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Improvement of Productivity at Kimitsu No.2 Steelmaking Plant*1

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Abstract

The Kimitsu No. 2 Steelmaking plant was operated with 3 converters, and only two out of three converters were operated during converter repair. This time, complete two out of three converter operation and the pre-treatment of the entire amount of hot metal were enabled by converter productivity improvement, and the benefits of cost reduction by reducing refractory and sub-materials have been obtained. Also, refining simplification (only RH treatment, KIP suspended) resulted in the reduction of converter blow end temperature and secondary refining cost. The main improvement issues are as follows: 1) MURC replacement of LD-ORP for steel grades, deregulation of components, 2) Increase in the oxygen supply rate at MURC Blow1, cycle time reduction, and basicity optimization to improve dephosphorization, 3) RH productivity improvement, and 4) Increase of molten steel ladle heat size.

1. Introduction

At the No. 2 Steelmaking plant of Kimitsu Works, two out of three converters were operated conventionally as a provisional operation mode during the repair of one of the converters in the basic simultaneous operation mode of the three converters. Then, we endeavored to improve the productivity of the converters, and by realizing consolidation of converter operation and stabilized converter operation thereby, fully-fledged two out of three converter operation mode was realized. This paper reports our efforts to improve the entire integrated capability of the No. 2 Steelmaking plant by improving the converter productivity.

2. Production Structure of No. 2 Steelmaking Plant at Kimitsu Works and Its Problem

Figure 1 shows the steel manufacturing process at Kimitsu Works, which has two steelmaking plants. The No. 1 Steelmaking plant produces blooms for wire rod mill and shape mill.

The No. 2 Steelmaking plant has three lines of converter-vacuum degassing (RH)-continuous casting machines (CC). Slabs for the hot-strip-rolling mill are cast by the No. 2 CC and No. 3 CC after the degassing process at either No. 2 RH or No. 3 RH. In addition, slabs for plate mill are cast at No. 6 CC via No. 1 RH. The total production capacity of the three converters and the total refining capacity of the three RHs are both higher than the total capacity of all three CCs.

In the past No. 2 Steelmaking plant operation mode, in the converter, three blowing modes of LD-ORP, MURC (Multi-Refining Converter), and basic blowing (with one time blowing) were employed and used (**Fig. 2**), the features of which are shown in **Table 1**. LD-ORP mode and MURC mode are applied for desiliconization and dephosphorization as a hot metal pre-treatment (Optimized Refining Process: ORP) in a converter-type blowing manner and are effective in the reduction of T.CaO and improvement of yield. In both blowing modes, Blow1 (ORP blowing for desiliconization and dephosphorization) and Blow2 (blowing for decarburization) are conducted in the same converter. However, the slag discharge (slag-off) method after Blow1 is different.

In LD-ORP, hot-metal is discharged to a ladle and recharged to the converter after slag is thoroughly discharged (slag-off). In MURC, slag is discharged through the throat after Blow1 with the hot metal remaining in the converter. Therefore, although LD-ORP is advantageous in high slag discharging ratio and smelting low-phosphorus steel, the cycle time is longer than that of MURC (approximately by 1.3 times), and furthermore, as there is large heat loss of the hot metal due to discharging and recharging, consumption of the heating agent in Blow2 increases and the refining cost is inferior. However, in the basic blowing wherein the hot metal pre-

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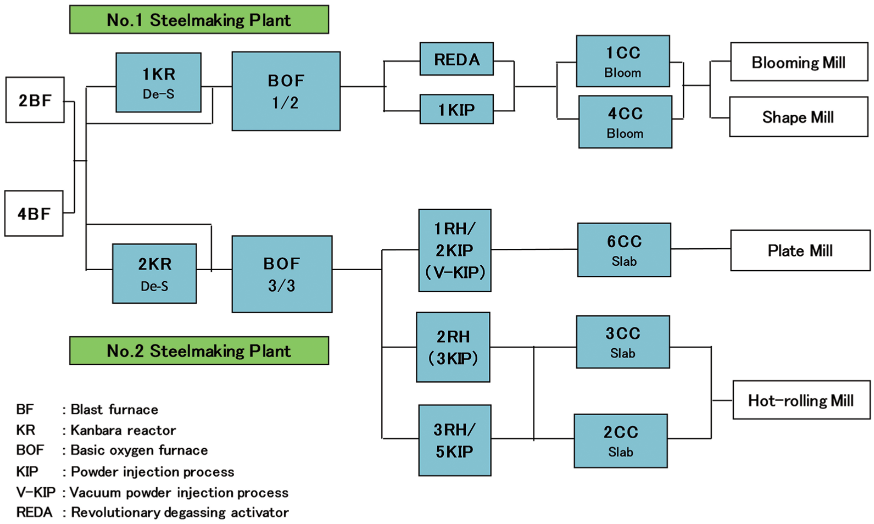

Fig. 1 Steel manufacturing process at Kimitsu Works

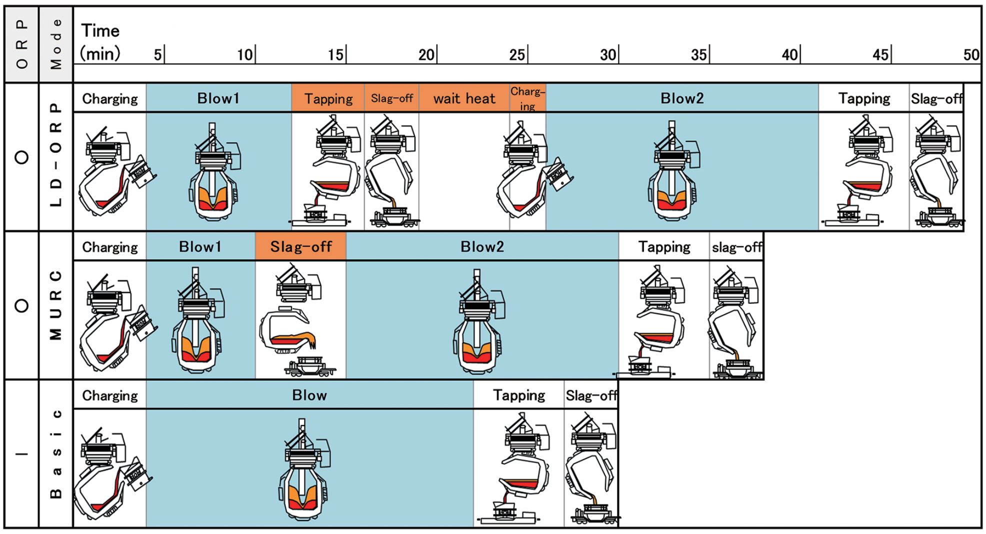

Fig. 2 Operational flow-diagram of BOF operation

Table 1 Characteristics of BOF operation mode

ORP	Operation mode	Dephosphorizing capacity	Productivity	Opex	Utilization of BOF's (%)		
					3 BOF's (base)	2 BOF's (base)	2 BOF's (improved)
○	LD-ORP	Very good	Low	Good	30	30	10
○	MURC	Good	High	Very good	70	10	90
–	Basic	Poor	Very high	Poor	0	60	0

treating blowing is not applied, the cycle time is much shorter than that of MURC. As the input [Si] is high in blowing, T.CaO increases and the cost is significantly reduced.

For this reason, in the No. 2 Steelmaking plant, operation priority was placed on MURC. When all three converters were routinely operated, LD-ORP was applied only to strictly-specified steel grades that are difficult to smelt by MURC ((1) ultra-low phosphorus steel specified by strict product specification of [P], (2) steel grades that require high blowing end point temperature such as high-alloy and/or ultra-low sulphur steels). Meanwhile, since the converter production capacity is decreased during the two converter operation period, the influence of the decrease of the production capacity was eased by shifting a part of the production by MURC to the conventional basic blowing and/or was treated by slab inventory adjustment between steelmaking and rolling.

In the secondary refining operation, RH and KIP (Kimitsu Injection Process) were operated jointly, the features of which are shown in **Table 2**. For the steel grades that require degassing essentially, RH normal treatment alone was applied and for the steel grades that require molten steel desulfurization and Ca addition, KIP normal

Table 2 Comparison of secondary refining process

Process	Vessels	De-gas	De-S	Ca treatment	Addition of alloy	Temperature control (heating)		
						Equipment		Up to
RH	3	Yes	No	No	Yes	Yes		to 50°C
KIP	3	No	Yes	Yes	Yes	2KIP	No	-
						3KIP	Yes	to 20°C
						5KIP	No	-

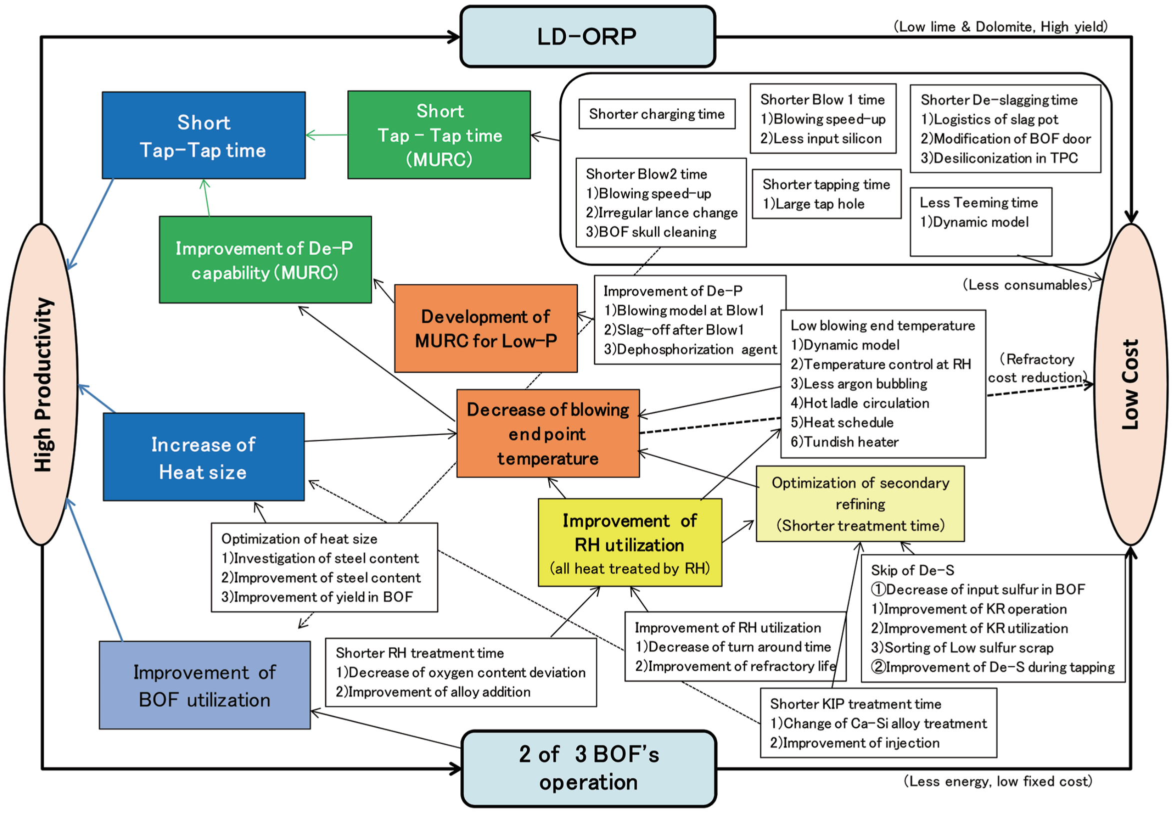

Fig. 3 Outline of improvement activity for high BOF productivity

treatment alone was applied. The steel grades that require both (heavy treatment steel) were doubly treated (KIP→RH) or triply treated (KIP→RH→KIP). Furthermore, for the general quality steel grades (light treatment steel) that require only compositional adjustment, to maintain smooth and normal flow of materials between the converters and the CC machines, either RH or KIP was selected so as to prevent time loss, and heating in the secondary refining was confined only to the suppression of temperature fluctuations.

The above is summarized as: in the refining process, (1) during the two converter operation, the ORP ratio (Optimized refining process in the secondary refining is termed simply as "ORP" hereafter) decreases and the refining operation cost deteriorates, (2) due to the decrease of the production amount during the two converter operation, scheduling between steelmaking and rolling could not be matched and optimized, and problems such as an increase in the slab inventory and the deterioration of the Hot Charge Rolling (HCR) ratio occurred. In addition, (3) to maximize the three converter utilization period ratio, the converter repair period was minimized and as a result, the requisite maintenance could not be rendered sufficiently. Then equipment problems that hamper stable operation occurred sporadically during the three converter operation period.

Therefore, in the No. 2 Steelmaking plant, the converter productivity was improved, targeting the reduction of the utility cost and the fixed cost by means of applying ORP fully to all heats and integrating the operations of the converter, RH, and CC during the two converter operation period, as well as securing stabilized converter operation by means of securing the requisite furnace repair period during the fully-fledged two out of three converter operation. As the framework of the activities in **Fig. 3** shows, the improvement activities were conducted targeting productivity improvement and cost reduction. Shortening of the converter cycle time and the increase of the molten steel ladle heat size as major targets are reported hereunder.

3. Shortening of Converter Cycle Time

To shorten the converter cycle time as a whole, shortening of the MURC cycle time, improvement of the dephosphorization capability of MURC to apply MURC to the steel grades that were smelted by LD-ORP, and decreasing of the converter blowing end point temperature were mainly promoted.

3.1 Shortening of MURC cycle time

The past conventional MURC cycle time is shown in **Fig. 4**. To shorten the MURC cycle time, the time periods of the following operations were shortened: (1) Blow 1 by increasing the oxygen supply rate, (2) Blow2 by increasing the oxygen supply rate, (3) teeming by increasing the direct tapping ratio and the reduction of after blow ratio, (4) charging by improving the skull deposit hot removal work of the hot metal ladle, and (5) tapping by enlarging the tap hole diameter. The activities of (1) to (3) as major items are described hereunder.

First, to shorten Blow 1 cycle time, the oxygen supply rate was increased. In MURC, as intermediate slag-off, slag needs to be discharged immediately after the completion of Blow 1 while maintaining the state of slag foaming. However, when slag foams excessively, intense slopping (the phenomenon whereby slag and skull overflow through the throat) occurs, and operators often have to suspend the oxygen supply on their own judgements even before the oxygen supply reaches its predetermined target oxygen consumption per ton of steel. However, since the judgement was based only on the observation of the slag flowing out through the throat and/or the tap hole, determination of the timing of blowing suspension became more difficult when the oxygen supply rate was increased. When the suspension of the oxygen supply is delayed and slopping occurs, the intermittent slag-off cannot be applied until the slopping is subdued. The cycle time is prolonged thereby and then further prolonged due to the removal work of the slag that flowed down onto the rail below the converter by a heavy machine.

Then, to provide new information for the determination of the blow suspension timing, the existing in-furnace state monitoring acoustic meter is used. Earlier, operators could monitor the in-furnace state through the acoustic meter only on a moment by moment basis, and it was difficult for them to determine the blow suspension timing based on the fluctuating acoustic signal level. Therefore, the display of the acoustic meter for the operators' monitoring was modified so that the amount of the oxygen supplied is linked to the in-furnace state acoustic signal level, and the trend thereof is displayed. Thus, the trend of the state of slag foaming is monitored during the blowing. Furthermore, the basis for the judgement of the suspension of blowing was enhanced by all operators sharing the in-furnace state acoustic signal level when the blowing is suspended.

Additionally, as an upper limit value was set for the oxygen supply rate in Blow 1 and further increase of the oxygen supply rate was restricted, the restriction was also relaxed. This upper limit was set formerly to suppress the dust emission during the initial stage of blowing. However, as the dust emission suppression equipment was expanded and completed for the better such as the additional installation of a dust collector, the upper limit set values (oxygen supply rate during the initial stage of blowing and the timer setting for the upper limit duration) were eased stepwise by confirming the state of the dust emission during operation. Due to these activities, the oxygen supply rate in Blow 1 could be increased from 28 000 Nm^3/h to a high rate 55 000 Nm^3/h, and the Blow 1 time period could be shortened by 0.9 min (**Fig. 5**).

Similarly in Blow2, the cycle time was shortened by increasing the oxygen supply rate (**Fig. 6**). When the oxygen supply rate was increased in Blow2, skull developed on the oxygen lance due to blown-up hot metal emerged as a problem. In particular, as the oxygen supply rate increased, frequency of the lance change due to the skull deposition on the lance grew rapidly and the countermeasures therefor were conducted. Specifically, these countermeasures were as follows: (1) control the growth rate of the skull deposition on the lance, (2) enhance the lance maintenance quality, and (3) review and revision of the lance exchange standard. For the control of the growth of the skull deposition on a lance, an existing lance weighing device was utilized, the control chart of the weight of the skull deposition per heat as shown in **Fig. 7** was developed based on the lance weight, and the trend thereof was analyzed.

As a result, it was confirmed that each lance has one of the following features: (1) skull is not formed readily, (2) skull is formed readily and falls off readily, and (3) skull is formed readily and does not fall off readily. Then, based on such features, a lance use schedule was devised wherein the use of the lance that does not form skull readily was prioritized. Furthermore, once skull is formed on the lance where skull is formed readily but does not fall off readily,

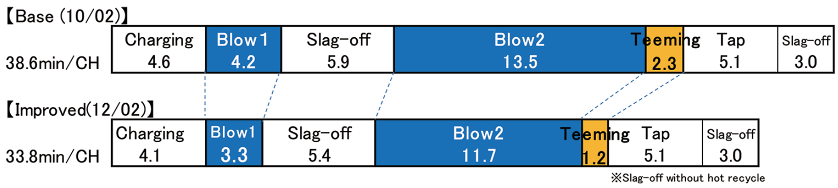

Fig. 4　Result of tap-tap time in MURC operation

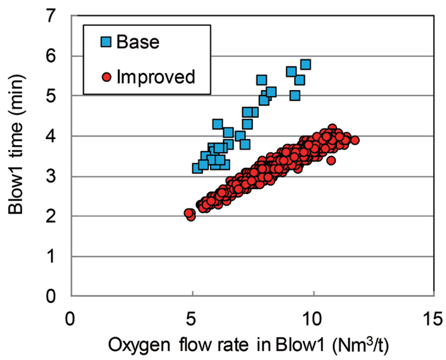

Fig. 5　Reduction of oxygen blowing time (Blow 1)

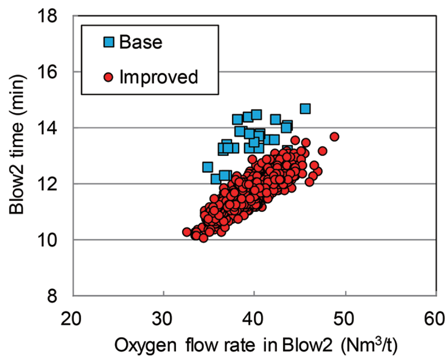

Fig. 6　Reduction of oxygen blowing time (Blow 2)

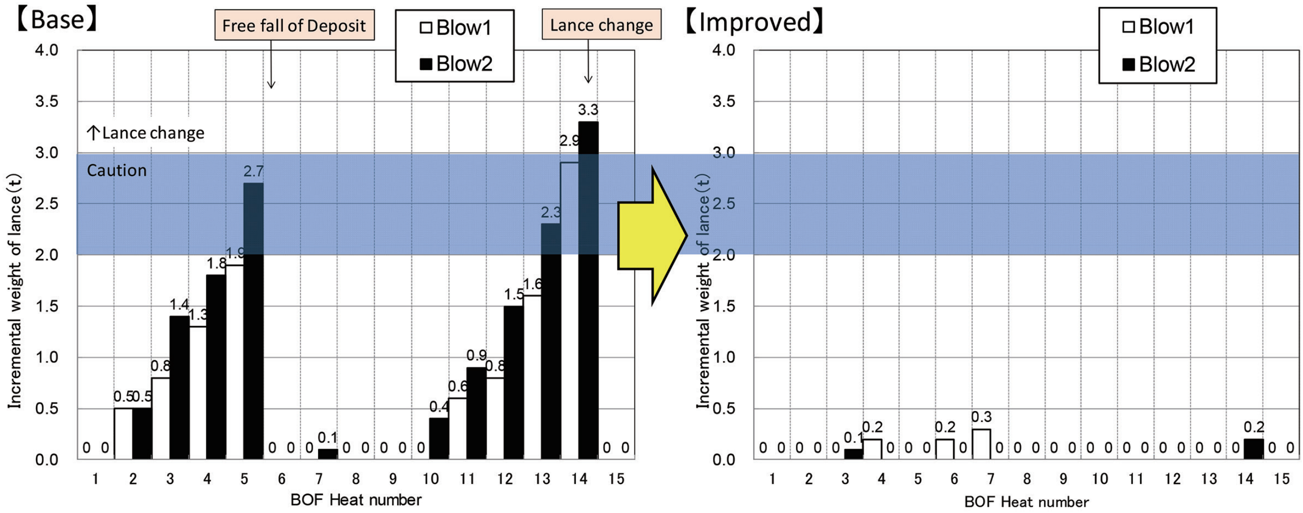

Fig. 7 Example of skull deposition on oxygen lance

the growth of the skull deposition is so rapid that the lance has to be replaced after the operation of about 5 heats. The cause of such rapid skull deposition growth was investigated. The actually used lance on which skull was formed readily and did not fall off readily was observed and it was confirmed that the skull growth was initiated at the welds of the lance tuyere. The lance tuyere welds are of the bead-welding type applied when the tuyere is exchanged. Although the welds are grinder-finished, the actual sample showed the height that remained.

Then, the grinder-finish method for the tuyere welds was reviewed and revised, and the maintenance work to render grinding work until the smallest possible height is obtained was implemented. Operators eyewitness and confirm the state of the completed maintenance work and the state of the maintenance is photographed for control. Thus, the maintenance quality was enhanced. Additionally, to prevent such a major problem from having an adverse influence on the operation such as the inability to pull the lance out of the lance hole due to skull deposition, the lance exchange standard was reviewed and revised. The lance exchange standard based on the quantified lance weight was then established, utilizing the skull deposition weight control chart.

Specifically, when the lance skull deposition exceeded 2 tons, after Blow1 and Blow2 of each heat, visual observation of the state of the skull deposition at the time of the lance being pulled out of the lance hole was required (lance to be exchanged depending on the situation) and the exchange of the lance was required when the weight of the skull deposition exceeded 3 tons. Furthermore, in addition to these activities, to stabilize operation, the throat opening area was maintained by utilizing the skull-cleaning type lance installed in April, 2011 and the lance height control was improved by increasing the frequency of the liquid level height measurement by a sub-lance. As a result of these activities, the oxygen supply rate in Blow 2 could be increased from 65 000 Nm^3/h to a high rate of 68 000 Nm^3/h with steady operation and the Blow2 time period could be shortened by 1.8 min (Fig. 6).

To shorten the teeming time period, the direct tapping ratio and the reduction of the after blow ratio were increased. The teeming time is the time period between the termination of the blowing in Blow2 and the start of the tilting operation for steel tapping. During this time period, sampling is conventionally conducted for Blow2 to confirm its blowing end point temperature and carbon [C], and after blow was applied when the deviations from the target values are large. In direct tapping, steel is tapped without sampling for the Blow2 blow end point temperature and shortening of the teeming time period is possible. The direct tapping was not adopted conventionally before because operations were conducted in such a way as to adjust the end point temperature to achieve the target value at the converter to the maximum extent possible so as to prevent temperature adjustment (heating in particular) in the secondary refining.

Then, on the premise that all heats are RH-treated as described later, the operation was modified so as to compensate the ladle temperature fluctuation caused by direct tapping with heating in RH. Upon promoting this operation of direct tapping, a criterion was set to judge the possibility of direct tapping based on the result of temperature measurement (dynamic) during Blow2. Furthermore, the temperature deviation range (actual blowing end point temperature vs. target blowing end point temperature), out of which after blow is required, was also reviewed and facilitated from the previous criterion. With these activities, the direct tapping ratio was increased from 6% to 60% (**Fig. 8**) and the after blow ratio was reduced from 6.5% to 2.0% (**Fig. 9**). As a result, the teeming time period was shortened from 2.3 min to 1.2 min. Owing to the cycle-time shortening activities as described above, the MURC cycle time was shortened from the past 38.6 min/heat to 33.8 min/heat (Fig. 4).

3.2 Improvement of MURC dephosphorization capability

Activities to shorten the converter cycle time by smelting by MURC the steel grades that were once smelted by LD-ORP are described hereunder. LD-ORP is applied to steel grades with a low end point [P] and high blowing end point temperature, and its application ratio was about 30%. Application of MURC replacing LD-ORP was promoted from the following three viewpoints: (1) improvement of MURC dephosphorization capability, (2) decrease of the converter blowing end point temperature, (3) facilitation of the product standard [P], and other compositional standards. MURC for low phosphorus steel introduced for the improvement of MURC dephosphorization capability of (1) is described hereunder.

Features of the conventionally practiced LD-ORP, MURC, and the MURC introduced for low phosphorus steel are shown in **Table 3**. In MURC and LD-ORP, the blowing pattern design is different. In MURC, since an intermediate slag-off has to be conducted after

Blow 1 while maintaining the state of slag foaming, charging basicity is lowered for Blow 1 operation. On the other hand, in the operation of LD-ORP, in order to promote the dephosphorization reaction in Blow 1, as the target oxygen consumption per ton of steel is large, to prevent the interruption of blowing due to slopping during blowing, charging basicity is increased to suppress slag foaming in Blow 1.

The operations of LD-ORP and MURC are featured as above. To improve the MURC dephosphorization capability, the state of slag foaming has to be maintained after Blow 1 while increasing the oxygen consumption. Then, in MURC for low phosphorus, the charging basicity that compromises larger oxygen consumption and slag foaming was investigated. First, by increasing the charging basicity for Blow 1 and delaying the timing of slag foaming compared with conventional MURC while securing the oxygen consumption, [P] after Blow 1 was decreased. Under this condition, by utilizing the aforementioned in-furnace state monitoring acoustic meter to suspend blowing for such case, the charging basicity was increased while confirming the amount of increase of oxygen blowing vs. the state of foaming at the intermediate slag-off, and the attainable [P] level in MURC was confirmed. As a result of this activity, the MURC for low phosphorus steel realized smelting by MURC of about 9% of the then LD-OPR-processed steel grades with T.CaO at the same level as that of LD-ORP.

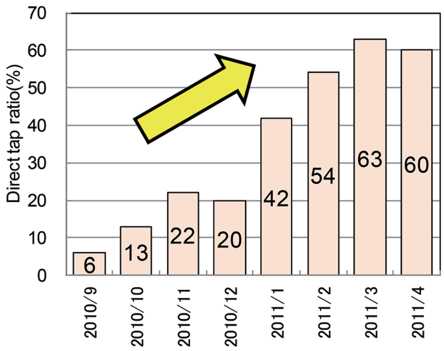

Fig. 8 Increase of direct tap* ratio
***No measurement at blowing end point**

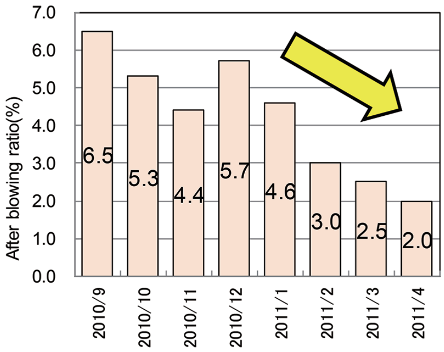

Fig. 9 Decrease of after blowing ratio

Table 3 Concept of MURC for low-P operation mode

BOF operation mode	De-P capability		Productivity	T.CaO consumption
	Ultra low-P	Low-P		
LD-ORP	Yes	Yes	Low	Low
MURC for low-P	No	Yes	Middle	Low
MURC	No	No	High	Very low

3.3 Decrease of converter blowing end point temperature

3.3.1 Improvement of RH productivity

In the No. 2 Steelmaking plant, to further increase the MURC ratio, in addition to the improvement of the converter process, the converter blowing end point temperature was decreased, spanning the entire integrated steelmaking process from the hot metal pretreatment to the continuous casting process. Among them, the most significant operation improvement was the reduction of the thermal load to the converter by shifting the temperature-securing function from the converter operation to the RH operation that has production capacity surplus. Specifically, RH treatment of all heats was investigated to utilize to the maximum extent possible the heating function of the top-blown oxygen through the top lance installed on RH and to suppress the heat loss from the vacuum chamber by continuous operation of RH.

In the No. 2 Steelmaking plant, there are three RHs of 1RH, 2RH, and 3RH. 2RH and 3RH are used for the treatment for 2CC and 3CC while 1RH is used for the treatment for 6CC (Fig. 1). Among them, 2RH has only one vacuum chamber and a nonoperation period (unavailable time periods) occurs during the repair of refractories of the vacuum chamber. Accordingly, since, in the treatment by 2RH, 3KIP was jointly used in the past conventional operation, to realize RH-treatment of all heats, treatment by 3RH with 5KIP for 2CC and 3CC was required and productivity improvement of 3RH was a necessity. Then, to improve the RH productivity, the following activities were undertaken: (1) shortening of 3RH cycle time, (2) shortening of 2RH nonoperation time (**Fig. 10**).

To shorten the 3RH cycle time, the treatment time period of the light treatment steel was shortened. The treatment flow of the light treatment steel of 3RH before and after improvement is shown in **Fig. 11**. In the past conventional treatment of light treatment steel, the following two-step treatment was conducted to enhance compo-

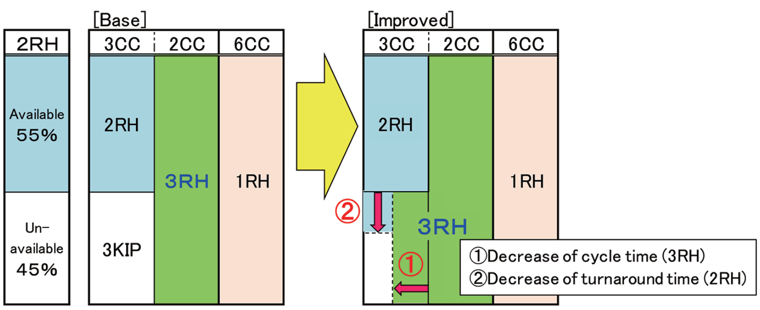

Fig. 10 Schematic view of RH productivity improvement

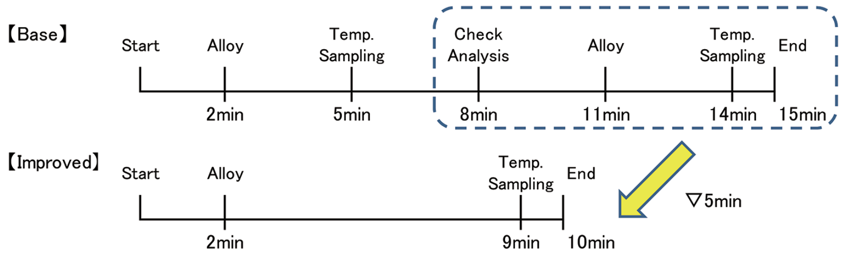

Fig. 11 Example of treatment flow diagram (3RH)

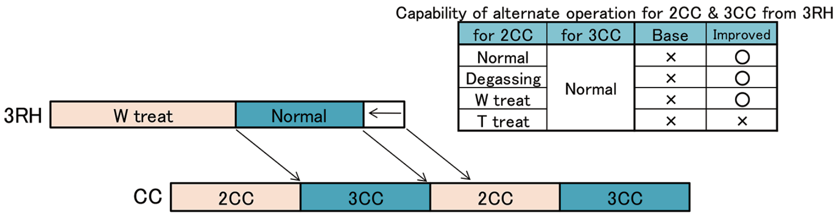

Fig. 12 Capability of alternate operation for 2CC & 3CC from 3RH

sition attainment accuracy: alloys were charged initially to roughly match the composition, the composition was confirmed by an intermediate sampling and analysis, and then to finely adjust the composition, alloys were charged again. Then, the treatment time period by single-step treatment was shortened, wherein the intermediate check sampling and the composition confirmation were abolished and the composition was confirmed only with final sampling.

The problem of the single-step treatment is the non-attainment of [Al] due to its dispersion after RH treatment, and the suppression of oxygen value dispersion before RH treatment and the improvement of the attainment accuracy of alloys during RH treatment were required. As the dispersion of the converter blow end point [C] in the previous process caused the oxygen value dispersion, the amount of charging of the deoxidization agent was standardized depending on the converter blow end point [C]. Furthermore, to improve the attainment accuracy of the alloys during RH treatment, the yields of the alloys in the single-step treatment were analyzed, and by operators' sharing the actual values, their skills were enhanced. Thus, the subject steel grades of the single-step treatment were increased stepwise. As a result of this improvement, the treatment time of the light treatment steel was shortened from 15 min/heat to 10 min/heat (Fig. 11).

In the past, although the treatment by 3RH for both of 2CC and 3CC was difficult, due to the abovementioned 3RH cycle time shortening, the treatment for both 2CC and 3CC was realized (**Fig. 12**). However, since compliance with the heavy treatment steel that requires triple treatment was not possible, the freedom of production scheduling was restricted. Therefore, the achievement of the RH-treatment of all heats was attempted by minimizing the restriction on production scheduling by shortening the 2RH non-operation time period. Specifically, the following activities were performed: (1) extension of the 2RH life and (2) shortening of the maintenance time period. Regarding the extension of the 2RH life of (1), refractory erosion was suppressed by optimizing the heating condition of the top burner for the lower end chamber of the vacuum chamber during the intermission of treatment. Since an excessive heating during the intermission of treatment for preserving heat and suppressing skull promoted the refractory erosion, the life of the lower end chamber was extended by reviewing and revising the heating condition such as the LPG flow rate, oxygen/LPG ratio, and upper limit of the heating time period so that the skull and slag thinly remain.

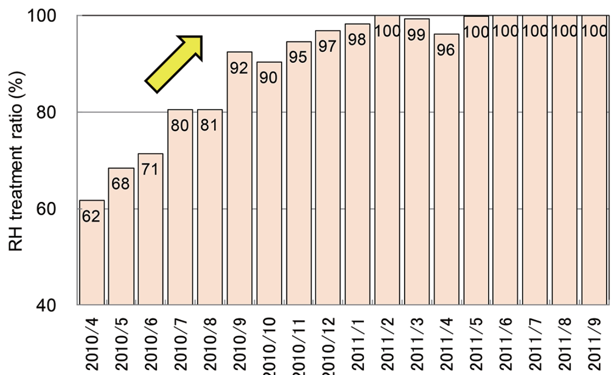

Fig. 13 Increase of RH treatment ratio

In addition to the abovementioned improvements, improvement of the refractory material was also promoted in parallel: durability of the lower end chamber was improved from 400 heats to 1000 heats. Regarding the shortening of the repair time period of (2), the skull cleaning time period at the time of the exchange of the lower end chamber of the vacuum chamber was shortened. By providing rinsing treatment before the exchange of the lower end chamber and skull cleaning during the intermission of treatment, the skull cleaning time period was shortened from about 13 hours to about 5 hours (reduction by about 8 hours). These activities enabled the nonoperation time of 2RH to be shortened from 45% to 35%.

Thus, the RH-treatment ratio was increased from 60% to 100% (**Fig. 13**). An RH-treatment ratio of 100% has been stably maintained since May, 2011.

3.3.2 Improvement of plant activity integrated as a whole based on the premise of RH-treatment of all heats

In the No. 2 Steelmaking plant, since the RH-treatment of all heats was achieved, activities of decreasing the converter blow end point temperature on the basis of integrated plant operation were promoted by utilizing RH treatment. Among them, the three major activities are as follows: (1) increase of RH heating, (2) abolition of ladle argon bubbling, and (3) ladle rotation schedule optimization.

Regarding converters, increase of RH heating and decrease of blow end point temperature by increasing the direct tapping ratio were investigated. Direct tapping targets shortening of the teeming time period between the blow end and the start of tapping by abolishing in Blow2 the sampling of the blow end point temperature, and suppressing the heat radiation loss during the teeming period. The blow end point temperature decreasing activity was promoted by the following steps.

(1) The temperature dispersion caused by the implementation of the direct tapping is compensated by heating by RH (operation on the premise of salvation heating by RH).
(2) Suppression of the temperature dispersion by improving the converter blowing accuracy (improvement of the target temperature attainment accuracy in converters).
(3) Determination of blow end point temperature on the premise of heating by RH (operation on the premise of planned heating by RH)

(1) was investigated as aforementioned by increasing the direct tapping ratio by taking advantage of the RH-treatment of all heats. Regarding (2), the heat balance calculation accuracy was improved so as to attain the target blow end point temperature. Conventionally, only the data of the heat balance calculation conducted for the heats sampled for measuring blow end point temperature were standardized and the heat balance calculation for another heat was conducted by comparing the subject heat data with the standardized data. Therefore, along with the increase of the direct tapping ratio, the standardized heat data decreased and the accuracy of the heat balance calculation deteriorated. Then, the system was modified so as to employ the directly-tapped heat data as standardized heat data. Thus, improvement of the target temperature attainment ratio accuracy of the converter was promoted. Regarding (3), to further exploit the heating function of RH by improving the converter blow end point temperature attainment accuracy as promoted in (2), decrease of the converter blow end point temperature was demanded for converters on the premise of heating by 10°C by RH (oxygen supply rate: 100 Nm^3/heat). Due to these activities, the direct tapping ratio was increased from 6% to 60% (Fig. 8) and the decrease of the converter blow end point temperature and shortening of the cycle time were promoted. Furthermore, by taking advantage of the RH-treatment of all heats, ladle argon bubbling (abolition of porous plug) was abolished. By injecting argon gas from the ladle bottom, molten steel is stirred and uniform temperature distribution of the molten steel within a ladle is realized. Therefore, in the past, ladle argon bubbling was applied to suppress the erosion of ladle refractories at the slag line when heating was conducted by 3KIP, and furthermore, to prevent the nozzle clogging during casting due to low temperature at the CC turret (non-uniform temperature distribution).

Argon bubbling was applied to about 30% of all heats including those of cast-starting on the CC turret. However, in addition to the decrease of the molten steel temperature due to heat loss by argon bubbling, installation of the ladle porous plug equipment was costly and the utility cost deteriorated due to the consumption of argon gas. Then, by taking advantage of the RH-treatment of all heats that enables suppression of the non-uniform steel temperature distribution in a ladle by stirring steel under vacuum, ladle argon bubbling was abolished. **Table 4** shows the needs for ladle argon bubbling application practiced conventionally in the past and countermeasures for the abolition thereof. With respect to the needs of ladle argon bubbling except those of cast-starting heats, the ladle argon bubbling application rule was eased by applying the RH-treatment of all heats and the extension of the RH treatment time period.

With respect to the cast-starting heats, the cast-start temperature was modified, being corrected for the steel temperature difference between the measured top temperature and the measured bottom temperature, and the casting operation was conducted without ladle argon bubbling. In the early stage after the start of casting operation without ladle argon bubbling, some of the cast-starting heats required ladle argon bubbling due to a prolonged matching time period and/or high ladle temperature. Thus, the ladle argon bubbling ratio was reduced by optimizing the cast schedule and/or by adjusting the cast-starting time as shown in Table 4. As a result, as shown in **Fig. 14**, the argon bubbling application ratio was reduced to zero, and in April 2011, porous plugs were totally removed.

Furthermore, to promote the decrease of blow end point temperature thoroughly, the blow end point temperature decreasing activities were promoted under the joint cooperation with the coordinat-

Table 4 Countermeasures for elimination of argon bubbling in ladle

Argon bubbling in ladle			Problem	Measures
Process	Apply			
3KIP	During chemical heating		Inhomogeneous temperature in ladle (erosion of slag line refractory)	No use of 3KIP by increase of RH utilization
CC	Heat from 3KIP		Inhomogeneous temperature in ladle (temperature gap between ladle top & bottom)	No use of 3KIP by increase of RH utilization
	Heat from BOF (without secondary refining)		Inhomogeneous temperature in ladle (temperature gap between ladle top & bottom)	Increase of RH utilization
	Uncirculated ladle (first heat after relining etc.)		Temperature drop during casting	Prevention of heat radiation by extension of RH treatment time
	Cast start		Inhomogeneous temperature in ladle (temperature gap between ladle top & bottom)	Proper aiming temperature control
		Problem without argon bubbling	Inhomogeneous temperature in ladle while waiting at CC	Optimization of cast schedule
			High superheat	Optimization of cast schedule Proper aiming temperature control
			Temperature drop from RH dispatch to CC arrival	Prevention of heat radiation by extension of RH treatment time

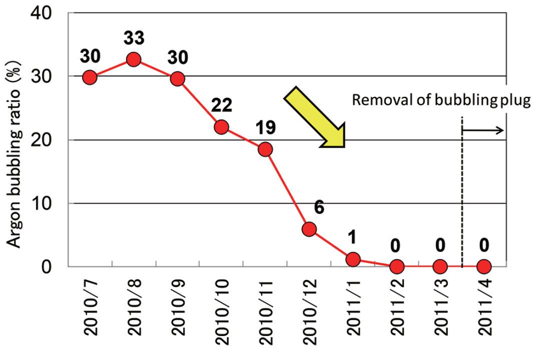

Fig. 14 Decrease of argon bubbling ratio

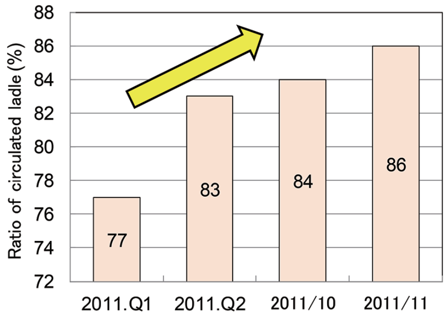

Fig. 15 Ratio of circulated ladle during hot condition

ing section in charge of ladle rotation scheduling. The ladle rotation scheduling work was conducted with priority given to preparing a ladle in time for continual converter tapping. However, as a result, such scheduling that yields surplus to the number of ladles in rotation was one of the factors that increased the blow end point temperature. Then, to decrease blow end point temperature, heat loss reduction activities were promoted by optimizing the ladle rotation schedule. Specifically, the following activities were promoted: (1) minimization of the number of steel ladles in rotation by setting the number of ladles appropriately in accordance with the production rate and (2) application of heat reservation measures frequently while ladles are standing by idly. Furthermore, an appropriate CC temperature was set, incorporating ladle conditions and in combination with casting adjustment, the temperature drop during casting was minimized. As a result of these activities, the ratio of the ladles in rotation in the hot condition (defined as the ratio of the numbers of ladles that are returned to converter tapping from the completion of casting within 180 min) was improved from 77% to 86% (**Fig. 15**).

The above converter blow end point temperature decreasing activities enabled the blow end point temperature to be decreased to 1662°C from 1681°C and the LD-ORP ratio to be reduced from 27.7% to 10.7% (**Fig. 16**).

4. Increasing Molten Steel Ladle Heat Size

In the No. 2 Steelmaking plant, the molten steel heat size was confined by the ladle capacity. Conventionally in the past, molten steel heat size was decided with the concept of making it the largest size possible for a ladle. However, the standard pertaining to the decision of free board that is the basis of deciding molten steel heat size was unclear in part and there were deviations among operators as to their decision procedure of heat size. Then, increase of molten steel ladle heat size was conducted. **Table 5** shows the decision pro-

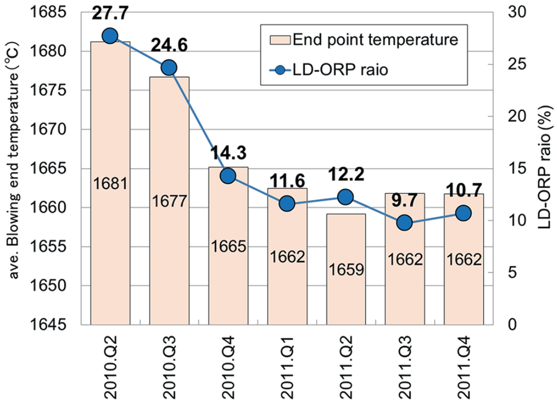

Fig. 16 Improvement of LD-ORP blowing operation

cedure of heat size and measures for improvement. Major improvement measures are as follows: (1) review of free board condition, (2) improvement of decision procedure of heat size demanded for a converter, and (3) improvement of yield decision method at converter.

With respect to the review and revision of the free board condition, the review and revision of (1) free board measuring standard and (2) the targeted free board were conducted. Free board has been measured after converter tapping, before secondary refining treatment, and at the ladle shop. The next heat size was decided based on the values measured before secondary refining treatment and at the ladle shop. However, as the measurement basis differed in each process and among operators, it was difficult to set appropriate free board. Therefore, in the first place, the positions to define free board in a unified manner were determined to be used commonly for the measurements at the converter, secondary refining, and at ladle shop. The free board was defined as the distance between the top brick line as the starting line and the slag/metal boundary line as the end line. Furthermore, since visual observation measurement of free board was conducted at the converter and the secondary refining, and deviations among operators were large, a method employed by certain operators that enables quantitative measurement was standardized. Such quantitative measurement was implemented for the converter by an ascent and descent type slag thickness measuring machine. For secondary refining, free board was measured based on the lifted ladle height at which the RH treatment chamber starts to be immersed in liquid.

Furthermore, pursuant to the set free board measuring standard, the target free board was reviewed and revised. As **Table 6** shows, in the past, the target free board standard was classified into two treatment categories: single treatment by RH · KIP and another treatment type (double, triple treatment). Then, the applicability of secondary refining with respect to free board was confirmed, reviewed, and revised as per the secondary refining process. As a result, the free board standard was reviewed and revised, and for the process wherein free board has surplus, the target free board was revised.

Regarding the decision of heat size demanded for a converter, the following improvements were made: (1) standardization of lower limit of free board that allows for the largest possible refining treatment, and (2) control of the set value and the actual value of the molten steel heat size demanded for a converter. The reason for setting the standard of lower limit of free board that allows for the largest possible refining treatment is that even though the target free board standard is clarified, upon deciding the demanded molten

Table 5 Improvement of decision procedure of heat size

Step	Incharge	Procedure	Problem	Measures
1	BOF	Weighing empty ladle at steel receiving car	Accuracy of weighing device	○ Maintenance of weighing device • Cleaning of receiving car • Cross-check between the receiving cars
2		Weighing steel ladle at steel receiving car after tapping		
3		Measurement of free board in the ladle	Accurate measurement	○ Improvement of free board measurement • Definition of measurement point (BOF, secondary refining and ladle shop) • Definition of measurement method (BOF and secondary refining)
4	Secondary refining	Measurement of free board in the ladle		
5	Ladle shop	Measurement of free board in the ladle		
6		Check aiming free board of next heat	Classification of aiming free board	○ Improvement of aiming free board • Classification depending on steel grade • Revision of aiming free board
7		Correction of heat size depending on ladle life	Deviation between individuals	○ Improvement of correction method by refractory erosion of ladle • Revision of correction value depending on ladle life
8		Correction of heat size by measurement of free board	Accurate correction	○ Decision of minimum free board for secondary refining operation ○ Check of heat size between set value and actual value
9	BOF	Correction of charging weight by yield	Accurate correction	○ Operation support system (yield correction) ○ Check of yield between set value and actual value

Table 6 Standard of free board in the ladle

Process			RH	KIP	W treat	W, T treat
Base	Aiming free board	mm	400		500	
Improvement	Aiming free board	mm	300	350		400
Revision	Minimum free board	mm	200	250		300

steel heat size for the converter, operators were prone to decide the molten steel heat size with a small allowance. The reason for this is that, if the free board is small, the RH treatment chamber may sometimes fail to be immersed and molten steel has to be discharged, causing major operation problems.

Then, increasing the molten steel ladle heat size was promoted based on the clarification of the free board lower limit standard below which the application of RH treatment is not possible and the counter measure method for the case of occurrence of such inability (molten steel discharging implementation standard and the control method of the availability of discharging pit capacity that allows for the discharge even when such inability occurs frequently). Furthermore, in the control of the demanded molten heat size set value vs. the actual demanded molten steel heat size, when the actual heat size and the demanded molten heat size set value agree with each other, the actual value of the free board is analyzed for every heat size, and the result is fed forward to the next demanded heat to improve the accuracy of the demanded heat size. These activities have improved the free board in the case of RH normal treatment by about 40 mm (about 5 t/heat) (**Fig. 17**).

With respect to the yield decision method at the converter, improvement was promoted by: (1) improvement of the accuracy of the recommended converter yield and (2) control of the set value and the actual value of the converter yield. The amount of charging of materials (hot metal, scrap, and mold pig iron) is determined at the converter process based on the demanded molten steel heat size with conditional converter yield modification. However, since diversified steel grades are produced in the No. 2 Steelmaking plant, heavy work was imposed on operators in calculating and modifying the converter yield per heat. Therefore, recommended converter yield setting values that have not been working sufficiently so far were rearranged and provided as an operator supporting function.

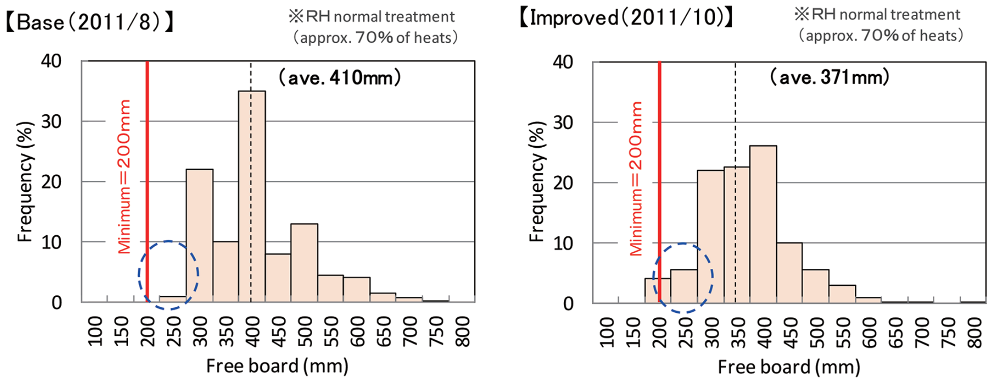

Fig. 17 Measurement results of free board in ladle

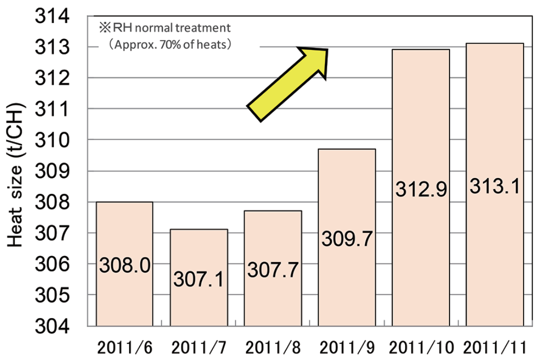

Fig. 18 Improvement of heat size (RH normal treatment heat)

Thus, improvement of the converter yield calculation accuracy was promoted.

Specifically, the system was improved so as to calculate the recommended converter yield values based on: (1) blowing method, (2) amount of charging of alloys calculated from the chemical composition standard, and (3) estimated amount of iron ore to be used. In the converter process also, likewise in the ladle shop, by correcting the converter yield of the next charge based on the set converter yield and the actual converter yield, the accuracy of the actual molten steel heat size vs. the demanded molten steel heat size was improved. As a result of implementation of the above activities, the weighed molten steel heat size of RH normal treatment was increased by 5 t/heat (**Fig. 18**).

5. Conclusion

Improvement of converter productivity was investigated in the No. 2 Steelmaking plant to realize consolidated and stabilized converter operation. As the relation between the production by two converter operation (calculated from the number of actual daily tapped heats) and the ORP in **Fig. 19** shows, the productivity of the two converter operation was significantly improved by this improvement. Therefore, in the No. 2 Steelmaking plant, toward the establishment of fully-fledged two out of three converter operation, extension of the two out of three converter operation period was promoted. As a result thereof, in the No. 2 Steelmaking plant, all ORP production structure was established in the fourth quarter of 2010 and furthermore, the production structure was shifted to the complete two out of three converter operation (**Fig. 20**). The total ORP two out of three converter operation has continued ever since and continues to be maintained today.

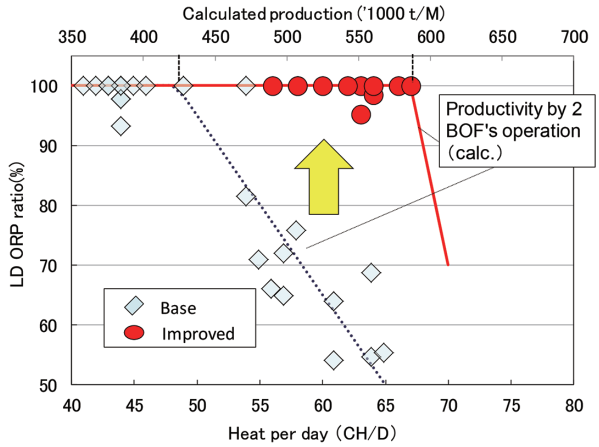

Fig. 19 Relation between productivity by 2 BOF's operation and LD-ORP ratio

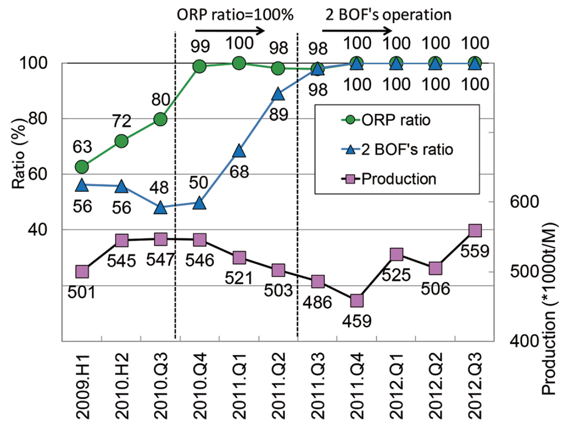

Fig. 20 Improvement of productivity by 2 BOF's operation and LD-ORP ratio


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