The effect of Na_2O and K_2O flux on the phosphorus partition ratio between CaO-SiO_2-Fe_tO-P_2O_5 slags and carbon saturated iron

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Abstract: In the present study, the experiments for the phosphorus equilibrium partition between CaO-SiO_2-Fe_tO-P_2O_5 slags with Na_2O or K_2O addition and solid pure iron foil were performed at 1573, 1623 and 1673 K respectively. The experimental results showed that both Na_2O and K_2O addition can enhance the dephosphorization ability of CaO-SiO_2-Fe_tO-P_2O_5 based slags and they have similar dephosphorization ability under the same temperature and main slag composition. The phosphorous partition ratio between slag and carbon saturated hot metal increased with the increasing basicity with a peak value in the range of R around 1.3~1.5. The phosphorous partition ratio(L_p)decreased with the increasing of $(w(CaO)+w(Na_2O))/w(Fe_tO)$ value in slags. The dephosphorization ability of CaO-SiO_2-Fe_tO-P_2O_5 based slags was relatively higher when the $(w(CaO)+w(Na_2O))/w(Fe_tO)$ values fell in the range of 0.5~0.8. L_p value decreased with the temperature increase. The linear relationships between the $\log L_p$ and $1/T$ were obtained for CaO-SiO_2-Fe_tO-P_2O_5 based slags with Na_2O. The information provides by present study would be useful for optimization of dephoshorization in hot metal pretreatment.

Keywords: Dephosphorization, hot metal, Na_2O, K_2O, phosphorus partition ratio

1. Introduction

China has become the largest iron ores importing country in the world, and about 50 %~80 % of the iron ores consuming are imported from aboard. The quality of the imported iron ores has become bad while the price of imported iron ore has shot up in recent years. In order to reduce the production cost, steel companies are seeking domestic iron ore resources. High phosphorus oolitic hematite containing phosphorus content beyond 0.5 mass% has large proportion in iron ore resources in China, and it is 1/9 of the iron ore deposit in China[1]. But they have been avoided being used as raw material in ironmaking in large scale up to now due to its high content of phosphorus, and their complicated chemical composition and mineral structure make the dephosphorization by dressing very difficult.

High phosphorus oolitic hematite can be used to produce high phosphorus hot metal by smelting and then can be used to produce phosphorus containing steel grades after dephosphorization treatment during hot metal pretreatment. In order to utilize high phosphorus oolitic hematite resource effectively, choose efficient and environmental friendly dephosphorization slag is the key. Although there were many basic researches about dephosphorization during steelmaking process[2-4], most of dephosphorization experiments aim at common hot metal with phophorus content lower than 0.15 mass%. These researches proclaimed dephosphorization mechanism of different dephosphorization slag and methods for improving dephosphorization ability. The main dephosphorization slag used in practical production is lime system, which is $CaO\text{-}SiO_2\text{-}Fe_tO$.

Ito et al[5-6] reported that the phosphate capacity of soda is greater than that of lime in the hot metal dephosphorization pretreatment process. Muraki et al[7] studied the effect of Na_2O on the phosphate capacity of $CaO\text{-}CaF_2\text{-}SiO_2$ slags, and found that the phosphate capacity was 10 times larger by adding 2.5% of Na_2O in the slags. Na_2O-based dephosphorization slag is seldom used due to its harm to equipment and environment caused by the vaporization of Na_2O. A few of Na_2O added into $CaO\text{-}SiO_2\text{-}Fe_tO$ slag is confirmed to increase dephosphorization ability[8], but its effect was limited because of high steelmaking temperature leading to vaporization of Na_2O.

A few of Na_2O added into $CaO\text{-}SiO_2\text{-}Fe_tO\text{-}P_2O_5$ slag used for dephosphorization during hot metal pretreatment was not yet reported since there was difficulty in experiment of oxidative dephosphorization slag reacting with carbon saturated iron. In order to provide basic reference datum for choose effective and low cost dephosphorization slag for high phosphorus hot metal, methods were adopt in this study according to those used by Werme et al[9] to measure equilibrium partition ratio between oxidative slag and carbon-saturated iron indirectly.

The same experiments for the effect of K_2O on dephosphorization had been done since it has similar physical chemistry property to Na_2O.

2. Experimental Principles

2.1 Measurement methods for equilibrium partition ratio of oxidative slag and carbon-saturated iron

It is difficult to study phosphorus partition between oxidative dephosphorization slag and carbon-saturated iron bearing high phosphorus content directly since high FeO in the slag reacts with the carbon dissolved in the hot metal, causes bubbling and the composition of the flux will change. Researchers often obtain the equilibrium data through indirectly experimental methods. In order to resolve the difficulty of measuring equilibrium partition ratio between oxidative slag and carbon-saturated iron, methods were adopted in this study according to those used by present authors before[10]. In this study, oxidative $CaO\text{-}SiO_2\text{-}Fe_tO\text{-}P_2O_5$ slag was equilibrated with solid iron in an iron crucible at a constant temperature and argon atmosphere. After experiments, the composition of the slag and phosphorus content in solid iron were analyzed. Phosphorus content in the carbon-saturated iron equilibrated with the same slag at the same temperature can be calculated by using the known thermodynamic data. Thus, the equilibrium partition ratios of phosphorus can also be calculated.

2.2 Transfer of phosphorus content $w[P]_{\text{in }\gamma\text{-Fe}}$ in solid iron to that of $w[P]_{\text{in Fe-C(Satd.)}}$ in carbon-saturated iron

When a simultaneous equilibrium among slag, solid iron, and carbon-saturated iron at a fixed oxygen potential is attained, the chemical potential of phosphorus in solid iron and carbon-saturated iron is identical.

Therefore, the activity of phosphorus in solid iron becomes the same as that in carbon-saturated iron when the same standard state of activity is used as indicated. Using Eqs. (1), phosphorus content in γ-Fe($w[\mathrm{P}]_{\mathrm{in}\ \gamma\text{-Fe}}$) can be transferred to that in carbon-saturated iron($w[\mathrm{P}]_{\mathrm{in\ Fe\text{-}C(Sat.)}}$) and T is the reaction temperature in Kelvin. The detailed deducing procedures were described in references[11, 12-15].

$$\ln\frac{w[\mathrm{P}]_{\mathrm{in\ Fe\text{-}C(Satd.)}}}{w[\mathrm{P}]_{\mathrm{in}\ \gamma\text{-Fe}}}=-\frac{4547}{T}+13.031-2.706\lg T \tag{1}$$

It is supposed that oxygen potential in the slag/metal interface is controlled by the activity of FeO in the slag and iron in the hot metal in the study. The activity of carbon saturated iron in the hot metal reference to γ-Fe will change with the carbon content in the hot metal($a_{\mathrm{Fe\text{-}C(Satd.)}}$) and the activity ratio of phosphorus between slag and carbon saturated iron is higher than that of slag and γ-Fe. The partition ratio of phosphorus between slag and carbon saturated iron L_{P} was expressed as Eq. (2), where $w(\mathrm{P})$ is mass percent of phosphorus in the slag. The activity of carbon saturated iron reported is 0.785 at 1573K when the reference state is γ-Fe[11]. The activity of carbon saturated iron at other temperature can also be calculated by using the same deducing method as reference [6].

$$L_{\mathrm{P}}=\frac{w(\mathrm{P})}{w[\mathrm{P}]_{\mathrm{in\ Fe-C(Satd.)}}\,a_{\mathrm{Fe\text{-}C(Satd.)}}^{5/2}} \tag{2}$$

3 Experiment

3.1 Experimental materials

Argon gas(99.999%) was flowed through the reaction tube during the experiments. Reagent grades of Fe_2O_3, CaO, SiO_2, $Ca_3(PO_4)_2$, and Na_2SiO_3 powders were uniformly mixed to form the slags for the experiments. Iron oxide, Fe_tO, was prepared by reaction between Fe_2O_3 and Fe powders in a pure iron crucible in an argon atmosphere at 1573K. The powders of CaO and $Ca_3(PO_4)_2$ were dried at 1273K to remove H_2O and CO_2 before experiments in the muffle furnace. Na_2SiO_3 (K_2SiO_3) was dried by decomposing $Na_2SiO_3\cdot 9H_2O$ ($K_2SiO_3\cdot nH_2O$) to remove H_2O at 423K in vacuum drier. Pure iron crucibles were used as experimental crucibles (38mm in outer diameter, 30mm in inner diameter, and 125mm in height). The impurity contents of the iron crucible are listed in **Table 1**. Pure iron flake which composition is the same as the iron crucible was also prepared.

Table 1 Compositions of industrial pure iron in the experiments (mass%)

Elements	C	Si	P	Mn	S	N
Content	0.008	0.002	0.006	0.017	0.005	0.008

3.2 Experimental equipments

A vertical type of electric resistant furnace heated by $MoSi_2$ heating elements with an alumina reaction tube (90mm in outer diameter, 80mm in inner diameter, and 845mm in height) was employed. The equilibrium experiments between pure iron flake and slags were carried out at the temperatures of 1573 K, 1623 K, and 1673 K, respectively. The temperature was controlled and measured by two S type thermocouples, respectively. The experimental temperature was controlled within ± 2 K by a PID controller. Argon gas (99.999%) was flowed through the rotor flowmeter into the reaction tube from the bottom during the experiments and kept a little positive pressure to atmosphere avoiding air permeating into the furnace.

3.3 Experimental procedures and composition analysis

3.3.1 Experimental procedures

In order to attain equilibrium between slag and iron(Fe_2O_3-FeO-Fe), 11 hours were selected as reacting time between slag and iron crucible according to the reported[9,16] results in the following experiments. At first, twenty grams of slag without Na_2SiO_3(K_2SiO_3) addition was placed in an iron crucible and melted at 1673K for 1 hour and then reacted for 10 hours at experimental temperature to ensure the equilibrium between the oxidative slag and the iron crucible. After this step, the slag along with the crucible was taken out, and then immersed into water for quenching with the protection of argon gas flow. Then the slag was taken out from the iron crucible and crushed. Secondly, the crushed previous slag equilibrated with iron crucible with addition of Na_2SiO_3 and solid iron foil were placed into another iron crucible and put back to the same furnace. In this step, the slag and solid iron were reacted at experimental temperature for 12 hours. After the second step experiment, the slag along with the crucible was quenched, the slag was ground. Then, the chemical compositions of the slag and phosphorus in iron were analyzed. Pure iron flake must be cleaned carefully in acetone and citric acid and then cleaned in deionized water by ultrasonic wave before analysis to ensure no slag adhere to the experimental iron foil.

3.3.2 Composition analysis

Phosphorus in iron and CaO, SiO_2, Na_2O, K_2O and P_2O_5 in the slag were analyzed by ICP-AES. Total Fe content was determined by titanium trichloride and potassium dichromate titration method, Fe^{2+}, metal Fe were determined by potassium dichromate titration method, and Fe^{3+} was obtained by subtracting Fe^{2+} and metal Fe contents from total Fe content.

4 Results and discussions

4.1 Results

Compositions of the slag with Na_2O addition and iron after equilibrium experiments at 1573 K, 1623 K and 1673 K were analyzed and the calculated partition ratio of phosphorus between slag with Na_2O addition and carbon saturated iron L_P according to the stated methods in section 1.2. The results are listed in table 2. The effect of K_2O on the partition ratio of phosphorus was reported in reference [17] in detail.

Table 2 Compositions of the slag and iron after equilibrium experiments (mass %) and L_P at different temperature

No.	T/K	w(T.Fe)	w(FeO)	w(CaO)	w(SiO_2)	w(Na_2O)	w(P_2O_5)	$w[P]_{\text{in }\gamma\text{-Fe}}$	L_P
1	1573	20.68	19.64	31.05	35.06	0.61	5.92	0.025	43.5
2		37.95	48.79	9.040	19.46	14.6	8.11	0.0077	189.8
3		16.73	21.51	35.82	34.54	0.68	7.46	0.013	107.5
4		23.68	30.45	28.65	30.85	2.51	7.55	0.0088	154.6
5-1		27.52	35.38	20.76	27.35	8.89	7.62	0.0081	169.5
6		34.87	43.28	19.16	15.91	9.11	10.8	0.0089	219.3
7		35.77	45.99	10.94	18.45	13.8	10.8	0.0100	194.9
8		14.78	17.39	39.67	32.05	0.67	8.42	0.0094	161.5
9		21.22	26.66	32.75	28.61	2.53	8.76	0.0066	239.2
10		24.92	31.79	26.95	23.60	6.56	10.8	0.0061	320.0
11		32.95	41.57	18.69	18.55	10.1	10.2	0.0056	328.2
12		35.69	45.37	10.52	19.34	14.7	9.49	0.0061	280.4
13		13.90	17.87	44.65	27.70	0.67	9.11	0.0072	228.0
14		20.68	26.58	37.59	23.87	2.35	9.61	0.0067	258.4
15		25.22	32.38	30.47	21.25	5.97	9.89	0.0052	342.6
16		31.59	38.81	22.17	16.67	9.38	11.0	0.0045	438.8
17		36.11	45.11	10.17	19.16	14.2	9.92	0.0056	319.2
18		13.75	17.68	46.78	26.57	0.63	8.34	0.0098	153.4
19		20.63	26.53	38.88	23.02	2.35	9.21	0.0094	176.6
20		26.62	34.12	30.59	19.26	6.10	9.82	0.0080	221.3
21		33.70	42.95	21.30	15.07	9.50	10.8	0.0087	222.9
22		35.07	44.50	10.67	18.99	15.5	9.70	0.0073	239.4
5-2	1623	34.46	44.31	24.73	21.33	4.84	4.80	0.011	75.8
5-3	1673	31.98	41.11	25.62	23.00	5.06	5.21	0.017	48.9

4.2 Discussions

4.2.1 Phosphorus partition ratio between slags and carbon-saturated iron

Phosphorus partition ratio between CaO-SiO_2-Fe_tO slags and carbon-saturated iron changing with the composition of slag at 1573K are shown in Fig.1. Phosphorus partition ratios corresponding with the composition of the final (CaO+Na_2O)-(SiO_2+P_2O_5)-Fe_tO experiment slags at 1573K are shown in Fig.1 by solid circle. The minimum partition ratio in present work is 43.5 while the maximum value is 438.8. Phosphorus partition ratios corresponding with the composition of the final (CaO)-(SiO_2+P_2O_5)-Fe_tO slags without Na_2O

addition at 1573K reported by IM[11] et al are shown in Fig.1 by solid square. The minimum partition ratio in their work is 0.7 while the maximum value is 450.8. Comparing with phosphorus partition ratio of the two types of slag, although the maximum value reported by reference [11] is higher than that measured in the present work, phosphorus partition ratios increase dramatically after Na_2O is added to the CaO-(SiO_2+P_2O_5)-Fe_tO slag in the approximate same composition of the slag in the phase diagram. Phosphorus partition ratios improve from 10~300 to 100~400.

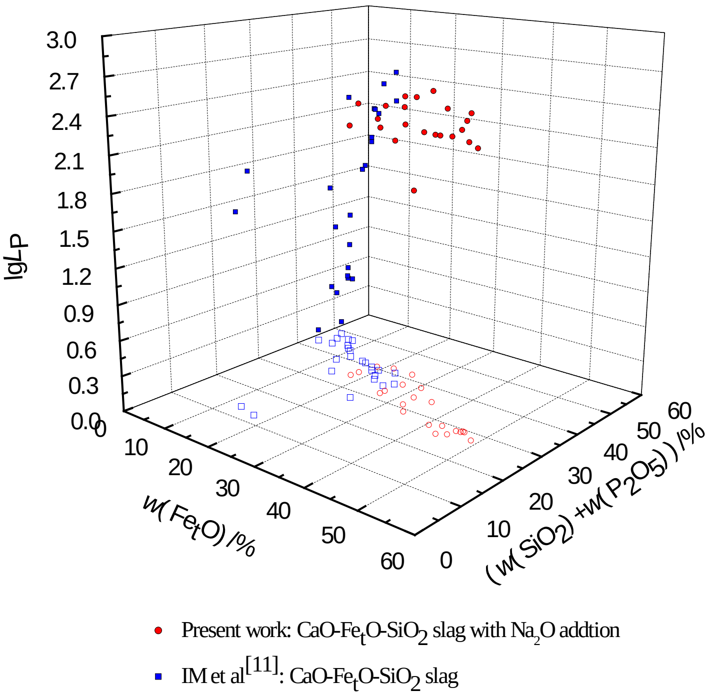


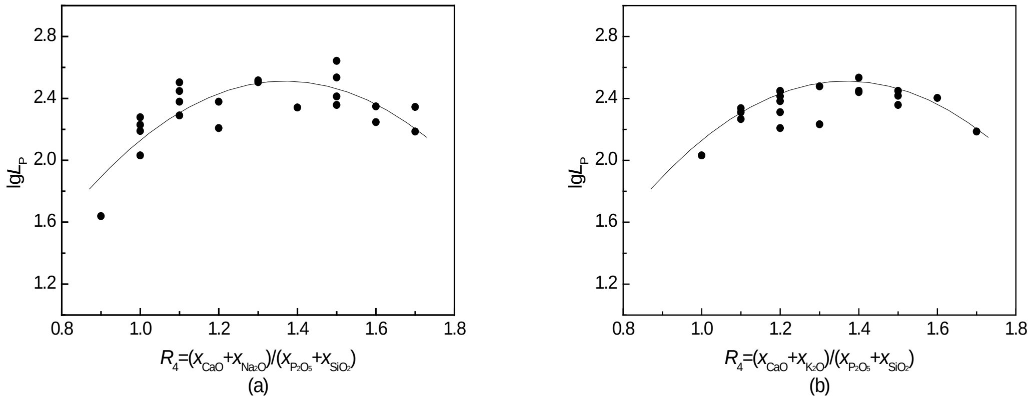
Fig. 1 Phosphorus partition ratio between slags and carbon-saturated iron changing with the composition of slag at 1573K.

4.2.2 Effect of the slag basicity on the partition ratios of phosphorus between slag and carbon-saturated iron

Quaternary basicity R_4 is defined by Eq. (3). There, x_{CaO}, $x_{\mathrm{Na_2O(K_2O)}}$, $x_{\mathrm{SiO_2}}$ and $x_{\mathrm{P_2O_5}}$ is molar fraction of CaO, Na_2O（K_2O）, SiO_2 and P_2O_5 in the slag respectively.

$$R_4 = (x_{\mathrm{CaO}} + x_{\mathrm{Na_2O(K_2O)}})/(x_{\mathrm{SiO_2}} + x_{\mathrm{P_2O_5}}) \tag{3}$$

The partition ratios of phosphorus plotted against quaternary basicity R_4 are shown in Fig. 2. Phosphorus partition ratios increase with basicity of the slag increasing from 0.9 to 1.5, and then it decreases which is shown in Fig. 2(a). This indicates that an oxidative slag with too high basicity has no benefit for dephosphorization. Because P_2O_5 is an acidic oxide, higher basicity has advantage for P_2O_5 combined with the alkaline components in the slag. But when basicity is beyond some degree, phosphorus partition ratios decrease conversely. When basicity of the slag increases, Fe_tO content in the slag decreases and the melting point of the slag increased, which has no advantage for dephosphorization. The maximum phosphorus partition ratio between slag and hot metal is 438.8 when the slag basicity is 1.5 and Fe_tO content in the slag is 31.59 mass% and Na_2O content in the slag is 9.38 mass% at 1573K. These results indicate that the equilibrium partition ratios of phosphorus in the experiments are affected by basicity of the slag, Fe_tO content simultaneously. The same effect of basicity of the slag after K_2O being added also can be seen from Fig. 2 (b).



(a)

(b)

Fig. 2 Relationship between phosphorus partition ratio and basicity of R_4 of slag added with Na_2O(a) and K_2O(b) at 1573 K

4.2.3 Effect of total Fe content (*w*(T.Fe)) in the slag on the partition ratios of phosphorus between slag and carbon- saturated iron

The effect of total Fe content in slag on the equilibrium partition ratios of phosphorus between $CaO-SiO_2-P_2O_5-Fe_tO$ slag and carbon saturated iron after Na_2O being added in the slag at different basicities is illustrated in Fig. 3. Phosphorus partition ratios increase with the increasing of total Fe content in the slag, and then they decrease when total Fe content in the slag isn’t beyond 40 mass%, as shown in Fig.3. The similar results were reported in reference [11] when total Fe content in the slag is beyond 30 mass%. Total Fe content in the slag increases Fe_tO content in the slag and decrease CaO and Na_2O content in the slag. Fe_tO provides more oxygen ions and increases the oxygen potential which benefits for phosphorus oxidation. So increasing total Fe content in some degree is beneficial for dephosphorization. Dephosphorization also requires high oxygen potential. But too much Fe_tO addition may increase the melt point of flux which deteriorates the kinetic conditions of dephosphorization. On the other hand, the decrease of CaO and Na_2O content in the slag decreases basicity of the slag which leads to low dephosphorization ability of the slag.

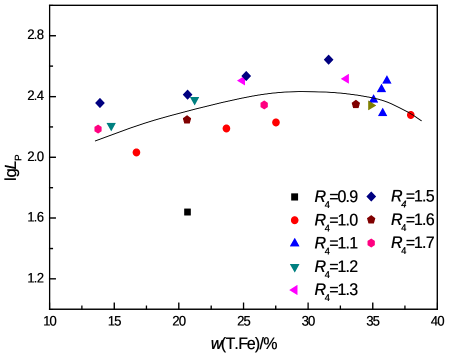


Fig. 3 Effect of total iron content in Na_2O-CaO-SiO_2-P_2O_5-Fe_tO slags on the phosphorus partition ratio at 1573 K

4.2.4 Effect of $Na_2O(K_2O)$ and CaO content in the slag on the partition ratios of phosphorus between slag and carbon- saturated iron

The effect of Na_2O and CaO content in slag on the equilibrium partition ratios of phosphorus between CaO-SiO_2-P_2O_5-Fe_tO slag and carbon saturated iron after Na_2O being added in the slag at different basicities is shown in Fig. 4. Phosphorus partition ratios increase with the increasing of Na_2O content in the slag, and then they decrease when Na_2O content in the slag is beyond 10 mass%. The maximum partition ratios of phosphorus obtains when Na_2O content in the slag is about 8 mass%~11 mass%, as shown in Fig. 4 (a). The reason is that the activity of O^{2-} (ion) increases because of weakness of the combination of metallic cation with O^{2-} when stronger alkaline oxide Na_2O compared with CaO is added into the slag. It contributes to making P_2O_5 combine with O^{2-} to form stable PO_4^{3-}. On the other hand, Melting point and viscosity of the slag decrease after Na_2O being added into the slag. The slag melts more quickly which improves dynamic conditions for dephosphorization and bring higher dephosphorization ability. Too much Na_2O added into the slag will decrease Fe_tO content in the slag and utilization of Na_2O aroused by its volatilization which have no advantage for dephosphorization. Phosphorus partition ratios increase with CaO content in the slag increasing when Fe_tO content in the slag changes a little which is shown in Fig.4(b). The effect of CaO content in slag on the equilibrium partition ratios of phosphorus has the similar trend as reference [11] reported and the effect of Fe_tO also is reflected in Fig.4(b). The similar effect of K_2O also can be seen from Fig.4(a).

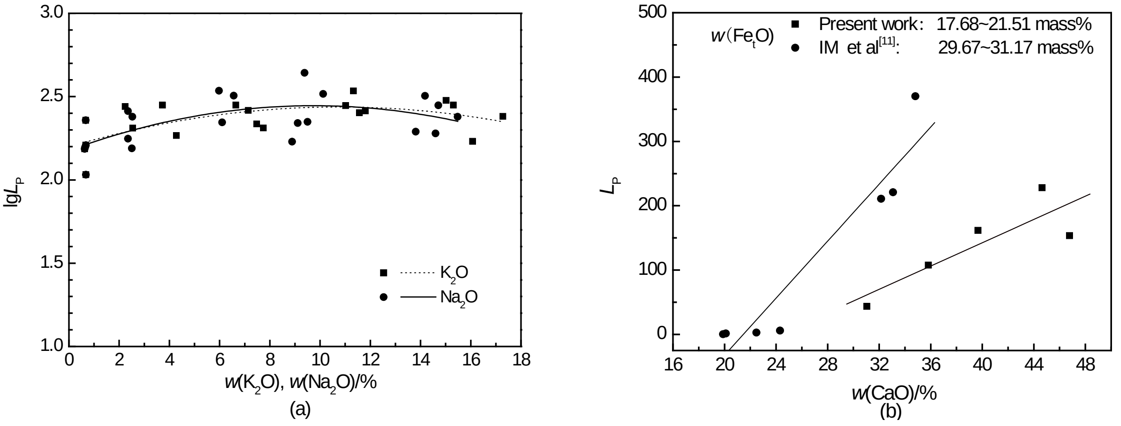


Fig. 4 Effect of Na_2O (K_2O) (a) and CaO (b) content in $Na_2O(K_2O)$-CaO-SiO_2-P_2O_5-Fe_tO slags on the phosphorus partition ratio at 1573 K

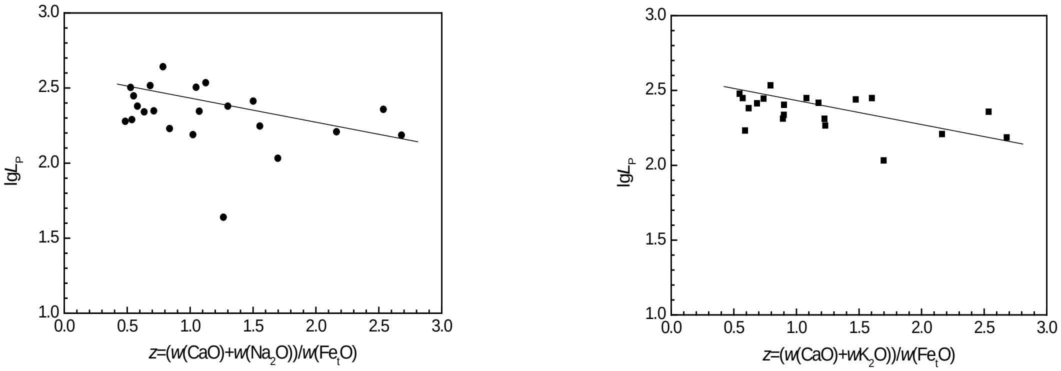
4.2.5 Effect of Na_2O (K_2O), CaO and Fe_tO content in the slag on the partition ratios of phosphorus between slag and carbon- saturated iron

Na_2O, CaO and Fe_tO content in the Na_2O-CaO-SiO_2-P_2O_5-Fe_tO slag are changeable when quantity of SiO_2 and P_2O_5 added into the slag is fixed. Defining multiple effect parameter Z is equal to (w(CaO)+w(Na_2O) (or w(K_2O))/w(Fe_tO). Multiple effect of Na_2O, CaO and Fe_tO content in the slag on the phosphorus partition ratio at 1573 K is shown in Fig. 5 (a). Phosphorus partition ratios increase with the decrease of parameter Z and when Z is 0.5~1.0, a relative good dephosphorization effect achieves. Multiple effect of K_2O, CaO and Fe_tO content in the slag on the phosphorus partition ratio at 1573 K is shown in Fig. 5 (b).

It is known from the following dephosphorization reaction equations (4) and (5) that dephosphorization requires a relative higher basicity and oxygen potential. Controlling parameter Z suitably will provide required basicity and oxygen potential for dephosphorization more effectively. Although Fe_tO content in the slag is high and provide high oxygen for dephosphorization by keeping Z low, stable phosphate can't form because basicity of the slag is low caused by lack of enough Na_2O and CaO in the slag since Z is low. On the contrary, high Z value has disadvantage for dephosphorization because of low oxygen potential for lack of Fe_tO in the slag and high CaO content in the slag leading to difficulty in melting the dephosphorization slag. A relative good dephosphorization effect achieves when Z is controlled among 0.5~1.0 under the experimental conditions.

$$2[\mathrm{P}]+5(\mathrm{FeO})+3(\mathrm{CaO})=(3\mathrm{CaO}\cdot\mathrm{P_2O_5})+5\mathrm{Fe} \tag{4}$$

$$2[\mathrm{P}]+5(\mathrm{FeO})+3(\mathrm{Na_2O})=(3\mathrm{Na_2O}\cdot\mathrm{P_2O_5})+5\mathrm{Fe} \tag{5}$$



(a)

(b)

Fig. 5 Effect of (w(CaO)+w(Na_2O))/w(FetO) and (w(CaO)+ w(K_2O))/w(Fe_tO)(b) in $Na_2O(K_2O)$-CaO-SiO_2-P_2O_5-Fe_tO slag on the phosphorus partition ratio at 1573 K

4.2.6 Effect of Temperature on phosphorus partition ratios between slag and carbon- saturated iron

Effect of temperature on the phosphorus partition ratio (which is defined as ratio of phosphorus mass percent in the slag to that in the carbon saturated iron) is shown in Fig. 6. The reaction of phosphorus oxidation is exothermic so that the equilibrium partition ratios of phosphorus is expected to decrease with temperature increasing, as can be seen from Fig. 6. Dephosphorization should be conducted in hot metal pretreatment or initial stage of converter blowing quickly in the practical process since low temperature has benefit for dephosphorization. The best dephosphorization effect will achieve only to ensure low operating temperature for the easy voporizing Na_2O (K_2O) added flux. The dephosphorization effect of the present CaO-based flux added with Na_2O (K_2O) is better than that Na_2O-SiO_2-Fe_tO-$PO_{2.5}$ slag used by Tsukihashi et al[6] at the same temperature, and Fe_tO content in their experimental slag is very low compared with that used by present work. Based on the experimental results, logarithms of phosphorus partition ratio L_P' obtained in the present work which Na_2O is added is regressed as a linear function of the reciprocal of temperature. The regressed equation (6) is as follows and the correlation coefficient is 0.99.

$$\lg L'_P = \lg \frac{w(P)}{w[P]} = \frac{14231}{T} - 7.11 (T = 1573 \sim 1673 \mathrm{K}) \qquad r = 0.99 \qquad (6)$$

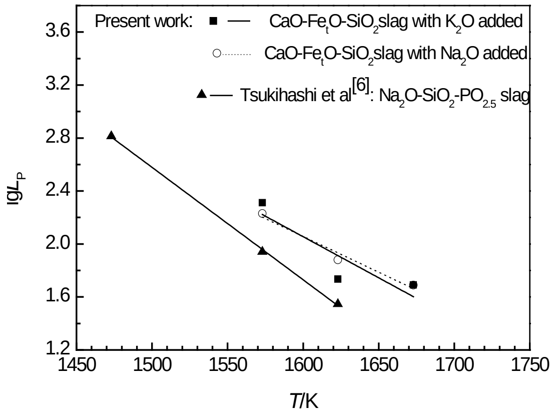


Fig. 6 Effect of temperature on the phosphorus partition ratio

5 Conclusions

Equilibrium datum of oxidative CaO-SiO$_2$-Fe$_t$O-P$_2$O$_5$ slag with Na$_2$O (K$_2$O) addition and carbon-saturated iron was measured indirectly in the study and the conclusions are as follows:

1) The experimental results showed that both Na$_2$O and K$_2$O addition can enhance the dephosphorization ability of CaO-SiO$_2$-Fe$_t$O-P$_2$O$_5$ based slags. and the effect is better than that of Na$_2$O-SiO$_2$-Fe$_t$O-PO$_{2.5}$ under certain condition. Na$_2$O and K$_2$O addition have similar effect on enhancing the dephosphorization ability under the same temperature and main slag composition.

2) Phosphorus partition ratios increase with the increasing of basicity of the slag from 0.9 to 1.5, and then it decreases. The maximum phosphorus partition ratios can be obtained when basicity of the slag is in the range from 1.2 to 1.5.

3) Phosphorus partition ratios increase with the increasing of total Fe content in the slag, and then they decrease when total Fe content in the slag isn't beyond 40 mass% while quaternary basicity of the slag is constant. Phosphorus partition ratios increase with the increasing of CaO content in the slag when Fe$_t$O content in the slag keeps constant.

4) The Dephosphorization ability decreases with temperature increasing notably.

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