Viscosity of Molten Slags containing Iron Oxide and Alumina

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ABSTRACT

We have measured the viscosity of melts in the system $CaO-SiO_2-Al_2O_3-Fe_2O_3$ using a counter-balanced sphere method to understand the effect of alumina on the viscosity of the molten slags. Then, we summarized the effects of the basicity and the alumina contents on the viscosity of the above systems to find the amphoteric behavior of alumina in the slag systems.

1. INTRODUCTION

In some metal-refining processes, it is quite important to understand physical properties of molten slags. Especially the viscosity of the molten slags have been reported in many investigations because of not only their importance in the process controls, but also the understanding of the structure of the molten slags. The effect of Al_2O_3 on the physical properties of the molten slags are dependent upon the composition of the slag due to the amphoteric behavior of alumina. The behavior of alumina, however, in the melts containing highly alumina and iron oxide is obscure yet. We, therefore, need to accumulate the information on the viscosity of molten $CaO-SiO_2-Al_2O_3-Fe_2O_3$, which may be produced in the refining processes of sintered ores in blast furnaces. In the present work, we have measured the viscosity of the molten $CaO-SiO_2-Al_2O_3-Fe_2O_3$ by a counter-balanced sphere method. Furthermore, we have discuss the effect of alumina on the slag systems containing iron oxide and alumina.

2. EXPERIMENTAL

2.1 Experimental Apparatus.

The apparatus for the counter-balanced sphere method is shown in Fig.1. The time, in which the sphere moves in a given distance, has been measured by using a photo-electric cell to determine the viscosity of the melt with highly reliability of the measurement of the time. The sphere moves totally 29mm, in which the first 5mm is the approach run section and the consequent 12mm is used as the range for the stationary movement of the sphere. The crucible was made of Pt-20%mass Rh, of which inner diameter was 35mm and depth was 70mm. We used two kinds of spheres, which were made of Pt-20%mass Rh, to measure also density of the melts by the Archimedean method. The diameter of the smaller sphere was 10mm and that of the larger one was 12.5mm. The atmosphere in the furnace was air. The specimens of slag systems were prepared from the mixing of CaO, SiO_2, Al_2O_3 and Fe_2O_3 powders. Fe_2O_3 and CaO powders were made by heating iron oxalate and $CaCO_3$ in air, respectively.

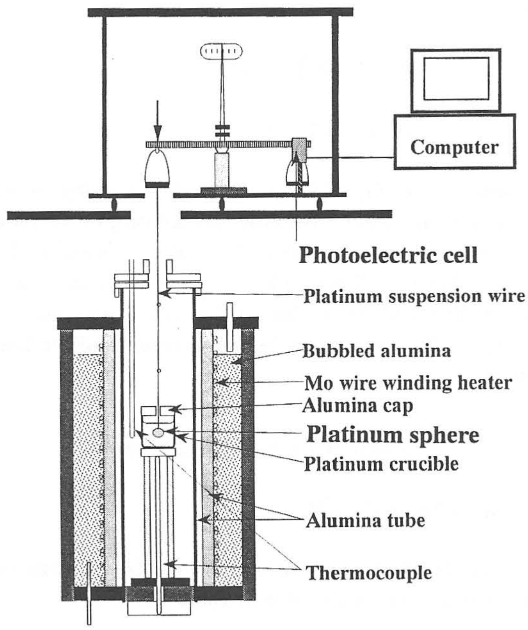

Figure 1 Schematic Diagram of Experimental Apparatus

2.2 Principle of the viscosity measurement.

In the viscosity measurement of a melt, of which viscosity is low (especially Reynolds number Re<0.1), the Stokes' law is not held strictly. We have, therefore, applied here the following Oseen's equation, which can be used for melts with Re>0.1.

$$f_1 = 3\pi\eta DV(1+3/16Re) \quad [1]$$

In Eq.[1], f_1 is viscosious resistance when a sphere of its diameter D cm moves at the velocity V cm/sec in the melt of its viscosity η .
When the sphere is raised by the weight W g, the sphere was affected by the force f_2 as follows :

$$f_2 = W g \quad [2]$$

where g is gravitational acceleration.
When f_1 is equal to f_2, the sphere moves at a constant velocity. In addition,

$$Re = VD\rho / \eta \quad [3]$$

Here, ρ is the density of the melt. Then, we obtain the following equation since the velocity V is given by L / t when the sphere spends the time t to move at a given distance L.

$$W t = A(\rho / t) + B \quad [4]$$

where A and B are constants determined from only the apparatus dimension and the viscosity of the melt as follows :

$$A = 9\pi D^2L^2/16g \quad [5]$$

$$B = 3\pi DL\eta / g \quad [6]$$

The relation in Eq.[4] was determined using several silicone oils, of which viscosities are known, to obtain the correlation between the value of B and the viscosity of the melt in Eq.[6]. Thus, when we get a linear relation between W t and ρ / t for molten slags, we obtain the viscosity of the melts from its intersection B of the linear relation.

3. RESULTS & DISCUSSION

3.1 Experimental Results

The chemical compositions of the oxide systems used in the present work are shown in Table 1.

Table 1 Chemical Compositions of Specimens.

No.	CaO	SiO_2 (mass%)	Al_2O_3	Fe_2O_3.
1	25	25	0	50
2	25	25	10	40
3	25	25	20	30
4	25	25	30	20
5	25	25	40	10

Figure 2 shows the temperature dependence of the viscosity of the specimens listed in Table 1. Those temperature dependences can be shown in the form of Arrhenius plots as indicated in Fig.3. From Figs. 2 and 3, the temperature dependence of the viscosity increases with the increase of Al_2O_3 contents.

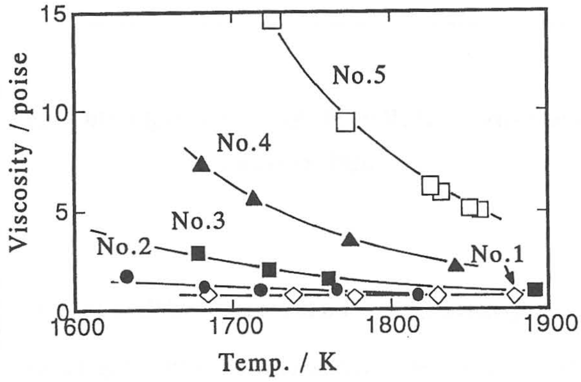

Figure 2 Variation of Viscosity of Molten Slags listed in Table 1 with Temperature

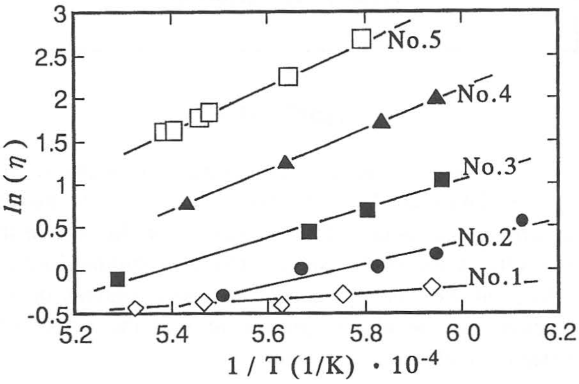

Figure 3 Arrhenius plots of Viscosity of Molten Slags listed in Table 1.

Figure 4 shows the variation of the viscosity with mass% Al_2O_3 (or mass% Fe_2O_3) in the specimens 25%CaO-25%SiO_2-X%Al_2O_3-(50-X)%Fe_2O_3. As shown in this figure, the viscosity of the melt in the above systems increases as increasing Al_2O_3 content accompanying the decrease of Fe_2O_3 content.

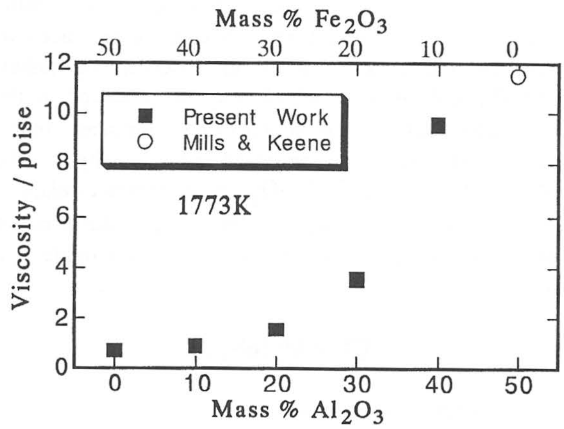

Figure 4 Variation of Viscosity of Molten 25%CaO-25%SiO_2-X%Al_2O_3-(50-X)%Fe_2O_3 with mass% Al_2O_3 (or mass% Fe_2O_3)

3.2 Effects of Alumina and Basicity on Viscosity of $CaO\text{-}SiO_2\text{-}Al_2O_3\text{-}Fe_2O_3$ Melts

There have been several trials[1,2,3] to make equations for the composition dependence of the viscosity of oxide melts, but it is very difficult to indicate those composition dependencies in an equation over wide composition range of the slag systems. In order to understand the effect of Al_2O_3 on the viscosity of the molten slags, we have summarized the variation of the viscosity with the basicity, e.g.,the ratio of mole fractions of $(CaO+Fe_xO+MgO)/SiO_2$ and the mole fraction of Al_2O_3 in the system of molten $CaO\text{-}SiO_2\text{-}Al_2O_3\text{-}Fe_2O_3$ as shown in Fig.5 by using some literature information. The data were obtained from Hara[4], and Seki & Oeters[5] for $CaO\text{-}SiO_2\text{-}Fe_2O_3$, and Bills[6] for $CaO\text{-}MgO\text{-}SiO_2\text{-}Al_2O_3$, and Kou et al.[7] for $CaO\text{-}SiO_2\text{-}Al_2O_3$ and the present work for $CaO\text{-}SiO_2\text{-}Al_2O_3\text{-}Fe_2O_3$. As shown in Fig.5, the viscosity of the melts are largely dependent upon the basicity, especially the SiO_2 contents. At a given content of alumina, the viscosity increases as the basicity decreases, in other words, the SiO_2 content increases. For the region of the basicity over unity, the viscosity increases as the alumina content increases at a given value of the basicity. On the other hand, in the region with the basicity under unity, the viscosity decreases slightly with the increasing of the alumina content. Therefore, when the alumina content increases at a given basicity around its value of unity, the alumina is considered to behave as the amphoteric oxide.

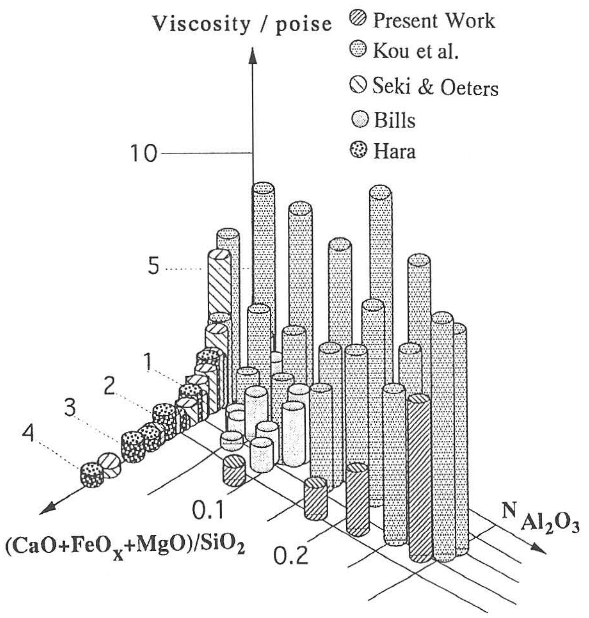

Figure 5 Viscosity of Molten $CaO\text{-}SiO_2\text{-}Al_2O_3\text{-}Fe_2O_3$ with Basicity$[(CaO+Fe_xO+MgO)/SiO_2]$ and Alumina Content.

4. CONCLUDING REMARKS

We measured the viscosity of molten $CaO\text{-}SiO_2\text{-}Al_2O_3\text{-}Fe_2O_3$ by the counter-balance sphere method with the photo-electric cell equipped. As alumina content X% increases in $25\%CaO\text{-}25\%SiO_2\text{-}X\%Al_2O_3\text{-}(50\text{-}X)\%Fe_2O_3$ melt, the viscosity and its temperature dependence of the melt increases. We summarized the dependence of the viscosity of molten $CaO\text{-}SiO_2\text{-}Al_2O_3\text{-}Fe_2O_3$ systems with the basicity and the alumina content to find that the alumina shows different effects on the viscosity in the basic region from that in the acid region. At a given basicity around its value of unity, the alumina is considered to behave as the amphoteric oxide.

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