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Hot Metal Dephosphorization Treatment in Torpedo Car

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1 Introduction

Chiba Works performs dephosphorization of hot metal in the torpedo car to lower refining costs and to stabilize the production of high-purity steel.

The development of hot metal pretreatment techniques began with the construction of process experimental facilities at No. 1 Steelmaking Shop in April 1982. In this shop, dephosphorized hot metal was used to refine high carbon steel and stainless steel and confirmed its usefulness.[1] On the basis of the result at the No. 1 Steelmaking Shop, a hot metal pretreatment center (PTC) was constructed at the No. 3 Steelmaking Shop[2] in October 1984, as a facility to treat a large tonnage of mass produceable type steel. The subsequent years proved the hot metal treatment to be indispensable in steel refining operations, establishing a total

quantity hot metal pretreatment system.[3]

This report summarizes ① stabilized operations under the total-quantity hot metal pretreatment system, ② the concept of the dephosphorization treatment facilities and their operations which have been aimed to realize the "total-cost minimum", and ③ the result[4,5] of the reaction behavior analysis of the oxygen gas in the torpedo-car which was performed prior to the adoption of the oxygen gas.

2 Outline of Hot Metal Pretreatment Facilities

The outline of the hot metal pretreatment process at Chiba Works is shown in **Fig. 1**. Hot metal, which has been desiliconized on the BF casting floor, is transported by the torpedo-car to the respective hot metal pretreatment centers of Nos. 1 and 3 Steelmaking Shops, and processed so as to have compositions suitable for processes of the respective steelmaking shops.

An outline and specification of the dephosphorization treatment facilities are shown in **Fig. 2** and **Table 1**, respectively. In designing the facilities, the following improvements have been made in order to cope with a drop in thermal allowance of hot metal arising from total-quantity treatment, to reduce the unit consumption of flux in dephosphorization treatment, and to prevent slag contamination in the torpedo-car:

(1) Use of a large quantity of oxygen gas into hot metal pretreatment

(2) Establishing the flux composition changing function matched with hot metal composition
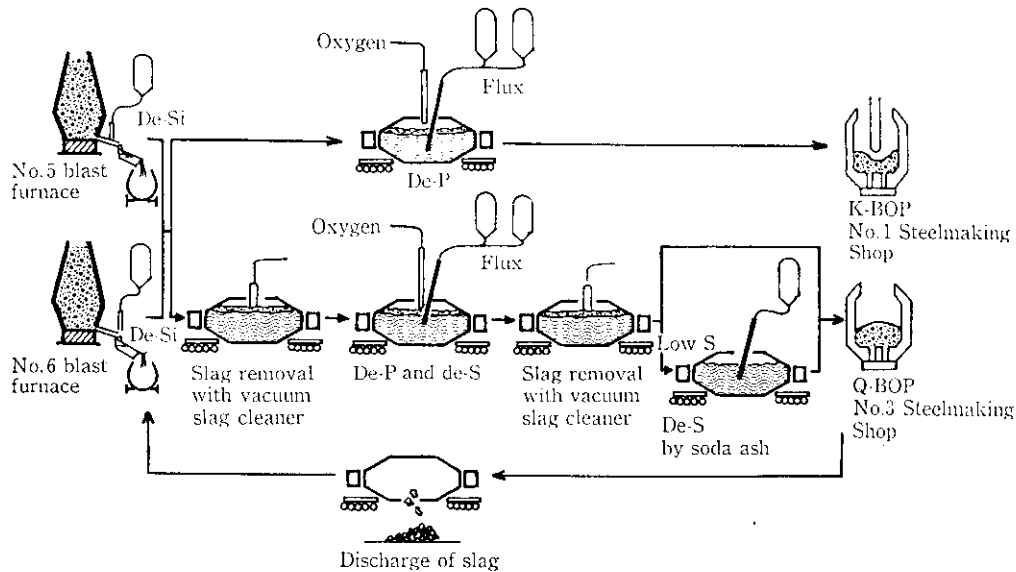
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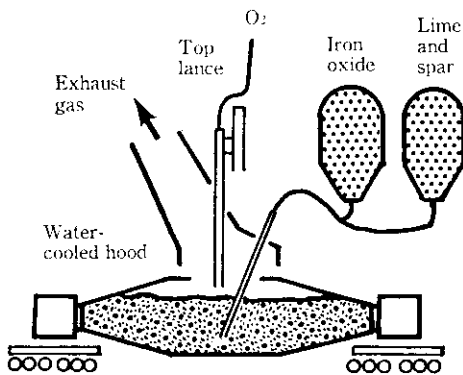Fig. 1 Hot metal pretreatment process at Chiba Works

Fig. 2 Schematic view of hot metal pretreatment equipment

Table 1 Specifications of main equipment

Item	Specification
Oxygen blowing	
Maximum flow rate	50 Nm³/min
Lance	Water cooled
Flux injection	
Dispenser	2 dispensers
Mixing type	Post-mixing
Injection rate control	Injection cross section control
Waste gas treatment	
Flow rate	15 × 10⁴ Nm³/h
Hood type	Upper drawing
	Water cooled (cooled area 97 m²)
Gas cooling	Boiler + plate cooler
Dust catcher	Bag filter

(3) Reinforcement of the function for removing residual slag in the torpedo car

The oxygen gas can be blown up to the maximum quantity of 50 Nm³/min, and in order to make it possible to use a large amount of the oxygen gas, a water-cooled top lance and a water-cooled hood have been adopted. For injecting dephosphorizing agency, a post-mix type is used which is provided with two units of dispensers so that the blending ratio of flux can be changed in correspondence to changes in composition of hot metal before treatment. The mixing control of the two kinds of flux is effected by the combined use of the injection cross section control employing a variable valve and the differential pressure control through changing pressure in dispensers, and stabilized injection is possible within a wide range of 50 to 500 kg/min. For removal of residual slag in the torpedo car, the operation of cleaning (cleaning around the hot metal receiving port) and that of deslagging are divided into two stations at the torpedo cleaning center (TCC), thereby securing processing capacity.[6]

3 Hot Metal Pretreatment Operation

3.1 Outline of Operation

At Nos. 1 and 3 Steelmaking Shops of Chiba Works, special processes matched with steel grades are adopted. Consequently, target compositions demanded of hot metal pretreatment also are different.

Namely, in K-BOP of No. 1 Steelmaking Shop, refining of high carbon steel by the catch-carbon method, which has adopted the reduction treatment in the converter,[1] and refining of stainless steel by the smelting reduction of chromium ore[7] are performed, and dephosphorized hot metal (P = 0.010 to 0.015%) suit-
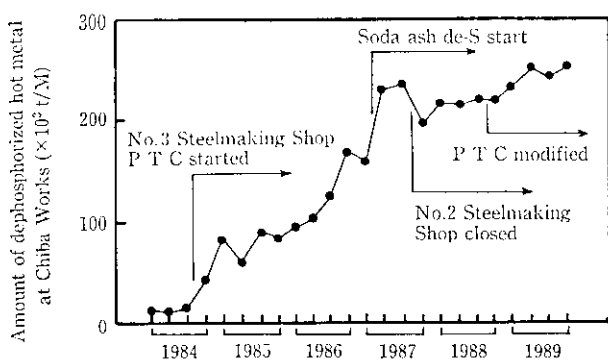
Fig. 3 Change in amount of dephosphorized hot metal at Chiba Works

able for these operations is necesary. At the Q-BOP of No. 3 Steelmaking Shop, refining of steel for ordinary cold-rolled sheets is carried out, and hot metal of $P = 0.035$ to 0.040% is required,[8] from the viewpoint of minimizing the total cost of pretreatment and converter operation.

The changes in the amount of dephosphorized hot metal at Chiba Works is shown in **Fig. 3**. Since the start-up in 1984 of the pretreatment center at No. 3 Steelmaking Shop, the amount of dephosphorized hot metal increased smoothly, and reached 230 000 t/month in June 1987. However, as a result of production consolidation to Mizushima Works effected in October 1987, the amount of dephosphorized hot metal dropped temporarily to a monthly level of 190 000 t. This drop was due to a rise in Si content before treatment accompanying the low productivity of blast furnace operation and to a temperature drop of hot metal accompanying a drop in the turn-round ratio of torpedo cars. However, the amount of dephosphorized hot metal increased again by the facility reinforcement in September 1988. Recently, a 250 000-t monthly level of hot metal is stably dephosphorized.

3.2 Effectiveness of Post-mixed Flux Injection

A typical example of the composition of flux for dephosphorization used by Chiba Works is shown in **Table 2**. This is the CaO-based flux, and for the oxide source, dust or mill scale is used which has been generated at the sintering plant and others in the Works. As a result, the cost of the oxide source is low, and a merit has been enjoyed in recovery of the iron source.

The slag composition during dephosphorization has been determined by taking into consideration the securement of the dephosphorization function, prevention of sulfur pick-up and slag fluidity, and the quantity of lime used is controlled according to the Si content before treatment. In the desulfurization process using soda ash[6] adopted by the Company, the necessity for desulfurization during dephosphorization is small, and low basicity operation is possible within the range not dropping (P)/[P] ratio. Ordinarily, the lime consumption

Table 2 Typical composition of dephosphorization agent (%)

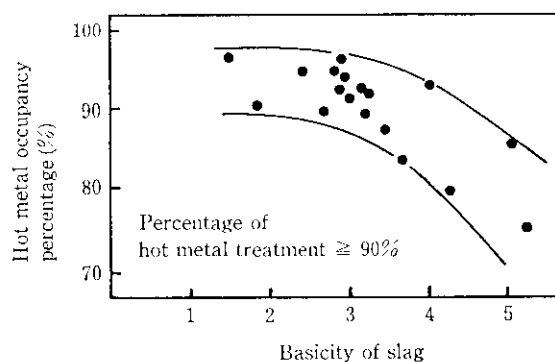| Sinter dust	Mill scale	Lime	Spar
38	35	25	2

Fig. 4 Influence of slag basicity after treatment on hot metal occupancy percentage in torpedo car

is controlled at $CaO/SiO_2 = 2$ to 3 as a target.

However, in the pre-mix method in which flux was blended in the dispenser before treatment, it was difficult to make the flux composition follow up fluctuations of hot metal Si dynamically, resulting in improper quantity of lime. Therefore, the authors have adopted the post-mix method, in which the injection of two kinds of flux, that is, iron oxide (dust + mill scale) and CaO-based (CaO + CaF_2) flux, from separate dispensers at suitable blending ratio is possible. According to this post-mix method, it is possible to select flux having suitable compositions depending upon hot metal Si and target P content after treatment, thereby permitting a reduction of 1.5 kg/t in unit consumption of lime.

Further, since the slag composition is maintained at an appropriate range, slag fluidity is maintained, and slag deposition in the torpedo car has become less. The relation between slag basicity after treatment and hot metal occupancy percentage in torpedo car is shown in **Fig. 4**, which indicates that for ensuring the amount of hot metal filling up a torpedo car, the control of slag basicity is important. The relation between hot metal pretreatment ratio and hot metal occupancy percentage in torpedo car is shown in **Fig. 5**. As the hot metal pretreatment ratio rises, slag remaining in the torpedo car increases, and the amount of hot metal filling up a torpedo car decreases, but through maintaining the fluidity of slag and reinforcement of processing capacity in TCC, it is possible to maintain the hot metal occupancy percentage at a high level, even under the situation where all hot metal is pretreated. Further, slopping, which sometimes occurred at the final stage of the desiliconization reaction in the past, has been almost completely suppressed by using a slag composition that
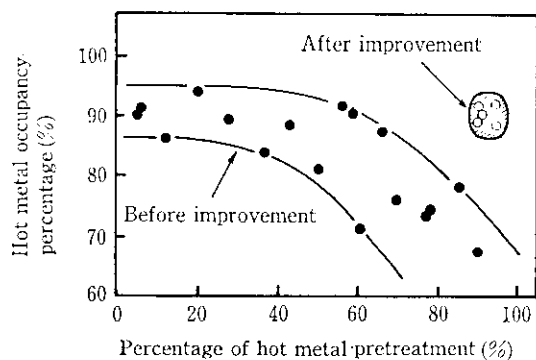
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Fig. 5 Influence of hot metal pretreatment ratio on hot metal occupancy percentage in torpedo car

Fig. 7 Comparison of hot metal temperature after treatment between before and after modification by applying oxygen gas

ensures $CaO/SiO_2 > 1.5$ at the desiliconization stage. These are techniques which will become a premise to the use of a large quantity of the oxygen gas, and form also important techniques for preventing an increase in trouble arising from slopping and for maintaining the total-quantity processing system.

3.3 Effectiveness of Using Oxygen Gas

The oxygen gas has been used in order to increase the thermal allowance in hot metal pretreatment. Since the oxygen gas ratio (= Oxygen gas/(oxygen gas + oxygen from iron oxide)) and the temperature drop during treatment have a relation shown in Fig. 6, the hot metal temperature after treatment can be controlled by changing the oxygen gas ratio.

As mentioned earlier, the hot metal pretreatment gives a merit of recovering a low-cost iron source by the use of iron oxides such as dust, and therefore, an optimum oxygen gas ratio exists depending upon the required level of hot metal [P]. Namely, at No. 1 Steelmaking Shop where the extremely lower phosphorus content is required, the temperature drop during treat-
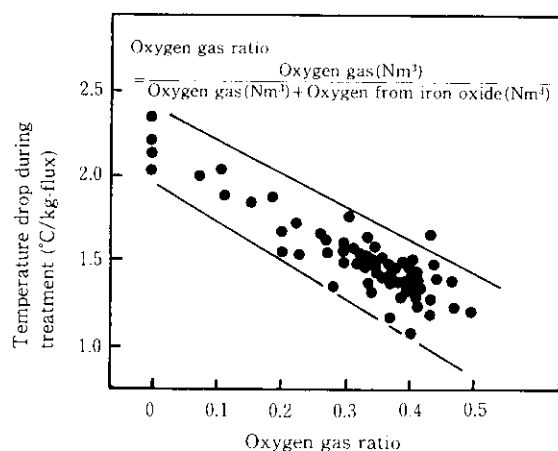

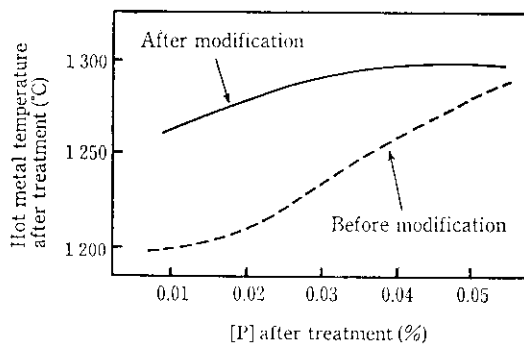Fig. 6 Influence of oxygen gas ratio on temperature drop during treatment

ment is significant, and therefore, it is necessary to increase the oxygen gas ratio during dephosphorizing stage, in order to increase the thermal allowance, even if the iron source recovering merit is slightly sacrificed. At No. 3 Steelmaking Shop where the demanded phosphorus content level is not so low, on the other hand, operation is carried out at the oxygen gas ratio which maximizes the total merits consisting of the merit in the converter due to a rise in the charging temperature of hot metal and that of iron source recovery from iron oxide.

The relation between phosphorus content after treatment and the temperature after treatment is compared with that before modification (no oxygen gas used) in Fig. 7. Through this control of the oxygen gas ratio, it is possible to control the temperature after treatment within 1 260 to 1 300°C independently from phosphorus content after treatment.

4 Reaction Behaviour of Oxygen Gas in Hot Metal Pretreatment[4,5]

4.1 Experimental Procedures

As for the use of the oxygen gas aimed at heat compensation in hot metal pretreatment, many reports have to date been made.[9] However, examples were few which compared reaction behaviours of the oxygen gas and oxygen from oxide, and there was no example which examined in detail post-combustion and its heat balance in the torpedo car. Therefore, at the time of constructing the oxygen top-blowing facilities, preliminary investigation by testing facilities was performed with the aim of evaluating the applicability of oxygen gas to hot metal pretreatment.

The test was conducted at the pretreatment center of No. 1 Steelmaking Shop of Chiba Works. At the time of this investigation, compositions and temperatures of the exhaust gas, hot metal and slag were measured at the respective stages of hot metal pretreatment, and the oxygen balance and heat balance were obtained. Fur-

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Table 3 Experimental conditions

Heat size	200~250 t/torpedo
Top lance	
Lance type	Non cooled
Nozzle diameter	20 or 30 mm
Height	0.4~1.2 m
Oxygen flow rate	0~15 Nm³/min

ther, in order to investigate the effect of the oxygen blowing conditions on the post-combustion behaviour, the oxygen gas flow rate, lance diameter and lance height were changed within possible ranges. The experimental conditions are shown in **Table 3**.

4.2 Behaviours of Decarburization, Desiliconization and Dephosphorization Reactions

As for the respective reaction behaviours of the oxygen gas and oxygen from iron oxide, oxygen (gas + oxide) which had arrived at hot metal was obtained from Eq. (1), and the respective reactions were compared and examined by obtaining their reaction efficiencies from Eq. (2) as follows:

$$q_T = q_C + q_{Si} + q_{Mn} + q_P + q_{Fe} \cdots\cdots(1)$$
$$\eta_i = q_i/q_T \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(2)$$

where q_i: Oxygen consumed for oxidation of i component (Nm³)

q_T: Effective oxygen which has arived at the hot metal bath

η_i: Oxygen efficiency for oxidized reaction of i component

The relation between effective oxygen efficiency for decarburization, which was obtained from Eq. (2), and the oxygen gas ratio is shown in **Fig. 8**. When the Si content in hot metal is 0.05% or below, the ratio of oxygen which is consumed by decarburization is not dependent on the oxygen gas ratio but is constant at 74%. From this result, it can be said that regarding the decarburization reaction, the reaction behaviours of the oxygen gas and oxygen from iron oxide are equal, as far as the oxygen gas ratio is within the range of 40%.

Similarly, effective oxygen efficiency for desiliconization are sorted out by Si content, and compared by the oxygen gas ratio. The result is shown in **Fig. 9**. Oxygen efficiency for desiliconization are strongly affected by Si content, but no difference by the oxygen gas ratio is observed. From this, it can be also said that regarding the desiliconization reaction, the reaction behaviours of the oxygen gas and oxygen from iron oxide are equal to each other.

Regarding dephosphorization reaction, a comparison has been made in reaction behaviours. The relation between the oxygen consumption and the logarithm of
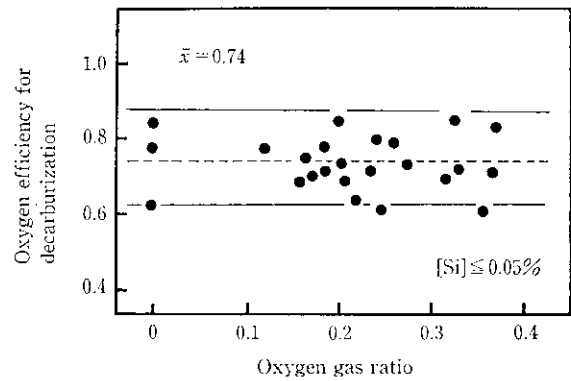

Fig. 8 Influence of oxygen gas ratio on oxygen efficiency for dacarburization
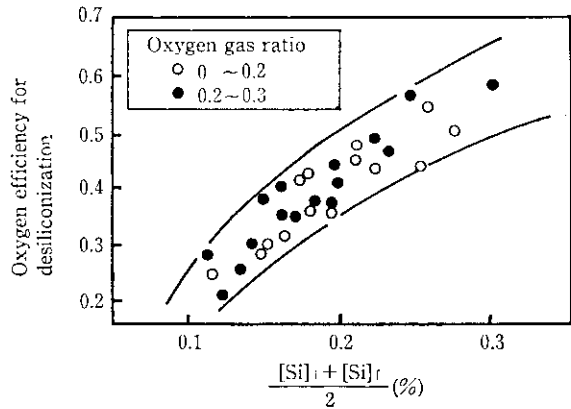

Fig. 9 Influence of silicon content and oxygen gas ratio on oxygen efficiency for desiliconization
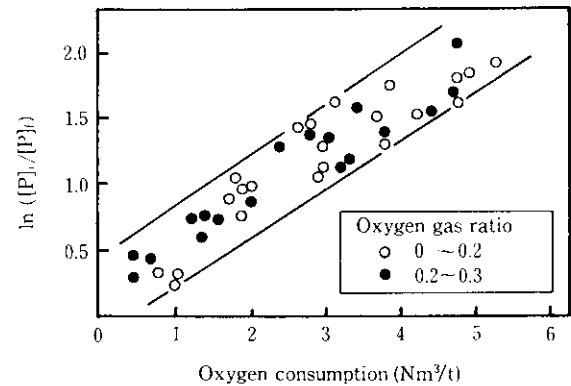

Fig. 10 Influence of oxygen gas ratio on dephosphorization behaviour

the hot-metal P content ratio before and after treatment is shown in **Fig. 10**. From this figure, it can be said that regarding the dephosphorization reaction, the reaction behaviours of the oxygen gas and oxygen from iron oxide are also equal to each other.

4.3 Post Combustion Behaviour

In the hot metal pretreatment facilities, CO in the

exhaust gas completely burns near the hot metal receiving port of the torpedo car, and therefore, it is difficult to measure the post-combustion ratio at right above the hot metal bath surface. Thus the authors have decided to estimate, from the oxygen balance, the oxygen gas efficiency for post combustion right above the hot metal bath surface.

If it is considered that the oxygen gas, which has not reached the hot metal bath, has all been consumed in CO combustion, the oxygen gas efficiency for post combustion in the torpedo car is expressed by Eq. (3).

$$\eta_{PC} = 1 - \eta_{MB} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (3)$$

where η_{PC}: The oxygen gas efficiency for post combustion

η_{MB}: The arriving ratio of the oxygen gas to the hot metal bath

Furthermore, the arriving ratio of oxygen to the hot metal bath can be expressed as Eq. (4) by deducing it from each efficiency for decarburization of the total oxygen gas and the oxygen gas arriving the hot metal bath.

$$\eta_{MB} = \eta_{C(G)}/\eta_{C(B)} \quad \cdots\cdots\cdots\cdots\cdots\cdots (4)$$

where,

$\eta_{C(G)}$: Apparent oxygen gas efficiency for decarburization

$\eta_{C(B)}$: Efficiency of oxygen gas arriving hot metal bath for decarburization

Out of these, regarding the efficiency of the oxygen gas, which has arrived at the hot metal bath for decarburization, there is no difference between the oxygen gas and oxygen from iron oxide as mentioned in Sec. 4.2, and therefore, it is possible to use the value of 0.74 for the efficiency of the hot-metal-bath arriving oxygen for decarburization.

Apparent oxygen gas efficiency for decarburization has been obtained ① by changing the flow rate of the oxygen gas under constant injection rate of the iron oxide and ② by measuring the decarburization reaction rate from changes in the CO generation rate which is to be obtained from the flow rate of the exhaust gas and CO_2 concentration in the exhaust gas. The outline of this measuring method is shown in Fig. 11. The oxygen gas efficiency for post combustion, which has been calculated from the above-mentioned measuring result and using Eqs. (3) and (4), is shown in Fig. 12. The oxygen gas efficiency for post combustion changes depending upon the lance diameter, oxygen flow rate and lance height, but it has been found that the effect of the lance height is the largest and that even by changing only the lance height, wide-range control is possible.

4.4 Heat Compensation Mechanism in Using Oxygen Gas

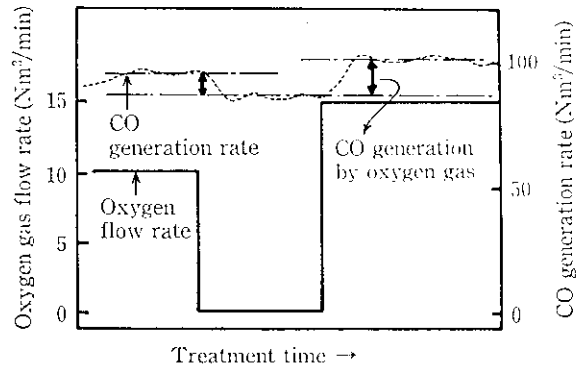Since the object of use of the oxygen gas during hot

Fig. 11 Outline of measuring method of CO generation rate by oxygen gas
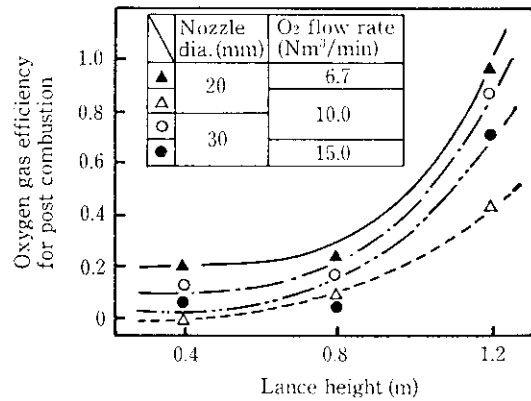

Fig. 12 Influence of blowing conditions on oxygen gas efficiency for post combustion

metal pretreatment lies in prevention of the temperature drop during treatment, examination has been made from the viewpoint of heat compensation.

The heat compensation by the use of the oxygen gas is due to the following two effects:

(1) Decreases in sensible heat and reduction heat due to replacement of the oxygen from iron oxide by oxygen gas

(2) Heat transfer of post combustion of the CO gas

To grasp quantitatively the heat compensation quantities due to the above-mentioned effects, the heat balance has been obtained. An example of the heat balance when the oxygen gas is top-blown under the conditions of a flow rate of 10 Nm^3/min and a lance height of 0.8 m is shown in Fig. 13. It has been found that the ratios occupied by the sensible heat of flux and the reduction heat of oxides are 30% and 60% of output heat respectively, and the heat transfer of post combustion by oxygen gas is 3% of the output heat.

To evaluate the heat transfer efficiency of post combustion, heat distribution of hot metal pretreatment has been calculated by using the model in which the main transfer of heat in torpedo car is radiation. An example of the calculated results is shown in Fig. 14. The heat transfer efficiency of post combustion in the torpedo
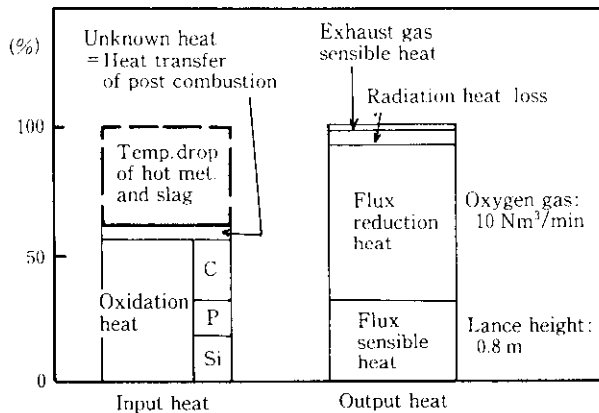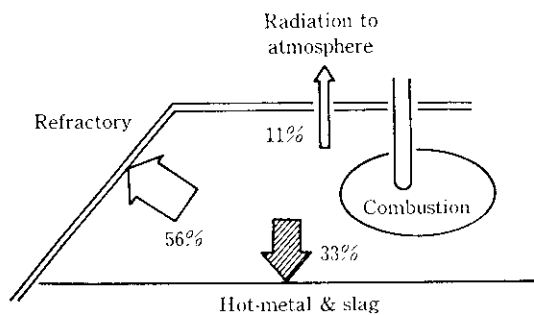
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Fig. 13   Example of heat balance

Fig. 14   Heat distribution of hot metal pretreatment
in torpedo car

car is about 33%, and the majority of the heat generation is transferred to the refractories of the inner walls.

On the other hand, the heat transfer efficiency of post combustion in the converter is generally 70 to 80%, which is more than double the heat-transfer efficiency in the case of hot metal pretreatment. The reasons why the heat transfer efficiency of post combustion in hot metal pretreatment is so low are considered to be the following two points:

(1) The temperature on the surface of the refractories is lower than that in the converter, and therefore, radiational heat transfer from the refractory surface to hot metal is not obtainable at an initial stage of treatment.

(2) Due to the shape difference in the combustion space, the ratio of radiational heat transfer to hot metal is low.

To sum up the effects of using the oxygen gas, the heat compensation quantities when an oxygen gas of 1 Nm^3 is replaced with oxygen from iron oxide or consumed in post-combustion will be about 7 380 kcal/Nm^3 and 1 990 kcal/Nm^3 respectively. In achieving the objective of heat compensation, positive replacement of the oxygen from iron oxide with oxygen gas can be said to be effective.

However, on one hand, replacement of oxygen from iron oxide with the oxygen gas reduces the merit of

recovering iron from a cheap iron source, and when this cost change is taken into consideration, post combustion takes less cost than the replacement of oxygen from iron oxide as a means of thermal compensation. Therefore, regarding the use of the oxygen gas, optimization should be planned, taking into consideration the total cost merit from hot metal pretreatment to the converter refining.

5 Conclusions

(1) The dephosphorization treatment system using the torpedo car at Chiba Works has been firmly established by the function of changing flux composition matched with hot metal composition, setting up of the removing function of slag remaining in the torpedo car and the use of a large quantity of the oxygen gas.

(2) By post mixing of flux, optimum control of the lime consumption matched with hot metal composition has become possible, thereby reducing the unit consumption of lime. Further, through control to appropriate slag composition and reinforcement of processing capacity at TCC, it has become possible to prevent slag contamination of the torpedo car under the total-quantity treatment system.

(3) For the use of the oxygen gas in the torpedo car, the authors have investigated the reaction behaviour and heat transfer behaviour of oxygen gas in the tests prior to facility construction, and confirmed the effectiveness of the oxygen gas. On the basis of such investigations, the optimum utilization methods have been established which are matched with the various processes.

As a result of these efforts, stabilized operations under the monthly 250 000-t total quantity pretreatment system have been realized with notable contribution to the reduction in the total cost.

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