KAWASAKI STEEL TECHNICAL REPORT
No.8 (September 1983)

Production of Stainless Steel by Top-and-Bottom-Blown Converter

Naoshi Otani, Masaru Shibata, Ryuichi Asaho, Shunji Hamada, Motoyasu Yaji, Yoshiei Kato

Synopsis :
At Chiba Works, an 80 t new UHP melting furnace (MF) was erected and the existing LD converter was converted into a top-and-bottom-blown converter (K-BOP) at its No.1 Steelmaking Shop. This was in line with a stainless steelmaking integration program modified from the former setup involving two steel works of Nishinomiya and Chiba. An entirely new process came on stream in March 1981 for the bilateral production of carbon steel and stainless steel by K-BOP and MF - K-BOP. Furthermore, equipment for hot metal treatment was installed to supply dephosphorized hot metal instead of iron scrap in MF practice. Owing to this change, a significant increase in productivity and cost reduction were achieved. Studies on the reaction model and standardization regarding decarburizing practice and metallurgical behavior in reduction period are also presented.

The body can be viewed from the next page.

Production of Stainless Steel by Top-and-Bottom-Blown Converter*

Naoshi OTANI** Masaru SHIBATA** Ryuichi ASAHO**
Shunji HAMADA** Motoyasu YAJI** Yoshiei KATO***

At Chiba Works, an 80 t new UHP melting furnace (MF) was erected and the existing LD converter was converted into a top-and-bottom-blown converter (K-BOP) at its No. 1 Steelmaking Shop. This was in line with a stainless steelmaking integration program modified from the former setup involving two steel works of Nishinomiya and Chiba.

An entirely new process came on stream in March 1981 for the bilateral production of carbon steel and stainless steel by K-BOP and MF–K-BOP.

Furthermore, equipment for hot metal treatment was installed to supply dephosphorized hot metal instead of iron scrap in MF practice.

Owing to this change, a significant increase in productivity and cost reduction were achieved. Studies on the reaction model and standardization regarding decarburizing practice and metallurgical behavior in reduction period are also presented.

1 Introduction

As a part of the stainless steel manufacture streamlining program of Kawasaki Steel Corporation, two conventional production units; one at Hanshin Works and the other at Chiba Works were integrated as the No. 1 Steelmaking Shop at Chiba Works. On that occasion, the existing two 85 t LD converters of No. 1 Steelmaking Shop were remodeled into top-and-bottom-blown converters (K-BOP), while a new 85 t UHP (Ultra High Power) melting furnace (MF) was erected, and the related ancillary facilities were installed. The production of stainless steel by MF and K-BOP came on stream in April 1981, and the stainless steel production at Hanshin's steelmaking plant terminated at the end of July that year.

The key point of this modernization program was to rationalize Kawasaki Steel's stainless steel production process by making the full use of the K-BOP refining featuring a multipurpose capability to a point of combining it with the existing continuous casting operation. The erection of the new UHP MF was aimed at widening the scope of selection of steelmaking raw materials whose cost forms a large proportion of the cost of stainless steel production.

* Originally published in *Kawasaki Steel Giho*, **15**(1983) 2, pp. 21–27

** Chiba Works

*** Research Laboratories

In K-BOP vessel design, specifications were determined in consideration of the product mix of the No. 1 Steelmaking shop. The steps of improvements and developments of converter refractories will be detailed in another report[1]. Operating results were improved through the optimum use of coolant process gas and the improvement of refractory work techniques and brick properties. It has been possible to smoothly increase the production of stainless steel owing to these technical developments and improvements.

2 Main Equipment for Mass Production Process of Stainless Steel

2.1 Melting Furnace

In stainless steel refining, the use of large amounts of inexpensive scrap is advantageous in terms of cost. This effect is great especially in nickel-containing stainless steels. The MF was installed to rapidly melt scrap and ferroalloys and supply them to the top-and-bottom-blown converters. **Table 1** gives the main specification of the MF.

To carry out multiheat continuous casting, it is necessary to set tapping intervals of the MF at less than 90 min. For this purpose, it is necessary that the net power input time be less than 60 min and that the preparation time be less than 30 min. Therefore, the UHP melting furnace has a transformer capacity

Table 1 Specifications of MF and auxiliary equipment

Items	Specification
1 Heat size	85 t
2 Shell diameter	6 300 mm
3 Transformer capacity	Regular 65 MVA Max. 78 MVA
4 Secondary voltage	Min. 350 V Regular 595 V Max. 770 V Tap step 35 V×13
5 Electrode	3° slanting 610 mmϕ×2 400 mml Pitch circle diameter : 1 160 mm
6 Charging bucket	70 m^3×3 36 m^3×3
7 Gunning machine	150 - 200 kg/min
8 O_2 gas lancing	40 - 60 Nm^3/min
9 Clean house	Inner volume 5 300 m^3
10 Dust collector	IDF (5 300 Nm^3/min)

of 65 MVA rating (78 MVA maximum). The vessel was designed so as to endure operation with high power input. Also, in order to reduce refractory consumption, the water-cooled cast block was adopted for 70% of the furnace roof area. Furthermore, to reduce hot-spot loads, the electrodes are held with 3° tilt and their pitch circle diameter is 1 160 mm, which is about 88% of that of conventional UHP melting furnaces.

In general, the noise level of UHP vessels is high at the initial stage of melting and reaches as high as 125 dB(A). As a soundproof measure, the whole MF equipment was arranged in an enclosure of the sound absorbing constructure (clean house). At the same time, carefully thought-out measures for preventing noise, dust, and NO_x were taken by connecting the whole clean house directly to dust catching equipment. Labor-saving was aimed at by installing automatic electrode connection equipment and automatic gunning machines.

2.2 Modification into K-BOP Vessels

In remodeling the existing top-blown converters into the top-and-bottom-blown converters, priority was given to securing the superiority of the top-and-bottom-blown converters over AOD furnaces. The top-and-bottom-blown converters have the following advantages over AOD furnaces:

(1) The K-BOP vessel can be used for producing also plain carbon steels by using the oxygen blowing lance.

(2) Tuyere protection can be strengthened by using propane and other coolant gases.

(3) This vessel is advantageous in desulfurization because lime powder injection is possible.

Furthermore, it is expected that new blowing techniques for stainless steel using the oxygen blowing lance of the K-BOP vessel will be developed.

The following are results of an investigation of the main specification of the top-and-bottom-blown converter.

2.2.1 Examination of gas flow rate

Chromium yields equal to or higher than that obtained in an AOD furnace were set as one of the basic conditions. Experiments on chromium losses due to oxidation were carried out using a 5 t experiment furnace by varying the ratio of bottom-blown oxygen gas to nitrogen gas (O_2/N_2). As shown in **Fig. 1**, it was confirmed that the smaller the ratio O_2/N_2 (the higher the dilution degree of O_2), the smaller the amount of chromium losses due to oxidation[2].

Figure 2 shows the relationship between the O_2 flow rate and [%Cr]/[%C][3]. From the results at an AOD furnace[4] shown in **Fig. 2**, it was suggested that the maximum bottom-blown gas volume is approximately 1 Nm^3/min·t. Furthermore, the relationship between the ISCO (Index for Selective Carbon Oxydation)-value and chromium losses due to oxidation[2] (see **Fig. 3**) was examined and it was found that the smaller the ISCO-value, the smaller the amount of chromium oxidized during blowing and that the amount of oxidized chromium can be held to almost the same amount of oxidized chromium as with an AOD furnace. To examine whether the limited bottom-blown gas volume of 1 Nm^3/min·t has an effect on

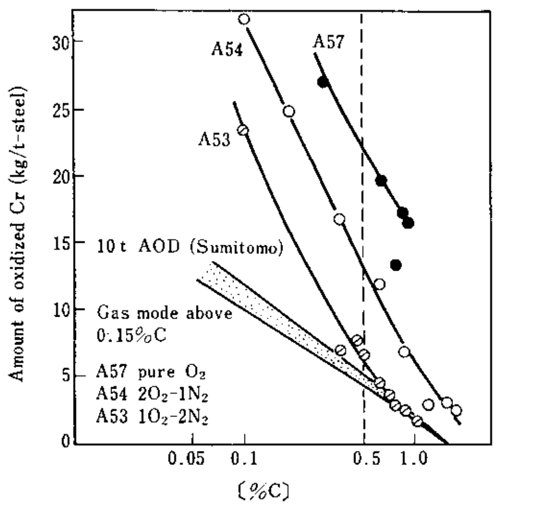

Fig. 1 Amount of chromium oxydized during bottom blowing[2]

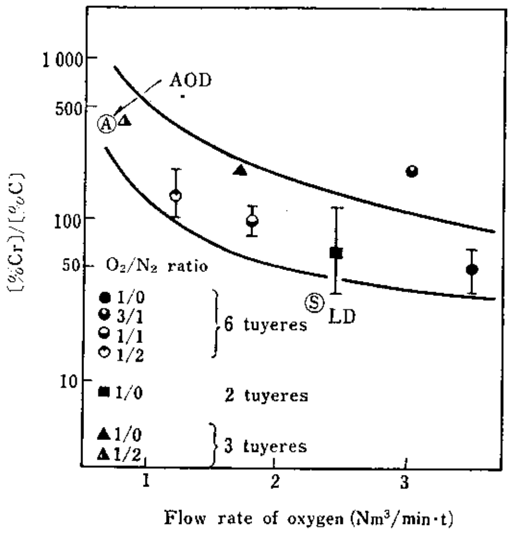

Fig. 2 Influence of the flow rate of bottom blown oxygen on the partition of [%Cr]/[%C] at 1 715°C

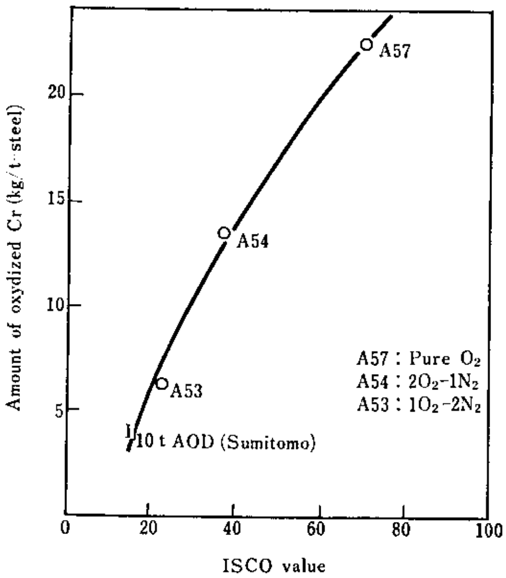

Fig. 3 Amount of oxydized chromium vs. ISCO values[2)]

the blowing time of the K-BOP vessel, an investigation was made under the operating conditions shown in **Table 2** and it was found that refining can be completed in about 80 minutes even at 1 Nm³/min·t. Moreover, the decarburization time can be shortened if the oxygen blowing lance is used in the high carbon range and, if this is taken into consideration, the steelmaking process can be sufficiently matched to multiheat continuous casting.

2.2.2 Factors for determining tuyere size

The following three conditions were set in determining the diameter of the tuyere inner pipe:

(1) To secure a gas flow rate of 1.0 Nm³/min·t during the blowing of stainless steel.
(2) To make possible the injection of approximately 5 kg/min·t of lime powder during the blowing of plain carbon steel.
(3) To set the gas holder pressure, supply pressure and the maximum tuyere base pressure as 23 kgf/cm², 17 kgf/cm² and 15 kgf/cm², respectively.

2.2.3 Factors for determining tuyere arrangement and vessel profile

Since the 230 t Q-BOP vessels at Chiba Works have shown a stable bottom life, the same tuyere spacing as in these vessels was adopted. The maximum number of tuyeres was set at 7 seeing that the bottom diameter is 2 800 mm. The tuyere position was determined in consideration of ① adhesion of skull to the oxygen blowing lance, ② spitting from the vessel, ③ intensity of steel bath stirring, ④ vibration in the axial direction of the trunnions, ⑤ arrangement in which the tuyeres are not immersed in hot metal during hot metal charging, etc. A water model experiment was conducted by changing the tuyere arrangement in various ways and the tuyere arrangement was determined by examining the above-described items.

The vessel profile was examined by attaching the

Table 2 Process gas flow rate and estimated refining time

		Decarburization step				Reduction	Sampling	Desulfurization	Total time
		Step I	Step II	Step III	Step IV				
O_2/(Ar or N_2)		4/1	2/1	1/2	1/3				
[%C]		2.0 0.6	0.25	0.12	0.06				
Gas flow rate (Nm³/min)	O_2	80	67	33	25	—	—	—	
	Ar, N_2	20	33	67	75	42-60	—	42-60	
	Propane	2.4	2.0	1.0	0.8	—	—	—	
O_2*	(Nm³)	1 919	676	262	208	—	—	—	
O_2**	(Nm³)	133	69	51	102	—	—	—	
Total O_2	(Nm³)	2 052	745	313	310	—	—	—	
Process time	(min)	25.7	11.1	9.5	12.4	6.0	10.0	6.0	80.7

* Amount of O_2 gas for decarburization of bath carbon
** Amount of O_2 gas for decarburization of carbon from dissociated C_3H_8 gas

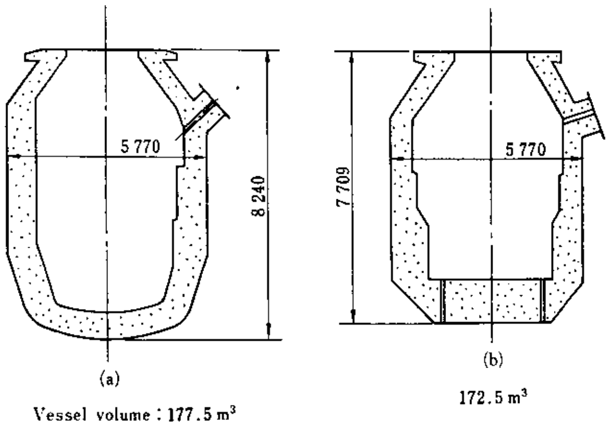

Fig. 4 Profile of converters (a) LD, and (b) K-BOP modified from LD

greatest importance to measures of preventing the erosion of bottom and bottom knuckle bricks. From operation results at the Q-BOP vessels, it has been revealed that the erosion of bottom bricks is greatly affected by the vibration of the metal bath; therefore, it is necessary to reinforce the knuckles of the bottom. Furthermore, a large metal bath depth is advantageous in promoting the decarburizing reaction of stainless steel. In view of these facts, the slant-laying method adopted in LD vessels was not adopted and furnace-wall bricks were vertically laid from the stationary parts of the bottom in the K-BOP vessels, as shown in **Fig. 4**.

2.3 Installation of Hot Metal Treatment Equipment

The market price of carbon steel scrap or purchased stainless steel scrap as the main raw material fluctuates greatly. For this reason, provisions were made so that hot metal can also be used depending on the market condition. The dephosphorizing function of hot metal was taken into consideration and hot metal treatment equipment of the torpedo injection type was installed. The characteristic of this equipment is that the reduction of temperature drops during dephosphorization and the improvement in the dephosphorization efficiency are aimed at by mixing O_2 gas with N_2 gas in the dephosphorizing agent injection pipe and injecting the mixture directly into hot metal. **Figure 5** shows an outline of the equipment and **Table 3**, an example of operating conditions.

3 Operation Results

3.1 Operation Results of Melting Furnace

Figure 6 shows the transition of the output of stainless steel by the MF–K-BOP process. **Figure 7** shows the melting and energizing pattern of the MF. To

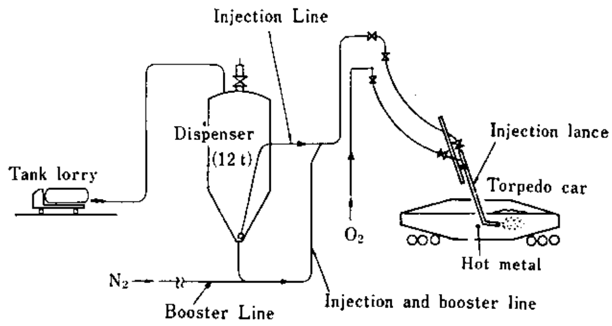

Fig. 5 Schema of pretreatment of hot metal

Table 3 An example of hot metal treating conditions in torpedo car

Weight of hot metal	150～180 t
Injection rate	200 kg/min
N_2 gas blowing rate	0.9 Nm³/min
O_2 gas blowing rate	3.0 Nm³/min

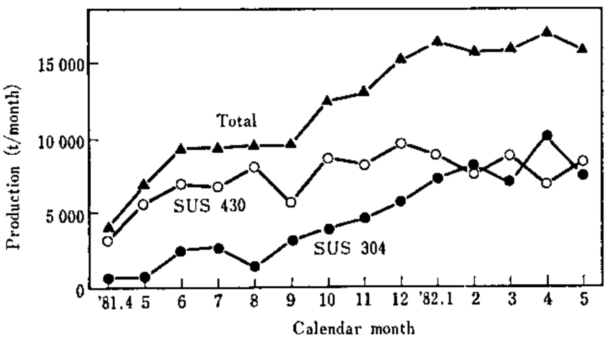

Fig. 6 Change of stainless steel production

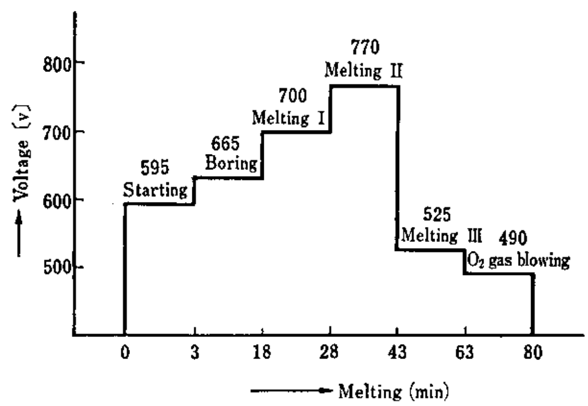

Fig. 7 Schematic presentation of tap voltage change

Table 4 Noise reduction by clean house (C.H.)

Inside of C.H.	Outside of C.H.
Boring period Max.125 dB	Vicinity of C.H.* 80 ~ 85 dB
Melting period 100 ~ 119 dB	Pulpit 67 ~ 76 dB

* 1 m apart from C.H. wall

prevent electrode breakage, low-power-factor operation is carried out in the ignition period and boring period and the arc is thus kept stable. In the main melting period, the operation time is shortened by using full power. In the heating period, the erosion of refractories in hot spots in the furnace wall is prevented by low-voltage operation. The refractory wear index, R_{er}, observed in this operation is 250 or less (when slag is present). The blowing of oxygen gas is started before the end of Period III of melting to shorten the operation time. When the clean house system is adopted, the noise level is very low as shown in **Table 4**.

3.2 Application of Hot Metal Pretreatment Process to Stainless Steel Production

To improve the productivity of continuous casting in the MF–K-BOP–CC process, it was necessary to shorten the melting time in the MF as much as possible. For this purpose, the burden to the MF was reduced and the improvement in the continuous casting efficiency was aimed at by using dephosphorized hot metal as the iron source for stainless steel, thus making the best use of the advantages of an integrated iron and steel plant.

Figure 8 shows an example of operation in this process. This process is characteristic in that only the melting of Cr-Ni ferroalloys and stainless steel scrap is carried out in the MF. As a result, the amount charged into the MF is reduced and the operation time is substantially shortened. Despite an increase in the initial [%C] in the converter due to a duplex process

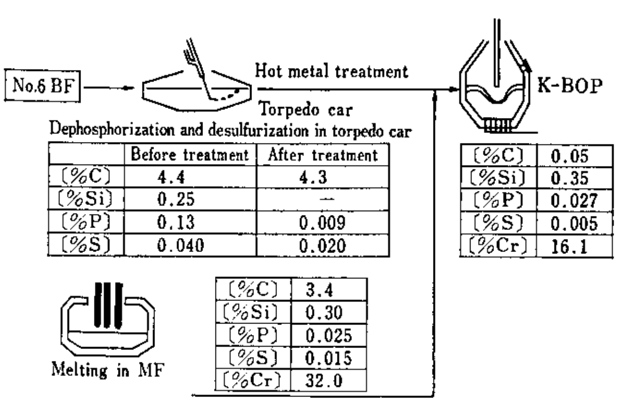

Fig. 8 Schematic illustration of process and operating results for stainless steelmaking

with hot metal, the refining time was reduced to below 60 minutes by using the oxygen blowing lance.

3.3 Operation Results of K-BOP

3.3.1 Top-and-bottom-blown process and behavior of molten steel composition

Figure 9 shows the operation pattern for type 304 stainless steel and an example of behavior of molten steel composition. After the start of blowing, oxygen is blown through the oxygen blowing lance in an amount suitable for the initial [%C]. The ratio $O_2/(N_2 + Ar)$ in Period III when the molten steel is decarburized to about 0.6%, is 4–8 if the gas from the bottom is included. In Period II and thereafter, oxygen is blown only from the bottom and the oxygen blowing lance is not used. At this stage, the proportion of N_2 and Ar is increased by stages according to [%C] and the oxidation of chromium is thus prevented. Chromium oxidation scarcely occurs in the high carbon range of Period I even if the oxygen blowing lance is used, while in Period II and thereafter this oxidation increases abruptly at 0.2% and below. **Figure 10** shows the relationship between [%C] and [%Cr] when the oxygen volume from the oxygen blowing lance is changed to various levels. In the high carbon range, almost no effect on chromium losses due to oxidation was observed even when oxygen was blown at a maximum rate of 1.5 $Nm^3/min \cdot t$.

Table 5 gives a comparison of operation results in the high carbon range between the bottom-blown process and the K-BOP process. In the K-BOP process, the rate of increase in molten steel temperature and

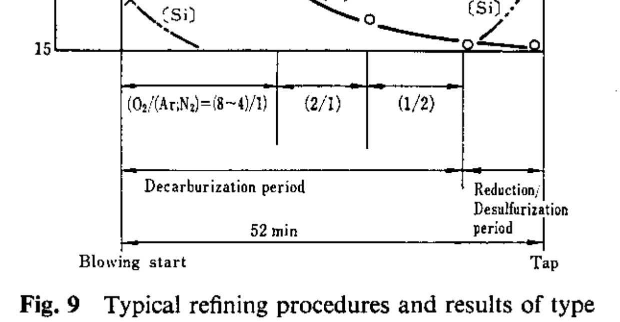

Fig. 9 Typical refining procedures and results of type 304 stainless steelmaking

the decarburization rate are very high. **Figure 11** shows a comparison of the time required for decarburization refining. The oxygen supply rate can be increased in the K-BOP process and, hence, this time is about 10 to 25 minutes shorter than in the bottom-blown process.

From the above, it was found that the refining process for stainless steel in the high carbon range by the K-BOP process has very high productivity and that the tap-to-tap time can be shortened from conventional 70–80 minutes to 45–60 minutes.

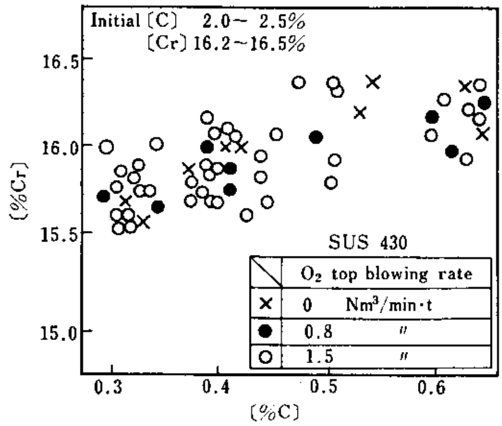

Fig. 10 Influence of oxygen top blowing rate on Cr oxidation during decarburizing period

Table 5 Comparison of results between bottom blowing and combined blowing

		Bottom	Combined
O_2 gas blowing rate (Nm^3/min·t)		0.84	2.10
Temperature increasing rate (°C/min)		12.9	32.6
Decarburization rate (%/min)		0.062	0.149
Refining time (min/heat)	SUS 430	85.5	62.8
	SUS 304	71.2	58.7
Si consumption for reduction (kg/t)	SUS 430	10.1	10.3
	SUS 304	11.1	11.2
Cr yield		Base	+0.2%

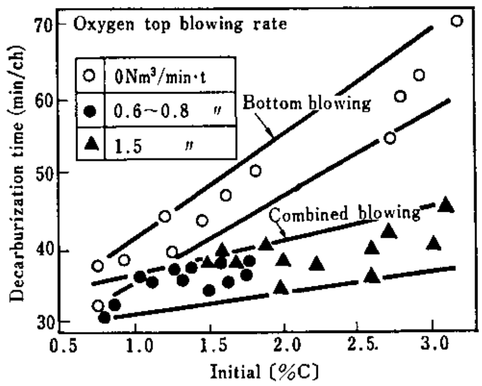

Fig. 11 Influence of oxygen top blowing on decarburization time required

3.3.2 Establishment of nontilting practice

The K-BOP vessels at Chiba Works are provided with sublance equipment. **Figure 12** shows a comparison of the operation pattern for stainless steel production between the conventional practice and the nontilting practice using the sublance. Sublances have been positively used since the start-up of these converters. However, there are problems about the sublance such as probe breakage and adhesion of skull to the sublance structure, problems concerning decarburization and heating models, etc. Therefore, temperature measurement and sampling were carried out by tilting the vessel once or twice during refining.

To solve the above-described problems with the sublance, improvements were made—for example, securing the bending strength of the probe sensor, controling the probe sensor immersion depth and time, and changing the shape of temperature sensing elements and molten steel sampling molds. As a result, it has become possible to carry out temperature measurement and sampling stably. Furthermore, samples are rapidly analyzed and the required oxygen volume is calculated by using a decarburization model and, therefore, what is called the nontilting practice has become possible in which refining proceeds directly to the reduction and desulfurization processes without the necessity of tilting the vessel. Through the establishment of the nontilting practice, the tap-to-tap time was shortened by 7 to 8 minutes and the blow-end temperature was lowered by approximately 20°C. As a result, effects such as an increase in vessel life and reduction of heat losses were achieved. As much as 60% of the total stainless steel output has recently been produced by the nontilting practice.

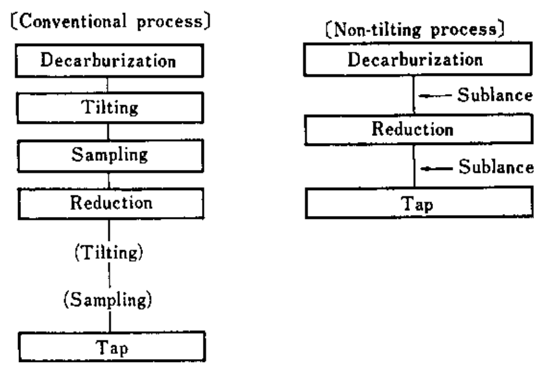

Fig. 12 Schematic comparison of process with respect to sampling method

4 Slag Composition during Stainless Steel Refining

4.1 Oxide of Chromium and Desulfurization Behavior in Reduction Period

Figure 13 shows the relationship between (%T.Cr) of slag after reduction refining and the actual basicity (%CaO)/(%SiO_2). The higher the actual basicity, the larger the amount of chromium recovered in the reduction period and (%T.Cr) is 0.5 or less at (%CaO)/(%SiO_2) $\geq$ 1.6. The following equation is valid if the reduction rate of Cr_2O_3 is mass-transfer controlled in terms of the Cr_2O_3 in slag:

$$-\frac{d(\%Cr_2O_3)}{dt} = \frac{k_S \cdot a \cdot \rho_S}{W_S} \cdot \{(\%Cr_2O_3)_t - (\%Cr_2O_3)_e\} \quad \cdots\cdots\cdots (1)$$

t: Time elapsed (min)
$(\%Cr_2O_3)_t$: Cr_2O_3 content of slag at time t
$(\%Cr_2O_3)_e$: Equilibrium Cr_2O_3 content of slag
k_S: Mass transfer coefficient of Cr_2O_3 in slag (m/min)
a: Area of reaction interface between slag and metal (m^2)
ρ_S: Density of slag (kg/m^3)
W_S: Weight of slag (kg)

Then, the rate constant, K_{Cr}, is defined as follows:

$$K_{Cr} = \frac{k_S \cdot \rho_S, a}{W_S} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots (2)$$

If the relationship between K_{Cr} and the actual basicity is determined by using the value indicated by the broken line in **Fig. 13** as $(\%Cr_2O_3)_e$, the result is shown in **Fig. 14**. Like the result obtained by Ikeda et al.[5], the higher the actual basicity, the higher the reduction rate. Furthermore, the stirring capacity of the K-BOP vessel is considered to be better than that of the AOD furnace, seeing that, with the same basicity, the rate constant is larger than in a 90 t AOD furnace. **Figure 15** shows the relationship between the sulfur distribution ratio, (%S)/[%S], after reduction and the actual basicity. As with the data obtained at a 2.5 t AOD furnace, it is found that the higher the actual basicity, the higher the sulfur distribution ratio. Therefore, actual basicity of 1.6 or more is required for effective desulfurization, for example, sulfur distribution ratio of 15 or more.

4.2 Slag Control during Stainless Steel Refining

A concept of slag control during stainless steel refining is shown in the following:

(1) The slag amount is minimized to suppress the chromium oxidation in the oxidation period.

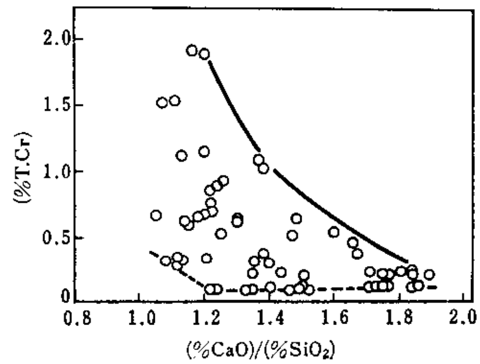

Fig. 13 Relation between (%T. Cr) in slag and observed basicity

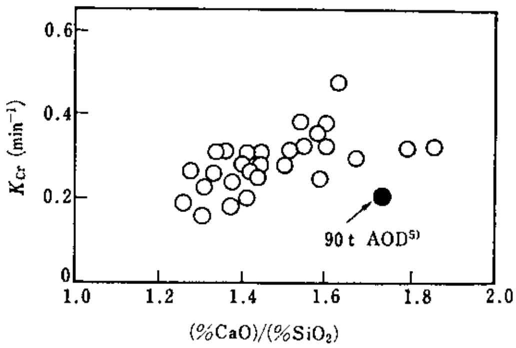

Fig. 14 Relation between rate constant at reduction period and observed basicity

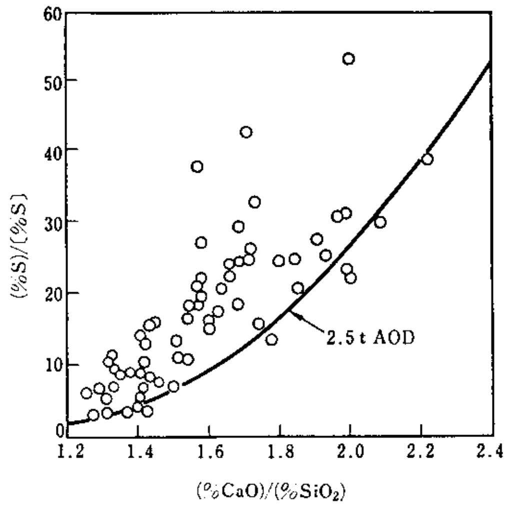

Fig. 15 Effect of observed basicity on sulfur distribution ratio at reduction period

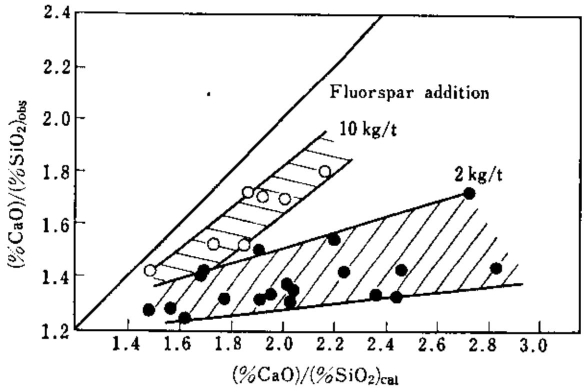

Fig. 16 Relation between observed and calculated basicities

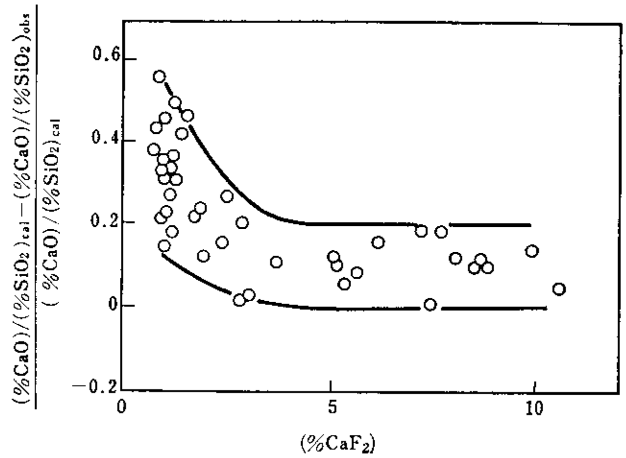

Fig. 17 Effect of fluorspar content in slag on slag formation

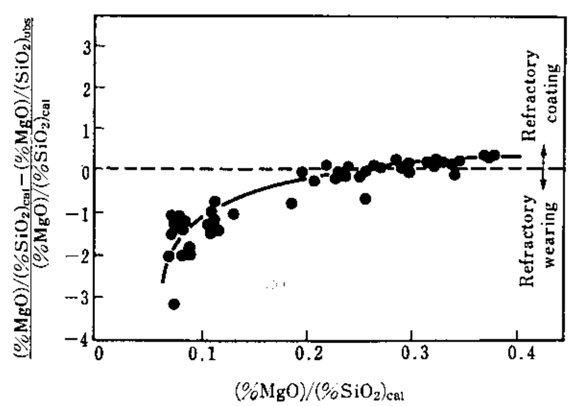

Fig. 18 Influence of calculated (%MgO)/(%SiO_2) on MgO balance at reduction period

(2) The slag basicity is increased to promote the desulfurization reaction and the reducing reaction of the chromium oxide at the same time.
(3) The erosion of converter refractories is held to a minimum.

Figure 16 shows the relationship between the actual basicity and the calculated. There is no agreement between the two and it is apparent that all CaO of added burnt lime, dolomite, etc., is not slagged. This difference between the observed and calculated basicity decreases if the amount of added fluorspar, a flux, is increased. Fluorspar is necessary for increasing the actual basicity by reducing the total amount of fluxes added.

Figure 17 shows the relationship between the unslagged CaO ratio and the CaF_2 content in slag. The unslagged CaO ratio is, so to speak, the proportion of unknown CaO and is the quotient obtained by dividing the difference between the amount of CaO added and the amount of CaO in slag by the amount of CaO added. In this figure, however, the unslagged CaO ratio is represented by approximate values calculated from basicity. The unslagged CaO ratio decreases with increasing CaF_2 content and is in the range of 0 to 0.2 at a CaF_2 content of 3 to 4%.

Figure 18 shows the relationship between the dissolved MgO ratio and calculated (%MgO)/(%SiO_2). The dissolved MgO ratio is the quotient obtained by dividing the difference between the amount of MgO added and the amount of MgO in slag by the amount of MgO added. The plus sign means that MgO adheres to furnace refractories and the minus sign means that MgO in refractories is dissolved in slag. In the figure, the ordinate represents the approximate values of the dissolved MgO. To suppress the dissolution of MgO, i.e., erosion of refractories, fluxes such as dolomite must be added so that the calculated (%MgO)/(%SiO_2) becomes 0.3 or more.

Thus, to inhibit chromium oxidation as much as possible, ensure stable reduction of the chromium oxide and desulfurization, and suppress the erosion of refractories, it is desirable to add fluxes so that the actual basicity (%CaO)/(%SiO_2) $\geq$ 1.6, CaF_2 in slag will be 3 to 4%, and the calculated (%MgO)/(%SiO_2) $\geq$ 0.3.

5 Conclusion

In consolidating Kawasaki Steel's stainless steel manufacturing line into the No. 1 Steelmaking Shop of Chiba Works, a new 85 t UHP melting furnace was installed, and the existing LD converters were remodelled into the top-and-bottom-blown converters (K-BOP). In these converters, plain carbon steels are refined by the K-BOP process and, at the same time, a mass production process for stainless steel by MF–K-BOP was established. In addition, hot metal treatment equipment was installed. A substantial decrease in the operation time and cost reduction were achieved by using dephosphorized hot metal instead of carbon steel scrap. Moreover, decarburization control techniques were established to carryout the nontilting practice, and optimum chromium reduction and desulfurization conditions by the single slag were considered to ensure stable operation.

References

1) R. Uchimura et al.: *Kawasaki Steel Giho*, **15** (1983) 2, p. 45
2) K. Nakanishi et al.: *Kawasaki Steel Technical Report*, No. 1 (Sept., 1980), p. 1
3) K. Nakanishi, H. Nakamura et al.: *Tetsu-to-Hagané*, **64** (1978) 11, S588
4) K. Ishihara, T. Sakane et al.: *Ibid.*, **64** (1978) 4, S182
5) R. Ikeda: The 19th Steelmaking Committee, Japan Society for the Promotion Science (JSPS), No. 19–10163