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Development of Energy-Saving Stainless Steelmaking Technology using Converter†

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Abstract:

The converter-type chromium ore smelting reduction method has been adopted for the stainless steel refining process at JFE Steel. Since chromium ore is used as a substitute for ferrochromium alloys in this process, this process is consistent with JFE's strategy of main raw materials for reasonable refining of stainless steel. To increase the feeding rate of chromium ore and decrease the amount of carbonaceous material used as a heat source, a burner lance for heating and feeding chromium ore was developed. Ore particles heated by the flame function as a medium of heat transfer from the flame. As a result, it is possible not only to improve the flexibility of the main raw material (chromium source), but also to achieve an energy saving due to the 17% reduction in supplied energy realized by this technique.

1. Introduction

JFE Steel has adopted the converter-type chromium ore smelting reduction method[1–3] as its stainless steelmaking process. Since chromium ore is used as a substitute for ferrochromium alloys in this process, it is important to increase unit utilization of chromium ore so as to improve flexibility in the selection of chromium raw materials. Because carbonaceous material is used as a reducing agent to reduce the chromium oxide in the chromium ore in the smelting reduction process, and this is a large endothermic reaction, it is essential to increase the heat supply to the furnace in order to increase the amount of reduction of chromium ore. For this reason, the smelting reduction process also consumes a large amount of carbonaceous material as a heat source. Heat is supplied by combustion of carbon with top and bottom blown oxygen. As measures for increasing the furnace heat supply, the oxygen supply rate was increased and high post-combustion techniques were developed, but both of these approaches have drawbacks. Increasing the oxygen supply rate increases the decarburization reaction, mainly by the reaction between C in the hot metal and oxygen, but because the amount of dust generation from the furnace also increases, yield of Fe and Cr is decreases. On the other hand, as high post-combustion techniques, practice of raising the lance height and development of a lance nozzle which realizes soft blowing of the oxygen jet have been conducted[4–6]. High post-combustion operation increases the amount of heat generated in the furnace, but because post-combustion occurs in the space in the furnace, the efficiency of heat transfer to the region where the chromium ore reduction reaction occurs is poor. For this reason, high post-combustion operation increases the thermal load on converter refractories, and thus has the problem of reduced refractory life.

Therefore, the authors carried out research and development aimed at reducing consumption of the carbonaceous material used as a heat source and realizing an energy-saving process by utilizing burner combustion heat as a new heat source to substitute for the heat generated by the decarburization reaction and post-combustion, by heating and feeding chromium ore, which is a powdery raw material, to the converter through the burner flame. Based on the results of that work, a burner lance for heating and feeding chromium ore was introduced at the actual smelting reduction furnace. The results of operation with the developed burner lance are

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reported in this paper.

2. Mechanism of Heat Transfer Improvement by Burner Heating and Feeding of Chromium Ore[7)]

A hot metal heating experiment with the burner was carried out using a 4-t melting furnace, and the heat transfer behavior of burner combustion heat to the hot metal depending on the chromium ore feeding conditions was investigated. The effect responsible for improving heat transfer to the hot metal by burner heating and feeding of a powdery raw material was also studied quantitatively by investigating the behavior of heat transfer from a high temperature gas to a powdery raw material by numerical simulation, and comparing the results with the results of the 4-t melting furnace experiment.

Figure 1 shows a schematic diagram of the experimental apparatus of the 4-t melting furnace. The burner was installed above the hot metal, and a hot metal heating experiment was performed using the burner. The burner used in the experiment had a triple concentric tube structure, in which chromium ore is fed through the center hole of the burner, and propane and oxygen were supplied through the surrounding tubes. The experimental conditions are shown in **Table 1**. The propane gas flow rate was set to 0.50 m^3-norm./min, and the oxygen flow rate was set at 6 times that of the propane.

In this experiment, in order to investigate the behavior of heat transfer from burner combustion heat to the hot metal by the chromium ore feeding method, the experiment was conducted under three conditions, namely, 1) "Without addition of ore" (using only the burner), 2) "With addition of heated ore," in which chromium ore was heated via the burner flame, and 3) "With addition of non-heated ore," in which the chromium ore was added from outside the flame. The experiment was performed using chromium ore with a mean particle diameter d_{50} of approximately 200 μm, which is the same as the ore used in the actual smelting reduction converter.

In the experiment, the initial hot metal temperature was set to 1 380°C to 1 430°C, and the hot metal temperature for investigating the behavior of temperature rise by burner heating was measured at appropriate times.

Figure 2 shows the relationship between the chromium ore feeding rate and the temperature rise $\Delta T/\Delta t$ of the hot metal. In the case "addition of heated ore," the temperature rise $\Delta T/\Delta t$ of the hot metal was 2.5–2.7°C/min. When compared at the same amount of chromium ore addition, this temperature rise was larger than in the case of "addition of non-heated ore."

Figure 3 shows the relationship between the chromium ore feeding rate and the sensible heat increment of the hot metal and slag. Here, the slag is the chromium ore added to the furnace. As the amount of heat transferred from the burner combustion heat to the hot metal and slag, the sensible heat increments of the hot metal and slag were calculated from the temperature change of the hot metal in the experiment. Under the condition of "addition of heated ore," the sensible heat increments of the hot metal and slag increased as the amount of chromium ore increased. In contrast, under the condition of

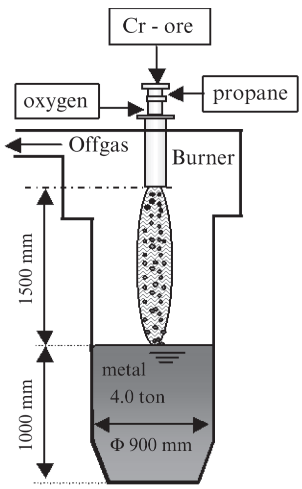

Fig. 1 Experimental apparatus

Table 1 Experimental condition

	Propane	Oxygen	Cr ore	Addition method of Cr ore
	m^3-norm./min	m^3-norm./min	kg/min	
No. 1	0.50	3.0	0	Without addition of ore
No. 2	0.50	3.0	3.9	With addition of heated ore by burner
No. 3	0.50	3.0	8.1	With addition of heated ore by burner
No. 4	0.50	3.0	4.5	With addition of unheated ore

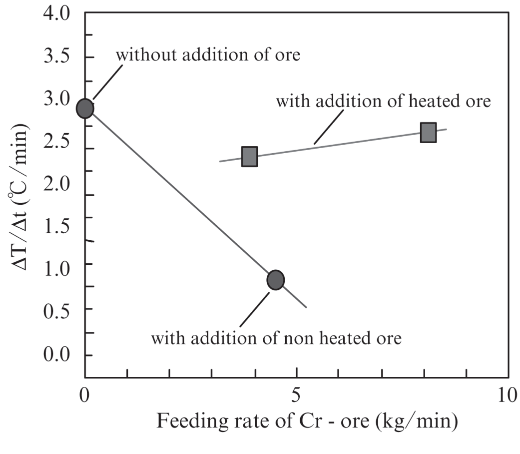

Fig. 2 Relationship between feeding rate of Cr-ore and temperature variation $\Delta T/\Delta t$

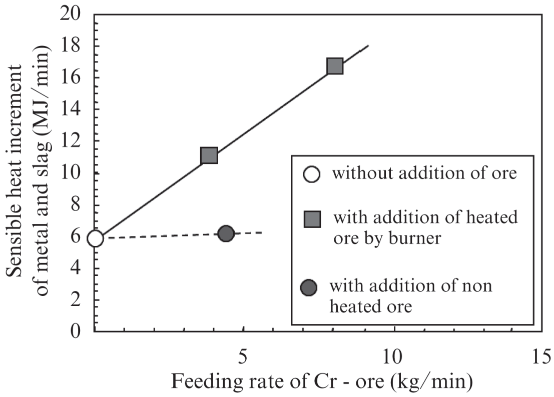

Fig. 3 Relationship between feeding rate of Cr-ore and sensible heat increment of metal

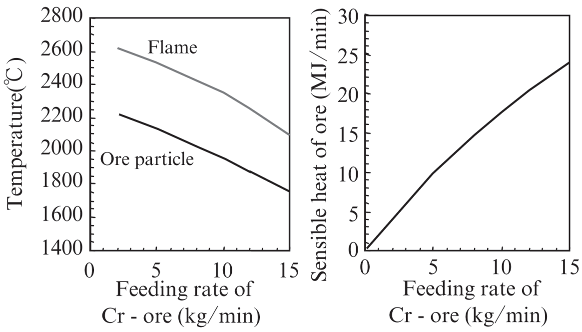

Fig. 4 Calculated temperature (particle, gas) and sensible heat of ore

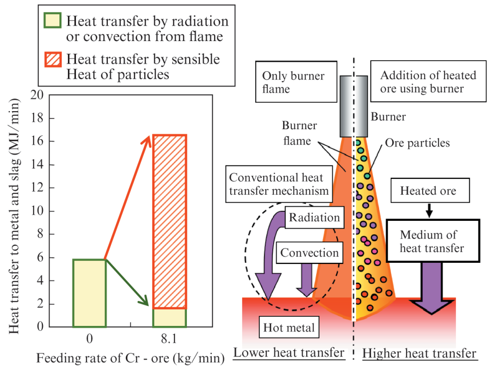

Fig. 5 Heat transfer balance and heat transfer mechanism by heated ore addition using burner

"addition of non-heated ore," the sensible heat increments of the hot metal and slag were small in comparison with the condition of "addition of heated ore," even at the same ore feed rate, and were similar to the results with only the burner, i.e., "without addition of ore." These results confirmed that the amount of heat transfer from burner combustion heat to the hot metal and slag increases as a result of feeding chromium ore while heating the ore via the burner flame.

Next, a numerical simulation was carried out to elucidate the mechanism of heat transfer of burner combustion heat to hot metal and slag by the "addition of heated ore" method. In this simulation, coupled calculations were performed for the particle heating time by an equation of motion for particles, for the combustion gas temperature by an equilibrium calculation, and for the particle temperature by heat transfer between the combustion gas and combustion gas particles[7)].

Figure 4 shows the relationship between the ore feeding rate and the ore particle temperature and sensible heat of all ore particles[8)]. As the particle feeding rate increases, the particle temperature and gas temperature decrease, but the sensible heat of all particles increases due to the increase in the heated ore feeding rate.

Based on the calculation results presented above, the breakdown of the amounts of heat transferred from burner combustion heat to the hot metal and slag in the experimental results was calculated. Here, the amount of heat transferred to the hot metal and slag by heated particles was assumed to be the sensible heat of the particles calculated in the numerical simulation. The difference between the amount of heat transferred from burner combustion heat to the hot metal and slag (experimental results), and the amount of heat transferred due to the sensible heat of the particles, was assumed to be the amount of heat transferred from the flame. **Figure 5** shows the breakdown of the amounts of heat transferred to the hot metal and slag and the mechanism of heat transfer[8)]. With the chromium ore feeding rate of 0 kg/min (i.e., flame only), only heat transfer by convection or radiation from the flame occurs, and the amount of heat transferred to the hot metal and slag is small. In contrast, with addition of heated ore, the amount of heat transferred from the flame deceases due to the decrease in the flame temperature; however, amount of heat transferred by the sensible heat of the heated particles becomes dominant, and total amount of heat transferred increases. These results confirmed that the heated ore particles function as a medium of heat transfer, and as a result, it is possible to transfer burner combustion heat to the hot metal efficiently by the addition of heated ore method.

3. Process Design by 5-t Converter Experiment[9)]

Figure 6 shows a schematic diagram of the experimental 5-t top and bottom blowing converter and the burner lance for addition of heated chromium ore. A four-hole straight lance was used as the main top blowing lance. In this experiment, the lance height from the tip of the main lance to the hot metal was set at 1.5 m. The burner lance for addition of heated chromium ore has a structure which makes it possible to feed chromium ore from the center hole while feeding the propane gas fuel and combustion improver oxygen from the nozzle surrounding the center hole. The lance height of

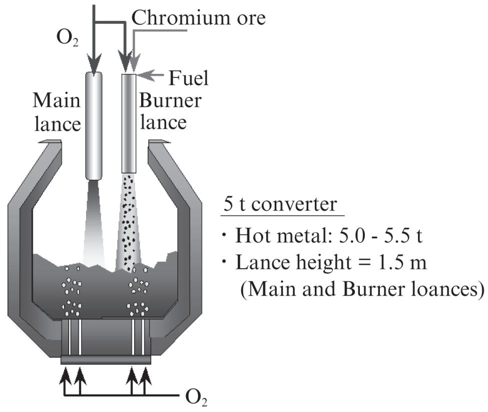

Fig. 6 Schematic diagram of experimental apparatus of 5 t converter

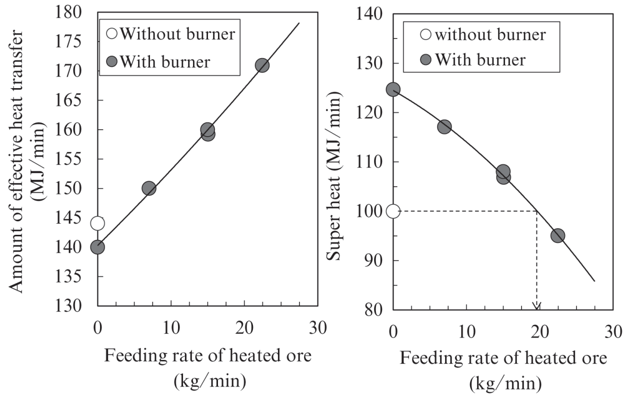

Fig. 7 Amount of effective heat transfer and super heat

Table 2 Experimental conditions

No.	Burner C_3H_8	Burner O_2	Total Cr ore	Heated Cr ore	
	m^3-norm./min	m^3-norm./min	kg/min	kg/min	
1	0	0	16	0	Without burner
2	0.5	3	15	0	With burner Unheated ore
3	0.5	3	16	7	With burner
4	0.5	3	15	15	With burner
5	0.5	3	23	23	With burner

the burner lance for heating and feeding chromium ore was set to the same 1.5 m as the top blowing lance.

The experimental conditions are shown in **Table 2**. Assuming the total oxygen blowing rate of the top-blown oxygen and the burner combustion improver oxygen is set at 20–23 m^3-norm./min, the fuel propane flow rate when the burner was used was set at 0.5 m^3-norm./min, and the combustion improver oxygen flow rate was set at 3 m^3-norm./min. In this experiment, the bottom blown oxygen flow rate was set to a constant condition, and changes in the oxygen flow rate were made by adjusting the amount of oxygen supplied from the top-blowing main lance.

In order to investigate the behavior of heat transfer from burner combustion heat to the hot metal by the chromium ore feeding method, an experiment was performed under three conditions: 1) “Conventional method,” in which chromium ore was added without firing the burner of the burner lance for addition of heated chromium ore (propane flow rate: 0 m^3-norm./min, combustion improver oxygen flow rate: 0 m^3-norm./min), 2) “With addition of heated ore,” in which the chromium ore was added from the burner lance via the burner flame, and 3) “With addition of non-heated ore,” in which the burner of the burner lance was ignited, but the chromium ore was added outside the flame, and not via the burner lance. The chromium ore feeding rate was set in the range of 15–23 kg/min.

In this experiment, after the hot metal was charged into the converter and heated to the specified temperature (1 550–1 580°C) by only top and bottom blown oxygen, smelting reduction blowing was performed for smelting reduction of the chromium ore. The burner lance for addition of heated chromium ore was used only during smelting reduction blowing. The coke and slag-forming flux necessary for heating-up were added during heat-up blowing, and the chromium ore and the coke which is necessary as a reductant for the chromium ore and as a heat source were added during smelting reduction blowing. The temperature of the hot metal was measured at appropriate times during blowing, and the chromium ore addition rate was adjusted so as to obtain the above specified temperature.

Figure 7 shows the relationship between the feeding rate of the heated ore and the amount of effective heat transfer and superheat. Amount of effective heat transfer was assumed to be the sum of the sensible heat increments of the hot metal and slag and the reducing heat of the chromium ore. Considering the amount of effective heat transfer and sensible heat of the off-gas (hot metal temperature), the amount of unknown heat obtained from the thermal balance of the sum of the two above-mentioned factors and heat input was defined as superheat of off-gas.

In the addition of heated chromium ore method using the burner, amount of effective heat transfer increased accompanying an increase in the heated chromium ore feeding rate. Amount of effective heat transfer increased 18% under the condition of a heated ore feeding rate of 22 kg/min. However, while superheat decreases as the heated chromium ore feeding rate increases, the possibility that superheat may encourage erosion of the refractory is a concern under the condition when the superheat is higher than the superheat with no burner.

Figure 8 shows the relationship between the heated ore feeding rate/burner calorific power and superheat.

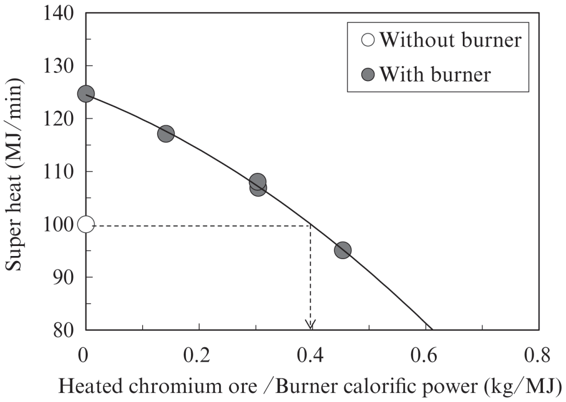

Fig. 8 Relationship between feeding rate of heated ore/burner calorific power and super heat

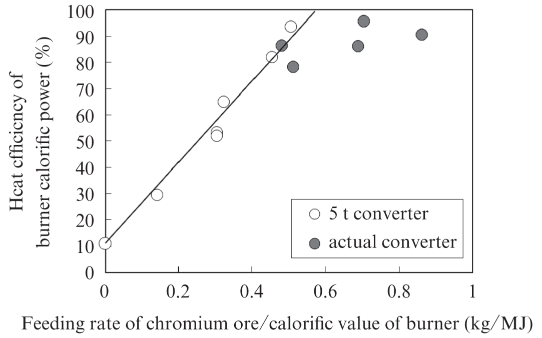

Fig. 9 Relationship between feeding rate of heated ore/burner calorific power and heat efficiency of burner calorific power

From this figure, it can be understood that the superheat becomes lower than in the case of no burner, and it is possible to reduce the thermal load placed on the refractory by the burner, by setting the ore feeding rate per unit of burner calorific power to 0.4 kg/MJ or more. The feeding rates of the burner fuel and chromium ore when this technique is applied to the actual converter were optimized based on this result.

4. Application of Burner Lance for Chromium Ore Heating and Feeding to Actual Chromium Ore Smelting Reduction Furnace[9)]

Based on the results described above, the burner lance for chromium ore heating and feeding, in which a burner function is added to the chromium ore feeding lance, was introduced in the top and bottom blown converter (heat size: 185 t) used as a chromium ore smelting reduction furnace at JFE Steel East Japan Works (Chiba).

As in the 5-t converter, the burner is used during the smelting reduction period when the chromium ore is added. The amount of bottom blown oxygen is the same as in the conventional method. As the amount of top blown oxygen, the amount of oxygen used as a combustion improver for the burner is reduced, and the total amount of the top and bottom blown oxygen and burner combustion improver oxygen is the same as the amount of top and bottom blown oxygen in the conventional method. When the burner is used, it is possible to reduce the amount of added carbonaceous material corresponding to the decrease in the amount of top blown oxygen. Propane gas was used as the fuel for the burner. The total amount of chromium ore can be supplied to the furnace from the burner lance for addition of heated chromium ore.

Figure 9 shows the relationship between the ratio of the feeding rate of heated ore/burner calorific power and the efficiency of heat transfer of burner combustion heat in the 5-t converter and the actual converter. Based on the knowledge gained with the 5-t converter, the ratio of the feeding rate of heated ore/burner calorific power was set to 0.5 kg/MJ or more, as shown in Fig. 8, so as not to increase the thermal load on the refractory. As a result, as in the 5-t converter, high efficiency of heat transfer of burner combustion heat of 80–90% was also achieved in operation of the actual converter, and the fact that there is no thermal load on the refractory due to the burner and stable operation is possible was confirmed.

Figure 10 shows the relationship between amount of chromium ore and supplied thermal energy before and after introduction of the burner lance for addition of heated chromium ore. Supplied thermal energy is the total of the energy of the decarburization reaction and post-combustion by top and bottom blown oxygen, and burner combustion heat when the burner is used. At a constant amount of supplied oxygen, supplied energy for the same unit of chromium ore could be reduced 17% by use of the burner lance for addition of heated chromium ore in comparison with before introduction of the burner, confirming that supplied energy can be used efficiently, and a large energy-saving effect is achieved.

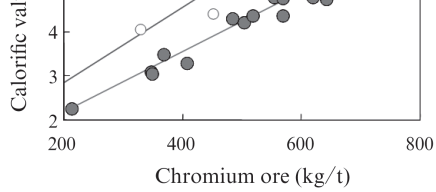

Fig. 10 Relationship between amount of chromium ore and supplied energy into furnace

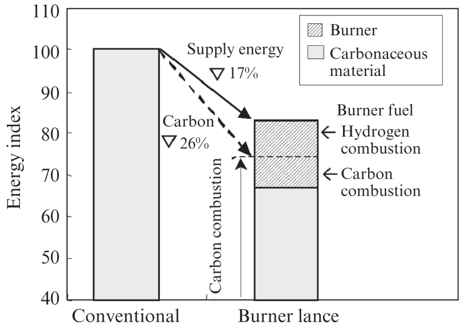

Fig. 11 Comparison of index of supplied energy per amount of chromium ore

Figure 11 shows a comparison of the supplied energy per unit amount of chromium ore in the smelting reduction furnace. In the conventional method, only carbonaceous material is used as an energy source. In contrast, with the developed technology, part of the energy source is replaced with a hydrogen-based fuel when the burner is used, and it is possible to transfer the burner combustion heat to the hot metal and slag more efficiently by the addition of heated ore technology. As a result, the amount of energy supply for the same unit amount of ore decreased 17%, and the amount of energy derived from carbonaceous materials decreased 26% in comparison with the conventional method.

As a result, introduction of the burner heating and feeding technology using hydrogen-based fuel in the chromium ore smelting reduction furnace not only improves flexibility in the selection of main raw materials, including chromium sources, etc., but also reduces amount of supplied energy in comparison with the conventional method, thereby achieving an energy-saving smelting reduction process.

5. Conclusion

A burner lance for addition of heated chromium ore using a hydrocarbon gas as the burner fuel was developed at the smelting reduction furnace at JFE Steel East Japan Works (Chiba). In the burner lance for addition of heated chromium ore, because the ore functions as a medium of heat transfer for the combustion heat of the burner, the new burner lance dramatically improves the efficiency of heat transfer. Introduction of this technology not only enhanced flexibility in the selection of main raw materials, including chromium sources, but has also reduced unit supplied energy by 17% in comparison with the conventional method, achieving a substantial energy saving in the smelting reduction process.

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