Subjects for Achievement of Blast Furnace Operation with Low Reducing Agent Rate

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The technology which reduces the reducing agent rate by the improvement in the reaction efficiency of blast furnace leads to reduction of hot metal manufacturing cost, but also solution of recent CO₂ emission reduction. The subjects for achievement of the blast furnace operation with low reducing agent rate were described on reduction measures of the carbon consumption and problem of the measures referring to the example of reducing agent rate of the present state blast furnace concerning blast operation and reactive improvement. And, carried out concrete measures were introduced in order to aim at the low reducing agent rate operation.

The following results were obtained.
1) Since it has reached the already high reaction efficiency in present state blast furnace, it is not easy to attempt further reduction of the reducing agent rate.
2) The blast furnace use of high reactivity coke or reduced iron is equal level or over it in comparison with the reduction effect by the assumed blast operation in this paper.
3) The promotion of coke reaction load with the gasification is worried, when it aims at the low reducing agent rate operation by the high reactivity coke use.
4) It is estimated that the threshold also exists for the reducibility of competing ore, when it aims at the low reducing agent rate operation using the high reactivity coke.
5) The use of the low SiO₂ sinter is effective for the improvement on the permeability in the blast furnace, when it aims at the low fuel rate operation. However, the new technology of the permeability improvement is desired, since there is some a limit for low SiO₂ of the sintered ore, when future raw material supply and demand is considered.

KEY WORDS: blast furnace; CO₂ emission; low reducing agent rate; reaction efficiency; high reactivity coke; low SiO₂ sinte; K; permeability; reduced iron.

1. Introduction

The technology which reduces the reducing agent rate by the improvement in the reaction efficiency of blast furnace leads to not only reduction of hot metal manufacturing cost (high productivity achievement), but also solution of recent CO₂ emission reduction. Japan's steel industry promotes the activity with the aim of energy consumption 11.5% reduction (for the consumption in fiscal 1990) of the steel industry of Japan by 2010, when international warming prevention measures are worked out. About 12% of domestic consumption quantity is occupied on the energy consumption of steel production of Japan, and whole 70% is occupied even in the inside on use energy of the blast furnace. The research activity on "Innovative Ironmaking Reactions In New BF To Aim At Halving Energy Needs And Minimizing Environmental Load" was positively promoted with the aim of drastically reducing energy consumption in blast furnace by Iron and Steel Institute of Japan. The research was made in not viewpoint of the enhancement of the present state blast furnace but in the viewpoint of the innovative and new blast furnace method.

Here, the consideration of the problem in aiming at the low reducing agent rate operation in the viewpoint of the enhancement of the present state blast furnace was done. CO₂ reduction goal as the whole industry of iron and steel aims at the reduction of 10.5% for fiscal 1990, when the energy consumption is seen in the conversion of the CO₂ discharge. To begin with, the example of reducing agent rate (carbon consumption rate) of the present state blast furnace is shown, when it coped with this problem by the reduction of reducing agent rate of the blast furnace at about 10% was assumed, in order to see whether the reduction is an achievable level by the present state blast furnace and in making the example to be a standard, the effect of various operation methods on the reducing agent rate was estimated. Next, the problem in aiming at the low reducing agent rate concerning the reaction efficiency improvement was described based on the kinetic analysis in blast furnace in addition to existing experimental approach. Finally, carried out concrete measure cases are reported in order to aim at the low reducing agent rate and this consideration wants...
to be contributory to problem arrangement for the blast furnace low reducing agent rate.

2. Reducing Agent Rate in a Present State Blast Furnace

Based on the equilibrium-theoretical balance model (The Rist model\(^3\)), the example of reducing agent rate (carbon consumption rate) of arranged present state blast furnace is shown in Table 1. The reducing agent rate of present state blast furnace including the carburization to the molten pig iron is about 500 kg/THM (carbon consumption rate 430 kg-C/THM). High reaction efficiency of 0.9 latter half stand are maintained, when it is observed at shaft efficiency which shows the reduction efficiency. It is indicated that the reaction progresses on this fact in the present state blast furnace by the reduction equilibrium neighborhood. The example of vertical sonde data of the present state blast furnace is shown as the supporting evidence data in Fig. 1. The gas composition is almost in the equilibrium state of FeO–Fe–CO–CO\(_2\) system in the wall side of the furnace which concentrates the gas and solid flow and it has reached the condition that the reduction of the ore does not progress. When the ideal blast furnace of shaft efficiency \(=1\) was assumed as shown in Fig. 2, though the carbon consumption rate is estimated with that the reduction of 422 kg/THM (reduction rate of about 2%) from 430 kg/THM of the present state blast furnace is possible, it is not easy to aim at the drastic reduction of the reducing agent rate at the operating range of the present state operation.

3. The Effect of Each Operating Condition on Carbon Consumption Rate

From the viewpoint of the CO\(_2\) emission control, the effect of the operation variously on the carbon consumption rate was estimated. The result is shown in Fig. 3. Taking carbon consumption rate of a present state blast furnace under a high pulverized coal rate operation as a standard, compound blast by the hydrocarbon system fuel injection was assumed. The carbon consumption rate is reduced to 416 kg-C/THM (\(-14\) kg/THM \([-3\%]\) reduction for the standard value) with natural gas (CH\(_4\)) injection 50 Nm\(^3\)/THM, when the upper limit of the heat flow ratio was set at 0.85 in order to avoid heat shortage in the shaft part. And, it can be reduced to 407 kg-C/THM (\(-23\) kg/THM \([-5\%]\)) by natural gas injection+blast temperature rise (100 K), and in addition, the reduction to 396 kg-C/THM (\(-34\) kg/THM \([-8\%]\)) is expected by the blast moisture lowering (5 g/Nm\(^3\): dehumidification blast). And, low-temperature molten pig iron tapping of 1,673 K becomes the reduction to 390 kg-C/THM (\(-40\) kg-C/THM \([-9\%]\)), if it is established. Although the reduction of the carbon consumption is possible through blast operation of high temperatures and dehumidification blasts or fuel injection of hydrogen high content, etc., cost phase and present plant capacity become the rate-limiting condition. Reaction efficiency improvement of the blast furnace by the acceleration of coke and sinter reactions seems to be main means of the reduction policy in order to drastically aim at the reduction of the reducing agent rate. On improvement of the blast furnace reaction efficiency by high reactivity coke use, Naito et al.\(^2\) has verified the effect experimentally using the adiabatic blast furnace simulator. If the thermal reserved temperature is made to lower by high reactivity coke use, the reduction effect which corresponds to natural gas injection+blast temperature rise can be expected by improving the reducing ability inside the furnace as shown in Fig. 4.
4. The Subjects in Aiming at the Low Reducing Agent Rate Concerning the Reaction Efficiency Improvement

Recently, a trial of use evaluation of a high reactivity coke using a commercial blast furnace was performed. Here, the subjects for realizing the low reducing agent rate through high reactivity coke use are discussed. Whether the reduction rate in the sinter side follows becomes a problem, when the thermal reserved temperature is made to lower using high reactivity coke. It is correspondent to maintaining the shaft efficiency, even if the thermal reserved temperature lowers in Fig. 4. And, it is anticipated that the inside of furnace condition also greatly changes with the lowering of the thermal reserved temperature. Then, the result of estimating the inside of furnace condition in high reactivity coke use by using a mathematical simulation model for blast furnace of cross section homogeneous condition is shown in Fig. 5. As well as the above-mentioned trial result based on the equilibrium, it was estimated, when the improvement in blast furnace reaction efficiency was able to be expected by using the high reactivity coke even in the calculation result based on the rate theory as shown in Fig. 5(a). However, reaction form of the direct reduction changes by high reactivity coke use. That is to say, it was estimated that the solution loss reaction rose and the smelting reduction reaction reversely lowered when it is observed at the reaction proportion as shown in Fig. 5(b). The promotion of coke reaction load with the gasification is worried, when it aims at the low reducing agent rate operation by the high reactivity coke use, if this prediction is correct. Therefore, establishment of the evaluation technology of post-reaction strength of coke in blast furnace is also important with of blast furnace reaction efficiency in high reactivity coke use. In addition, the effect of the reduction kinetics (here, the reductive reaction-ness of the sinter is expressed at JIS-RI) in the sinter side on the reducing agent rate was also estimated with that it was large, when the high reactivity coke was used, as it is shown in Fig. 6. It was estimated that the threshold exists for the reducibility of competing ore when the reduction of reducing agent rate is attempted by the change of the reactivity of the coke, as the reaction efficiency in blast furnace has been concluded as a consequence of competition reaction of coke and sinter.

Figure 7 shows the effect of the JIS-RI on CO/(CO + CO₂) and reaction rates in the time. It was indicated that the reduction state in blast furnace greatly changed in proportion to reactivity of the coke and reducibility of the sintered ore, as it is shown in the figure. This calculation result means that both of the shaft efficiency and the position
of the W point (wustite-iron reduction equilibrium point) change according to ratio of the reaction rates between sintered ore reaction and coke reaction, when it explains in the Rist diagram of above-mentioned Fig. 4. Here, by using the reaction analysis model composed of 3-Interface Core Model7) and material balance equation of sintered which reproduces the JIS-RI test which is the sintered ore reaction experiment of the isothermal fixed bed type based on a Japanese Industrial Standard, the JIS-RI was obtained by adjusting reaction rate constant of the wustite in order to become a fixed value. And, in the blast furnace analysis, by correcting its rate constant under $1/10^6$ in the downward in order to agree with the actual reducing agent rate, it was used.

5. Carried Out Concrete Measures to Aim at the Low Reducing Agent Rate Operation

5.1. The Effect of Blast Furnace Permeability Improvement by the Low SiO$_2$ Sintered Ore Use

O/C value under present high PCI operation is about 5 (in PC rate=$190$ kg/THM). The value increases (O/C=5.9–6.8) in the above-mentioned trial) more and more as the low reducing agent rate operation is pursued. Therefore, the cohesive zone which controls gas flow resistance inside the furnace is anticipated with that it enlarges than the present state level further, and it will exceed the range of usual blast furnace operation. Whether it is well able to maintain the permeability at such high O/C value is a largest problem in the low reducing agent rate operation. For permeability improvement of the cohesive zone, experimental blast furnace operation and permeability evaluation of commercial blast furnace were carried out in order to verify that the use of the low SiO$_2$ sintered ore is effective. 8) In the time, the KS value 9) which is defined at the integral area measured in the softening-melting test was used as the evaluation function of the gas flow resistance of the sintered layer in cohesive zone as shown in Fig. 8. In the experimental blast furnace operation, the permeability evaluation test was carried out using sintered ore produced by the commercial sintering machine in which the KS value differed (sintered ore in which the KS value differs). And, it was included in a mathematical simulation model for blast furnace6) by modeling test method and result of the KS value for quantitatively grasping the effect of the KS value on the permeability. The result was shown in Fig. 9, and the permeability improvement effect in changing from the high SiO$_2$ sintered ore to the low SiO$_2$ sintered ore was confirmed by the test and the calculation. Next, permeability improvement effect by the low SiO$_2$ sintered ore use was able to be confirmed as a result of permeability analysis of commercial blast furnace using this permeability evaluation model in the commercial blast furnace, as it was shown in
Fig. 10. Blast furnace use of the low SiO$_2$ sintered ore is effective, when it aims at the low reducing agent operation. However, the new technology of the permeability improvement is desired, since there is some a limit for low SiO$_2$ of the sintered ore, when future raw material supply and demand is considered.

5.2. Effect of Reduced Iron Use on Reduction of the Reducing Agent Rate and Increase of the Productivity

Since the most part of the carbon consumption is needed for the reduction of iron oxide, drastic carbon reduction of consumption is difficult for molten pig iron manufacturing of the iron ore 100% use by the blast furnace method. In the meantime, drastic reduction of the reducing agent rate can be expected, since the reduction of iron oxide is not required, if scrap and reduced iron can be utilized as an iron source of blast furnace. In the reuse of scrap, there is a problem of the tramp element (Cu, Sn, etc.), and it becomes an effective iron source, if the recycle system can be thoroughly constructed as whole industrial world. On the reduced iron utilization, though there are problems of the
price and the transportation system, there is no tramp element problem like the scrap. Blast furnace is suitable for mass production, and it is difficult to deal with the flexible adjustment of an output. As an iron source which can deal with the request of both sides of low reducing agent rate and flexibility of production, the possibility of exposing to the attention with new iron source such as the carbon composite iron ore hot briquette\(^{10}\) in the near future is high for the reduced iron. The case in which metallic iron (Fe=100\%) is put with the sintered ore is considered here. The effect in changing charge ratio of the metallic iron for the charge total iron was investigated using the Rist diagram.

The effect of the metallic iron charge ratio on the operation diagram is shown in Fig. 11. In the metallic iron 10\% charge, it becomes a decrease of 29 kg/THM (7\%) further than standard operation (present state furnace, shaft efficiency of 1, carbon consumption primary unit 422 kg/THM) described at Chapter 3, and it is effective over the natural gas injection. The blast volume rate was 6.6\% decrease of the standard operation at 945 Nm\(^3\)/THM, and the production rate was estimated with the increased production of 6.6\% at 2.2 t/d/m\(^3\).

It is shown that the carbon consumption can be drastically reduced, if metallic iron is put in the part as an iron source as a substitution in the sintered ore. In our company, basic experiment of the permeability characteristic including dissolusion behavior of reduced iron and 100\% use test of reduced iron using the experimental blast furnace were carried out in order to grasp increased production effect and reduction effect of reducing agent rate.\(^{11}\) The particle size of reduced iron used for the test was 30–100 mm HBI (Hot Briquette Iron), and commercial manufacturing ore of the 10–25 mm size was used on the sintered ore. Each chemical composition is shown at Table 2. As the result, reduction of reducing agent rate and increased production effect were confirmed according to the increase of reduced iron charge as shown in Fig. 14, while the permeability was well maintained as well as the basic experiment result of Fig. 12 as shown in Fig. 13.

6. The Conclusion

It was entitled subjects for achievement of blast furnace operation with low reducing agent rate, and referring to the example of reducing agent rate of the present state blast furnace, reduction measures of the carbon consumption and problem of the measures were described concerning blast operation and reactive improvement. And, carried out concrete measures were introduced in order to aim at the low reducing agent rate operation. It is not easy to attempt the reduction of the reducing agent rate more and more by present blast furnace method, as the above be described.

Table 2. Chemical compositions used in the experiments. (wt.-%)

<table>
<thead>
<tr>
<th></th>
<th>TFe</th>
<th>FeO</th>
<th>MFe</th>
<th>SiO(_2)</th>
<th>CaO</th>
<th>Al(_2)O(_3)</th>
<th>MgO</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>HBI</td>
<td>91.4</td>
<td>15.9</td>
<td>79.0</td>
<td>2.0</td>
<td>0.9</td>
<td>0.8</td>
<td>0.3</td>
<td>0.88</td>
</tr>
<tr>
<td>Sinter</td>
<td>58.4</td>
<td>6.9</td>
<td>0.0</td>
<td>4.5</td>
<td>9.2</td>
<td>1.7</td>
<td>1.1</td>
<td>—</td>
</tr>
</tbody>
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Fig. 11. Effect of the metallic iron charge ratio on the operation diagram.

Fig. 12. Observed pressure drop through the softening-melting test.
Realistically, it seems to advance in the combination of the measures in which the reduction of the carbon consumption is high in proportion to future situation. In this paper, though it was not described, the accuracy improvement of burden distribution control and management control in every day is also important in order to realize the low reducing agent rate operation.

And, analysis method which can predict effects of reactivity, strength, particle size of ore and coke on permeability and reaction efficiency in blast furnace at the good accuracy are also necessary in order to properly design reduction measure of reducing agent rate.

REFERENCES

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Fig. 13. Observed pressure drop through the experimental BF.

Fig. 14. Effect of HBI charging on the operation results of the experimental BF.

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