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VISCOUS PROPERTIES OF SYNTHETIC HIGH ALUMINA BLAST FURNACE SLAG

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ABSTRACT *The viscosity of the blast furnace slag, which is greatly influenced by its composition, has to be low at the operating temperature in order to make the slag easy flowing. Such a slag encourages an acceleration of the rate of slag metal reactions/exchanges, thus influencing the efficiency of the blast furnace process. The present project aims at measuring the viscosity of synthetic high alumina Indian blast furnace slags in agreement with the slag compositions encountered in the industries using inner-cylinder-rotating type viscometer (VIS 403). It is observed that the viscosity is greatly influenced by the CaO/ SiO_2 (C/S) ratio, MgO and TiO_2 contents.*

KEYWORDS : Synthetic High Alumina B/F Slag, Viscosity, Viscometer,

INTRODUCTION

In a blast furnace the viscosity of the slag governs the reaction rates in the furnace by its effect on diffusion of ions through the liquid slag to and from the metal slag interface. Therefore it is substantial effect on the speed and completeness of reduction reactions, heat transfer etc.

The viscosity of the slag is very much dependent on composition and temperature on the other hand the variation of viscosity with temperature and composition helps in understanding the structure of the slag. An understanding of the structures of the slag leads to compositional adjustments for suitable modifying the structures so as to give an optimum viscosity under the operating temperature. It can be stated with emphasis that the slag if highly viscous intervenes with the reactions and heat and mass transfer and if very fluid it brings in an imbalance in the heat distribution of blast furnace.

The blast furnace slag in addition to being free flowing must have appreciable affinity for the gangue constituents to facilitate the production of metal of choice. The quality of metal produced cannot be better than the quality of slag produced. One of the most important factor influencing the quality of the slag being its viscosity which is primarily composition dependent under the operating condition of temperature and pressure. Therefore it is useful to measure and analyses the viscosity of the blast furnace slag in terms of its composition.

In the present work an attempt is made towards this goal looking to the high alumina content of Indian blast furnace slags synthetic slags are prepared in the laboratory in agreement with high alumina industrial blast furnace slags. The viscosity measured using a high temperature viscometer at different temperatures is analyzed in terms of its composition.

EXPERIMENTAL

A. Materials and its composition

In the present work the analysis of composition of slags, from different blast furnace of different steel plants of India, was done and on the basis of that we determined an average slag composition. After getting an average slag composition we prepared nine numbers of synthetic slags, keeping fixed Al_2O_3, MnO, Na_2O, K_2O and Fe_2O_3 content and varying the C/S ratio (basicity), MgO and TiO_2 content, in the laboratory. The materials used are, reagent grade oxides with more than 99% purity.

The compositions of synthetic slags prepared in laboratory are listed in table.

Table. The composition of synthetic slag prepared in laboratory

Slag No.	Al_2O_3	MnO	Na_2O	K_2O	Fe_2O_3	MgO	TiO_2	SiO_2	CaO	C/S
1.	20.0	0.1	1.0	0.5	1.0	9.0	0.55	31.56	36.29	1.15
2.	20.0	0.1	1.0	0.5	1.0	12.0	1.0	26.83	37.57	1.40
3.	20.0	0.1	1.0	0.5	1.0	6.0	0.1	29.71	41.59	1.40
4.	20.0	0.1	1.0	0.5	1.0	12.0	0.1	34.37	30.93	0.9
5.	20.0	0.1	1.0	0.5	1.0	6.0	1.0	37.05	33.35	0.9
6.	20.0	0.1	1.0	0.5	1.0	6.0	1.0	29.33	41.07	1.40
7.	20.0	0.1	1.0	0.5	1.0	12.0	1.0	33.89	30.50	0.9
8.	20.0	0.1	1.0	0.5	1.0	6.0	0.1	37.53	33.77	0.9
9.	20.0	0.1	1.0	0.5	1.0	12.0	0.1	27.21	38.09	1.40

B. Apparatus for Viscosity Measurement

The high temperature viscometer, VIS403, measures the dynamic viscosity of materials with Newtonian behavior such as glasses, slags or mold powder. The working principle of this viscometer is measuring the shear stress and shear rate of a rotating bob immersed in a sample (in fluid form) filled crucible under controlled temperature. Two different bob and crucible configurations are available based on the viscosity of the test fluid. Tests may be conducted in controlled stress or controlled rate conditions, and under isothermal or temperature ramp programs.

RESULT AND DISCUSSION

Effect of chemical composition on Viscosity

The detailed measured values of viscosity with the help of viscometer are presented in the table below.

Viscosity (Pa.s) at temperature (K)				
Slag No.	1673 K	1723 K	1773 K	1823 K
Slag No. 1	1.2725	0.7688	0.5271	0.3889
Slag No. 2	1.7076	0.9623	0.6119	0.4598
Slag No. 3	1.2004	0.7194	0.4862	0.3657
Slag No. 4	1.3246	0.8263	0.5713	0.4273
Slag No. 5	1.4357	0.8987	0.6642	0.4561
Slag No. 6	1.3392	0.7831	0.5219	0.3858
Slag No. 7	1.4095	0.8604	0.6111	0.4324
Slag No. 8	1.3901	0.8872	0.6212	0.4625
Slag No. 9	1.4834	0.8591	0.5675	0.4246

These experimental viscosities are plotted against temperature, C/S ratio, MgO and TiO_2 content. With the help of these plots we analyzed the effect of these variables on viscosity. It is observed that the viscosity is greatly influenced by the C/S ratio, MgO and TiO_2 contents.

A. Effect of C/S ratio on Viscosity

As evident from Fig.1 the viscosity of the high alumina blast furnace slag decreases with increase of C/S (CaO/ SiO_2) ratio when the MgO content of slag is low irrespective of the high /low levels of TiO_2. Also it is evident from the figure that when MgO level is high, highest level of C/S ratio, irrespective of the high/low level of TiO_2, increase the viscosity of the slag.

The viscosity of a slag is structure oriented. The viscosity of blast furnace slag is affected by the network breaking cations like Ca^{2+}, Mg^{2}+and the degree of polymerization of the silicate network. As explained by Lee et al. CaO and MgO, the basic monoxides lower the viscosity by destructing the silicate network i.e, by depolymerizing while SiO_2 and Al_2O_3, which are highly covalent oxides contribute to the increase of the slag viscosity. Thus it is expected that increase of C/S ratio should decrease the slag viscosity at all levels.

However, detailed analysis would reveal the following:

i. Al_2O_3 in the silicate melts can act both as a network former and a network modifier depending on the amount of other oxides present. When sufficient basic oxide is present in the melt, i.e., when sufficient oxygen is available in the melt, Al adopts a four-fold co-ordination with oxygen. In this case the melt would contain AlO_4^{5-} and SiO_4^{4-}ions. In this situation polymeric ions will be present in the melt to a higher extent, contributing towards the increase of the viscosity.

ii. On the other hand when the amount of basic oxides like CaO and MgO is less, i.e., when sufficient oxygen is not available in the melt, Al would assume a six fold co-ordination (AlO_6). Here these AlO_6 groups would enter the interstices in the structure and cause depolymerisation reducing the percent of polymeric ions presented above and would contribute to the decrease of the slag viscosity.

The above explains the decrease of the viscosity with increase of C/S ratio at lower levels of MgO. This is because here the CaO and MgO combination would be low, lower extents of oxygen would be available in the melt. Al would adopt six-fold co-ordination and result in reduction of slag viscosity disintegrating the structure into smaller anionic units.

The reverse is also true. When C/S ratio is increased at higher levels of MgO the CaO, MgO combination would be high, higher oxygen would be available; Al would assume a four-fold co-ordination and the polymeric ions would be available in higher extents in the melt, increasing the viscosity of the slag.

Here, high and low M means MgO is 12 and 6 wt %respectively and high and low T means TiO_2 1.0and 0.1 wt % respectively.

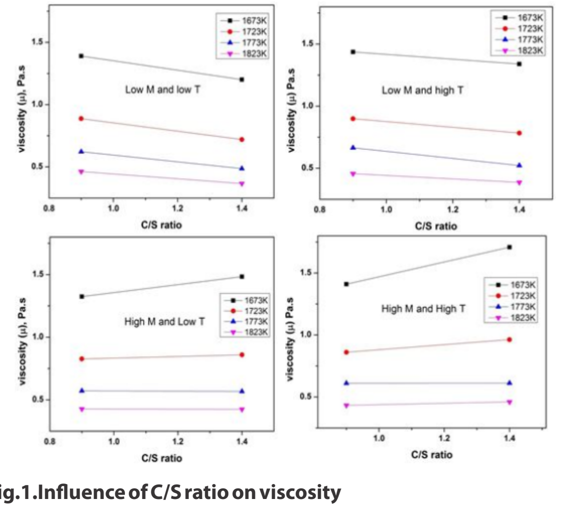

Fig.1.Influence of C/S ratio on viscosity

B. Effect of MgO on Viscosity

The variation of viscosity with MgO variation is presented in Fig.2. As evident from the figure, at higher level of C/S ratio increasing MgO increases the viscosity. Also at lower levels of C/S ratio increase of MgO levels decrease the viscosity. This trend of viscosity variations with MgO variations can be explained on the basis of four or six fold co-ordination of Al with oxygen. When the C/S ratio is high increased MgO levels increase the availability of oxygen thus favoring a four-fold co-ordination of Al with oxygen. This development increases the percentage of polymeric ions in the melt as explained above and is responsible for the increase of viscosity. On the other hand at lower levels of C/S ratio even an increase of MgO level does not provide sufficient amount of oxygen to melt, Al assumes a six-fold co-ordination with oxygen and breaks the anionic network decreasing the viscosity.

Here, high and low R means C/S ratio is 1.4 and 0.9 respectively and high and low T means TiO_2 is 1.0 and 0.1 wt% respectively.

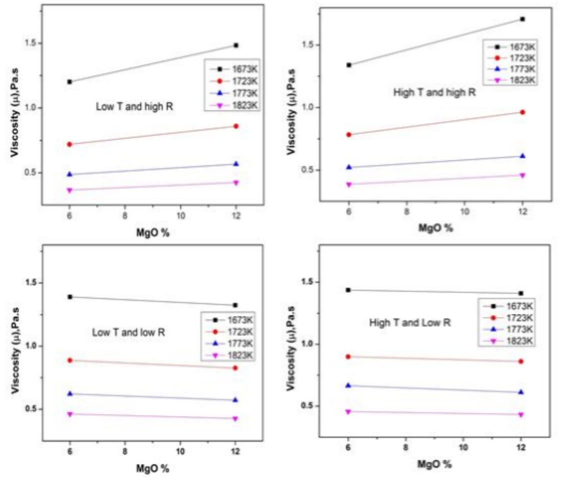

Fig.2. Influence of MgO on Viscosity

C. Effect of TiO2 on Viscosity

Fig.3. represents the variation of viscosity with TiO2 variations. It is observed that TiO_2, under the two levels of 0.1 and 1.0 wt % in the slag, has minimal effect on the viscosity. The viscosity of the slag seems to increase slightly with the increase in the TiO_2 levels. The rate of increase of viscosity, however, is seen to be the highest at high levels of both MgO and C/S ratio variations with increasing levels of TiO_2 content. This trend may be attributed to the availability of higher oxygen in the melt with high C/S ratio and MgO content. Such a situation would favour a four-fold co-ordination of Al with oxygen and assist faster polymerization of the silicate network.

Here, high and low R means C/S ratio is 1.4 and 0.9 respectively and high and low M means MgO is 12 and 6 wt % respectively.

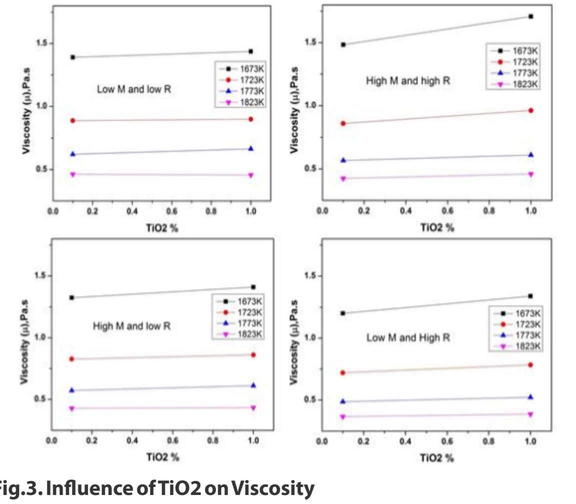

Fig.3. Influence of TiO2 on Viscosity

D. Effect of Temperature on Viscosity

The viscosity of the slag continuously decreases with the increase in temperature; this is because temperature works as stimulant energizes the ions and makes the slag better flowing or making it more fluid. Fig.4. illustrates the same result graphically. This evident that slag no.2 is a short slag; here the viscosity increases abruptly with a small decrease in temperature. This slag has the highest C/S ratio at 1.4. This rise of viscosity may be due to the precipitation of a solid phase, namely Dicalcium Silicate (2CaO. SiO_2). The literature states that Dicalcium Silicate precipitation out of the melt when the C/S ratio exceeds 1.3. In such slag the temperature needs to be closely monitored and should not be allowed to fall below a certain value. If the temperature falls down below a certain value the slags becomes viscous hindering the slag metal separation, slag metal reaction rate and the slag metal exchanges.

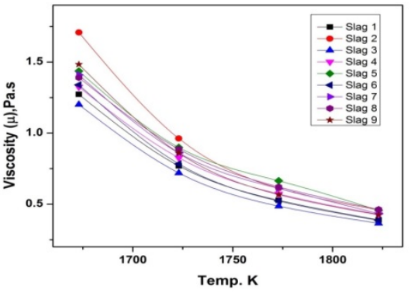

Fig.4. Effect of temperature on Viscosity

CONCLUSIONS

- It is established that being amphoteric in nature Alumina works both as a network former and a network breaker.
- With the presence of higher quantities of basic oxide, i.e., when higher amount of oxygen are available in melt aluminum adopts a four-fold co-ordinations and work as a network former.
- When the basic oxides are low in quantities, oxygen levels are not sufficient, Al assumes as six-fold co-ordination with oxygen and works as a network breaker.

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