Efforts to improve the processing ratio of the BOF type furnace for hot metal dephosphorization at the Kakogawa Works

BY

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SYNOPSIS:

In the BOF-type furnace for hot metal dephosphorization at Kakogawa Works, it is difficult to remove the metal adhering from the slag line part to the throttle part of the furnace, meaning that the treatment ratio has decreased. In addition, slopping was promoted by the decrease in furnace internal volume due to adhesion of the metal, and this resulted in a decrease in iron yield.

In this paper, the focus of the report is on the removal method of adhered metal by utilization of the slag with high temperature using post combustion of CO gas in foaming slag.

Keywords: Dephosphorizing Furnace, Iron yield, metal melting

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1. Introduction
At Kakogawa Works, one steel mill manufactures semi-finished products for sheet, wire, rod and plate, and a wide variety of steel types are produced, ranging from very low carbon steel to high carbon steel.

At Kakogawa Works, both mechanically agitated desulfurization equipment (KR) and converter type dephosphorization equipment were installed in 2014 for the purposes of lowering phosphorus and sulfurization of steel and reducing refining costs and improving yield. Improvement of the treatment ratio and reduction of refining cost were also tried.

In this paper, the focus is on the introduction of new equipment and efforts to improve iron yield by improving operation after introducing new equipment.

2. Process flow of steel making process at Kakogawa Works
Figure 1 shows the process flow of Kakogawa Works. It shows the desulfurization of molten pig iron which is tapped to the torpedo car from the blast furnace in KR; dephosphorization in torpedo cars or desulfurization step in KR, through the dephosphorization process of the BOF type furnace for hot metal dephosphorization from the desulfurization step in KR, converter. After the temperature rises in the converter, it is sent to the molten steel process, which is the subsequent process, and molten steel is then supplied to each Continuous caster.

Fig. 1  Process flow of steel making process at Kakogawa Works
3. Change due to new facility operation

Figure 2 shows the flow of molten pig iron from the blast furnace to the converter in the new plant. With the operation of a new hot metal processing plant, the desulfurization process is 98% treated in KR. Also, in the dehydration process, this involves 58% of the BOF type furnace for hot metal dephosphorization, 10% of the torpedo car (TP), and 32% of the converter.

![Diagram of refining process at Kakogawa Works](image)

Fig. 2 Changes in refining process flow and processing ratio at Kakogawa Works
4. Issues after starting up the BOF type furnace for hot metal dephosphorization

Figure 3 shows the actual transition of the cycle time and processing ratio of the BOF type furnace for hot metal dephosphorization. In order to improve the processing ratio by shortening the cycle time at the beginning of the operation of the BOF type furnace for hot metal dephosphorization, the processing ratio was improved to 58%. This was done by shortening the refining blowing time due to the improvement of the oxygen feed rate and shortening the refining time by suppression of slag formation prior to tapping.

However, due to the factors shown in Figure 4, subsequent to October 2014 the BOF type furnace for hot metal dephosphorization processing ratio fell to 48%. Among them, efforts were made to raise the processing ratio concerning the increase of the metal melting time of the adhesion metal in the BOF type furnace for hot metal dephosphorization. The following is a full report on the contents.

![Figure 3](image1.png)

**Fig. 3** Changes in cycle time and processing ratio of the BOF type furnace for hot metal dephosphorization

![Figure 4](image2.png)

**Fig. 4** Factors that indicate the processing ratio has not been reached

5. Improvement of adhered metal melting method in furnace
Figure 5 shows the state of bare metal attachment of the BOF type furnace for hot metal dephosphorization. It adheres to the entire circumference from the furnace entrance to the slug line. Adhesion of the metal was promoted by slopping due to the decrease in internal volume of the furnace, and yield reduction occurred.

![Bare metal attachment in BOF type furnace](image)

**Fig. 5 Adhesion status of bare metal in the BOF type furnace for hot metal dephosphorization**

In the BOF type furnace for hot metal dephosphorization and the H furnace of the Kobe Works (H-furnace), the metal in the furnace is removed by the method shown in Figure 6. In the BOF type furnace for hot metal dephosphorization using metal melting lance for metal melting from the vicinity of the furnace entrance to the slag line. However, as for the metal melting lance, it takes about 10 minutes extra to switch from the oxygen lance used in blowing. In addition, at the beginning of the start-up, since the adhesion range of the slag line part was wider than expected from the furnace entrance, the frequency of use of the metal melting lance effective for partially melting the metal was planned to be once a day. It was necessary to increase this to about 3 times / day, which resulted in a decrease in processing rate of ▲4%. In addition, the decline in iron yield due to promotion of slopping was also caused by the decline in furnace internal volume due to adhesion of metal. Therefore, the metal melting method was investigated using a blowing lance capable of melting a wider range of metals.

<table>
<thead>
<tr>
<th>Method</th>
<th>Current status</th>
<th>Kobe works) H-furnace</th>
<th>After improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceptual diagram</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><img src="image" alt="Conceptual diagram" /></td>
<td><img src="image" alt="Conceptual diagram" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Extended processing time</th>
<th>10min</th>
<th>0min</th>
<th>0min</th>
</tr>
</thead>
<tbody>
<tr>
<td>De-Si</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>De-P</td>
<td>○</td>
<td>×</td>
<td>○</td>
</tr>
</tbody>
</table>

1) Investigation of metal melting method

As a method of dissolving the extensively adhered metal, there is a method of melting the
metal using slag which has attained a high temperature. This is done by secondary combustion of CO gas in the forming slag. Table 2 shows a comparison of working conditions.

The treatment condition of the dephosphorization stage in the dephosphorizing furnace against the condition of the metal melting period in the hot metal pretreatment furnace at Kobe Works (H-furnace) is within a range of somewhat higher collision pressure related to the burning rate of the top blown oxygen. It was also confirmed that oxygen accumulation related to the amount of dissolved gold was also equivalent. However, the value of I / R which is an index related to the melting range of the metal is larger than the range of the H-furnace. Here, I is the distance from the point farthest from the center of the gas jet contact surface on the bath surface to the furnace wall, and R is the distance from the center of the lance to the furnace wall. As shown in Figure 6, since the adhesion of the upper portion of the metal in the actual dephosphorizing furnace is relatively large over the furnace mouth from the slag line, under the condition that the melting range is expanded to the upper by raising the lance, it was found that it was necessary to optimize I / R.

Table 2 Metal melting condition comparison of H-furnace and the BOF type furnace for hot metal

<table>
<thead>
<tr>
<th>Impact pressure (Pa)</th>
<th>Oxygen accumulation (Nm3/t)</th>
<th>I/R</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1600~6500 <del>200</del>1200</td>
<td>8.3×[Si]~1.9 ~8.3×[Si]~4.1</td>
<td>0.08~0.25</td>
<td>Optimization necessary</td>
</tr>
<tr>
<td>3500<del>4000 800</del>1200</td>
<td>7.9×[Si]<del>2.6 3.8</del>6.9Nm3/t</td>
<td>0.41~0.47</td>
<td></td>
</tr>
</tbody>
</table>

I was calculated by the formula (2) using the hard core length Zc of the gas jet described in formula (1).

\[ Z_c = (4.12 \cdot P_o - 1.86) \cdot d \]

\[ I = -H \cdot \tan(\theta + \alpha) + Z_c \cdot \cos\theta \cdot \tan(\theta + \alpha) - Z_c \cdot \sin\theta - D + R \]

Where:
- I= Distance from the point farthest from the center of the gas jet contact surface on the bath surface to the furnace wall refractory(mm)
- R= Distance from lance center axis to furnace wall(mm)
- H= Distance from the static bath surface to the lower end of the lance(mm)
- D= Distance from lance center axis to nozzle exit outermost periphery(mm)
- \( Z_c \)= Gas jet hardcore length(mm)
- \( \Theta \)= Nozzle inclination angle(°)
- \( \alpha \)=Ejection spread angle after nozzle ejection(°)
- \( P_o \)=Nozzle front pressure(kgf/cm2)
- \( D \)=Nozzle throat diameter(mm)

2) Optimization of top-blown oxygen condition

Figure 8 shows the relationship between I / R and the amount of dissolved gold (= yield difference between normal processing). Conditions with a large degree of metal melting are
in good agreement with the proper range of H furnace (I / R = 0.08 to 0.25). As the lance height increased, the collision pressure was 200 ~ 800 Pa, and it was confirmed that it was consistent with the proper range (200 ~ 1200 Pa) of H-furnace.

Figure 9 shows the relationship between de-Si external oxygen (air acid + solid acid) and de-C amount in the treatment charge under the above-mentioned top-blown oxygen condition. The amount of de-C was reduced by + 0.09% before and after the improvement.

Furthermore, as shown in Figure 10, the temperature after treatment (calculated temperature - actual temperature) according to the molten iron and presence or absence of the metal melting under the same treatment condition was compared, and it was confirmed that the temperature had decreased by Δ 5 °C. From this result, the of secondary combustion heat was estimated.

As shown in Figure 11, the secondary heat of combustion is generated by the surplus oxygen generated by the decrease in the reaction amount of desulfurization and the CO gas in the slag, and some of the heat is dissolved / Was calculated as the proportion that contributed
as temperature rise. The heat efficiency is defined by formula (3), and the premise used for the calculation is shown in Table 3.

\[
\text{heat efficiency } \gamma (\%) = \frac{(\Delta T \cdot W \cdot m_{Fe} - Q_{CO} + Q_{Fe})}{Q_{CO2}} \quad \cdots (3)
\]

Fig. 11 Concept of heat efficiency of secondary combustion

Table 3 Calculation of heat efficiency of secondary combustion heat

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Item</th>
<th>Unit</th>
<th>Precondition</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>(q_{CO})</td>
<td>CO reaction heat</td>
<td>kJ/kg</td>
<td>9,240</td>
<td>(C + 1/2O_2(g) = CO(g))</td>
</tr>
<tr>
<td>(q_{CO2})</td>
<td>CO→CO2 reaction heat</td>
<td>kJ/kg</td>
<td>23,700</td>
<td>(CO(g) + 1/2O_2(g) = CO_2(g))</td>
</tr>
<tr>
<td>(q_{Fe})</td>
<td>FeHeat of dissolution</td>
<td>MJ/t</td>
<td>-277</td>
<td>(Fe(s) = Fe(l))</td>
</tr>
<tr>
<td>(m_{Fe})</td>
<td>Specific heat of iron(1300℃)</td>
<td>kJ/kg℃</td>
<td>0.907</td>
<td></td>
</tr>
<tr>
<td>(\Delta T)</td>
<td>Hot iron temperature change</td>
<td>℃</td>
<td>351</td>
<td>metal temperature 1000℃, after melting temperature 1351℃</td>
</tr>
<tr>
<td>(\Delta w)</td>
<td>Metal melting amount</td>
<td>t/ch</td>
<td>1.86</td>
<td>Fe melting amount + 0.7% × 265t = 1.86t</td>
</tr>
<tr>
<td>(W)</td>
<td>Amount of hot metal</td>
<td>t/ch</td>
<td>260</td>
<td>Actual amount of hot metal molten metal</td>
</tr>
</tbody>
</table>

Figure 12 shows the calculation results. Under the current top-blown oxygen condition, it is estimated that the heat efficiency is 38% on average and about 62% of the other is discharged outside the system as exhaust gas, heat of slag or the like. In addition, the thermal balance
was confirmed to be a decrease in the amount of de-C at -9 °C., a melting of the metal at -5 °C. (melting at -2 °C, a temperature rise -3 °C) and the heat of secondary combustion heat at +9 °C.

3) Results of actual application

Figure 13 shows the frequency of use of the bare metal melting lance before and after improvement and the metal melting processing ratio. By applying 40% of the metal melting treatment, the use frequency of the bare metal lance was reduced to 0.9 times / day. As a result, there has been an improvement of +0.17% (excluding single furnace +0.28%), +0.22% in dew-furnace yield improvement by +0.05% in addition to +0.05% improvement by improving processing ratio.

5. Conclusion

Improvement of metal melting method
By improving the metal melting process, the metal melting processing ratio was applied up to 40%, and the usage frequency of the metal melting lance was reduced, from 3.0 times / day to 0.9 times / day. As a result, in addition to a consistent yield + 0.05% improvement by processing ratio + 4%, integrated yield improved by + 0.22% due to iron loss reduction + 0.17% due to melting of the metal.