1. Introduction

The alternatives to blast furnace process, COREX and FINEX are 2-stage smelting reduction processes. Iron ore is pre-reduced in a shaft furnace or fluidized bed reactors, and then the pre-reduced iron ore is fully reduced and melted in a melter-gasifier. By almost separating reduction and melting like this, pre-treatment processes of raw material, i.e., sintering and coking processes, could be omitted. Figure 1 compares blast furnace process and smelting reduction process.

![Fig. 1. Schematic diagram comparing blast furnace process and smelting reduction process.](image)

However, it is actually difficult to maintain a high reduction degree in a pre-reducing unit because the reduced iron ore can agglomerate each other or stick to any facilities in furnaces inhibiting normal operation. The agglomeration rate of hematite iron ore increases much when the reduction temperature increases from 800°C to 900°C and the sticking index increases when the reduction degree is high.

Hence, it can be more advantageous to operate a pre-reducing unit in lower temperature range because the maintenance cycle can be increased. Although a pre-reducing unit can not reduce iron ore much, the melter-gasifier can reduce it completely when considering the high temperature and the high reducing potential inside a melter-gasifier. But no research has not determined the minimum pre-reduction degree required for a melter-gasifier.

When less pre-reduced iron ore is charged to a melter-gasifier, at first, indirect reduction will take place in the upper layer of the charged material bed in the same way as before. But the reduction will continue into the deeper layer of the charged material bed, which is hotter than the upper layer. So if the pre-reduction degree is less than some value which can be changed by operational conditions, the product gases, CO₂ or H₂O, of indirect reduction can react with the carbon in the heated coal in the melter-gasifier.

The indirect reduction accompanying the reaction of CO₂ or H₂O with carbon, called the Boudouard reaction, is equivalent to direct reduction, which is a strongly endothermic reaction. In a blast furnace, the CO or H₂ amount necessary for reducing of iron ore is a key determinant of the carbon ratio, the amount of carbon used for making 1-ton of hot metal. Therefore, direct reduction is necessary to reduce the...
carbon ratio in a blast furnace.\textsuperscript{4)}

But in a melter-gasifier into which pure \textit{O}_2 in room temperature is injected instead of hot air, the heat requirement is a key determinant of carbon ratio. In a melter-gasifier, the volatile matter of coal generates a lot of \textit{CO} and \textit{H}_2, so most of the oxygen in iron oxide can be removed indirectly without increasing carbon ratio. But if direct reduction happens, additional carbon has to be burned at the tuyere to compensate the heat loss by direct reduction.

Then which factors and how they control the direct reduction ratio, the key determinant of the carbon ratio? If the \textit{CO}_2 content of the ascending gas is zero due to the termination of reduction and calcination when the coal charged in room temperature is heated up to the temperature at which the carbon in the coal can react with \textit{CO}_2 or \textit{H}_2O, then no direct reduction will take place. Thus the direct reduction ratio will be changed by the reduction rate of Pre Reduced Iron ore (PRI), the temperature at which coal can react with \textit{CO}_2 or \textit{H}_2O and the reaction rate above the temperature.

Regarding the reduction rate of iron ore, the effect of temperature\textsuperscript{5)} and the effect of \textit{H}_2\textsuperscript{6)} were researched well by many researchers. But the reduction of PRI can be different with that of unreduced iron ore because PRI was made by being semi-reduced and compacted again. It has been also researched well about coal’s reactivity by many researchers,\textsuperscript{7)} but the condition of melter-gasifier can affect coal’s reactivity because the coal charged into a melter-gasifier is carbonized moving down continuously and swelling more freely than in a coke oven.

This research considered, first, the influence factors for the \textit{CO}_2 content in the ascending gas and the reactivity of coal with \textit{CO}_2. The reduction rate of PRI was compared with that of iron ore, and the effects of possible operational variables on the reduction rate, i.e., temperature and gas composition, were measured. Coal was made into char in the condition simulating melter-gasifier and then, the reaction rates of the char with \textit{CO}_2 were compared with that of coke and measured at several temperatures and gas compositions. Second, it was discussed with the measurement results about how the direct reduction ratio will be determined and how it can be minimized.

2. Experimental

To measure the reduction rate of Pre-Reduced Iron ore (PRI), PRI pellets were prepared simulating HCI (Hot Compacted Iron in FINEX), one of PRIs. First, 9.5 to 13.0 mm lump ores with 10 mass\% lump fluxes (5 mass\% limestone and 5 mass\% dolomite) were semi-reduced inside a quartz sample holder in a horizontal furnace at 750°C. Then, after being ground under 1 mm and mixed at room temperature, the pre-reduced iron ore and flux were pressed at 20 bar of pressure to make cylindrical pellets, of which the diameter is 10 mm, the height is 7 mm and the weight is 1.60 g. The composition of the output gas from the sample holder was monitored by QMS (Quadrupole Mass Spectrometer, GAM 400) so that the reduction degree of lump ores could be estimated roughly \textit{in situ}. According to the reduction degree, the ratio of removed oxygen amount versus original oxygen amount excluding gangue’s oxygen, two kinds of PRI pellets were made, low (39\%) and highly (49\%) reduced PRI pellets, respectively. Figure 2 shows the reducing facilities and Table 1 shows the chemical composition of lump ore, fluxes and PRI pellets.

The reduction rates of low reduced PRI pellets were measured by TGA at 700°C, 800°C, 900°C and 1 000°C. The composition of the reducing gas were 85 vol.\% \textit{CO}, 5 vol.\% \textit{CO}_2, 10 vol.\% \textit{Ar} and 70 vol.\% \textit{CO}_2, 15 vol.\% \textit{H}_2; 5 vol.\% \textit{CO}_2, 10 vol.\% \textit{Ar} at each temperature. At 900°C, 2 more tests were done in the conditions of 5 and 10 vol.\% \textit{H}_2, while maintaining the sum of \textit{CO} and \textit{H}_2 contents as 85 vol.\%. After a PRI pellet reached the target temperature in \textit{Ar} atmosphere, the reducing gas was injected. The reduction rates of highly reduced pellets were measured in the several conditions through the same procedure. The reduction rate of the lump ore used to make the PRI pellets was also measured at 900°C, 15 vol.\% \textit{H}_2 through the same procedure as that for the PRI pellets. The total flow rate of the reducing gas was 1 L/min which made the linear velocity of the gas to 2.9 cm/s. A total flow rate of 1.3 L/min did not show any significant difference in the result with that of 1 L/min in the condition of 900°C and 15 vol.\% \textit{H}_2.

The reduction rates of low reduced PRI pellets were also measured at the heating rate of +4°C/min from 700 to 1 100°C. The total flow rate of the reducing gas was 1.0 L/min and the compositions of the reducing gas were 85 vol.\% \textit{CO}, 5 vol.\% \textit{CO}_2, 10 vol.\% \textit{N}_2 and 70 vol.\% \textit{CO}, 15 vol.\% \textit{H}_2, 5 vol.\% \textit{CO}_2, 10 vol.\% \textit{N}_2. A PRI pellet was heated to 700°C in \textit{N}_2 atmosphere and the reducing gas was injected from 700°C. The same experiment was also done in \textit{N}_2 atmosphere up to 1 100°C without injecting the reducing gas.

To measure the reaction rates of coal with \textit{CO}_2, two groups of identical coal were carbonized in melter-gasifier condition and coke oven condition each. To simulate melter-gasifier condition, lump coal of 20 to 60 mm diam-

![](image)

**Fig. 2.** Chemical diagram of the facilities reducing lump iron ore.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>T. Fe</th>
<th>M. Fe</th>
<th>Fe(^{2+})</th>
<th>CaO</th>
<th>SiO(_2)</th>
<th>MgO</th>
<th>Al(_2)O(_3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lump ore</td>
<td>60.9</td>
<td>–</td>
<td>0.1</td>
<td>0.1</td>
<td>4.9</td>
<td>0.0</td>
<td>2.2</td>
</tr>
<tr>
<td>Lim estone</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>50.5</td>
<td>1.5</td>
<td>3.4</td>
<td>0.5</td>
</tr>
<tr>
<td>Dolomite</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>30.1</td>
<td>0.7</td>
<td>21.5</td>
<td>0.2</td>
</tr>
<tr>
<td>PRI P. (L)</td>
<td>60.7</td>
<td>7.6</td>
<td>47.9</td>
<td>4.0</td>
<td>5.0</td>
<td>1.3</td>
<td>1.9</td>
</tr>
<tr>
<td>PRI P. (H)</td>
<td>60.7</td>
<td>15.3</td>
<td>42.7</td>
<td>4.0</td>
<td>7.6</td>
<td>1.8</td>
<td>2.3</td>
</tr>
</tbody>
</table>
eter was put into a 200 mm diameter of drum rotating at 2 rpm, which was kept at 1000°C in N2 atmosphere. Several fins were equipped with inside of the drum like Fig. 3 to lift and drop the coal simulating the instability due to its descending inside a melter-gasifier. 30 min after placing coal into the drum, the rotation of drum was stopped and the inside of the drum was naturally cooled down to room temperature. The carbonized coal in melter-gasifier condition, i.e. char, was withdrawn and ground to under 1 mm, 30 μm in average.

To simulate coke oven condition, the experiment method employed by Sung-Man Kim was used. The identical lump coal was ground to under 1 mm, and 32 g of it was put into the cylinder of 40 mm inner diameter and 70 mm inner height as shown in Fig. 4. The height of coal inside the cylinder was 23.3 mm. Then the coal inside the cylinder was pressed at 100 bar of pressure and the empty space above the coal was filled with glass wool of 31.4 g. The cylinder was capped with a cover which has several hole for later and drop the coal simulating the instability due to its fins were equipped with inside of the drum like Fig. 3. The reaction rates of the char with CO2 were also measured by TGA at 950°C, 1000°C, 1050°C, 100% CO2, and 1150°C. The ground char was heated to the target temperature in N2 atmosphere. After the ground char reached the target temperature, the reacting gas was injected. The gas compositions of the reacting gas were 3 kinds. N2 was 10% in all compositions, CO2 was changed to 9%, 18%, 27%, and CO was the rest. The total flow rate of the injecting gas was 1 L/min which made the linear velocity of the gas to 2.9 cm/s. A total flow rate of 1.5 L/min showed no difference in the result with that of 1 L/min in the condition of 1150°C, 18 vol.% CO2.

To compare the reaction rates of the char and the coke with CO2 and each activation energies, non-isothermal experiments were also performed injecting only CO2 at the rate of 1 L/min with increasing temperature from room temperature to 1050°C.

3. Results

3.1. Reducibility of PRI Pellet

When a PRI pellet was heated to the target temperature in Ar atmosphere for measuring the reduction rate, the weight of a PRI pellet decreased in the temperature range of 700 to 850°C due to calcination of the flux in the PRI pellet. Right after the reducing gas was injected at the target temperature, the weight of a PRI pellet started to decrease again being reduced like Fig. 5. Before injecting the reducing gas the weight losses were almost same as 3.0% in all low reduced PRI pellets.

In the experiments at 800°C, the reducing gas was injected after the temperature reached higher than 850°C and came back to 800°C like Fig. 5(b). This means that the reducing gas was injected after the termination of calcination in the experiments at 800°C, 900°C, 1000°C. But in case of the experiments at 700°C, the reducing gas was injected right after the temperature reached 700°C without calcination like Fig. 5(a). This was because some of the CO2 from reduction would have been absorbed to calcined flux in a PRI pellet at 700°C and increased the sample’s weight if the reducing gas was injected after calcination.

Through these isothermal measurements of the reduction rates of PRI pellets, four characteristics were observed. The first was that the reduction rates of PRI pellets were slower than that of a lump ore. Figure 6 shows that even though the PRI pellets were already reduced up to 39% and 49%, they took longer or almost same to be reduced completely than a lump ore. In Figs. 6, 7, 8, 9, the weight change means the ratio of the weight change after the reducing gas was injected versus the original weight of the sample. So the weight change is proportional to the reduction degree and when the weight change keeps constant level, the reduction degree can be presumed to 100%. But in case of PRI pellets, the weight change of 0% means the reduction degree

![Fig. 3. Schematic diagram of carbonization drum simulating melter-gasifier condition.](image)

![Fig. 4. Schematic diagram of the carbonization cylinder and the heating furnace simulating coal oven condition.](image)

**Table 2.** Chemical composition of the same kind of coal as the tested lump coal (unit: %).

<table>
<thead>
<tr>
<th>Proximate Analysis</th>
<th>L.M</th>
<th>F.C</th>
<th>V.M</th>
<th>Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.7</td>
<td>56.1</td>
<td>32.5</td>
<td>8.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ash Composition</th>
<th>SiO2</th>
<th>CaO</th>
<th>MgO</th>
<th>Al2O3</th>
<th>Fe2O3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>63.4</td>
<td>1.1</td>
<td>0.8</td>
<td>24.5</td>
<td>5.2</td>
</tr>
</tbody>
</table>

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[276]
of 39% and 49% each.

The second was temperature dependence and Figs. 7, 8 show this. When the reduction temperature was increased from 700°C to 900°C, the reduction rate increased rapidly. At 700°C and 800°C, carbon decomposition was detected after some reduction. This tendency appeared whether the reducing gas contains H₂ or not. When the reduction temperature increased from 900°C to 1000°C, the reduction rate increased slightly and if the reducing gas contains H₂, the increase of reduction rate was a little bit more. At 700°C, if the reducing gas does not contain H₂, the reduction did not proceed much.

The third was H₂ content dependence. As shown in Fig. 9, when the reducing gas contained H₂ at each temperature the reduction rates were generally faster. At 900°C, when the H₂ content was increased from 0 to 10 vol.%, the reduction rate increased appreciably. But when the H₂ content was increased from 10 vol.% to 15 vol.%, the reduction rate increased slightly.

The fourth was that the reduction rates of highly reduced PRI pellets were slower than those of low reduced PRI pellets. But when the reducing gas contained H₂, the reduction rates of highly and low reduced PRI pellets were not much different as shown in Fig. 10.

When the reducing gas was injected with increasing tem-
temperature, the weight changes with the temperature which was proportional to the reduction time were shown in Fig. 11. The weight changes of PRI pellets were converted to CO$_2$ generation rate as shown in Fig. 12. Again, the CO$_2$ generation rates were converted to the accumulated CO$_2$ amounts which were estimated from high temperature to low temperature. When the reducing gas contained H$_2$, the completion of reduction was faster than when the reducing gas did not contain H$_2$ by about 70°C. Although CO$_2$ generation rate had some up and down, the change of the accumulated CO$_2$ were almost linear like Fig. 13. It means that the CO$_2$ content of the ascending gas in the charged material bed in a melter-gasifier, roughly, increases linearly, which means that the effects of temperature increase and shrinkage of the reaction interface in a PRI cancel out each other.

3.2. Reactivity of Char with CO$_2$

Next experimental results are about the reaction rate between char and CO$_2$. When the CO$_2$ content of the reacting gas was 100% and the temperature increased continuously the char reacted from lower temperature than the coke by about 70°C as shown in Fig. 14.

Figure 15 shows the reaction rate, i.e., conversion rate, between char and CO$_2$ with reaction time. The reaction rate is the ratio of the infinitesimal weight change of the sample to the initial sample weight per infinitesimal reaction time. Generally the reaction rate increased at first and maintained the maximum value for some time. Thus these maximum values of all the cases were gathered and compared in Fig. 16. The reaction rate increased exponentially with temperature, and was almost proportional to CO$_2$ content.

![Fig. 10. Difference between the reaction rates for initial 30 min of low and highly reduced PRI pellets when the reducing gas contained H$_2$ or not.](image10)

![Fig. 11. Weight change with reaction time when PRI pellets were calcined and reduced with increasing temperature. The small dot line shows the weight change only due to calcination of fluxes in a PRI pellet.](image11)

![Fig. 12. CO$_2$ generation rate with reaction time when PRI pellets were calcined and reduced with increasing temperature.](image12)

![Fig. 13. CO$_2$ amount generated from calcination and reduction which was accumulated reversely from high temperature to low temperature when PRI pellets were calcined and reduced with increasing temperature.](image13)

![Fig. 14. Comparison between the CO$_2$ reaction rates of char and coke in the atmosphere of CO$_2$ 100%.](image14)
4. Discussion

The reduction rates of PRI pellets were much slower than that of a lump ore, i.e., unreduced iron ore as expected due to the absence of the transformation from hematite to magnetite. As also expected, temperature was the most dominant factor to determine the reduction rate. But above 900°C, temperature did not affect much. When the reducing gas contains H₂, the reduction rate was faster and the reduction completed earlier than when it does not. If H₂ is expensive, 10 vol.% would be the optimum content of H₂.

The reaction rate of char with CO₂ started from lower temperature than coke by about 70°C when the reacting gas contained CO₂ 100%. The reaction rate of char with CO₂ increased exponentially with increasing temperature and was proportional to the CO₂ content in the reacting gas as the theory. If the reduction degree of PRI is low, then the possibility that direct reduction takes place in a melter-gasifier would be high because the PRI pellet was reduced more slowly than unreduced iron ore and the char reacted with CO₂ than coke. Direct reduction is equivalent to the Boudouard reaction right after indirect reduction. So, at certain height of the charged material bed, the direct reduction rate can be expressed as the product of the rate constant of the Boudouard reaction and the CO₂ content in the ascending gas, which is determined by the amount of the reduction by CO under the height like Eq. (1). In Eq. (1) CO₂* can be assumed to be zero in the high temperature range that the Boudouard reaction can take place.

\[
\text{rate}(v_c) = k_{\text{eff}} \left[ CO_2^a - CO_2^* \right] \quad \quad \quad (1)
\]

- \(v_c\) : moles of carbon reacted/cm³.s
- \(k_{\text{eff}}\) : effective rate constant, 1/s
- \(CO_2^a\) : the CO₂ content in gas phase, mole/cm³
- \(CO_2^*\) : the CO₂ content in gas phase in equilibrium with C and CO, mole/cm³

The rate constant will increase exponentially with increasing temperature as confirmed through the experiments measuring the reaction rate of char with CO₂. If the temperature of the charged material bed increases linearly from top to tuyere, then the CO₂ content in the ascending gas will, roughly, increase linearly as checked through the non-isothermal PRI reduction experiments. The curves of the rate constant and then CO₂ content in the ascending gas with the charged material bed height can be plotted schematically as shown in Fig. 17. The direct reduction rate curve can also be drawn schematically like the curve that has a peak in the middle height in Fig. 17.

The CO₂ content will not be changed only linearly because the calcination of fluxes in PRI, the slowdown of the increase in the reduction rate above 900°C, initial decrease of the temperature of PRI and the volatile matter from coal, etc., can affect the CO₂ content complicatedly.

The rate constant will not continue to increase exponentially, either, with increasing temperature because the rate controlling step of the Boudouard reaction changes from chemical surface reaction to pore diffusion and boundary layer diffusion with increasing temperature. But in the middle height of the charged material bed that direct reduction can take place, the curves in Fig. 17 will closely resemble the real shape.

The area under the direct reduction rate curve in Fig. 17 is...
proportional to the direct reduction ratio. Thus the problem of how the various factors determine the direct reduction ratio is the same as how the various factors affect the area under the direct reduction rate curve. If the reducibility of PRI increases, the down slope of CO₂ content curve will increase, and reaches zero at higher level like the change from A to A’ in Fig. 18. On the other hand, if coal is carbonized strongly in a melter-gasifier like in a coke oven, the rate constant curve will start to increase at lower level just like the change from B to B’ in Fig. 18.

According to the measured results, to move the CO₂ content curve from A to A’, it is most important to heat PRI up to 900°C as soon as possible. The most desirable way of heating PRI rapidly will be to prevent its heat loss during transfer from a pre-reducing unit to a melter-gasifier. Meanwhile, the result of the simulation of Subrata Pal et al. shows that PRI loses its heat by coal through radiation rather than being heated by gas at the level near the top of the right after being charged into a melter-gasifier. If coal and PRI mix well, the heat loss of PRI will increase. Therefore, it will be desirable to isolate PRI from coal by the distribution control technique using the Gimbal, the charging chute in a melter-gasifier.

The other way of heating PRI rapidly is to increase the amount of O₂ through dust burners, and supply much heat to the surface of the charged material bed. Although the increase of heat supply can go to the coal, the temperature of the coal will not increase rapidly because the specific heat of coal usually would be a maximum value at 400 to 600°C and it is 3 to 4 times larger than that of iron in the temperature range. Furthermore, there can be some difference in distance between the charged PRI and coal from the dust burner flame. Additionally, finding the optimal size of PRI is also important to rapidly heat the internal part of PRI. If the size of PRI is larger than some critical one, the reducibility also starts to decrease.

Adding H₂ to the reducing gas will be important to move the CO₂ content curve A to A’ in Fig. 18 in case there is no way to heat PRI rapidly. According to the simulation result by Subarata Pal et al., the H₂ content in the ascending gas is already more than 20% from the mid-point between tuyere and the top of the charged material bed. But it can be changed by coal characteristic. If coal generates H₂ at lower temperatures, then most of H₂ will be generated at the upper part of the charged material bed, and it will leave the charged material bed without participating in the reduction of PRI. Most coal generates H₂ at the temperatures above 600°C. But some coal generates H₂ at lower temperature, about 400–600°C. When the reduction degree of PRI is increased, adding H₂ is also important. If the reducing gas does not contain H₂ then the advantage of high reduced PRI can disappear as checked in Fig. 10.

The activation energies of the reaction between char/coke and CO₂ were calculated using the result of non-isothermal experiments where the CO₂ content in the reacting gas was 100%. The values were 216 kJ/mol-C for char and 245 kJ/mol-C for coke and that the activation energy of char is lower than that of coke confirms that the condition of melter-gasifier hinders the strong carbonization of coal.

Thus, in order to move the rate constant curve from B to B’ in Fig. 18, the condition of a melter-gasifier should be changed to be closer to that of a coke oven. Although the descending and rolling behaviour of coal in a melter-gasifier is unavoidable, if the active zone in the charged material bed become larger, then the coal can descend more stably. If fine coal is briquetted and used instead of lump coal, there can be several ways of strengthening the carbonization by mixing several coals of various characteristics or adding proper additives.

If fine coal is used after being briquetted with binder, the curve B can move leftward instead of rightward because binders normally contain alkali metals which are the catalysts of the reaction between carbon and CO₂. According to the research by Sung-Man Kim, those catalysts can lower the temperature where coke starts to react with CO₂ by 100°C. The research results by Yanqin Huang et al. also showed that metals lower the temperature at which the reaction of wood char with CO₂ takes place at the maximum rate by about 100–200°C. Therefore, the binder not containing catalysts should be used.

In real operation, it is difficult to estimate the accurate distribution of CO₂ content and the temperature of coal along the charged material bed height. But we can assume the direct reduction ratio using the amount of injected O₂ and charged carbon amount. When assuming that the all injected O₂ is burned to CO, not CO₂, the difference between charged carbon amount and 2 times of injected O₂ amount in molar base is the same as the amount of carbon participating in carburization and direct reduction.

In summary, the direct reduction rate along the charged material bed height can be expressed as the product of the curve of CO₂ content in the ascending gas and the Boudouard reaction rate constant of char. To minimize the direct reduction ratio, there are two ways, one is for PRI, and the other is for coal. If the direct reduction ratio has been decreased separating the two curves as shown in Fig. 18 by rapid heating of PRI, supplying H₂ suitably, or eliminating some catalysts of the Boudouard reaction, then it can be monitored by calculating the ratio of input C to input O₂.

![Fig. 18. Approximate diagram showing the way to minimize the direct reduction ratio.](image-url)
5. Conclusion

It was investigated to figure out what is the mechanism that determines the direct reduction ratio in a melter-gasifier and how it can be minimized. The direct reduction ratio would not be determined by only one of the reducibility of PRI and the reactivity of coal with CO₂. Rather, although the characteristic of one of PRI and coal is fixed, the direct reduction ratio would be able to change according to the change in the other’s characteristic. It also means that if one of PRI and coal is improved regarding minimizing the direct reduction ratio, then the other can have some freedom. For example, if the reducibility of PRI is improved, then more various binders for coal briquetting can be utilized. If the reactivity of coal with CO₂ is decreased, then larger size of PRI can be used to improve the permeability of the charged material bed.

The direct reduction rate is the product of CO₂ content in the ascending gas and the Boudouard reaction rate constant of coal. To make the CO₂ content in the ascending gas start to increase from as high level as possible, the way to minimize the heat loss of PRI in the transfer from pre-reducing unit to a melter-gasifier or the way to heat PRI separately using dust burners and the distribution control of PRI and coal should be researched. Additionally, the adequate size of PRI should be researched and the method to adjust the size of PRI should be developed. To make coal react with CO₂ in higher temperature, first of all, catalysts should be avoided if fine coal is used after being briquetted with binder. The effect of descending behaviour of coal in a melter-gasifier on its carbonization should be researched for the next step.

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REFERENCES