Viscosity of SiO_2-MgO-Al_2O_3-FeO Slag for Nickel Laterite Smelting Process

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Abstract.

Since the SiO_2 content in nickel laterite is high, it is suggested to add a certain amount of lime into the slag for achieving good fluidity and desulfurization capacity in industrial smelting process. However, it leads to additional cost of lime and the increase in slag volume, then the decrease of effective furnace volume. In order to avoid this problem, the partial reduction of Fe_2O_3 is suggested, then a considerable amount of SiO_2, less MgO and FeO, and very little CaO slag is formed, which has been less studied in the literature. In this study, the effects of binary basicity (MgO/SiO_2: mole ratio) and FeO content on the slag viscosity were investigated. The experimental results indicate that the slag viscosity decreases with basicity increasing, and a sharp change of viscosity which was called "turning point" appeared in the vicinity of 1500℃. The slag viscosity certainly drops from 4.5 P to 3.0 P by raising the FeO content from 15% to 25% at 1490℃. In addition, the critical temperature of the slag drops with increasing binary basicity or FeO content.

Keywords: *Nickel laterite, slag viscosity, binary basicity, FeO content*

1 INTRODUCTION

As an important strategic metal, nickel plays a vital role in modern infrastructure and technology, which is mainly used in stainless steel (about 58%) and nickel-based alloys (about 14%)[1]. Economic Ni resources are found in either sulfide- or laterite-type ores. The bulk of Ni production has been extracted from sulfide ores, but the majority of Ni resource exists in nickel laterite. In recent years, the rapid increase in demand for stainless steel has led to a significant rise in ferronickel production. And with the continuous depletion of sulfide ores, much more attention has been drawn to nickel laterite [2][3].

The widely used process for nickel laterite is rotary kiln-electric furnace (RKEF)[4-7]. Due to high SiO_2 content in nickel laterite, it is suggested to add a certain amount of lime into the slag in order to achieve good fluidity and desulfurization capacity in industrial smelting process. However, it leads to additional cost of lime and the increase in slag volume, as well as the decrease in effective furnace volume. In order to avoid this problem, the partial reduction of Fe_2O_3 is suggested, then a considerable amount of SiO_2, less MgO and FeO, and very little CaO slag is formed, which has been less studied in literature. In this work, the viscosity of SiO_2-MgO-Al_2O_3-FeO slag was investigated by using the rotary cylinder method.

2 THERMODYNAMICAL CALCULATION

In this paper, the viscosity of SiO_2-MgO-Al_2O_3-FeO slag was calculated by FactSage in theory. FactSage is a software for thermodynamical calculation, especially in ironmaking and steelmaking[8]. The viscosity of the slag was calculated at high temperature by viscosity model of FactSage. The slag viscosity from 1450 ℃ to 1550℃ in the step of 10℃ was calculated.

3 EXPERIMENTAL

3.1 Materials and Experimental Scheme

The slag used in the study was synthetic slag. Silica, magnesia, aluminium oxide, and calcium oxide used in the work were of chemical grade. Ferrous oxide can be obtained with the thermal decomposition of ferrous oxalate ($FeC_2O_4 \cdot 2H_2O$).

Table 1 shows the experimental scheme. In this work, the binary basicity was defined as MgO/SiO_2 (mole ratio). For the study of the effect of basicity on the slag viscosity, the basicity was between 0.6 and 1.0, ferrous oxalate, aluminium oxide and calcium oxide were fixed at 8%, 5% and 1.5%, respectively. For researching the effect of FeO content on the slag viscosity, the basicity was chosen as 0.9, ferrous oxalate content in slag was 5% to 25%.

Table 1: Experimental Scheme, wt %

Basicity	FeO	MgO	SiO_2	Al_2O_3	CaO
0.6	8	24.4	61.1	5	1.5
0.7	8	27.2	58.3	5	1.5
0.8	8	29.7	55.8	5	1.5
0.9	8	32.1	53.4	5	1.5
1.0	8	34.2	51.3	5	1.5
0.9	5	33.2	55.3	5	1.5
0.9	10	31.3	52.2	5	1.5
0.9	15	29.4	49.1	5	1.5
0.9	20	27.6	45.9	5	1.5
0.9	25	25.7	42.8	5	1.5

3.2 Experimental Apparatus

In the work, the viscosity of SiO_2-MgO-Al_2O_3-FeO slag was measured by using the rotary cylinder method. The schematic diagram of the viscosity measurement apparatus in this work is given in **Figure 1**.

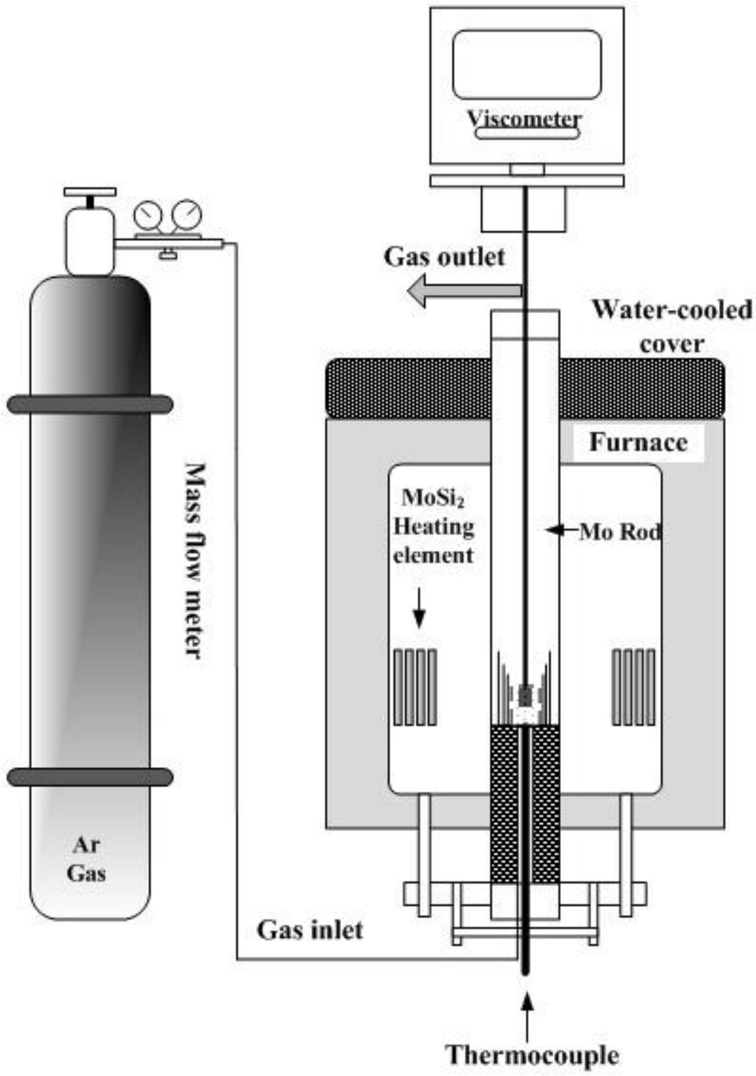

Figure 1: The schematic diagram of the viscosity measurement apparatus

3.3 Methods

The viscosity test was carried out by carbon tube furnace in the laboratory. A molybdenum crucible was put in graphite crucible, and then both crucibles were put in the furnace. Before heating, the furnace was vacuumized, then argon was let into the furnace to release the air as the vacuum pressure reached 20 Pa and that operation was repeated twice. After that, the air outlet valve was opened when the furnace was full of argon and the inlet valve was kept open at the same time. The rate of argon was 1 L/min throughout the experiment. Furnace was heated according to the heating rule until it reached setting temperature and the temperature was kept constant for 2 hours to homogenize the melting slag. After inserting the detector measuring head into the melting slag, the slag temperature slightly reduced immediately. For this reason the test was maintained for sufficient amount of time until the measured value of viscosity was constant. The rotation speed of the measuring head was 12r/min throughout the whole test.

4 RESULTS AND DISCUSSION

4.1 Thermodynamical Calculation

The viscosities of SiO_2-MgO-Al_2O_3-FeO slag with variable binary basicity (R for short) (ranging between 0.6 and 1.0) and variable FeO content (ranging from 5% to 25%) in theory are shown in **Figure 2** and **Figure 3,** respectively. As can be seen from **Figure 2**, the slag viscosity decreases with the increase in temperature at the same basicity. Similarly, with the basicity rising from 0.6 to 1.0, the viscosity decreases at the same temperature. Moreover, the viscosity curve at R=0.9 almost coincided with that at R=1.0. It can be seen from **Figure 3** that the viscosity of SiO_2-MgO-Al_2O_3-FeO slag decreases with temperature increase at the same FeO content in the slag, and it decreases with the FeO content rising from 5% to 25% at the same temperature. The slag viscosity is between 5 P and 10 P when FeO content is 20% and 25%, and the viscosity is suitable for melting slag.

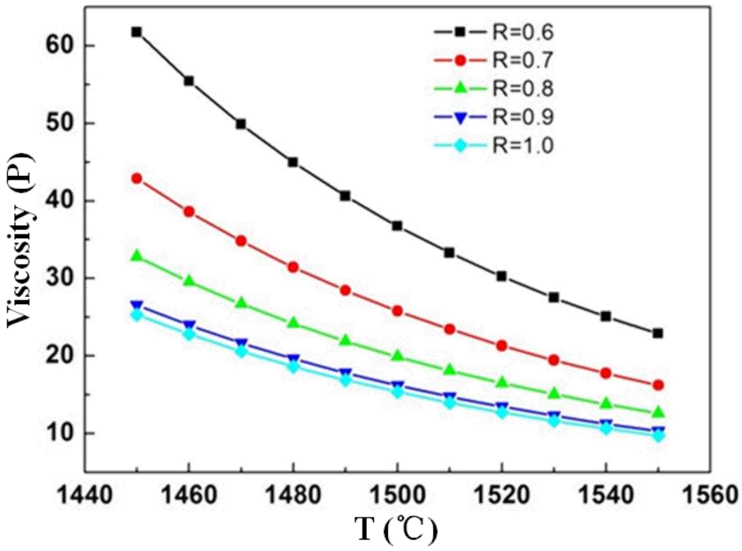

Figure 2: Effect of basicity on viscosity in the theoretical calculation

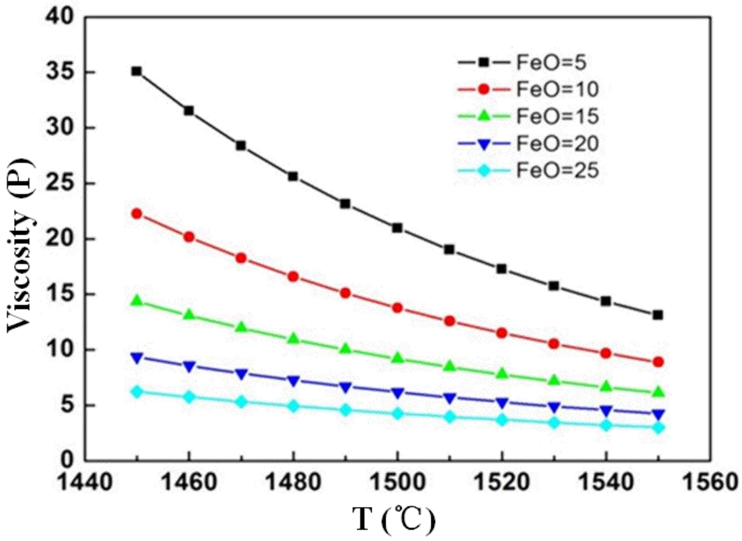

Figure 3: Effect of FeO content on viscosity in the theoretical calculation

4.2 Effect of Binary Basicity on the Slag Viscosity

Figure 4 shows the viscosity with variable binary basicity in the experiment, the experimental temperature was fixed from 1470℃ to 1550℃. It can be seen that the viscosity decreases with the increase of binary basicity. And slag viscosity has a little change when temperature is higher than 1530 ℃. [SiO_4]-tetrahedral forms a three-dimensional interconnected networks through bonding oxygen atoms[6,7] in the silicate melt. Metal oxides such as magnesium oxide and calcium oxide work on the silicate melt viscosity indirectly by influencing the silicon-oxygen anion structure. And the addition of magnesium ion results in the progressive breaking of these oxygen bonds with the formation of non-bridging oxygen, and the three-dimensional interconnected network depolymerizes to $Si_2O_4^{2-}$-sheet,$Si_2O_6^{4-}$-ring,$Si_2O_7^{6-}$-dimer or SiO_4^{4-}-monomer, which lead to the decrease of the viscosity[9][10].

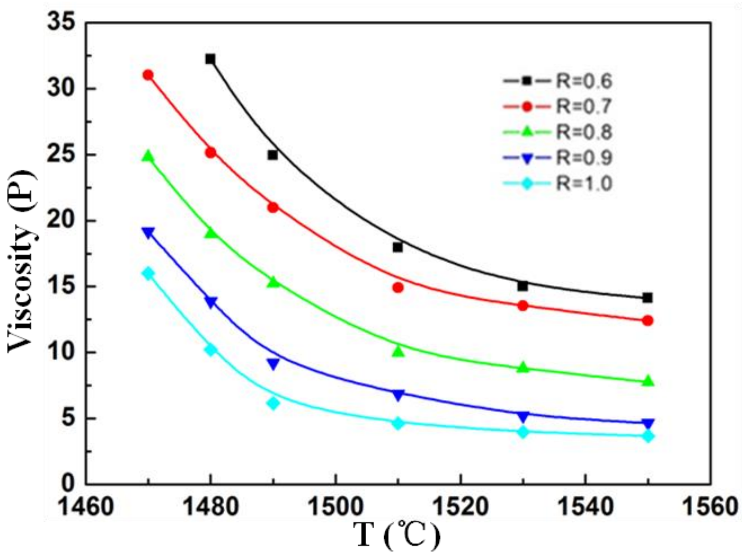

Figure 4: Relationship between binary basicity and the slag viscosity

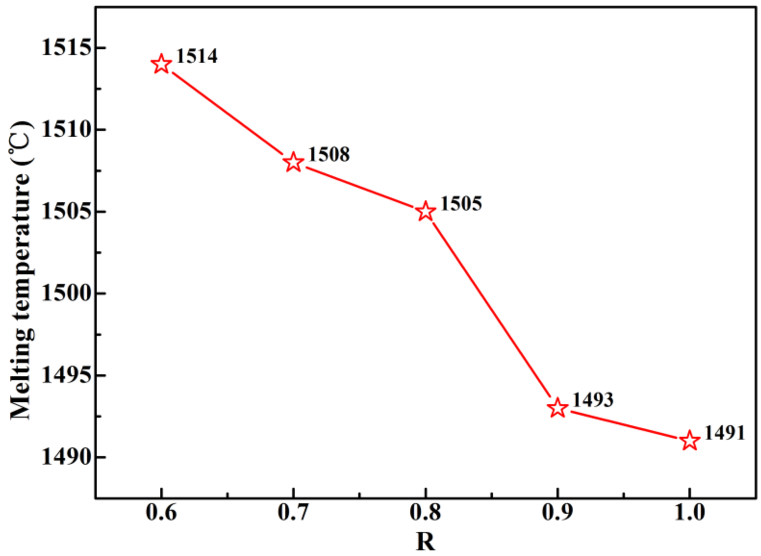

Figure 5: Impact on the melting temperature of basicity

The melting temperature of the SiO_2-MgO-Al_2O_3-FeO slag under different basicity is given **Figure 5**. The results show that the melting temperature decreases gradually from 1514 ℃ to 1491 ℃ with the increase in basicity。

4.3 Effect of FeO Content on the Slag Viscosity

The effect of the FeO content on the viscosity in the laboratory test is shown in **Figure 6**. The experiment was carried out at 1450 ℃ to 1550 ℃. It can be seen that the slag viscosity decreases with the increasing of FeO content in slag, and the viscosity decreases from 4.5 P to 3.0 P by raising the FeO content from 15% to 25% at 1490℃. Temperature has a great influence on the viscosity when FeO content is low, slag viscosity decreases from 30 P to 4 P with the temperature increase from 1450 ℃to 1550 ℃, it means that the slag is more sensitive to temperature. And the viscosity curve has a feature of acidic slag in which the curve of viscosity is smooth, so it can be concluded that the slag belongs to acidic slag. There is an inflection point in the temperature of 1480℃.

According to the ion theory of slag, FeO can destroy the silicate system network. The viscosity is high at the same temperature when FeO content is 5% and 10%, then viscosity decreases obviously with the increase of FeO content to 15%. The influence of FeO content on viscosity decreases when FeO content is more than 20%. **Figure 7** shows the melting temperature of the slag at various FeO content in slag, and the melting temperature decreases from 1491℃ to 1476 ℃ with the increase of FeO content from 5% to 25%. This indicates that addition of FeO content contributes towards reduction of the melting temperature.

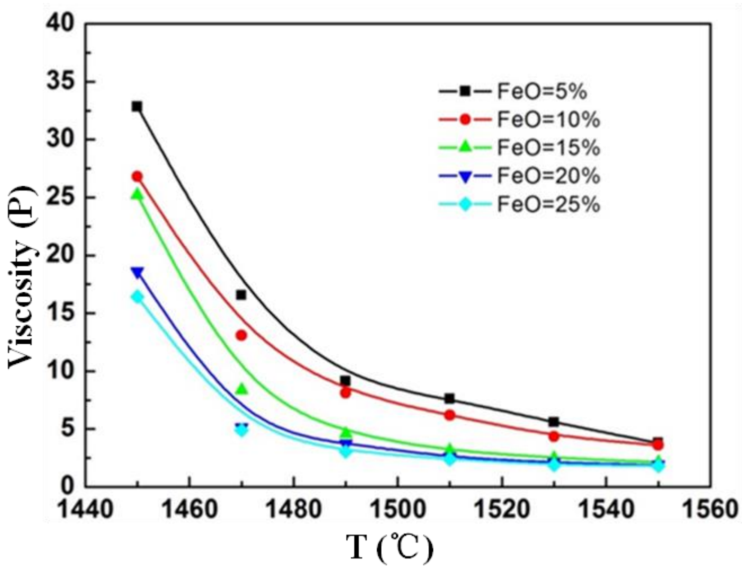

Figure 6: Relationship between FeO content and the slag viscosity

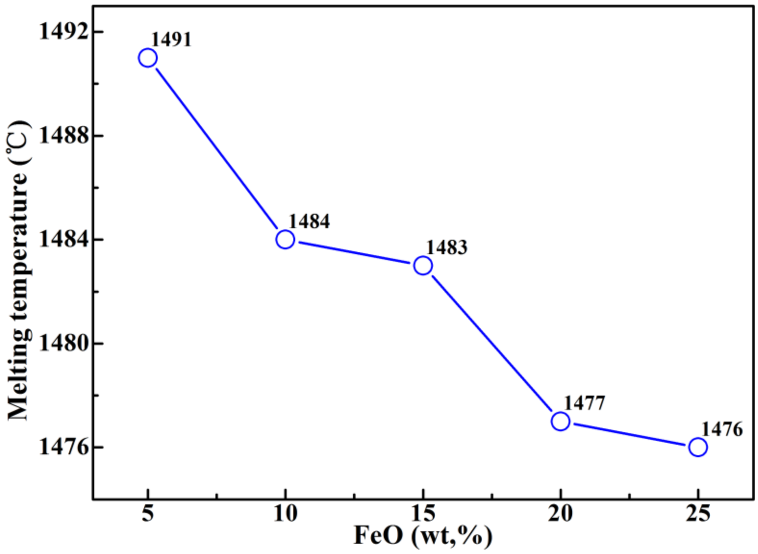

Figure 7: Impact of FeO content on the melting temperature

5 CONCLUSIONS

In this work, the viscosity of SiO_2-MgO-Al_2O_3-FeO Slag for nickel laterite smelting process was investigated. And the conclusions can be summarized as follows:

(1) The viscosity of SiO_2-MgO-Al_2O_3-FeO slag decreases with the levels binary basicity (ranging between 0.6 and 1.0) and increase of FeO content (ranging from 5% to 25%) in theoretical calculation.

(2) Increasing the basicity has a significant effect on decreasing the viscosity of the slag, and the melting temperature of the slag can be reduced from 1514 ℃ to 1491 ℃.

(3) The viscosity of the slag decreases with the increasing FeO content in slag. The slag is more sensitive to temperature at low FeO content. And the melting temperature of the slag can be reduced from 1491 ℃ to 1476 ℃ as a result of increase of FeO content from 5% to 25%.

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