

## INFLUENCE OF COAL SORT ON THE DIRECT REDUCTION OF HIGH-IRON-CONTENT RED MUD<sup>†</sup>

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**Abstract** The technology of coal-based direct reduction of high-iron-content red mud is studied. The factors affecting this kind of direct reduction mainly are: coal sort, carbon amount, time, temperature and etc. has been investigated. It has been shown that an ideal coal sort must have the following qualities: high reactivity, large ratio of  $(F_c + V_m)/A$  and  $(\text{SiO}_2 + T_{\text{Fe}})/(\text{Al}_2\text{O}_3 + \text{Others})$  and the ability of forming a moderate porosity.

**Key word:** red mud; coal sort; direct reduction

The main chemical composition of the gibbsite bauxite in Guangxi Province, with low aluminium content and high iron content is 27.5%  $\text{Al}_2\text{O}_3$ , 42.99%  $\text{Fe}_2\text{O}_3$ , 6.89%  $\text{SiO}_2$ . Apparently, aluminum and iron must be synthetically retrieved in order to make this deposit worthy of extracting.

According to the characteristics of the deposit, the plan of "Aluminum first, iron second" has been put forward by CSUT and great progress has been made. One of the key items of the plan is to utilize the Bayer's red mud from the gibbsite bauxite. Based on the fact that in China coal is plentiful and scrap steel is limited, the technology of coal-based direct reduction of high-iron-content red mud is studied.

### 1 EXPERIMENTAL

#### 1.1 Material

The main composition of the red mud is 54.60%  $\text{Fe}_2\text{O}_3$ , 15.08%  $\text{Al}_2\text{O}_3$ , 8.90%  $\text{SiO}_2$  and 1.85%  $\text{Na}_2\text{O}$ .

Five sorts of coal are used as the reductive and their natures are listed in Table 1 and Table 2.

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**Synopsis of the first author** Qiu Guanzhou, professor, born in Feb., 1949. Speciality: fine mineral processing, synthetic utilization of natural resources and direct reduction. He has won prizes given by SEC and CNNC, achieved 2 Chinese patents, published more than 50 scientific papers and 2 monographs. In 1994, he was chosen as one of the 40 Talents through the Century by SEC.

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Table 1 Coal's main nature

	fixed carbon( $F_c$ )(%)	volatile matter( $V_m$ )(%)	ash $A$ (%)	$(F_c+V_m)/A$	Reactivity (g/min)
NC-1	67.64	11.50	20.86	3.79	0.11
NC-2	68.00	14.53	17.47	4.72	0.15
NC-3	70.15	16.33	13.52	6.40	0.20
NC-4	68.50	5.19	26.31	2.80	0.08
NC-5	90.57	—	9.43	9.60	0.24

Table 2 Ash composition (%)

	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	T <sub>Fe</sub>	CaO	MgO	Others
NC-1	44.17	33.86	9.09	*	*	12.88
NC-2	48.75	34.44	6.23	*	*	10.58
NC-3	49.33	29.00	6.72	*	*	14.95
NC-4	47.25	31.03	3.11	*	*	18.61
NC-5	47.76	27.69	9.53	*	*	15.02

\* : trace

## 1.2 Method

The coal and red mud are mixed and agglomerated into the lumps with the size of  $\Phi 12 \times 12$  mm under the pressure of  $1.96 \times 10^7$  Pa. After the lumps are dried at the temperature of 378 K, they are put into the tube furnace to be reduced in the reducing atmosphere. Then, the reduced product is removed, cooled in water, finely ground and magnetically separated. Metallization degree ( $\eta_{Me} = M_{Fe}/T_{Fe}$ ), reduction degree ( $R = 1 - Fe^{2+}/3T_{Fe} = 1 - 0.2591FeO/T_{Fe}$ ) and slag-iron separation degree are used as the main basis of judging the experiment.

## 2 RESULT AND DISCUSSION

### 2.1 The Main Factors Affecting the Reducing Process

As for the coal-base direct reduction of iron oxide, there's a formula<sup>[1,2]</sup>:

$$t_R = \frac{R'}{A \cdot \exp(-\frac{E}{R^0 T}) \cdot K_a M_c} + \frac{r_0 \rho_0}{3D_e} \cdot [\frac{1}{2} - \frac{1}{3}R' - \frac{1}{2}(1 - R')^{2/3}]$$

where

$t_R$ —time needed for the iron oxide pellet to be reduced to  $R=R'$ , sec

$R'$ —reduction degree of the reduced product, %

$A$ —carbon's reactivity constant

$E$ —activation energy, J/mol

$R^0$ —ideal gas constant, 8.314 J/mol·K

$T$ —temperature, K

$K_a$ —the balance constant of the reaction  $FeO + CO = Fe + CO_2$

$M_c$ —carbon amount, %

$r_0$ —the radius of iron oxide pellet when  $R=R'$

$\rho_0$ —the initial oxygen content of the iron oxide pellet, mol/m<sup>3</sup>

$D_e$ —the diffusion coefficient in solid phase, m<sup>2</sup>/s

From this formula we can know that the factors affecting the direct reduction are  $M_c$ ,

$T$ ,  $E$  and coal sort.

1423 K was chosen as the experiment temperature<sup>[3]</sup>. The effect of activation energy  $E$  was thoroughly discussed in another group of experiments and will not be mentioned here.

## 2.2 The Influence of Carbon Amount

After NC-5 was chosen as the reductive, different red mud lumps in which 0.5 Ct, 1 Ct, 1.5 Ct and 2 Ct (Ct: theoretically needed carbon amount) were added respectively were reduced at two different temperatures; 1373 K and 1423 K. The reducing time was 90 min and the result was shown in Fig. 1.

It can be seen that the highest metallization degree and the lowest  $\text{Al}_2\text{O}_3$  content of the iron concentrate were achieved when 1Ct was added. When the carbon amount was low, the reducing atmosphere was weak and the reducing reaction was undeveloped. When the carbon amount was too high, the lump porosity became large and partial reducing reaction was developed very quickly. The fact that the metal iron formed in a short while covered the unreduced part made it difficult for the gas  $\text{CO}$  or  $\text{CO}_2$  to pass through the iron layer and diffuse inside or outside, so the reducing reaction was difficult to continue and to be completely finished.

## 2.3 The Influence of Coal Sort

Different kinds of coal were used to directly reduce the red mud in different time at the temperature of 1423 K and the results are given in Fig. 2.

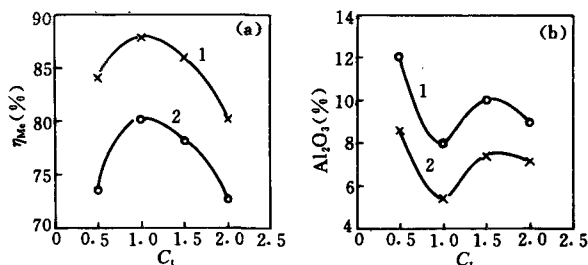


Fig. 1 The relation between  $\eta_{Me}$ ,  $\text{Al}_2\text{O}_3$  and  $M_c(C_t)$

1—1423 K 2—1373 K

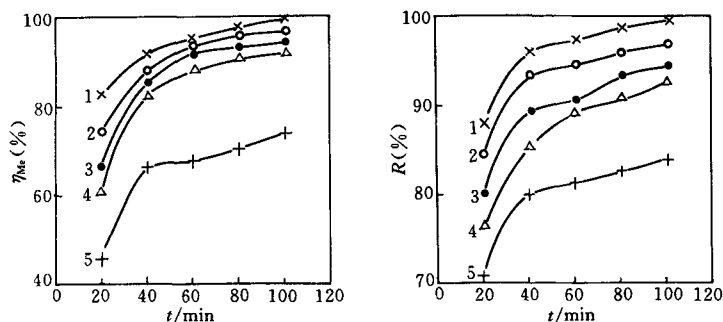


Fig. 2 The influence of coal sort on  $\eta_{Me}$  and  $R$

1—NC-5; 2—NC-3; 3—NC-2; 4—NC-1; 5—NC-4

It follows that the coal order from good to bad was  $\text{NC-5} > \text{NC-3} > \text{NC-2} > \text{NC-1} > \text{NC-4}$ . This order was set by different reactivity,  $(F_c + V_m)/A$  and porosity formed by different coal (see Fig. 3).

The reducing atmosphere increased and the reaction developed with the increase of the reactivity, so  $\eta_{Me}$  and  $R$  rise.

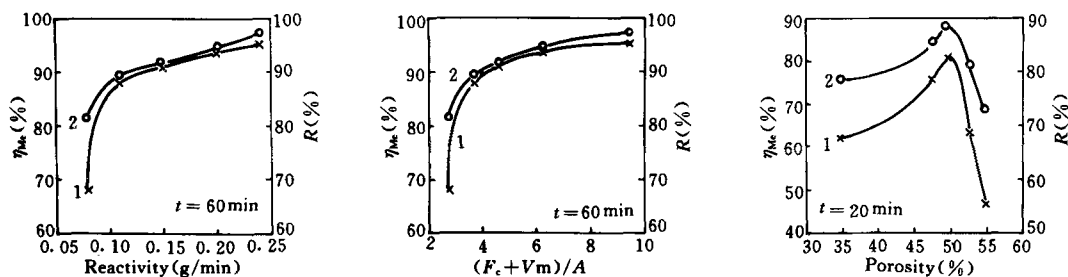


Fig. 3 The relation between reactivity,  $(F_c + V_m)/A$ , porosity and  $\eta_{Mc}$ ,  $R$   
 1— $\eta_{Mc}$ ; 1— $R$

When  $(F_c + V_m)/A$  became large, the amount of fixed carbon was relatively high and this was of course beneficial to the direct reduction. At the same time, the increased matter may be volatile. Along with the increase of volatile, the reductives, such as  $\text{CO}$ ,  $\text{H}_2$  and  $\text{CH}_4$ , were raised. When the volatile spilled, the porosity increased and the diffusion of reducing gas became easier. In addition, ash content decreased too and this was also beneficial to the direct reduction because of the following reason. When ash content increased, it became easier for the ash to react with  $\text{Al}_2\text{O}_3$  or  $\text{FeO}$  to form complicated compounds, such as  $2\text{FeO} \cdot \text{SiO}_2$ , and low melting point compounds which stopped gas holes and hampered the diffusion of reducing gas.

The porosity has obvious influence on the reduction process. When the organism obtained in the coal volatiled during the reducing process at high temperature, enormous micro holes were formed and this could accelerate the reducing process. When the ash content was high and the melting point was low, big holes were formed during the reduction process because of the low-melting-point compounds. It seems that the porosity has increased, however, the efficient reacting area decreased, so  $\eta_{Mc}$  and  $R$  dropped.

In addition, five coal sorts, from NC-1 to NC-5, were used to study the coal's influence on the slag-iron separation and the result was shown in Fig. 4.

In pace with the raise of reactivity, the reducing atmosphere became stronger;  $\eta_{Mc}$  and  $R$  were enhanced, so slag-iron separation was improved and there existed a descending tendency for the content of  $\text{Al}_2\text{O}_3$ ,  $\text{SiO}_2$ , Na.

Furthermore, the ash composition has an obvious influence on the slag-iron separation. During the reducing process, it is easy for  $\text{FeO}$  to react with  $\text{Al}_2\text{O}_3$  or  $\text{SiO}_2$ , resulting in the formation of  $\text{FeO} \cdot \text{Al}_2\text{O}_3$  or

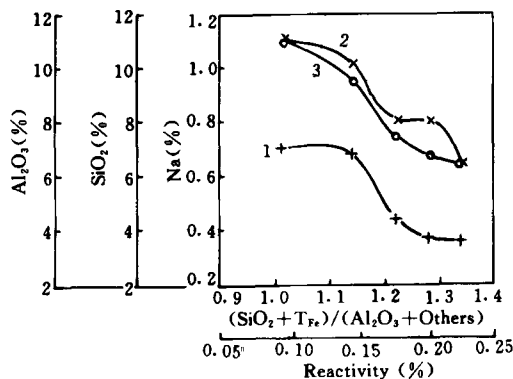
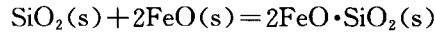
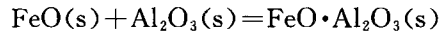


Fig. 4 The influence of coal sort on slag-iron separation  
 1—Na; 2— $\text{SiO}_2$ ; 3— $\text{Al}_2\text{O}_3$

$2\text{FeO}\cdot\text{SiO}_2$ ,



$$\Delta G = -33231 + 15.26 T$$



$$\Delta G = -49324 + 22.70 T$$

Within the temperature range permitted by the direct reduction,  $\text{FeO}\cdot\text{Al}_2\text{O}_3$  was more difficult to be reduced than  $2\text{FeO}\cdot\text{SiO}_2$ . At the same time, the increase of  $T_{\text{Fe}}$  content also meant the decrease of impurity content. So, as  $(\text{SiO}_2 + T_{\text{Fe}})/(\text{Al}_2\text{O}_3 + \text{Others})$  rose, the impurity ( $\text{Al}_2\text{O}_3$ ,  $\text{SiO}_2$ , Na) content decreased and it was easier to separate slag from iron.

### 3 CONCLUSION

The ideal reducing condition for the coal-base direct reduction of high-iron-content red mud includes using the reductive containing as much carbon as theoretically needed and having the following qualities: high reactivity, large ratio of  $(F_c + V_m)/A$  and ash composition  $(\text{SiO}_2 + T_{\text{Fe}})/(\text{Al}_2\text{O}_3 + \text{Others})$ , the ability of forming a moderate porosity.

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