play an important role in various metallurgical operations such as iron production blast furnaces, pre-treatment of pig iron in ladles, steel refining, continuous casting etc. For example, in the case high alumina burden in blast furnace practice, the resulting slag has high viscosity at normal tapping temperatures. Hence the furnace operation has to be done at high temperatures, which results in high silicon contents in the pig iron and higher coke consumption. In this case, one has to find ways and means to reduce the viscosity by addition of other oxides.Addition of MgO in the form of dolomite as flux in the blast furnace charge composed of high alumina ores or sinter, should enable operation at relatively lower temperatures leading to lower coke consumption and better control of silicon content of the metal[1)].

Fluid slags in general decrease metal losses in slag phase[2)], improve reaction efficiency in addition to improving slag-metal interface promoting higher efficiency of mixing. The variations in the slag compositions resulting from the transport of different ions through boundary layer of the slag phase with the metal as well as transport of reaction products into the slag and the temperature have an important influence on the viscosity which, in turn determines the mass transfer coefficients for boundary layer control.

In general blast furnace slags are composed of CaO, SiO_2, Al_2O_3 and MgO (95 %) with varying contents of other oxides like TiO_2 ,etc. depending upon the type of ores and fluxes used in the process . Hence viscosity of such slags can be estimated approximately considering the quaternary systems of CaO, SiO_2, Al_2O_3 e MgO.

In view of the great importance of the viscosity composition relationship of the slags both from the point of view of theory and practice, there has been considerable work on the subject[1-21] including attempts to correlate viscosity and compositions of slags. In this work, the criteria used by in some of the correlations for viscosity cited in the literature have been adopted to evaluate the data on viscosity of blast furnace type of slags with a wide composition range.

2 - Important Correlations for the viscosity

The influence of temperature on viscosity slags (η) is usually expressed by the Arrhenius equation:

$$\eta = A e^{-\frac{B}{T}} \qquad (1)$$

The preexponential coefficient (A) and (E), activation energy for viscous flow (E/R = B), are complex functions of the composition of the slag and there have been several attempts to develop correlations relating these parameters with composition.

The correlation of these parameters with slag composition exrpressed as molar fractions of components as given by Riboud and Larrecq[14)] was developed on the basis of Frenkel equation by regression analysis considering,

$$N_{SiO2} = N_{SiO2} + N_{P2O5} + N_{TiO2} + N_{ZrO2}$$
$$N_{CaO} = N_{CaO} + N_{MgO} + N_{Fe2O3} + N_{MnO} + N_{B2O3}$$

$$\eta = A T e^{-\frac{B}{T}} \qquad (2)$$

where,

$$\ln A = -20.81 - 35.75 N_{Al_2O_3} + 1.73 N_{CaO} + 5.82 N_{CaF_2} + 7.02 N_{Na_2O} \qquad (3)$$

$$B = 31351 + 68833\, N_{Al_2O_3} - 23896\, N_{CaO} + - 46351\, N_{CaF_2} - 39519\, N_{Na_2O} \quad (4)$$

The equations (3) and (4) are valid for the composition range: 33 < $\%SiO_2$ < 56, 12 < %CaO < 45, 0 < $\%Al_2O_3$ < 11 , 0 <, $\%Na_2O$ < 20 e 0 <% CaF_2 < 20.

Another important correlation proposed[15,16] relates viscosity and corrected optical basitcity .

$$A = e^{\left(\frac{1}{0.15 - 0.44\, \Lambda_{cor}}\right)} \quad (5)$$

and

$$B = e^{\left[-1.77 + \frac{2.88\, \Lambda_{cor}}{T}\right]} \quad (6)$$

The parameter, corrected optical basicity (Λ_{cor}) used in the above equation takes into consideration the cations required to balance the ionic species AlO_4^{5-} with cations in basic oxides in the following hierarchy namely: Li_2O > Na_2O > K_2O > MgO > CaO > (SrO), (BaO).

3 - Results and discussion

A computer code was developed to evaluate experimental data on viscosity of slags as a function of composition and temperature using a statistical program (Minitab). Criteria that form the basis for the equations 2-4 and 5-6 have been applied to evaluate the experimental data on viscosity of slags of wide ranging compositions [1,10,12,17,18] having 20< % SiO_2 < 60, 9.0 < % CaO > 50, 0 < %MgO > 40 , 10 < $\%Al_2O_3$ >35, A total of more than 1000 slag compositions were considered in the statistical and regression analysis. The following expression for the preexponential factor (A) resulted, with the application of the criteria of Riboud et al [14]

$$\ln A = - 19.791 - 35.75\, N_{Al_2O_3} + 1.73\, N_{CaO} + + 5.82\, N_{CaF_2} + 7.02\, N_{Na_2O} \quad (7)$$

FT test = 1146.21 FT(95%, 1 ,159) = 3.95 and R^2 = 0.99

Regression analysis for parameter B gave the same coefficients as in equation (4) The discrepancy in the first term obtained for the preexponential factor A as per equation (7) as compared with Equation (4) should be attributed to the large number of data analyzed in this work and also the composition range of the slags covered. However the first term in both the equations is only sightly different. Mills[12] reports for this first term, a value equivalent to - 17.51. The same data was analyzed with the computer code on the basis of optical basicity concept and the following equations for A and B resulted:

$$A = e^{\left(\frac{1}{0.15 - 0.44\, \Lambda_{cor}} - 1{,}374\right)} \quad (8)$$

and

$$B = e^{\left[-2.624 + \frac{2.88\, \Lambda_{cor}}{T}\right]} \quad (9)$$

Viscosities of the slags can be expressed by equation (1) substituting for A and B in the above equations and the confidence limit is given by (F test = 11235 FT(95%, 1,1059) = 3.95)

Equations 8 and 9 are different from those proposed by Mills[15,16]. This is probably due to the large number of data analyzed and also the range of compositions covered.

Figure 1 gives the variation of viscosity slags with corrected optical basicity predicted by equation (1). Variation of preexponential factor and activation energy with corrected optical basicity are represented in Figures 2 and 3

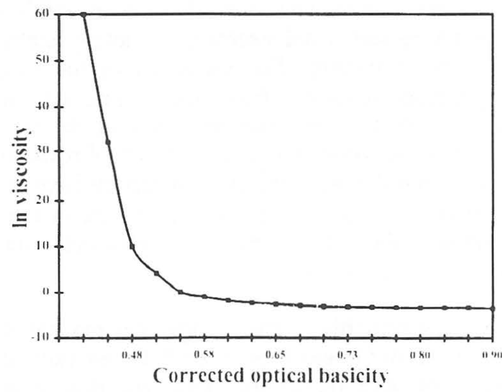

Figure 1 - Variation of viscosity (η) with corrected optical basicity of blast furnace slags.

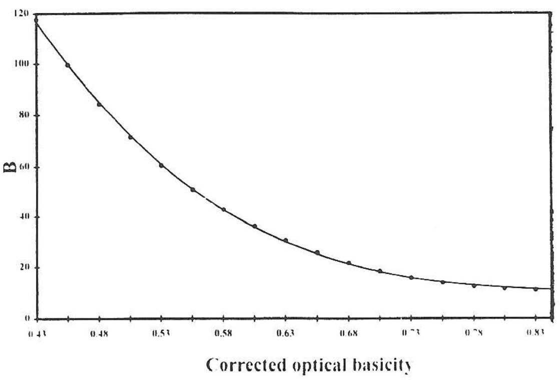

Figure 2 - Variation of B with corrected optical basicity.

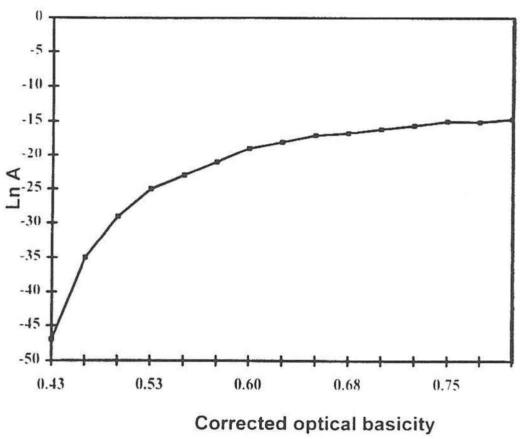

Figure 3 - Variation of preexponential factor (A) with corrected optical basicity

It is also possible to develop a correlation, assuming viscosity is given by equation (2).Analysis of the same data in this case resulted in,

$$B = e^{\left[-2.624 + \frac{2.88\,\Lambda_{cor}}{T}\right]} \qquad \textbf{(10)}$$

$$A = e^{\left(\frac{1}{0.15 - 0.44\,\Lambda_{cor}} - 8.793\right)} \qquad \textbf{(11)}$$

A and B can be substituted in equation 2 to calculate viscosities of slags. The confidence limit for the determination of viscosities was found to be quite satisfactory (F test = 106.5 FT(95%, 1,1059) = 3.95)

For blast furnace type of slags[20] containing titania (17-23%) the following equation obtained by multiple regression analysis of the data gave satisfactory results with (R^2 = 98.8.) in comparison with the use of equations 1 and 2 together with expressions for A and B proposed in this work (Eqns. 8-11)

$$\ln\eta = -46.8 + 0.281 Al_2O_3 + 0.347 SiO_2 + 0.482 TiO_2 + 0.168 MgO + \frac{1776}{T} + 31.8 + 31.8\Delta_{th} \qquad \textbf{(12)}$$

In the above equation, Λ_{th} signifies theoretical optical basicity of the slag.

4 -Conclusion

Criteria for correlations for viscosity in the literature were applied to analyze experimental data for wide range of compositions of blast furnace type of slags. The resulting correlations between optical basicity and viscosity were slightly different from to ones proposed in the literature probably due to the wide range of compositions considered. However they seem to be satisfactory from the statistical point of view for predicting viscosities of slags of wide ranging compositions.

5 - References

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