Reducing Rate of Iron Oxide in Molten Slag by Carbon in Molten Iron*

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Synopsis

In the research of a continuous ironmaking process from reduced iron, or pre-reduced iron ore, the reduction rate of iron oxide in molten slag by carbon in molten iron was investigated to know the optimum condition. Mixture consisted of, mainly, 40 g master slag and 17.1 g iron oxide, was added onto the molten iron in a graphite crucible, the molten copper in a graphite crucible, or the molten iron in an alumina crucible to measure the amount of CO gas evolved in the range of 1 320~1 620 °C. The following results were obtained:

(1) The reduction rate of iron oxide in molten slag by carbon in molten iron, or graphite was proportional to the second power of the iron oxide content in the molten slag except for the starting and the ending periods of the experiment.

(2) The rate constant and the apparent activation energy of the reduction of iron oxide in molten slag by carbon in molten iron were obtained from the data of the experiment with a graphite crucible-molten iron and a graphite crucible-molten copper.

(3) The maximum rate constant of the reduction of iron oxide in molten slag by carbon in molten iron, or graphite was observed around $\text{CaO/SiO}_2 = 1.5$ of molten slag.

1. Introduction

The melting behavior of directly reduced iron pellets into molten iron is considered to be very significant for the continuous iron and steelmaking process which has been studied at the National Research Institute for Metals since 1974. There is a molten slag on the molten iron inevitably, which is formed from the gangue component in pellets. The molten slag is necessary to stabilize the arc. The iron oxide retained in pellets dissolved into the molten slag on the molten iron as shown in the previous report.¹⁾ In order to improve the iron yield in the furnace, it is very important to examine the reduction rate of the iron oxide in the molten slag.

In this report, the reduction rate of iron oxide in the molten slag by carbon in the molten iron was investigated to grasp the optimum reduction condition.

1. Previous Research

Many studies have been reported on the reduction of iron oxide in molten slag by solid carbon.²⁾ But as for the reduction of iron oxide in molten slag by the carbon in molten iron, the researches were carried out mainly with the blast furnace slag whose iron oxide content was less than 15 %. These are as follows:

Philbrook and Kurkbride³⁾ measured the FeO content in molten slag of 47%CaO-38%SiO₂-15%Al₂O₃ melted in a graphite crucible. The initial content of FeO in the molten slag was less than 5 %. The rate

of the slag-metal reaction was $5.8 \times 10^{-4} \text{ g-FeO/min} \cdot \text{cm}^2 \cdot (\text{wt}\% \text{FeO})^2$ at 1 430 °C.

Tarby and Philbrook⁴⁾ measured the FeO content in molten slag of 50%CaO-10%SiO₂-40%Al₂O₃ and 50%CaO-40%SiO₂-10%Al₂O₃ melted in a graphite crucible under a stream of CO gas. The initial content of FeO in the molten slag was less than 5 %. The reaction rates obtained at 1 500 and 1 575 °C were proportional to the 1.5th~2nd power of the FeO content in the molten slag during the first period when the CO gas evolved vigorously, and proportional to the content in the second period when the CO gas evolved stangnantly.

Sommerville *et al.*⁵⁾ made a dual crucible to avoid using a graphite crucible. The inner and the outer crucibles were composed of alumina and steel, respectively. CO gas evolved was measured by a manometer. The molten slag of 40%CaO-40%SiO₂-20%Al₂O₃ containing 2~3 % FeO reacted with the molten iron in nitrogen atmosphere. The reaction rate obtained was $2.0 \times 10^{-2} \text{ mol/min} \cdot \text{cm}^2 \cdot \text{atm}$ at 1 380 °C.

2. Attempt of the Present Research

The previous reports show that graphite is the only usable crucible material at present for conducting the experiment on the reaction between the molten iron and molten slag containing iron oxide.⁶⁾ When a graphite crucible is used, it is required to discriminate the slag-metal reaction from the slag-graphite reaction.

When molten copper is used in stead of molten iron, the reduction of iron oxide in the molten slag by carbon in the molten metal can be excluded because the molten copper has a very low carbon solubility.⁷⁾

The reaction mechanism proposed so far are those based on the chemical and the electro-chemical reactions.^{6,8)} The chemical reactions at the graphite and the molten iron interfaces are expressed by Eqs. (1) and (2), respectively.

The electro-chemical reactions in the case of molten copper in a graphite crucible are exhibited by Eq. (3), (4) and (5), respectively.

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The reaction, $\text{FeO} + 2\text{Cu} = \text{Cu}_2\text{O} + \text{Fe}$, can be negligible because the concentration of Cu_2O in the molten copper is below 3×10^{-5} wt% even at 1620 °C.⁹⁾ The iron reduced can dissolve in to the molten copper because they make a solution.

The electro-chemical reactions in the case of molten iron in a graphite crucible are as follows:

It has been confirmed that the slag-metal and -graphite reactions proceed electro-chemically by the fact that the reaction rate is affected by the electric current flowed. The anodic reaction is reported to determine the rate of SiO_2 reduction by carbon in the molten iron for up to 20 of the interfacial area ratio of the slag-graphite to the slag-metal.^{8,10)} This ratio is nearly 1.4 at most in the present experiment. The reduction rate of FeO is greater than that of SiO_2 . The slag containing FeO is strongly agitated by the CO gas evolution. Therefore, the reduction of iron oxide in the molten slag is considered to be determined by the anodic reaction.

The cathodic reaction (5) can be regarded as the same as that of (9), because both the molten copper and iron have electric conductivity. There is, however, no evidence that the anodic reaction (7) has no effect on the anodic one (6) in the case of the molten iron in the graphite crucible. Nevertheless, the anodic reaction (3) in the case of the molten copper in the graphite crucible can be considered the nearly same as that of (6) in the case of the molten iron in the graphite crucible as far as the anodic reaction determines the rate.

It is reported, moreover, that a quantitative rate equation of the electro-chemical reactions can not be obtained right now, though the results can be explained excellently by the electro-chemical reactions.⁶⁾ Hence, the chemical reactions (1) and (2) must be used in the present report. The rate of the slag-metal reaction can be calculated on the base of the assumption that the rate of the slag-graphite reaction in the case of the molten copper in the graphite crucible is the same as that in the case of the molten iron in the graphite crucible.

The rate of slag-metal reaction was examined using the alumina crucible to whose bottom a graphite block was bonded, because the erosion of this crucible by the molten slag was much less than that of the other crucibles except for a graphite one.

Considering that the composition of the molten slag during the reaction may not be uniform, and that the sampling for the chemical analysis may disturb the reaction, the reaction rate is determined by measuring the amount of CO gas evolved.

The main experimental condition are as follows: The FeO content in the molten slag is decided to be

30 % in consideration of steelmaking slags. The weight of the master slag is 40 g (2.7 % of the metal), and the thickness of the molten slag without foramin is about 1 cm. The experimental temperature is 1520 °C.

II. Experimental

A Tammann furnace was used for the reduction experiment under a controlled atmosphere.¹⁾ The molten metal was kept at a desired temperature within ± 5 °C. The amount of CO gas evolved was measured with an integrating gas meter. Nitrogen gas was flowed at the rate of 60 l/h in order to measure a small amount of CO gas evolved, because the measurable range of this meter was 5~300 l/h.

The master slag powder of under 1 mm diameter was made from CaO (95.2 % CaO), SiO_2 (99.8 % SiO_2) and Al_2O_3 (first grade chemical reagent) in a graphite crucible in an induction furnace. The chemical compositions of the slags having the ratios CaO/SiO_2 of 0.5, 1, 1.5 and 2 were as follows:

24.0% CaO -65.5% SiO_2 -10.5% Al_2O_3

44.2% CaO -45.0% SiO_2 -10.8% Al_2O_3

53.2% CaO -36.1% SiO_2 -10.7% Al_2O_3

57.5% CaO -31.8% SiO_2 -10.7% Al_2O_3 .

FeO (93.8 % FeO) powder was made from Fe_2O_3 one equivalent to the first grade chemical reagent.

The molten metal was made from electrolytic iron and electrode graphite, or cathode copper.

Figure 1 illustrates an example of the crucible arrangement and the addition method of slag-iron oxide powder mixture. The inner diameter and the depth of the crucible were 5.5 cm and 19 cm, respectively.

The experimental procedure was described as follows: Metal weighing about 1.5 kg was melted under nitrogen atmosphere and held at the experimental temperature for 30 min. The surface of the molten metal was cleaned before and after the addition of a small amount of Fe_2O_3 . The samples for the chemical analysis of Si and C were taken to con-

Fig. 1. Schematic diagram of the crucible arrangement and the addition method of the master slag and iron oxide powder mixture.

firm the initial experimental condition. The container of slag-iron oxide powder mixture was set in the apparatus. Then, the container was lowered at the position about 5 mm high above the molten metal surface, after the nitrogen gas flow rate was measured for 2 min. The aluminum foil which covered the bottom of the container was melted and the mixture fell down onto the molten metal surface. From that moment, the flow rate of gas was recorded every minute for 30 min. After the end of each experimental run, the molten slag was taken out by a nickel bar, and the contents of FeO, Al₂O₃, SiO₂ and CaO were analyzed. A metal sample for Si analysis was taken after the removal of the molten slag. The reproducibility was confirmed by the results of the duplicated runs in the same experimental condition.

III. Results

The master slag-iron oxide mixture which was added onto the molten metal surface was melted within 1~1.5 min in almost all the experimental conditions. In the case of the experimental temperature of 1 320 °C, the master slag of CaO/SiO₂=2, or the master slag weight of 80 g, the time for melting of the mixture was within 3 min. The molten slag foamed in the present experiment as a result of the CO gas evolution. The foaming phenomenon was observed remarkably in the case of the alumina crucible.

The aluminum foil which covers the bottom of the container is thin enough, and the weight of FeO required to oxidize the foil is 0.1 g at most.

The Al₂O₃ contents in the molten slag after 30 min experimental runs in the case of the alumina crucible at 1 320, 1 420, 1 520 and 1 620 °C were about 10, 20, 30 and 40 %, respectively.

No significant increase of the silicon content in the molten iron was observed when the CaO/SiO₂ of the molten slag was 1.5 and 1. The Si content in the molten iron increased by about 0.08 % even when the molten slag of CaO/SiO₂=0.5 was reduced at 1 620 °C in a graphite crucible. This indicates that about 10 % of SiO₂ in the 40 g molten slag is reduced. Therefore, the reduction of SiO₂ in the molten slag is considered to be negligible.

The ratio of the amount of CO gas measured to that calculated from the FeO analysis of the molten slag after 30 min experimental run was about 1.2, while it was less than unity in the case of the molten slag of CaO/SiO₂=0.5 at lower temperature.¹¹⁾ The FeO content along with the experimental time was calculated according to the initial FeO content and the amount of CO gas evolved.

Figure 2 indicates the effects of the crucible materials, the kinds of molten metal and the slag weights on the relations between the amount of FeO reduced and the times. The experimental conditions used were 1 520 °C of the temperature, unity of CaO/SiO₂ in the molten slag and 30 % of the initial FeO content. When the weight of the master slag was 80 g, no significant difference was observed in the relation with the kinds of the molten metal in graphite crucible.

On the other hand, the reduced amount of FeO was greater on the molten iron than that on the molten copper in the cases of the master slag being 40 and 20 g.

The difference in the crucible material had hardly the effect on the relations when the weight of the master slag was 10 g, but the FeO reduced amount was more in a graphite crucible than in an alumina one when the weights of the master slag were 80, 40 and 20 g.

Figure 3 denotes the effects of the crucible material and the initial iron oxide content on the relations between the iron oxide concentration in the molten slag and the time. The temperature, the ratio CaO/SiO₂ and the weight of the master slag used in the experimental runs were 1 520 °C, unity and 40 g,

Fig. 2. Effects of the crucible material, the metal melt and the slag weight on the relations between the amount of FeO reduce and the time.

Fig. 3. Effects of the crucible material and the initial iron oxide content on the relations between the iron oxide content in the molten slag and the time.

respectively. The kind of molten metal had barely the effect on the relations. On the other hand, the iron oxide content in the molten slag was much higher in an alumina crucible at the same experimental time than that in a graphite one. The final iron oxide content in the molten slag in an alumina crucible increased with increasing the initial iron oxide content.

Figure 4 points out the effects of the crucible material and the molten metal (a), and the CaO/SiO₂ of the molten slag (b) on the relations between the FeO content in the molten slag after the 30 min experimental runs and the temperature. The FeO content in the molten slag was lowest with the molten iron in a graphite crucible, and highest with the molten iron in an alumina one. This value was lowest with the molten slag of CaO/SiO₂=1.5, and highest with that of CaO/SiO₂=0.5. The difference of this value between molten slags of CaO/SiO₂=1.5 and 0.5 increased with decreasing temperature. This value for the molten slag of CaO/SiO₂=1 was slightly higher than that of CaO/SiO₂=1.5. Moreover, this value was very high at 1 320 °C while it was low at

1 620 °C.

IV. Discussion

The result shown in Fig. 2 can be explained well by the difference in the interfacial area of slag-metal and slag-graphite. When the weight of the master slag is 80 g, the slag-graphite reaction is dominant between the molten slag and the crucible wall. Therefore, the molten metal has small effect on the reduction rate. On the other hand, when the weight of the master slag is 10 g, the slag-metal reaction is dominant between the molten slag and iron. Accordingly, the crucible material has small effect on the reduction rate.

The effects of the temperature, the crucible material, the molten metal and the CaO/SiO₂ of the master slag on the FeO content in the molten slag after the 30 min experimental runs can be explained by the viscosity of the molten slag,¹²⁾ the area of the reaction interface and the activity of iron oxide in the molten slag.¹³⁾ For the progress of the reaction of iron oxide in the molten slag, the low viscosity, the large area and the high activity are desirable. Therefore, a high temperature, a graphite crucible, molten iron and the molten slag of CaO/SiO₂=1.5 are favorable to reduce the FeO content in the molten slag. The reason why the FeO content in the molten slag after the 30 min experimental runs increased with increasing the initial FeO content in an alumina crucible can be attributed to the adhesion of the molten slag to the alumina crucible wall.

The reduction rate is calculated by Eq. (10) proposed by Philbrook and Kurkbride.³⁾ This equation is valid when the slag is mixed completely.

$$\frac{-dW_{FeO}}{dt} = \frac{S}{100} \cdot \frac{-dC_{FeO}}{dt} = k \cdot A \cdot (C_{FeO})^\alpha \cdot (C_C)^\beta$$

.....(10)

- where, $-dW_{FeO}/dt$: the weight of FeO reduced in 1 min (g/min)
- S : the weight of molten slag (g)
- C_{FeO} : the FeO content in molten slag (wt%)
- C_C : the activity of carbon in molten iron (Raoult) or the purity of graphite
- A : the area of the reaction interface (cm²)
- k : the apparent rate constant of reaction [g-FeO/min·cm²·(wt% FeO)^α·(C_C)^β].

C_C can be regarded as unity, because the carbon saturated molten iron or the pure graphite was used in the present experiment. Philbrook and Kurkbride assumed that S was constant because the initial FeO content in the molten slag was less than 5 %. However, S changes with the time in this experiment because the initial FeO content in the molten slag is mainly 30%. In the following suffixes 1 and 2 denote the reaction of slag-metal and slag-graphite, respectively.

Fig. 4. Effects of the crucible material and the metal melt (a) and the CaO/SiO₂ of the molten slag (b) on the relation between the FeO content in the molten slag after the 30 min experimental runs and the temperature.

In the case of the molten iron in an alumina crucible, the following equation can be used under the assumption that the weight increase of alumina from the crucible wall can be negligible.

$$\left[\log \left(-\frac{dC_{\text{FeO}}}{dt} \right)_1 - \log \left(\frac{A_1}{S} \right) \right] = \alpha_1 \log C_{\text{FeO}} + \log k_1 + 2 \dots\dots\dots(11)$$

The increasing rate of alumina in the molten slag from the crucible wall is unknown. However, assumed that the alumina content in the molten slag increases with the time up to the value obtained by the analysis, the weight change of the molten slag can be estimated very small. In this case Eq. (12) can be used.

$$\log \left(-\frac{dC_{\text{FeO}}}{dt} \right)_1 = \alpha_1 \log C_{\text{FeO}} + \log k_1 + \log \left(\frac{A_1}{S} \right) + 2 \dots\dots\dots(12)$$

Moreover, the result calculated through Eq. (12) where S was assumed constant did not differ from that by Eq. (11) greatly. Therefore, Eq. (12) is used in the case of molten iron in an alumina crucible.

It is very difficult to estimate the area of the reaction interface between the molten slag and the wall of the graphite crucible because of the foaming of the molten slag. A_2/S is determined by the diameter of the crucible and the density of the molten slag, and S can be eliminated. However, the density of the molten slag changes with the foaming and can not be estimated. Therefore, the value of 2.5 g/cm³ is used for the calculation.¹²⁾ The effect of the FeO content in the molten slag on the density is also negligible, and Eq. (13) is obtained in the case of molten copper in a graphite crucible.

$$\log \left(-\frac{dC_{\text{FeO}}}{dt} \right)_2 = \alpha_2 \log C_{\text{FeO}} + \log k_2 + \log \left(\frac{A_2}{S} \right) + 2 \dots\dots\dots(13)$$

Equation (14) is obtained when the reactions of slag-metal and slag-graphite are not discriminated in the case of molten iron in a graphite crucible.

$$\left[\log \left(-\frac{dC_{\text{FeO}}}{dt} \right) - \log \left(\frac{A_1 + A_2}{S} \right) \right] = \alpha \log C_{\text{FeO}} + \log k + 2 \dots\dots\dots(14)$$

Equation (15) is obtained when the slag-metal reaction can be distinguished from the slag-graphite reaction in the case of molten iron in a graphite crucible. This is based on the assumption of the complete mixing of the slag.

$$\left[\left(-\frac{dC_{\text{FeO}}}{dt} \right)_1 + \left(-\frac{dC_{\text{FeO}}}{dt} \right)_2 \right] = \frac{100}{S} \cdot k_1 A_1 \cdot (C_{\text{FeO}})^{\alpha_1} + \frac{100}{S} \cdot k_2 A_2 \cdot (C_{\text{FeO}})^{\alpha_2} \dots\dots\dots(15)$$

Figure 5 shows the effect of the slag weight on the rate constant at 1 520 °C. The CaO/SiO₂ and the FeO content in the slag were unity and 30 %, respec-

Fig. 5. Effect of the slag weight on the rate constant.

tively. The rate constants in the case of a graphite crucible are nearly constant. The change in the rate constant in the case of the smaller amount of the slag is considered to be great because of the following reasons: The fluctuation of the area due to the slag foaming is large. The rate of the reduction of FeO in the molten slag is affected by the formation and the runaway of CO gas bubbles.³⁾ The reason why the rate constant in the case of an alumina crucible is low and appears to have increased slightly with increasing the amount of the slag should be due to the dissolution of alumina from the crucible wall and the adhesion of the molten slag to the crucible wall. This figure indicates that the molten copper has little effect on the reaction rate. In the case of molten copper in a graphite crucible, the rate constants are overestimated because the increase in the interfacial area caused by the slag foaming is neglected.

When the rate of slag-graphite reaction can be obtained by the experiment with molten copper in a graphite crucible, Eq. (11) can be used to calculate the rate of the slag-metal reaction in the case of molten iron in a graphite crucible.

Figures 6, 7, 8 and 9 show the results calculated by Eqs. (12), (13), (14) and (11), respectively. In the most periods except for the beginning and the ending ones of the experiment, the reduction rate of iron oxide in the molten slag is proportional to nearly the second power of the concentration of iron oxide in the molten slag regardless of the kinds of the crucible material and the molten metal, the CaO/SiO₂ of the master slag, the experimental temperature, the weight of the molten slag, and the initial iron oxide concentration in the molten slag. In the beginning period, the deviation from the above mentioned relation is considered to be due to the time required for melting of the mixture of the master slag and iron oxide. In the ending period, the deviation is considered to be due to the low concentration of iron oxide in the molten slag. When the concentration of iron oxide in the molten slag is low, the reduction rate decreases with decreasing the stirring effect of CO gas which evolved slowly.⁴⁾ In this range of the iron oxide concentration in the molten slag, it is necessary to use a new apparatus to measure more

Fig. 6. Relations between $\log(-\frac{dC_{FeO}}{dt})_1$ and $\log C_{FeO}$ based on Eq. (12).

Fig. 8. Relations between $[\log(-\frac{dC_{FeO}}{dt}) - \log(\frac{A_1}{S} + \frac{A_2}{S})]$ and $\log C_{FeO}$ based on Eq. (14).

Fig. 7. Relations between $\log(-\frac{dC_{FeO}}{dt})_2$ and $\log C_{FeO}$ based on Eq. (13).

Fig. 9. Relations between $[\log(-\frac{dC_{FeO}}{dt})_1 - \log(\frac{A_1}{S})]$ and $\log C_{FeO}$ based on Eq. (11).

precisely the small amount of CO gas evolved than that used in this experiment. Therefore, this range is neglected in the present report.

The experimental result that the reduction rate is proportional to the second power of the iron oxide concentration in the molten slag coincided with that obtained by philbrook and Kurkbride.³⁾ It is considered to be due to the acceleration of the reaction by the stirring effect of the CO gas evolved as proposed by Wagner.¹⁴⁾

The reaction rate of slag-graphite looks greater than that estimated by the second power relation in the range of 5~10 % FeO in the molten slag as shown in Fig. 6. This can be explained by the increase in the reaction area as a result of the severe foaming of the molten slag which has been observed from the window.

Figure 10 to 12 show the relation between the logarithm of the rate constant of the reaction and the reciprocal of the temperature on the assumption that all the proportional constants in Eqs. (12), (13) and

(11) are 2. The straight relation can be obtained for each CaO/SiO₂ of the master slag. The apparent activation energies of the slag-metal reaction in an alumina crucible are 63, 39 and 46 kcal/mol for the slags of CaO/SiO₂ of 0.5, 1 and 1.5, respectively. Those of the slag-graphite reaction in a graphite crucible are 82, 63 and 57 kcal/mol for the slags of CaO/SiO₂ of 0.5, 1 and 1.5, respectively. Those of the slag-metal reaction in a graphite crucible are 39, 47 and 59 kcal/mol for the slags of CaO/SiO₂ of 0.5, 1 and 1.5, respectively. The apparent activation energies obtained in the present work are nearly the same as those reported up to now^{2,4,11,15,16)} except for that of the slag-graphite in the case of CaO/SiO₂=0.5. The very great temperature dependence of the reaction for the slag of CaO/SiO₂=0.5 is considered to be due to the very high viscosity of the slag at the low temperature.¹⁰⁾

The activation energy of 90~130 kcal/mol is obtained for the reduction of SiO₂ in the slag by carbon in the iron in a graphite crucible.¹⁰⁾ The rate of the

Fig. 10. $\log k_1$ and $1/T$.
 k_1 is calculated by Eq. (12) on the assumption of $\alpha_1=2$.

Fig. 11. $\log k_2$ and $1/T$.
 k_2 is calculated by Eq. (13) on the assumption of $\alpha_2=2$.

Fig. 12. $\log k_1$ and $1/T$.
 k_1 is calculated by Eq. (11) on the assumption of $\alpha_1=2$.

Fig. 13. Effect of the CaO/SiO_2 of the molten slag on the rate constant.

reaction is determined by the interfacial reaction, and the activation energy obtained is explained from the break of the bond between silicon and oxygen. On the other hand, the activation energy obtained in the present experiment is 40~80 kcal/mol. The rate of the reaction is considered to be mainly determined by the interfacial reaction, though the activation energy can be explained from the reduction of FeO and the oxygen diffusivity in the slag because the diffusion plays the more important role with increasing the reaction rate.

Figure 13 demonstrates the effect of CaO/SiO_2 in the molten slag on the rate constant of the slag-metal and slag-graphite reactions at 1520 °C. The rate constant is the maximum around 1.5 of CaO/SiO_2 . The rate constant of the slag-metal reaction in a graphite crucible is greater than that in an alumina crucible. The activity coefficient of iron oxide in the molten slag is greatest at 2 of the CaO/SiO_2 , estimated from the diagram at 1600 °C.¹³⁾ Therefore, it increases with increasing the CaO/SiO_2 in the range of this report. On the other hand, the viscosity of molten slag is the minimum around 1.2 of CaO/SiO_2 .¹²⁾ Accordingly, the maximum rate constant around 1.5 of CaO/SiO_2 can be considered by the effect of both the activity coefficient of iron oxide

in the molten slag and the viscosity of the molten slag. The low rate constant in an alumina crucible is considered to be due to the increasing viscosity and the decreasing activity coefficient of iron oxide in the molten slag because of the increase in alumina in the molten slag from the crucible wall.

V. Conclusion

In the research on a continuous ironmaking process from direct reduction iron, or pre-reduced iron ore, the reducing rate of iron oxide in molten slag by carbon in molten iron was investigated to grasp the optimum reducing condition. Mixtures consisted of, mainly, 40 g master slag (2.7 % of molten metal) and 17.1 g iron oxide (30 % FeO in molten slag) were added onto molten iron in a graphite crucible, molten copper in a graphite crucible, or molten iron in an alumina crucible to measure the amount of the CO gas evolved in the range of 1320~1620 °C. The following results were obtained:

(1) The reduction rate of iron oxide in the molten slag by carbon in the molten iron and graphite was proportional to the second power of the iron oxide concentration in the molten slag in the period except for the starting and ending ones of the experiment.

(2) The apparent activation energies of the slag-graphite reaction obtained by the experiment with molten copper in a graphite crucible were 82, 57 and 63 kcal/mol for the slags of CaO/SiO_2 of 0.5, 1 and 1.5, respectively.

(3) The apparent activation energies of the slag-metal reaction obtained by the experiment with molten iron in a graphite crucible using the data of the slag-graphite reaction obtained by the experiment with molten copper in a graphite crucible were 39, 47 and 59 kcal/mol for the slags of CaO/SiO_2 of 0.5, 1 and 1.5, respectively.

(4) The rate constant of the slag-metal reaction in an alumina crucible was smaller than that in a graphite crucible as a result of the alumina dissolution into the molten slag from the crucible wall.

(5) The maximum rate constant of the reduction of iron oxide in the molten slag by carbon in the molten iron or graphite was observed around 1.5 of the CaO/SiO_2 of the molten slag.

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