Effect of CaO on Dephosphorising Ability of Deoxidation Slag for Effective Utilisation of Phosphorus in Steel

Yoshinao KOBAYASHI1) and Shinji KODAMA2)*

1) Department of Metallurgy and Ceramics Science, Graduate School of Science and Engineering, Tokyo Institute of Technology, 2-12-1-S8-22, Ookayama, Meguro-ku, Tokyo, 152-8552 Japan.  2) Graduate Student, Tokyo Institute of Technology. Now at Sumitomo Metal Industries, Limited, 3, Hikari, Kashima, Ibaraki, 314-0014 Japan.

(Received on October 11, 2011; accepted on February 2, 2012)

Recent proposal of utilisation of impurities in steel requires preservation of phosphorus in molten steel during its refining process. To know the phosphorus absorbing ability of deoxidation by-product slag having CaO, the phosphorus partition has been investigated between the MnO–SiO2–Fe2O–CaO–MgO–P2O5 slag and molten iron in this study. The phosphate capacities ($C_{PO_4^{3-}}$) for the present slag having CaO content from 4.73 to 19.6 mass% have been determined to be from $2.22 \times 10^{15}$ to $1.25 \times 10^{17}$ at temperatures from 1843 to 1923 K. Focused on the slag basicity, a thermodynamic discussion gives the capacity as functions of optical basicity ($\Lambda$) and temperature ($T$) as follows;

$$\log C_{PO_4^{3-}} = \frac{(11 300 \Lambda + 54 560)}{T} + 18.30 \Lambda - 27.43$$

Estimated values of phosphorus distribution ratio ranges from 0.0003 to 0.008 between the present slags and molten iron in practical operations according to empirical phosphate capacities. CaO is useful to improve phosphate capacity of this system to some extent.

KEY WORDS: recycle process; steel scrap; phosphorus; deoxidation; MnO–SiO2–Fe2O–CaO–MgO system; thermodynamics; phosphate capacity; utilisation of impurities.

1. Introduction

Nowadays, the environmental problem such as waste emission arises as a matter of urgency. In the steelmaking process, use of degraded iron ore with high phosphorus will be inevitable in near future due to a depletion of high quality ores, resulting in the increament of refining slag amount.

As a countermeasure to this problem, utilisation of impurities attracts more attention recently. Some favourable results have been reported on microstructure refining and improvement of steel property.1) If the detrimental problems of impurities disappear by well controlled processes, only the preferable effect of each element will be eminent. With regard to phosphorus, as-cast austenite grain size in steel greatly reduces by the presence of phosphorus. The mechanism involves a segregation of phosphorus to condense in the inter dendritic region retarding the ferrite/austenite transformation during cooling by a pinning effect.2–4) To preserve phosphorus in steel during deoxidation process, elements having high deoxidising and low dephosphorising abilities are suitable for use such as manganese and silicon.

One of authors has previously investigated the phosphate capacity for the MnO–SiO2–Fe2O system5) and showed very low phosphorus distribution ratios between the slag and molten iron.

However, there may be an optimal value of phosphorus content in steel since too high phosphorus will bring about the welding problem and so on. Therefore, control of the phosphorus content to some extent would be necessary. Addition of CaO will be a good candidate to control phosphorus content during deoxidation; however, the thermodynamic property of phosphorus is not available for the manganese-silicon deoxidation system having CaO.

Accordingly, the present work aims to evaluate phosphate capacities as an index of dephosphorising ability for the MnO–SiO2–Fe2O–CaO–MgO system by measuring phosphorus partition between the slag and molten iron and to estimate phosphorus distribution ratio in practical operations.

2. Experimental

2.1. Preparation of Premelted Slag

Raw material for the present slag was a mixture of CaO and MnO calcined from CaCO3 (99.9% in purity) and MnCO3 (99.9% in purity), SiO2 powder (99.9% in purity), dehydrated 2MgO·P2O5, and Fe2O3 (99% in purity) powder in an iron crucible. The purpose of addition of iron oxide is to control oxygen partial pressure in main experiments. Table 1 gives nominal composition of the slag and Fig. 1 shows these compositions plotted on the CaO–MnO–SiO2 pseudo-ternary system.6) The CaO content varies with incremental steps up to 22 mass% on the composition line with MnO/SiO2 ratio of 2. After complete mixing, the powders were melted in an iron crucible (26-mm in outer diam-
heating up, the temperature was controlled within
a proportional-integral-differential (PID) controller with Pt-Pt/6 pct Rh thermocouple. After resistance furnace having a proportional-integral-differential is helpful for this understanding; have the degree of freedom of zero. The Gibbs phase rule
data shown in the following paragraphs. The Table 3 lists the interaction parameters necessary for evaluation of the activity coefficient of each element in molten iron.

2.4. Sample Analysis
After equilibration, the crucible was quickly removed from the furnace and cooled in a jetting argon gas. The slag and metal were separated each other from the sample. The slag was magnetically selected to eliminate the contamination of metallic iron. Then, they were subject to chemical analyses. Containing SiO₂, the sample was dissolved into aqueous solution of hydrochloric acid and nitric acid with addition of small amount of hydrofluoric acid. Then, the content of manganese, silicon, iron, calcium, magnesium and phosphorus in the slag and metal were measured by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). The oxygen content of the metal was determined with a LECO* oxygen analyser.

*LECO is a trademark of Leco Corporation, St. Joseph, MI.

3. Results and Discussion
3.1. Preliminary Experiments
Figures 2 through 4 show the change in content of each component with the holding time for the system of 10CaO–52MnO–26SiO₂–10FeO–2Mg₂P₂O₇ slag (on mass basis) and molten iron in an MgO crucible in an argon atmosphere at 1 873 K. The content of each component shows constancy after about 4 h; thus, the holding time has been determined to be 6 h for equilibration. In addition, the constancy in the slag composition confirms the attainment of equilibrium state in the present system.

3.2. Experimental Results
Table 2 gives all the results for the equilibrium experiments. The slags after experiment keeps the intended composition ratios among major components, MnO, SiO₂, FeO and CaO, with exception of considerable amount of MgO originating from the crucible. Iron ion may be present in the form of both divalent and trivalent cation. However, the present slag coexisted with molten iron and contained the limited amount of CaO as strongly basic oxide up to 20 mass%; thereby, the valency of iron ion could be shifted to two. Accordingly, all the iron ion has been treated as FeO in the calculation. On the basis of these experimental data, thermodynamic properties of each component in the slag have been elucidated in the following paragraphs.

3.3. Activity coefficient of FeO and MnO in the MnO–SiO₂–FeO–CaO–MgO–P₂O₅ System
Equation (2) presently defines oxygen distribution ratio between slag and metal considering possible oxygen poten-
tial domination by the presence of FeO.

\[ L_O = X_{FeO} \times [mass\% \text{ O}] \] .......................... (2)

where \( X_{FeO} \) is the molar fraction of FeO in slag, \( [mass\% \text{ O}] \) is the oxygen content in iron on mass basis. Figure 5 shows that the distribution ratio of oxygen does not change much along with the CaO content. It indicates the almost constant thermodynamic property of iron oxide in all the slags, considering the equivalent replacement of MgO by CaO on mole basis and unchanged MnO/SiO\(_2\) ratio to be 2. On the other hand, the \( L_O \) value decreases with an increase in temperature, corresponding to the exothermic reaction of iron oxide formation.

The activity coefficient of FeO relative to pure substance in Raoultian standard describes the thermodynamic nature of iron oxide in the slag and holds;

\[ \gamma_{FeO} = a_{FeO} / X_{FeO} \] .......................... (3)

where \( \gamma_{FeO} \) is the activity coefficient of FeO and \( a_{FeO} \) is the activity of FeO, both being relative to pure substance in Raoultian standard. The activity of FeO can be obtained for each slag using Eq. (3) by knowing oxygen content in iron, \( [mass\% \text{ O}] \), activity coefficient of oxygen relative to 1 mass\% Henrian standard, \( f_O \), derived from the interaction parameters listed in Table 3 and the standard Gibbs energy for the dissolution of FeO into molten iron, \( \Delta G_{FeO}^{\circ} \), which is reported as Eq. (6).

\[ a_{FeO} = f_O [mass\% \text{ O}] \times a_{FeO} \times 1 \times \exp(\Delta G_{FeO}^{\circ} / RT) \] .......................... (4)

\[ FeO(l) = tFe(l) + O(mass\% \text{ in Fe}) \] .......................... (5)

\[ \Delta G_{FeO}^{\circ} = 117 700 - 49.83 T \text{ [J/mol]} \] .......................... (6)

Figure 6 shows activity of FeO plotted against molar fraction. A very good linear correlation exists although they are the results at different temperature levels. The activity coefficient of FeO in the present MnO–SiO\(_2\)–FeO–CaO–MgO–

<table>
<thead>
<tr>
<th>No. Temp./K</th>
<th>Experimental results for the present system.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Chemical composition of slag/mass%</td>
</tr>
<tr>
<td></td>
<td>CaO</td>
</tr>
<tr>
<td>1</td>
<td>1843</td>
</tr>
<tr>
<td>2</td>
<td>1843</td>
</tr>
<tr>
<td>3</td>
<td>15.9</td>
</tr>
<tr>
<td>4</td>
<td>5.02</td>
</tr>
<tr>
<td>5</td>
<td>10.3</td>
</tr>
<tr>
<td>6</td>
<td>15.6</td>
</tr>
<tr>
<td>7</td>
<td>19.7</td>
</tr>
<tr>
<td>8</td>
<td>4.92</td>
</tr>
<tr>
<td>9</td>
<td>10.7</td>
</tr>
<tr>
<td>10</td>
<td>1923</td>
</tr>
<tr>
<td>11</td>
<td>19.6</td>
</tr>
</tbody>
</table>

Table 3. Interaction parameters between i and j, \( e_{ij} \) at 1 873 K. 7)

<table>
<thead>
<tr>
<th>i</th>
<th>j</th>
<th>Mn</th>
<th>O</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mn</td>
<td>0.0034</td>
<td>-0.083</td>
<td>-0.0035</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>-0.021</td>
<td>-1 750/T+0.76</td>
<td>(1 823–1 923 K)</td>
<td>0.07</td>
</tr>
<tr>
<td>P</td>
<td>0</td>
<td>0.13</td>
<td>0.053</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5. Distribution ratio of oxygen between slag and molten iron.

\[ \gamma_{FeO} = a_{FeO} / X_{FeO} \] .......................... (3)

where \( \gamma_{FeO} \) is the activity coefficient of FeO and \( a_{FeO} \) is the activity of FeO, both being relative to pure substance in Raoultian standard. The activity of FeO can be obtained for each slag using Eq. (3) by knowing oxygen content in iron, \( [mass\% \text{ O}] \), activity coefficient of oxygen relative to 1 mass\% Henrian standard, \( f_O \), derived from the interaction parameters listed in Table 3 and the standard Gibbs energy for the dissolution of FeO into molten iron, \( \Delta G_{FeO}^{\circ} \), which is reported as Eq. (6).

\[ a_{FeO} = f_O [mass\% \text{ O}] \times a_{FeO} \times 1 \times \exp(\Delta G_{FeO}^{\circ} / RT) \] .......................... (4)

\[ FeO(l) = tFe(l) + O(mass\% \text{ in Fe}) \] .......................... (5)

\[ \Delta G_{FeO}^{\circ} = 117 700 - 49.83 T \text{ [J/mol]} \] .......................... (6)
$P_2O_5$ system is 2.01 from the slope of the straight line. This confirms that the oxygen partial pressure could be regulated without a large scattering owing to the almost constant thermodynamic property of FeO.

Equation (7) defines the manganese distribution ratio between slag and metal;

$$L_{Mn} = (mass\% Mn)/(mass\% Mn) \ldots \ldots \ldots (7)$$

where $(mass\% Mn)$ and $(mass\% Mn)$ are manganese content in the slag and iron on mass basis. The distribution ratio of manganese decreases with an increase in CaO content. This indicates the repulsive interaction between MnO and CaO, both being basic oxide components in the slag. The value of $L_{Mn}$ decreases with an increase in temperature, reflecting the exothermic reaction of manganese oxide formation.

The activity coefficient of MnO relative to pure substance in Raoultian standard describes the thermodynamic nature of manganese oxide in slag as Eq. (8) expresses.

$$\gamma_{MnO} = \alpha_{MnO}X_{MnO} \ldots \ldots \ldots (8)$$

where $\gamma_{MnO}$ is the activity coefficient of MnO and $\alpha_{MnO}$ is the activity of MnO; their standard states are Raoultian and pure substance. The activity of MnO can be obtained for each slag using Eq. (9) by knowing the oxygen and manganese content in iron, the activity coefficient of both elements relative to 1 mass% Henrian standard, $f_O, f_{Mn}$, derived from the interaction parameters in Table 3, and the standard Gibbs energy for the dissolution reaction of MnO into molten iron, $\Delta G_{MnO}^{\infty}$, which is reported as Eq. (11)

$$\alpha_{MnO} = f_0[\text{mass}\% Mn]/f_{Mn}[\text{mass}\% Mn] \exp(\Delta G_{MnO}^{\infty}/RT) \ldots \ldots (9)$$

MnO (l) = Mn(mass% in Fe) + O(mass% in Fe) \ldots \ldots \ldots (10)

$\Delta G_{MnO}^{\infty} = 248\,900 - 108.2\,T$ [J/mol] \ldots \ldots (11)

Figure 7 shows the activity coefficient of MnO plotted in the CaO–MnO–SiO2 pseudo ternary system together with reported iso-activity lines at 1923 K.11) The value increases with an increase in CaO content reflecting the behaviour of MnO as a basic oxide in the present system. Then, the predicted iso-activity curve could be drawn by the dashed line in the higher MnO content region as shown in the Fig. 7, assuming the constant increment of MnO activity along the liquidus line from CaO side to MnO side. The empirical activities show deviation from the reported data; however, it is due to the projection treatment of the present data to pseudo-ternary CaO–MnO–SiO2 system and could be permissible.

3.4. Activity Coefficient of $P_2O_5$ in the MnO–SiO2–FeO–CaO–MgO–P2O5 System

Equation (12) defines the phosphorus distribution between slag and metal;

$$L_p = (mass\% P)/(mass\% P) \ldots \ldots \ldots (12)$$

where $(mass\% P)$ and $(mass\% P)$ are phosphorus content in slag and iron on mass basis. The distribution ratio of phosphorus, $L_p$, increases with an increase in CaO content, indicating attracting force between $P_2O_5$ and CaO supported by the fact that the former is acidic oxide and the latter is basic one. The $L_p$ decreases with an increase in temperature, indicating the fact that the formation of phosphorus oxide is an exothermic reaction.

Phosphorus and oxygen in molten iron react to form $P_2O_5$ in the present system according to the following equation;

$$2P(\text{mass}\% \text{ in Fe}) + 5O(\text{mass}\% \text{ in Fe}) = P_2O_5 \ldots \ldots \ldots (13)$$

$$\Delta G_{P_2O_5}^{\infty} = -781\,100 + 557\,T$$ [J/mol] \ldots \ldots (14)$$

Hence, there appears activity coefficient of $P_2O_5$ in the slag in the Raoultian standard, $\gamma_{P_2O_5}$, in $\Delta G^\circ$ for Reaction (13) as Eq. (15);

$$\Delta G_{P_2O_5}^{\infty} = -RT\ln\{(\gamma_{P_2O_5}X_{P_2O_5})(f_O^2[\text{mass}\% P]^2f_{Mn}^2[\text{mass}\% \text{O}]^4)\} \ldots \ldots \ldots (15)$$

where $X_{P_2O_5}$ is the molar fraction of $P_2O_5$, $f_O$ is the activity coefficient of phosphorus relative to 1 mass% Henrian standard derived from the interaction parameters in Table 3. The obtained activity coefficient, $\gamma_{P_2O_5}$, from Eq. (15) was multiply-regressed as functions of temperature and content of CaO, MnO and MgO to be Eq. (16). Figure 8 shows the regression lines at each temperature.

$$\log\gamma_{P_2O_5} = -29.3(X_{CaO} + 0.88X_{MnO} + 0.61X_{MgO}) - 37\,200/T + 19.8 \ldots \ldots \ldots \ldots (16)$$

More strictly, the logarithm of activity coefficient of $P_2O_5$ should be described by using four terms, that is, composition term, inverse temperature term, their cross term, and constant term according to the regular solution model.13) In
this part, the form of Eq. (16) is adopted due to insufficiency of data to determine each modulus for four terms. However, each modulus of content term in Eq. (16) is close to the optimal basicity value listed in Table 4, presumably showing each contribution to the tendency of the slag to accept P2O5. At any rate, this formula is useful for the prediction of the activity coefficient of P2O5 by the content of each oxide component and temperature; thereby, industrially meaningful.

3.5. Phosphate Capacity for the MnO–SiO2–FeO–CaO–MgO System

Equation (17) expresses the phosphate ion formation reaction from the gaseous phosphorus, oxygen and oxide ion in the slag:

$$\frac{1}{2}P_2(g) + \frac{5}{4}O_2(g) + \frac{3}{2}(O^2-) = (PO_4^{3-})$$ .......... (17)

Wagner has proposed phosphate capacity to evaluate the phosphate absorbing ability of a slag as follows;

$$C_{PO_4^{3-}} = \left(\frac{mass\% \text{PO}_4^{3-}}{P_{P_2}^{1/2}P_{O_2}^{5/4}}\right) = K_{17}a_{O_2}^{3/2}f_{PO_4^{3-}}$$ .......... (18)

where \((mass\% \text{PO}_4^{3-})\) is the content of phosphate ion on mass basis, \(P_i\) is the partial pressure of species \(i\), \(K_{17}\) is the equilibrium constant of Reaction (17), \(a_{O_2}\) is the activity of oxide ion and \(f_{PO_4^{3-}}\) is the activity coefficient of phosphate ion relative to 1 mass% Henrian standard. The right-hand side of Eq. (18) describes the nature of a slag, each term of which cannot be determined separately. However, measurable values in the middle can give the value for phosphate capacity. To know the partial pressure of phosphorus and oxygen, one requires the standard Gibbs energy for the Reactions of Eqs. (19) and (21) and the experimental contents of phosphorus and oxygen in iron.

$$\frac{1}{2}P_2(g) = P_{\text{mass\% in Fe}}$$ .......... (19)
$$\Delta G_{P_2}^0 = -155 700 + 5.4 T \ [\text{J/mol}]$$ .......... (20)
$$\frac{1}{2}O_2(g) = O_{\text{mass\% in Fe}}$$ .......... (21)
$$\Delta G_{O_2}^0 = -117 110 - 3.39 T \ [\text{J/mol}]$$ .......... (22)

The phosphorus content in the slag provides the mass content of phosphate, \((mass\% \text{PO}_4^{3-})\). Then, the phosphate capacity can be calculated from the data experimentally obtained. Figure 9 shows the phosphate capacity as functions of CaO content for each temperature level, together with the data for the slag without CaO. The phosphate capacity increases with an increase in CaO content and decreases with an increase in temperature. This result confirms that the addition of CaO is effective to improve the phosphate absorbing ability of the present system.

For the total understanding of the contribution of all the oxide components, the optical basicity would be helpful since the basicity of the slag may be major factor essential to the phosphate absorbing ability. The following formula evaluates the theoretical value of optical basicity for a given slag with a certain composition;

$$A = \sum X_i n_i / \sum X_i$$ .......... (23)

where \(X_i\) is molar fraction of component \(i\), \(n_i\) is the number of oxygen atoms which belong to each oxide and \(A\) is the optical basicity of component \(i\). Table 4 gives the values used in the calculation. Figure 10 shows the relationship between optical basicity and the phosphate capacity. Much better linearity than shown in Fig. 9 confirms the reasonability of expressing phosphate absorbing ability by way of optical basicity. Moreover, the phosphate capacity derived here was multiply-regressed as functions of temperature and optical basicity as Eq. (24). Figure 11 shows the regression lines at each level of optical basicity as functions of temperature.

$$\log C_{PO_4^{3-}} = (11 300A + 54 560)/T + 18.30A - 27.43$$ .......... (24)

Accordingly, the phosphate capacity for a given slag could be evaluated by optical basicity and temperature at least...
3.6. Dissolution Enthalpy of Phosphorus Oxide into the MnO–SiO$_2$–FeO–CaO–MgO System

Equation (25) expresses the phosphate formation reaction including dissolution reaction into the slag. The equilibrium constant of the reaction is Eq. (26).

$$\frac{1}{2}P_2(g) + \frac{5}{4}O_2(g) = (PO_{2.5}) \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldot...
4. Conclusions

Effect of CaO on absorbing ability of phosphorus for the MnO–SiO$_2$–FeO–CaO–MgO system has been investigated by a chemical equilibration technique. The phosphorus distribution ratio has been estimated in a practical condition. The findings are summarised as follows:

- The phosphate capacities for the present system with CaO content from 4.73 to 19.6 mass% have been determined to be from $2.22 \times 10^{15}$ to $1.25 \times 10^{17}$ at temperatures from 1843 to 1923 K and obtained as functions of optical basicity and temperature;

$$\log C_{PO_4^{3-}} = \frac{(11\,300 \Lambda + 54\,560)}{T} + 18.30 \Lambda - 27.43$$

- The enthalpy change for the dissolution reaction of P$_2$O$_5$ has been obtained as functions of optical basicity;

$$\Delta H = -216.0 \Lambda - 277.0 \text{ [kJ/mol]}$$

- Estimated phosphorus distribution ratio between the present slag and molten iron varies from 0.0003 to 0.008 by adding CaO in a moderate deoxidation condition. Addition of CaO improves dephosphorising ability of this system to some extent.

REFERENCES