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The KTB Method in the World Steel Industry: Recent Progress in Kawasaki Steel's Advanced Top Oxygen Blowing Method for the Vacuum Degasser*


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1 Introduction

Higher customer requirements for improved mechanical properties in cold-rolled steel sheets have increased the necessity of stable mass production technologies for ultra-low carbon steel (ULC). In the conventional ULC refining process, vacuum degassing is performed on non-deoxidized steel using only the oxygen disolved in the steel without oxygen gas supply. This practice involves several problems, as summarized in groups I-III of **Table 1**[1], which in turn have various undesirable effects on the steel refining and casting process as a whole, as shown by ① through ⑧. However, the cause of all these problems can be summarized by saying that, in all conventional processes, it is necessary to supply the oxygen which will be required for vacuum decarburization in the degasser to the steel in the converter refining process. To solve this fundamental problem, Kawasaki Steel developed the KTB (Kawasaki Steel top oxygen blowing) method, in which oxygen gas is supplied to the surface of the molten steel in the vacuum

Table 1 Problems in producing ULC steel by conventional methods

I High tapping temperature · LCAK [base] · ULC [base] + 40°C	① Increase of refractory cost ② Decrease of steel yield ③ Obstacle to longer sequential casting ④ Decrease of RH vessel life → obstacle to sequential casting
II Longer RH treatment time · LCAK 20 min · ULC 26 min (+ 6 min)	⑤ Usage of expensive low carbon FeMn ⑥ SEN clogging → obstacle to sequential casting
III Quality (Slab defect ratio) · LCAK 0.2% · ULC 2.2%	⑦ Limitation on throughput ⑧ Full face slab conditioning

LCAK : Low carbon aluminum killed steel
ULC : Ultra low carbon steel

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vessel through a water-cooled lance.

Because the KTB method supplies the oxygen gas from outside the reaction system, to increase vacuum decarbrization rate, it is possible to begin the vacuum decarburization reaction from substantially higher [C] levels than with conventional techniques, and at the same time, it is also possible to compensate for temperature drop in the molten metal by post-combustion of the CO gas generated by the decarburizing reaction in the vessel. By solving the problems listed in the table in this manner, the KTB method makes an important contribution to reducing production costs and realizing stable product quality. As further benefits, the KTB method makes it possible to supply oxygen gas at any time during the vacuum degassing treatment, enabling the user to control the temperature of the molten steel by using the oxidizing reaction heat of Al. It is also possible to remove the skull inside the vessel by melting using the KTB lance. The combination of these and other effects has contributed to both greater stability and greater flexibility in the refining process.

As evidence of the excellent reputation which this technology enjoys in the world steel industry, 29 units of KTB equipment (including 6 at Kawasaki Steel) have been ordered for vacuum degassers in Japan and other countries, as shown in **Table 2**, and are now either operating smoothly or under construction. This paper will summarize the features of the KTB method and the published results of its introduction and operation at many companies, and will briefly discuss the possibilities for future development.

Table 2 KTB supply list (up to June, 1996)

Company	Number of KTB	Nation
ARMCO Steel Co., L.P. Middletown Works	1	USA
Baoshan Iron & Steel Corp.	1	China
BHP Steel Port Kembla Works	1	Australia
British Steel PLC. Port Talbot Works	1	UK
China Steel Corp.	1	Taiwan
Companhia Sirerugica National	1	Brazil
Eregli Iron & Steel Works Inc.	1	Turkey
Hanbo Steel & General Construction	2	Korea
LTV Steel Flat Rolled Co. Cleveland Works	1	USA
National Steel Corp. Great Lakes Division	1	USA
POSCO Kwanyang Works	2	Korea
Usinas Siderurgicas de Minas Gerais SA	1	Brazil
USX Corp. Edgar Thomson Works	1	USA
Wuhan Iron & Steel	1	China
Kobe Steel Ltd. Kakogawa Works	1	Japan
Nakayama Steel Works,Ltd. Funamachi Works	1	Japan
Nisshin Steel Co.,Ltd. Kure Works	1	Japan
NKK Corp. Fukuyama Works	2	Japan
NKK Corp. Keihin Works	1	Japan
Toa Steel Co. Ltd. Sendai Works	1	Japan
Kawasaki Steel Corp. Chiba Works	2	Japan
Kawasaki Steel Corp. Mizushima Works	4	Japan
Total	29	—

2 Outline and Features of KTB Method

The KTB method is a process which supplies oxygen gas to the molten steel in the vacuum vessel through a water-cooled top lance, as shown schematically in **Fig. 1**. Top blowing of oxygen gas in the vacuum vessel during the vacuum decarburization treatment of ULC has the following two purposes.[2)]

(1) Promotion of the decarburization reaction by supplying oxygen gas during the first half of treatment, when the oxygen supply is the rate controlling step in this reaction.

(2) Post-combustion of the CO gas generated in the vessel by the decarburization reaction, and use of the heat of the post-combustion reaction to provide heat compensation to the molten steel.

As another important function of the KTB method, it is also possible to control the temperature of the molten steel by using the top-blown oxygen gas to burn Al, which can be added to the melt regardless of the steel grade when it is necessary to raise the temperature of the molten steel.

When top oxygen gas blowing is not performed, the lance is held in the waiting position at the top of the vacuum vessel. A very small amount of purge gas is necessary to prevent splash from entering the lance hole, but the effect of the purge gas on the vacuum degree in the vessel is held to the absolute minimum, and therefore does not require upgrading of the vacuum unit when the KTB method is installed on an existing degasser.

The KTB equipment, as shown in **Fig. 2**, comprises the supply of oxygen and purge gas to the lance, the sup-

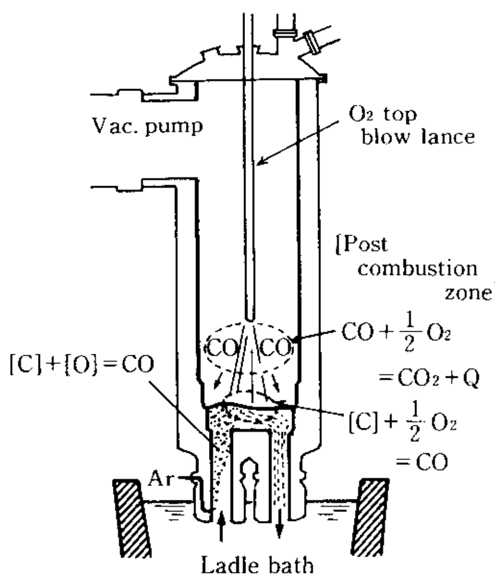

Fig. 1 Schematic illustration of KTB method

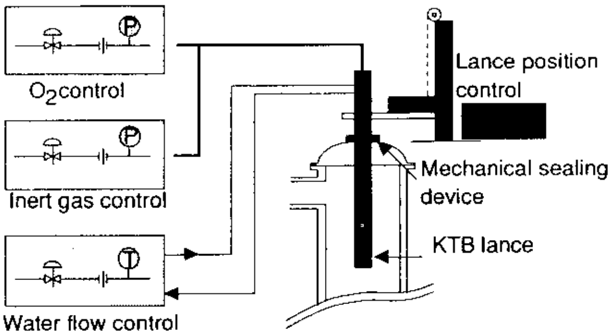

Fig. 2 Composition of KTB system

ply and return of water for lance cooling, the lance hoisting device, and the seal equipment at the top of the vessel. It should be noted that this simple equipment composition makes it possible to retrofit the KTB equipment easily on vacuum degassers of all types at a modest investment cost.

3 Results of KTB Operation at Other Mills

This chapter presents a summary of the operation of KTB equipment by clients supplied to date by Kawasaki Steel, together with the benefits obtained, based on reports published by KTB users. (Note: Some clients use other equipment or process names for the KTB; for convenience, all these units are referred to as KTB in this report.)

3.1 Improvement of Vacuum Decarburization Operation

At Kawasaki Steel, the decarburization coefficient in vacuum decarburizing increased from 0.21 to 0.35 following the introduction of the KTB method, making it possible to relax the tapping [C] at the converter from 250 ppm to 500 ppm.[1,2] The benefits of the KTB method in the vacuum decarburizing of ULC can therefore be broadly summarized in the following two items.

(1) Increase of the decarburization coefficient

(2) Improvement of tapping conditions at the converter (increased [C], decreased [O])

As one factor in the increase in the decarburization coefficient in item (1), an analysis by Nisshin Steel Co., Ltd. showed that control of the oxygen gas supply rate makes it possible to maintain the proper relationship of the C-O content of the molten steel for avoiding stagnation of the decarburization reaction. Kobe Steel, Ltd. uses a different oxygen supply method, but reports that increasing the free oxygen in the steel by supplying oxygen gas in the high carbon region, where the oxygen supply is rate controlling for the decarburization reaction, increases the driving force of the reaction,[3] and this effect may contribute to the higher decarburization coefficient in the KTB method. Kobe Steel, Ltd. also reports that changing the method of supplying oxygen gas from the lower vessel tuyere to the KTB lance increased the maximum vacuum degree from 3 torr to 1.5 torr,[4] which can be assumed to contribute to improvement of the vacuum decarburization operation. From the viewpoint of practical operations, the KTB also merits a positive evaluation for its role in reducing skull in the vessel (C contamination due to melting of the skull was originally a concern, but has not proved to be a problem in any actual operation after installation of KTB), and in reducing input C by enabling KTB shops to decrease their use of coolants to adjust the temperature of the molten steel, as discussed in the following.

Because the supply of oxygen gas makes it possible to achieve decarburization from a substantially higher [C] level than with conventional techniques in the same or a shorter decarburization time, various companies have reported that the KTB is effective in relaxing the initial conditions before decarburization treatment, in other words, in relaxing the tapping conditions at the converter, as shown in **Table 3**. This, in combination with the temperature compensation effect discussed below, suggests that it should be possible to reduce the load on the converter in the conventional ULC steelmaking process (as summarized in Table 1).

Controlling excess oxidation in the converter contributes to improvement of the quality of ULC. For example, **Fig. 3** shows the monthly trend in tapping [O]

Table 3 Effect of KTB on decarburization

Company	Decarburization rate coefficient, Kc (min^{-1})		Tapping [C] (ppm)		Tapping [O] (ppm)	
	Conventional	KTB	Conventional	KTB	Conventional	KTB
Nakayama Steel Works, Ltd.[5,6] Funamachi Works	0.14	0.18	430	540	—	—
Nisshin Steel Co., Ltd.[7] Kure Works	—	0.5	base	base + 200	—	—
British Steel PLC[8] Port Talbot Works	—	—	303	490	668	420
National Steel Corp.[9] Great Lakes Division	0.25	0.30 ~ 0.32	≦ 500	≦ 1 000	≧ 700	≧ 400
Kawasaki Steel Corp.[1,2] Chiba Works	0.21	0.35	250	500	—	—

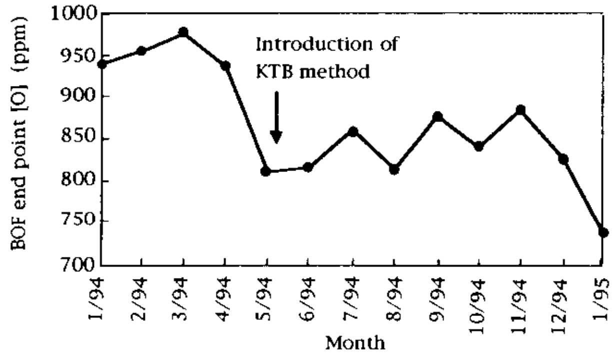

Fig. 3 Trend of BOF end point oxygen at National Steel Corp. Great Lakes Div.

at Great Lakes Div. of National Steel Corp., which has reported improved quality in ULC.[9] This figure indicates that the [O] at blow-end has decreased markedly since the introduction of the KTB method.

As a secondary benefit of the relaxation of converter tapping conditions, several companies[6,7] have also reported a reduction in the N content of steel at tapping. As reported by Nakayama Steel Works, Ltd., it can be argued that this reduction in tapping [N] is attributable to the increase in tapping [C] with the KTB method, because it is now possible to reach blow-end in a relatively high carbon region, where a denitrification effect of the CO gas generated in the converter can be expected.

3.2 Temperature Compensation Capability during Vacuum Degassing Operation

The supply of oxygen gas through the KTB lance during vacuum decarburization promotes post-combustion of the CO gas generated in the decarburization reaction, and is therefore effective in reducing the temperature drop of the molten steel. As a result, it is no longer necessary to increase the tapping temperature at the converter, which had been one problem in the conventional ULC steelmaking process. In fact, the tapping temperature has been reduced by 26°C at Kawasaki Steel since the KTB method was adopted.[2] **Table 4** shows the change in the tapping temperature before and after introduction of the KTB method by various users. All companies have realized a tapping temperature reduction of 20°C or more.

The 20°C decrease in the tapping temperature reported by Nakayama Steel Works, Ltd. was categorized into 4 contributing factors, as shown in **Table 5**.[6] In particular, the temperature decrease listed under "reduction of coolant" is attributable to the fact that the KTB method enables the user to control the molten steel temperature by burning Al in the vacuum vessel, which makes it possible to set the target tapping temperature at a lower level than with conventional methods.

The temperature compensation effect of 16.7°C (30°F) which was obtained in operation at Great Lakes Div. of National Steel Corp. with a decarburizing time of 15 min and an oxygen gas supply from the KTB lance for 6 min was analyzed as follows using the concept of a bath heat insulation effect.

Table 4 Effect of KTB on thermal compensation

Company	Decrease of tapping temp. (℃)	Reduction of temp. drop rate during O_2 blowing (℃/min)
Nakayama Steel Works, Ltd.[5,6] Funamachi Works	20	1
Nisshin Steel Co., Ltd.[7] Kure Works	about 20	2
National Steel Corp.[9] Great Lakes Division	27.8(50°F)	—
Kawasaki Steel Corp.[2] Chiba Works	26	1.5

Table 5 Prevention of heat loss for molten steel at Nakayama Steel Works, Ltd. Funamachi Works

(1) Increase of C combustional heat	1.2℃
(2) Effect of secondary combustion	7.8℃
(3) Al combustional heat	7.9℃
(4) Reduction of coolant	3.1℃
Total	20.0℃

(1) Heat generated by post-combustion of CO gas produced in the decarburization reaction (contribution: 5%)
(2) Suppression of heat loss by radiation from the molten steel by the "cloud" formed by post-combustion above the molten steel in the vacuum vessel (contribution: 50%)
(3) Reduction of the thermal gradient between the refractories and the space above the molten steel in the vessel due to the increased temperature of the refractories in the post-combustion region (contribution:45%)

According to Table 4, National Steel Corp. reported a reduction in tapping temperature of 26.7°C following the introduction of the KTB method.[9] Although this is larger than the above-mentioned 16.7°C, the difference can be attributed to the fact that temperature compensation in the vacuum degasser makes it possible to avoid high-temperature tapping, as mentioned above.

In addition to the temperature compensation effect of post-combustion during vacuum decarburization touched on above, it should also be noted that the KTB method can be used as a molten steel temperature control function even with steel grades and treatments that do not require decarburization. With this method, the temperature of the molten steel is controlled by the oxidation combustion heat of Al, which is added to the steel and burned by oxygen gas supplied from the KTB lance. In this type of operation, it has been possible to increase the temperature of the molten steel by as much as approximately 5°C/min.[1]

In comparison with conventional vacuum degassing processes, which offer virtually no means of controlling the temperature of the molten steel, the flexibility of the KTB method in controlling the temperature of the molten steel makes it possible to reduce the tapping temperature at the converter, and combined with the improvement of tapping conditions described in section 3.1, can be said to stabilize the converter operation as a whole.

3.3 Effect of KTB Method in Improving Product Quality

As discussed in section 3.1, the improvement of the vacuum decarburization operation by the KTB method is also effective in suppressing excess oxidation in tapping at the converter. As a result, the cleanliness of the molten steel is improved. At Kawasaki Steel, the defect ratio in cold rolled strip has been reduced from 2.2% to 0.3%.[1] The Great Lakes Div. of National Steel Corp. has also reported a remarkable improvement in quality, as can be seen in **Fig. 4**. This index of the trend in surface defects originating in inclusions in ULC[8] shows a broad drop in rejected coils following the introduction of the KTB method.

A number of reports[10-12] have indicated that slag deoxidation immediately after tapping is effective in preventing quality problems due to excess oxidation of the ladle slag. However, it is possible that some of the molten steel, as well as the ladle slag, is also deoxidized in this operation. If this is the case, it would be necessary to secure the oxygen required for vacuum decarburization from outside the system. This strongly suggests that a method such as the KTB, which can easily supply oxygen gas, is required in the refining of ULC, as this product tends to show quality problems when the ladle slag is overoxidized.

Moreover, ULC is included in the concept of interstitial-free (IF) steel, in which the negative influence of interstitial elements on the mechanical properties of the product is minimized. The effect of the KTB method on quality stability also deserves mention in this connection, because the improvement of vacuum decarburization performance with the KTB method has made it possible to obtain ultra-low carbon contents stably, and as mentioned in section 3.1, has also reduced the tapping [N].

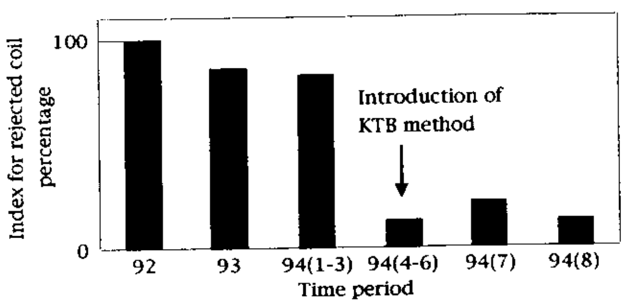

Fig. 4 Trend of ULC products flex bend test at National Steel Corp. Great Lakes Div.

3.4 Solution of Skull Problem in Vacuum Vessel

After the introduction of the KTB method, the problem of skull in the vacuum vessel was no longer an obstacle to long-sequence continuous casting of ULC at Kawasaki Steel. The effect of the KTB method against the problem of skull in the vacuum vessel is summarized as follows:

(1) Skull in the vessel is suppressed by post-combustion during vacuum decarburizing.

(2) Skull can be melted by blowing oxygen gas from the KTB lance at the operational position when decarburizing treatment is not in progress.

In this operation, efficient removal of skull is possible by adjusting the height of the KTB lance and using an attachment which changes the direction of the oxygen gas jet flow to select the position where skull is to be dissolved.

Figure 5 shows the condition of skull before and after introduction of the KTB method and the effects of skull removal at Nakayama Steel Works, Ltd. In the conventional practice, skull removal work was performed once every 70 heats and required heavy physical labor by the operators, but Nakayama Steel Works, Ltd. reports that it is now possible to remove skull using oxygen gas supplied by the KTB lance, and the actual amount of skull has decreased to 1/3 the amount with the conventional method.[6] Similar results have also been confirmed at Toa Steel Co., Ltd.[13] Moreover, Nakayama Steel Works, Ltd. also reports that there has been no ill effect on qual-

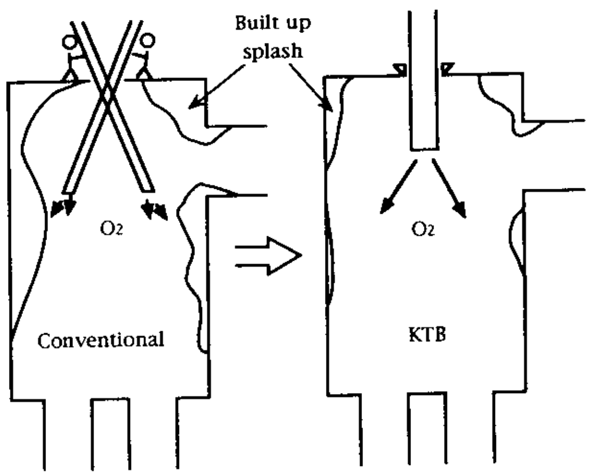

Fig. 5 Schematic drawing of built up splash removal at Nakayama Steel Works, Ltd. Funamachi Works

ity from an increase in product $[O]_T$ (total oxygen content) due to skull melting following the introduction of the KTB method.[6]

3.5 Effect of Improvements on Steelmaking Refractories

As another benefit which is also related to the skull removal work discussed above, Nakayama Steel Works, Ltd. has reported an improvement of approximately 100 heats in the life of the lower vessel refractory. This was analyzed as being the result of ① elimination of trouble resulting from direct impact of the oxygen gas jet on the refractory surface, which was unavoidable in conventional skull-cleaning work by the operator, and ② the higher temperature of the refractories in the vessel, which contributes to preventing thermal spalling.[6]

In an example from Kawasaki Steel, refractory costs were improved across the entire steelmaking operation by relaxing the tapping conditions at the converter, contributing to a 15% extension of refractory life at the converter and a 10% extension of ladle and the vacuum degasser snorkels.[14]

3.6 Stability of KTB Equipment and Operation

In the reports received by Kawasaki Steel, the stability of the KTB equipment is good at all user companies. Users also report that the water-cooled lance, which is the key element in this technology, has shown consistently high durability, and long life can be expected.

The KTB method has also won an excellent reputation for incorporating equipment and features designed to ensure the safety of personnel and reduce the load on operators. As an example of safety-related equipment, when the lance hole socket at the top of the vacuum vessel and the lance are retracted out of the vessel, automatic remote-controlled exchange with a closed top is possible. As a feature for operator guidance, the calculation model for determining the amount of oxygen required in each type of KTB treatment has reached a level where is it possible to indicate highly accurate calculated values.

4 Expansion of Vacuum Degassing Treatment Functions by Applying the KTB Method

The previous chapter has summarized the reports of user companies on the benefits of the KTB method in refining ULC. This chapter will present examples of the application of the KTB method to high alloy steel and the use of the KTB as a supplementary means of desulfurizing molten steel in the vacuum degasser, and will discuss the possibilities which the KTB method offers for improving secondary refining technology.

4.1 Decarburization of High Alloy Steel by KTB Method

Before introducing the KTB method, Nisshin Steel

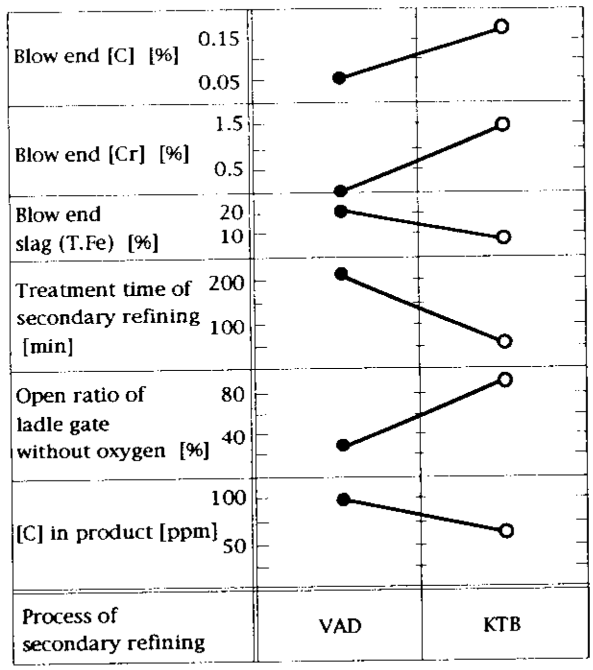

Fig. 6 The comparison of results between VAD and KTB process for producing low C-Cr steel at Nisshin Steel Co., Ltd. Kure Works

Co., Ltd. produced low-C, high-Cr steel by the conventional converter-VAD route. However, after recognizing the superiority of the KTB, this user succeeded in changing the process to the converter-RH vacuum degasser,[7] and achieved the improvements in operational indexes shown in **Fig. 6**.

The superiority of the KTB in refining low-C, high-Cr steel can be summarized as follows:

(1) It is possible to increase blow-end [C] before the vacuum degassing treatment because high-speed decarburizing can be performed in the vacuum degasser under high [Cr] conditions without causing Cr loss. This means that low-cost, high-C FeCr can be used in the converter, and at the same time, improved Cr yield can be achieved.

(2) Large increases in the tapping temperature can be avoided because it is possible to control the temperature of the molten steel in the vacuum vessel.

(3) Where quality is concerned, workability is improved by the reduction in product [C], and product cleanliness is improved by the increased ratio of natural opening of the ladle nozzle, which is attributable to the higher tapping [C] and shorter secondary refining time.

At Kawasaki Steel's Mizushima Works No. 1 steelmaking shop, stable refining of 5%Cr steel has become possible since introduction of the KTB method, and at Kawasaki Steel's Chiba Works, the KTB method is actively used in decarburizing stainless steel.[15,16]

Considered together, these examples suggest that vacuum decarburizing using the KTB method is not limited to general ULC, but can also be applied to a wide variety of steel grades.

4.2 Desulfurizing Using the Vacuum Degasser

The molten steel desulfurizing treatment which is generally used to meet the needs of ultra-low sulfur steel production involves injecting a de-S flux into the molten steel in the ladle, and then compensating for the resulting drop in the molten steel temperature by the LF or other means. However, Nisshin Steel Co., Ltd. has reported an operation in which the desulfurizing of low-C, high-Mn, ultra-low-S steel ($[S] \leqq 10$ ppm) is performed in the vacuum degasser using the molten steel temperature control function of the KTB method.[7] The technical background which makes this type of operation possible includes the following two points.

(1) It is possible to compensate for the drop in the molten steel temperature which accompanies the addition of the flux necessary for desulfurizing because the KTB method allows control of the molten steel temperature.

(2) The concentration of (T.Fe) + (MnO) in the slag, which is an obstacle to desulfurizing, can be reduced because the KTB makes it possible to increase the tapping [C].

Desulfurizing in the vacuum degassing vessel using the KTB method has the following advantages:

(1) The N content of the molten steel can be reduced because there are few opportunities for contact between the molten steel and air.

(2) A total secondary refining function can be realized in one vacuum degassing process by adding de-S and temperature control capabilities to the fundamental vacuum degassing function.

Finally, considering the fact that increasingly high efficiency has been achieved in this type of treatment by supplying flux through the KTB lance, it is perhaps no exaggeration to say that there is a high possibility that all the secondary refining functions can be concentrated at the vacuum degasser, with the KTB method as the basic technology.

5 Conclusion

The usefulness of the KTB method in vacuum decarburizing by the vacuum degasser has won wide acceptance in Japan and other major steel producing countries, and the expected benefits have been achieved consistently by all the companies which have introduced the KTB. The examples reported by users suggest that the KTB technology has reached a stage where a revolutionary change in the steelmaking process, in which the secondary refining functions are concentrated on the vacuum degasser, can now be expected.

In the future, the authors hope to contribute to the stable mass production of ultra-low carbon steel, responding to the increasing need for this material worldwide, not only through simple supply of the KTB method, but also through technical assistance which includes quality assurance.

The authors wish to express their respect and sincere appreciation to all the companies whose efforts have contributed to the optimization of the converter-vacuum degasser process incorporating the KTB method.

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