ISSN 2176-3135

ICSTI
6th International Congress on the Science and Technology of Ironmaking - ICSTI
42th Ironmaking and Raw Materials Seminar/ 42ª Seminário de Redução de Minério de Ferro e Matérias-primas
13th Brazilian Symposium on Iron Ore/ 13º Seminário Brasileiro de Minério de Ferro

CALCULATION MODEL OF NEW BLAST FURNACE IRONMAKING PROCESS BY USING HIGH REACTIVITY COKE[1]

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Abstract

The technology of using high reactivity coke in the blast furnace ironmaking process is proved to promote iron ore reduction in lump zone by both theoretical analysis and experimental research. However, the absent of relative process calculation model makes it difficult to determine the coke saving potential quantitatively and supply substantial guidance for practical production. Based on ironmaking process theories, the effect of using high reactivity coke on RIST operation line is firstly analyzed. Taking the heat conservation zone and high temperature zone as investigation targets, a new process calculation model based on material and heat balance is established to study the influences of charging high reactivity coke on iron oxide reduction, shaft efficiency, fuel rate as well as coke saving potential. The results show that: The charging of high reactivity coke on the one hand encourages endothermic boudouard reaction, on the other hand promotes the exothermic indirect reduction. The total heat balance reduces the temperature of the heat conservation zone. Although there is partly direct reduction happened in the heat conservation zone, the increasing iron oxide reduction efficiency would greatly reduce direct reduction in the high temperature zone. The charging of high reactivity coke reduces not only direct reduction, but also heat consumption of high temperature zone by allocating the direct reduction region reasonably, which leads to lower fuel rate.

Key words: Blast furnace; High reactivity coke; Heat conservation zone; Process calculation model.

[1] Technical contribution to the 6th International Congress on the Science and Technology of Ironmaking – ICSTI, 42nd International Meeting on Ironmaking and 13th International Symposium on Iron Ore, October 14th to 18th, 2012, Rio de Janeiro, RJ, Brazil.

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ISSN 2176-3135

1 INTRODUCTION

Nowadays, to save the coke rate further, using high reactivity coke in the blast furnace is concerned. The traditional viewpoint is that using high reactivity coke in the blast furnace would lower the coke strength after reaction (CSR) and damage the permeability of stock column.[1] However, recent researches and experiments show that using high reactivity coke in the blast furnace can be beneficial.[2] The common coke takes the boudouard reaction in the high temperature zone and enhances the direct reduction while high reactivity coke can take the boudouard reaction in the heat conservation zone of lower temperature because of its high reactivity, which makes differences in the heat conservation zone.[3,4] Without charging high reactivity coke in the blast furnace the indirect reduction mainly reacts in the heat conservation zone as follow. [5]

$$FeO+CO=Fe+CO_2 \quad (1)$$

New reactions take place in the heat conservation zone when high reactivity coke is used as the following equations.

$$C+CO_2=2CO \quad (2)$$

$$FeO+CO=Fe+CO_2 \quad (3)$$

$$FeO+nCO=Fe+(n-1)CO+CO_2 \quad (4)$$

The endothermic boudouard reaction on the one hand lowers the temperature of the heat conservation zone, on the other hand increases the CO amount, which results in an increasing driving force of the indirect reduction in the heat conservation. In addition, the sufficient boudouard reaction makes the direct reduction move up to take place in the heat conservation zone, which reduces the heat consumption in the high temperature zone. As a result, decreasing direct reduction degree and reducing energy consumption of the blast furnace are achieved.
The influence of high reactivity coke on the blast furnace can be obviously observed from the RIST diagram. As Figure 1 shows the chemistry equilibrium point moves toward right because of decreasing CO equilibrium concentration caused by lower heat conservation zone temperature. The heat equilibrium point moves downward because of decreasing heat consumption caused by higher reduction efficiency. Therefore, the slope of the ideal operation line becomes smaller to supply a greater coke saving potential.[6-8]

ISSN 2176-3135

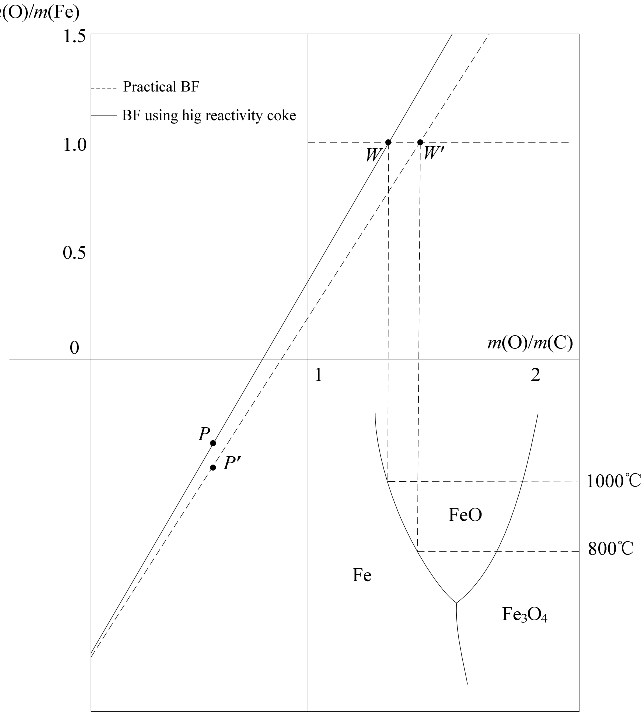

Figure 1. Ideal RIST operation line of practical and using high reactivity coke in BF.

However, the relative process calculation model is absent, which makes it difficult to determine the coke saving potential quantitatively and supply substantial guidance for practical production. In this paper, a new process calculation model is established to study the influences of charging high reactivity coke in the blast furnace on the heat conservation zone temperature, iron oxide reduction, shaft efficiency, fuel rate and coke saving potential.

2 ESTABLISHMENT OF THE NEW PROCESS CALCULATION MODEL

On the basic of material and heat balance in the blast furnace, the influence of charging high reactivity coke in the blast furnace on the heat conservation zone and high temperature zone is analyzed and the calculation module of theoretical coke rate which can determine the saving coke rate is established, and then investigate the coke rate, reduction degree, shaft efficiency and saving coke potential through the RIST operation line. In the new process calculation model the amount of high reactivity coke participating boudouard reaction varies in order to pursue the suitable amount of reaction by studying the changing parameters.

The model mainly includes five modules: the material balance module, the heat balance module, the heat conservation zone and high temperature zone calculation module, theoretical coke rate calculation module and the RIST operation line module, among which the third and the fourth ones are the core of the model.

The heat conservation zone and high temperature zone calculation module is established on the basis of the following theories. In the heat conservation zone, the boudouard reaction impels the direct reduction of FeO. CO produced by direct reduction participates in the FeO indirect reduction along with CO leaving from the lower high temperature zone. The increasing amount of CO and lower temperature enhance the indirect reduction. The indirect reduction degree can be obtained on the condition of the total CO amount in this zone and the varied temperature. The calculation process is shown in Figure 2.

ISSN 2176-3135

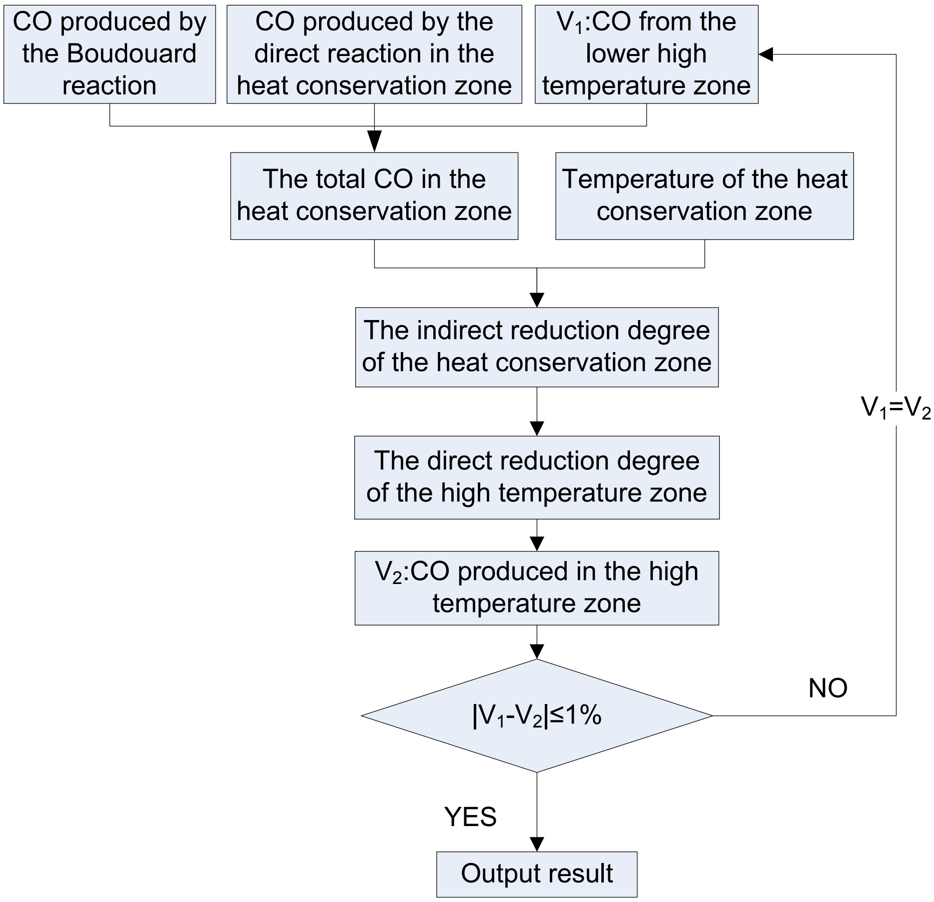

Figure 2. Calculation process of the heat conservation zone and high temperature zone module.

In the theoretical coke rate module, the saving coke rate can be obtained through the study of theoretical coke rate and direct reduction degree. The variation trends of the theoretical and practical coke rate are assumed to be the same. Based on above assumption, the variation of the practical coke rate can be reflected from the theoretical coke rate. The coke rate is mainly related with the carbon consumption in front of the tuyere and carbon consumption of FeO direct reduction. In this module the heat equilibrium and the carbon-oxygen equilibrium in the high temperature zone are established to work out the theoretical coke rate. Saving coke amount can also be obtained.

In the operation line module, the reduction degree, shaft efficiency, saving coke potential and other parameters can be obtained to analyze the quantitative influence of high reactivity coke on the blast furnace production.

3 RESULTS AND DISCUSSION

As the new process calculation model has been established, it can be used to investigate the practical blast furnace charging high reactivity coke. In this paper, we assume that the coke amount participating boudouard reaction (CAPBR) increase from 0 to 40 kg/t by 10kg/t and compare the parameters with each other. The results are analyzed in the followings sections.

ISSN 2176-3135

3.1 The Heat Conservation Zone Temperature

Usually, the heat conservation zone temperature is considered to be 1,000 °C. As shown in Figure 3 and Table 1, the heat conservation zone temperature decreases gradually with increasing CAPBR. The temperature could decrease to 970 °C when the CAPBR is 40 kg/t. With a higher reactivity the high reactivity coke can take endothermic boudouard reaction in the heat conservation zone which is in a lower temperature compared with the high temperature zone. The boudouard reaction and indirect reduction can be considered together to be direct reduction. Therefore the strongly endothermic direct reduction lowers the temperature of the heat conservation zone.

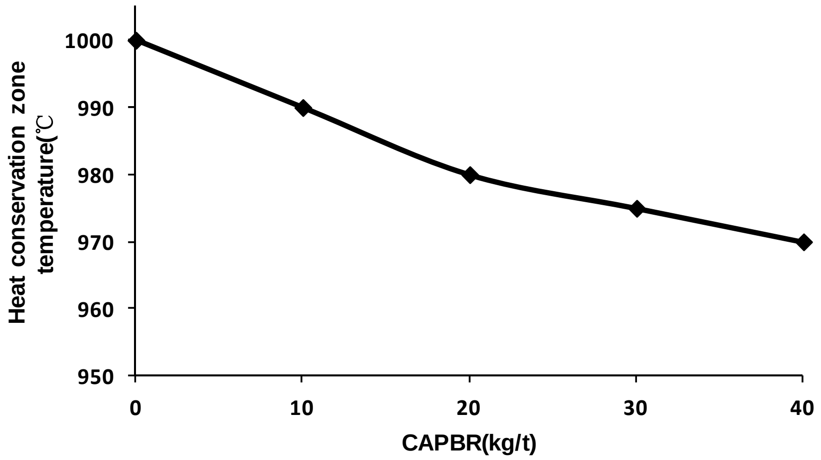

Figure 3. Relationship of heat conservation zone temperature and CAPBR.

Table 1. Relationship of heat conservation zone temperature and CAPBR

CAPBR(kg/t)	0	10	20	30	40
Heat conservation zone temperature(%)	1000	990	980	975	970

3.2 The Reduction Degree

As is shown in Figure 4 and Table 2, with increasing CAPBR the direct reduction degree decreases while the indirect reduction degree increases. The direct reduction degree reaches 0.369 when the CAPBR is 40 kg/t, which is very close to the theoretical suitable direct reduction degree. Therefore charging high reactivity coke can lower the direct reduction degree remarkably.

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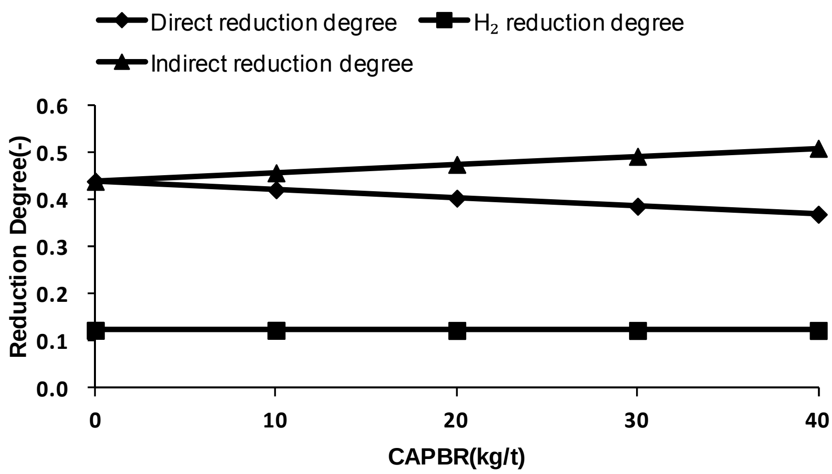

Figure 4. Relationship of reduction degree and CAPBR.

Table 2. Relationship of reduction degree and CAPBR

CAPBR(kg/t)	Direct reduction degree	H_2 reduction degree	Indirect reduction degree
0	0.439	0.123	0.439
10	0.421	0.123	0.457
20	0.403	0.123	0.474
30	0.386	0.123	0.492
40	0.369	0.122	0.509

3.3 The Shaft Efficiency

Without using high reactivity coke, the shaft efficiency of practical blast furnace is 92.30%. As the CAPBR increases, the shaft efficiency almost increases in liner (shown in Figure 5 and Table 3). Obviously, using high reactivity coke has a positive influence on improving the efficiency of blast furnace. However, when the CAPBR reaches 40kg/t, the shaft efficiency is close to 100%, which illustrates that the suitable CAPBR can be about 40kg/t.

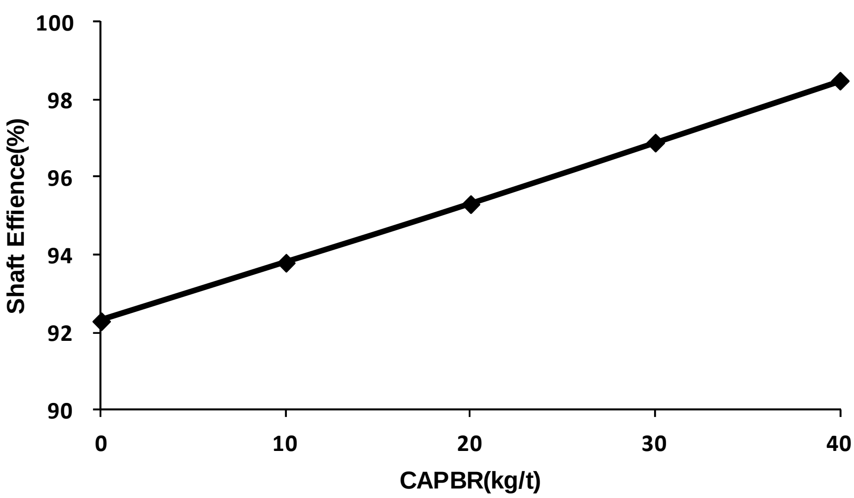

Figure 5. Relationship of shaft efficiency and high reactivity coke.

Table 3. Relationship of shaft efficiency and CAPBR

CAPBR(kg/t)	0	10	20	30	40
Shaft efficiency(%)	92.30	93.80	95.31	96.90	98.50

ISSN 2176-3135

3.4 The Fuel Rate

The slope of operation line stands for the carbon atom number that needs to produce a Fe atom, which is similar to the coke rate. Thus the coke rate can be obtained easily from the operation line. The trends of theoretical coke rate, practical coke rate and practical fuel rate are shown in Figure 6 and Table 4. It shows that the saving coke rate increases as the CAPBR increases. the saving coke rate reaches 16.80 kg/t as the CAPBR is 40 kg/t, which obtains a good effect.

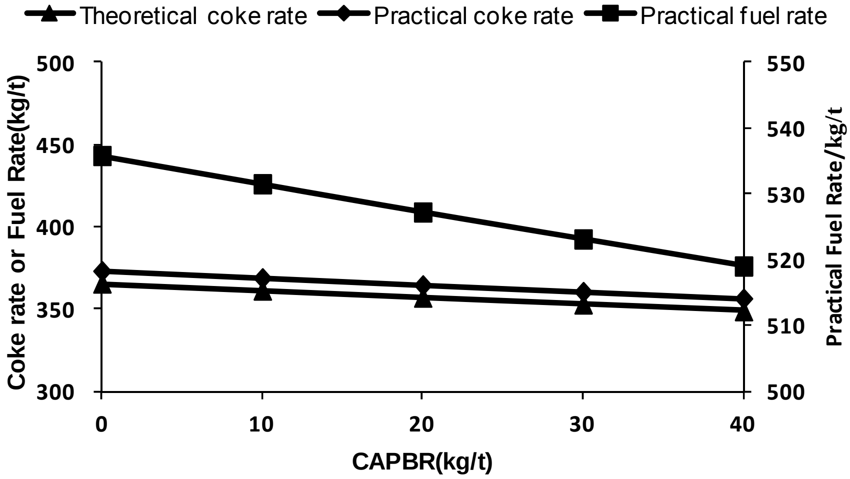

Figure 6. Relationship of fuel rate and CAPBR.

Table 4. Relationship of fuel rate and CAPBR

CAPBR(kg/t)	Theoretical coke rate(kg/t)	Practical coke rate(kg/t)	Practical fuel rate(kg/t)	Saving coke amount(kg/t)
0	365.53	373.00	535.77	0
10	361.24	368.71	531.47	4.29
20	356.95	364.42	527.18	8.59
30	352.84	360.31	523.08	12.69
40	348.74	356.20	518.97	16.80

3.5 Coke Saving Potential

The coke saving potential or the possible saving coke rate (PSCR) refers to the gap between the slope of ideal operation line and practical operation line. The calculation results of slopes of operation line are shown in Figure 7. The slope of operation line tends to decrease as the CAPBR increases. However, the gap between the ideal operation line and the practical operation line tends to decrease gradually, which means that the PSCR is getting smaller because of the increasing CAPBR. The less the PSCR is, the better efficiency the blast furnace reaches. The trend of PSCR can be seen more obviously from Figure 8 and Table 5. As the CAPBR increases to 40 kg/t, the PSCR decreases to 6.5 kg/t, which illustrates that the blast furnace using high reactivity coke have almost achieved a perfect state.

ISSN 2176-3135

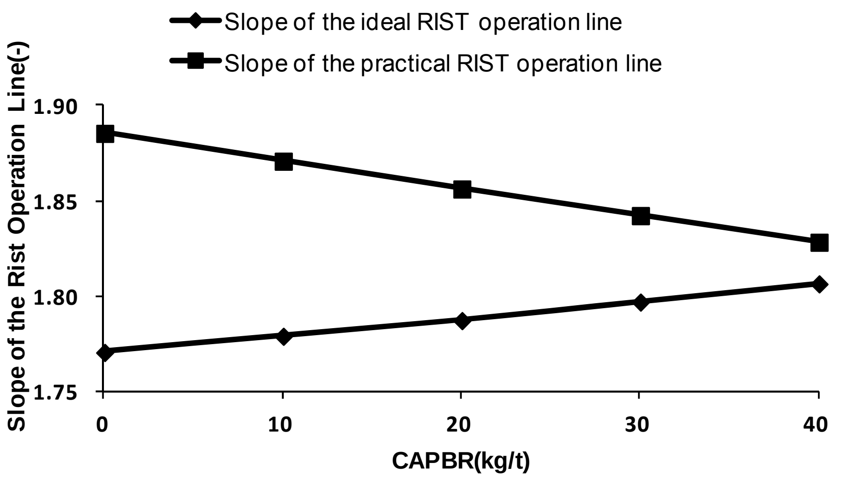

Figure 7. Relationship of the slope of RIST operation line and CAPBR.

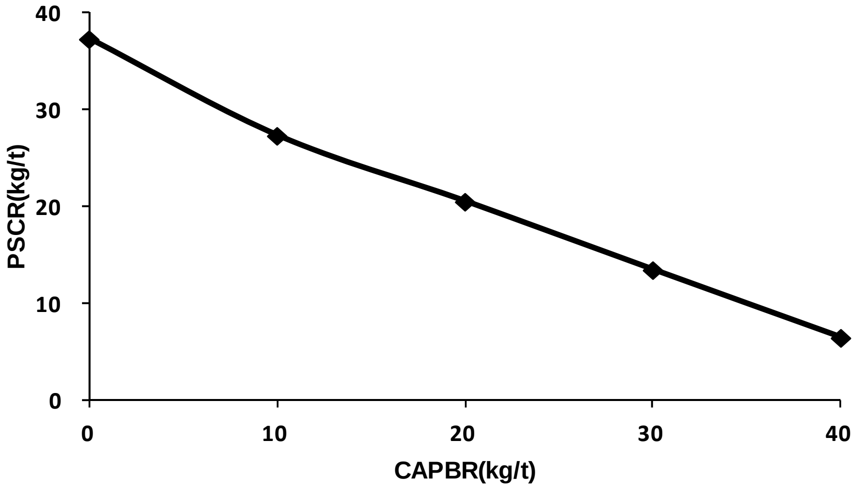

Figure 8. Relationship of PSCR and CAPBR.

Table 5. Relationship of PSCR and CAPBR

CAPBR(kg/t)	0	10	20	30	40
PSCR(%)	37.32	27.35	20.55	13.50	6.50

4 CONCLUSIONS

On the basis of establishment and study of new process calculation model of using high reactivity coke in the blast furnace in this paper, the following conclusions are obtained.

- The charging high reactivity coke which takes endothermic boudouard reaction in the heat conservation zone lowers the temperature of this zone. The temperature decreases 30 °Cwhen the CAPBR is 40 kg/t.
- Although there is partly direct reduction happened in the heat conservation zone, the increasing iron oxide reduction efficiency would greatly reduce direct reduction in the high temperature zone. The direct reduction degree decreases from 0.439 to 0.369 as the CAPBR increases from 0 to 40 kg/t.
- The charging of high reactivity coke reduces not only direct reduction, but also heat consumption of high temperature zone by allocating the direct reduction region reasonably, which leads to lower fuel rate. When the CAPBR reaches 40 kg/t, the coke rate decreases 16.80 kg/t.

ISSN 2176-3135

Acknowledge

The financial support of the National Natural Science Foundation of China (50974143) and Fundamental Research Funds for the Central Universities (FRF-TP-12-021A) is gratefully acknowledged.

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