KAWASAKI STEEL TECHNICAL REPORT
No.15 (October 1986)

Production of High Carbon Steel Using Pretreated Hot Metal in Top-and-Bottom-Blown Converter

Hiroshi Nomura, Hajime Bada, Keizo Taoka, Sumio Yamada, Ryuichi Asaho, Kanji Emoto

Synopsis :
Approximately 90% of high carbon steel is produced by a process newly developed at No.1 Steelmaking Shop of Chiba Works. This new process, which uses dephosphorized hot metal and top-and bottom-blown converter (K-BOP), can achieve the maximum benefits of compound metallurgical techniques. Its features are following. (1) Heat compensation by coke charging through application of desulfurization in gas phase to prevent sulfur pick-up (2) Reduction of manganese ore by carbon in low oxygen potential (3) Desulfurization, deoxidization and chemical adjustment by reduction refining. Significant benefits, such as decreases in flux and alloy consumption, lowering of tapping temperatures, and improvement on quality including cleanliness are achieved by this newly-developed process.

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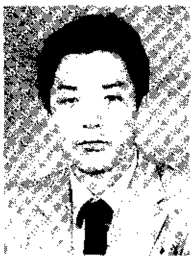

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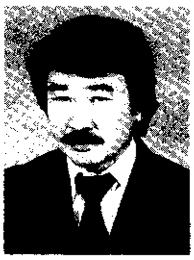

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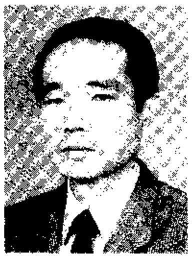

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Approximately 90% of high carbon steel is produced by a process newly developed at No. 1 Steelmaking Shop of Chiba Works. This new process, which uses dephosphorized hot metal and top-and botom-blown converter (K-BOP), can achieve the maximum benefits of compound metallurgical techniques. Its features are following.

(1) Heat compensation by coke charging through application of desulfurization in gas phase to prevent sulfur pick-up

(2) Reduction of manganese ore by carbon in low oxygen potential

(3) Desulfurization, deoxidization and chemical adjustment by reduction refining

Significant benefits, such as decreases in flux and alloy consumption, lowering of tapping temperatures, and improvement on quality including cleanliness are achieved by this newly-developed process.

1 Introduction

Progress in steelmaking processes in recent years centering around the converter has been remarkable. Typical examples are the hot metal treatment technique[1] and combined blowing technique.[2] These two techniques have been developed in the course of seeking process rationalization and optimization in response to requirements for higher quality steels and diversification of the blowing function; application of these techniques is producing various beneficial effects.[3]

The No. 1 Steelmaking Shop at the Chiba Works is realizing various process improvements by combining (1) the hot metal dephosphorizing technique[4] in which low Si hot metal, obtained by low-Si-operation[5] at the No. 6 blast furnace and by use of the cast house desiliconization technique[6], is dephosphorized using lime-based flux and (2) the combined blowing technique of the top-and-bottom-blown converter (K-BOP)[7] developed by incorporating the respective advantages of the Q-BOP and LD. An example of these improvements is the refining of ferritic or martesitic stainless steel, previously reported.[8] Further, as a result of applying these techniques to the refining of high carbon steels, marked economical benefits and quality improvements as well as useful findings about metallurgical characteristics have been obtained. This report describes, in particular, the contents of such findings.

2 Refining Process

In the conventional high carbon steel refining process, sulfur was removed at the hot metal stage, and the dephosphorizing reaction was performed in the converter. This process had the following problems:

(1) It was necessary to blow down carbon and raise oxy-

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gen potential; thus the iron loss to slag and unit consumption of the deoxidizer were high.

(2) It was necessary to add alloys such as Mn and recarburizing materials at the stages of tapping and thereafter, resulting in higher tapping temperatures.

(3) To promote the dephosphorization reaction in the high temperature zone, lime consumption was necessarily higher.

The present process has been developed with the aim of solving the above-mentioned problems.

2.1 Hot Metal Pretreatment

One of the features of the process is the removal of phosphorus at the hot metal stage and elimination of the dephosphorization workload in the converter. A schematic diagram of hot metal pretreatment facilities is shown in **Fig. 1**, and changes in chemical composition and temperatures of hot metal before and after treatment are shown in **Table 1**. This table indicates that [Si] in hot metal before treatment is stabilized at about 0.10%, and that [P], after treatment with a flux consumption of about 80 kg/t, has dropped to 0.015%, which is below the target value of the product. At this time, there is no particular need to pay attention to the value of sulfur, because a reduction period is provided at the converter, as mentioned later. Drop of hot metal temperature during the treatment is significant, reaching about 150°C. With the aim of preventing this temperature drop, high speed injection of flux at a rate of 500 kg/min is adopted, thereby allowing completion of treatment of two heats within 60 min.

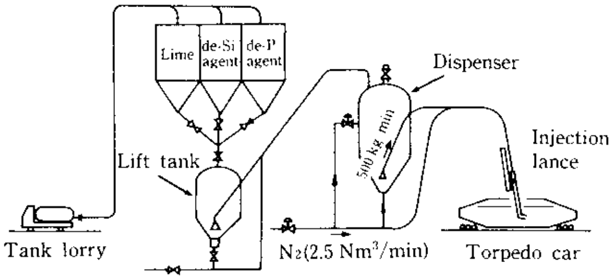


Fig. 1 Schematic diagram of pretreatment of hot metal

Table 1 Changes in chemical composition and temperature of hot metal

	Chemical composition (%)					Temp. (°C)
	C	Si	Mn	P	S	
Before treatment	4.49	0.10	0.19	0.133	0.049	1 370
After treatment	4.23	—	0.08	0.015	0.036	1 220

Table 2 Specifications of K-BOP

Top and bottom blowing converter		85 t × 2
Combination of gases		Inner: O_2, O_2+Ar(N_2), Ar(N_2) Outer: Propane, Propane +Ar(N_2), Ar(N_2)
Oxygen flow rate	Top lance	175 Nm³/min max.
	Bottom tuyere	100 Nm³/min max.
Flux injection (CaO or $CaCO_3$)		500 kg/min max.
Waste gas treatment		OG type

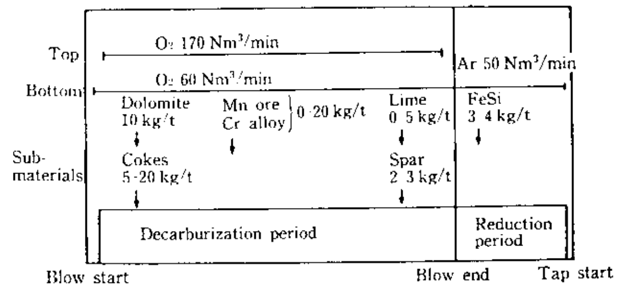


Fig. 2 Typical refining procedure of new process

2.2 K-BOP Blowing

Specifications of the K-BOP are shown in **Table 2**. One of the features of this converter is its combination of the powerful stirring force of K-BOP bottom-blowing and the metallurgical effect of the top lance. The typical refining procedure in this process is shown in **Fig. 2**. In the K-BOP, components such as Mn, Ni, Cr, and Mo are adjusted to the target values, and simultaneously, heating-up using coke is performed. At the target blow-end carbon and temperature, oxidization-and-decarburization blowing is stopped. Then FeSi is added into the converter and desulfurization and deoxidization are performed by reduction blowing using Ar gas, until the molten steel is tapped.

3 Operation Results and Discussion

3.1 Heat Compensation

Heat balance in high carbon steel with coke addition is shown in **Fig. 3**. In this process, heat compensation becomes essential for the following reasons:

(1) Temperature drop during hot metal pretreatment is significant, and thus the hot metal temperature is low.

(2) Addition and melting of alloy elements such as Mn, Ni, Cr, and Mo are performed in the converter.

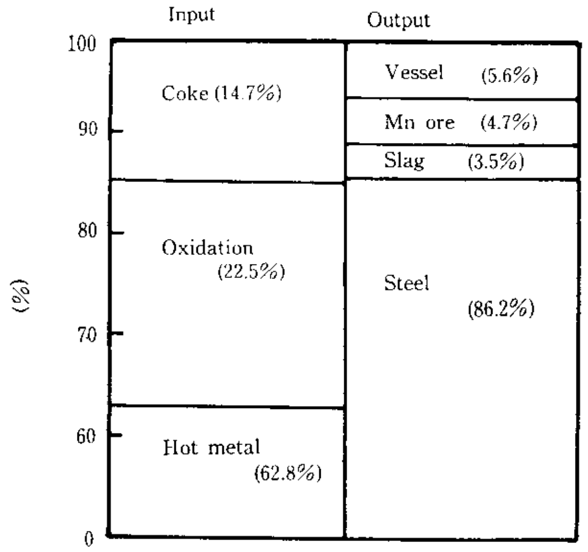


Fig. 3 Heat balance in high carbon steel with coke addition

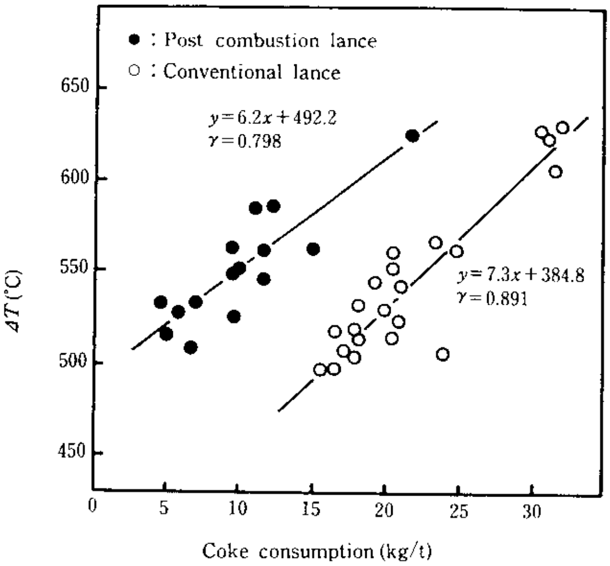


Fig. 4 Relationship between coke consumption and increase in temperature of molten metal (ΔT) (ΔT: includes the heat content increase equivalent to increase in coolant)

(3) Since no phosphorization is required and oxygen blowing is stopped in the high carbon zone, oxidation reaction heat of Fe, Mn, etc. cannot be expected.

For heat sources, coke is economically most suitable, because coke has few slagging components and the exhaust gas can be recovered as CO gas. However, sulfur content in coke is as high as about 0.5%, and it may be feared that if the efficiency of recarburization of the steel bath is lower, control in hitting the end-point carbon will become unstable. To cope with the former problem, K-BOP benefits from its high capacity for desulfurizing in the gaseous phase and for execution of reduction-desulfurization, explained later. With the latter, uniform steel bath composition is achieved by powerful stirring by the bottom blown gas. Heat compensation technique by addition of coke from the top of the furnace is under steady operation, and as indicated in **Fig. 4**, which shows the relation between coke consumption and the temperature rise in molten steel, the heating-up capacity by coke addition reaches about 6.8°C per 1 kg/t-coke.

Another heat compensation technique used is secondary combusion by top-blown oxygen. Although it is alleged that execution of secondary combustion will promote damage of converter refractories, trouble-free operation is being realized by optimization of the lance nozzle shape and the position of the auxiliary hole. The effectiveness of this procedure is illustrated in Fig. 4. A decrease in coke consumption of about 13 kg/t has been achieved, thereby contributing to a decrease in heating-up costs.

3.2 Smelt Reduction of Mn Ore

This process is applied to steels whose target carbon content is 0.15% or above. Since the stirring power of the bottom blown K-BOP is great, oxygen potentials in the steel bath and slag during the decarburization period show low values. The relation between [C] in the steel bath at the blow-end and after reduction, T.Fe in slag, and [O] in steel is shown in **Fig. 5**. In this process, there is no need to promote the dephosphorizing reaction, and blow-end carbon can be set to a high value. This low oxygen potential at the blow-end, reduction-desulfurization, and small slag volume by slag-forming material such as lime in quantities of about 15 kg/t, necessary for protection of converter refractories, are very advantageous to the smelt reduction of Mn ore.

Smelt reduction of Mn ore is shown in **Fig. 6**, which clearly indicates that reduction of Mn ore by [C] in molten steel is progressing during the decarburization period, and Mn yield is higher than with the conventional method owing to the small slag volume. In the conventional process, Mn yield at the blow-end was about 25%, whereas in this process blow end C can be set at a higher value because no dephosphorization operation exists, and thus Mn yield has reached as high as 80 to 95%. However, in the region where carbon content is 0.30% or below, Mn yield drops. This may be due to the rise in oxygen potential as the carbon drops. Therefore, for steels whose target carbon content is within 0.15 to 0.30%, a decarburization method under the diluted oxygen gas is employed in which an inert gas is mixed in the bottom blown oxygen in the final period of decarburization blowing, in an effort to prevent Mn reoxidization.

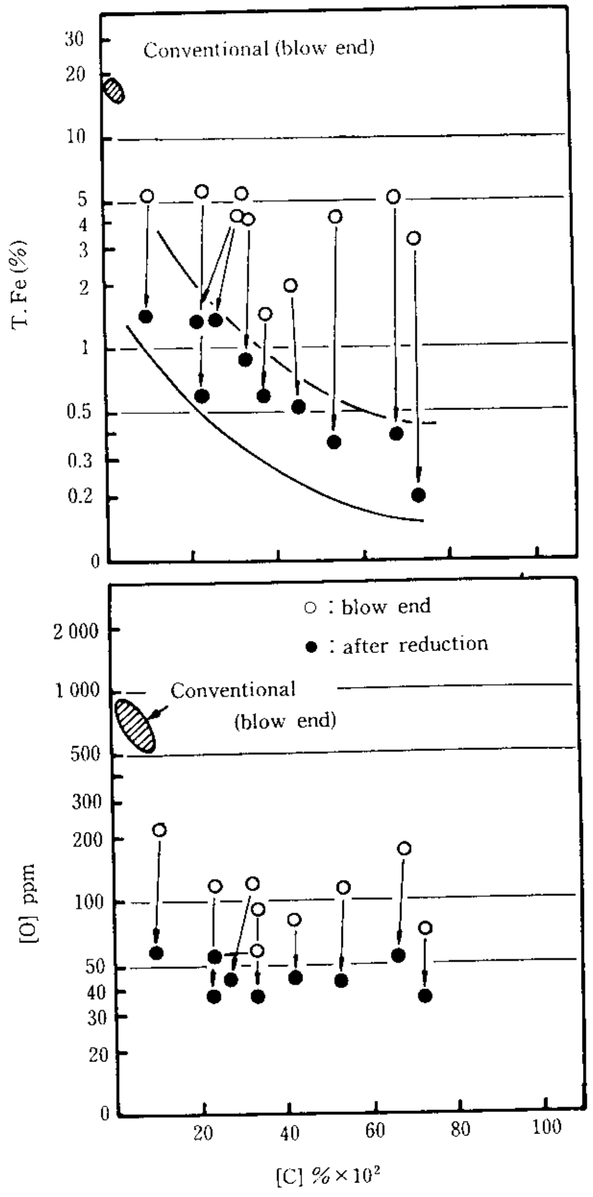
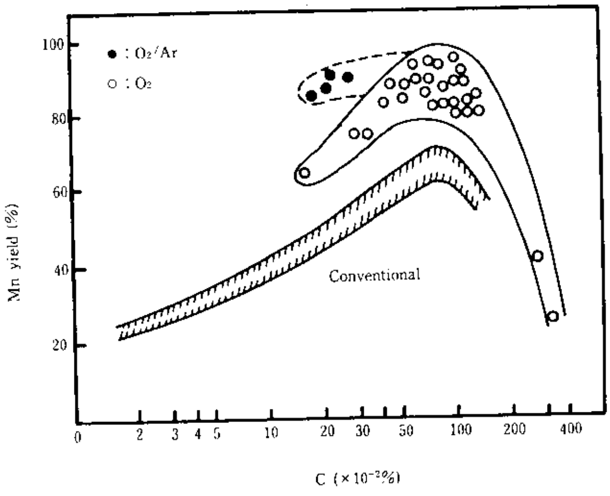


Fig. 5 Relation between [C], (T. Fe) and [O]



$$\text{Mn yield} = \frac{[\%\text{Mn}]_{\text{end point}} \times 10}{W_{\text{Mn ore}}(\text{kg/t}) \times 0.342 + [\%\text{Mn}]_{\text{hot metal}} \times 10}$$

Fig. 6 Relation between %C and Mn yield

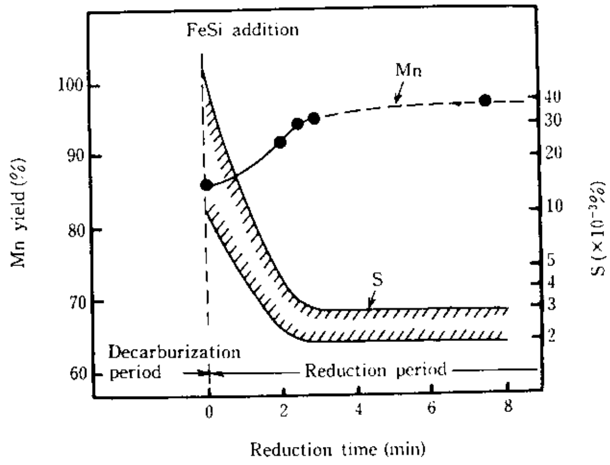


Fig. 7 Changes in Mn yield and S content during reduction period

Smelt reduction of Mn ore thus progresses mostly during decarburization blowing, and further, reduction of MnO in slag due to Si addition during reduction blowing boosts the Mn yield to more than 95%. Consumption of FeSi (75% Si) which is added during the reduction period is 3 to 4 kg/t, including that used for chemical adjustment. Changes in chemical composition during the reduction period are shown in **Fig. 7**. In about three minutes of stirring, the reduction reaction of Mn is completed simultaneously with the desulfurization reaction.

3.3 Desulfurization Reaction

When a great deal of coke is used for the purpose of heat compensation, sulfur pick-up from coke poses a problem. Since this process provides a reduction period, it is advantageous for desulfurization, but if the sulfur pick-up is too great, prolongation of reduction time and a rise in the basicity of the slag are potential problems. In K-BOP, however, blow-end sulfur is, as shown in **Fig. 8**, much lower than input sulfur, in which sulfur pick-up from coke is taken into consideration and desulfurization of as high as about 70% is observed. Therefore, the sulfur balance at the blow-end was investigated. The result is shown in **Fig. 9**, which indicates about 50% of input sulfur is unknown output sulfur.

The above phenomenon can be explained as follows: Although direct gasification of sulfur from molten steel is difficult to expect thermodynamically, it is well known that sulfur in slag is liable to gasify.[9, 10] In this process, it

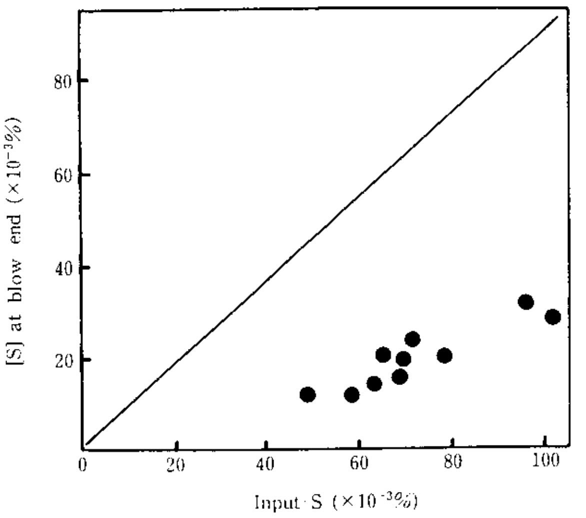


Fig. 8 Relation between input-S content and blow-end-S content

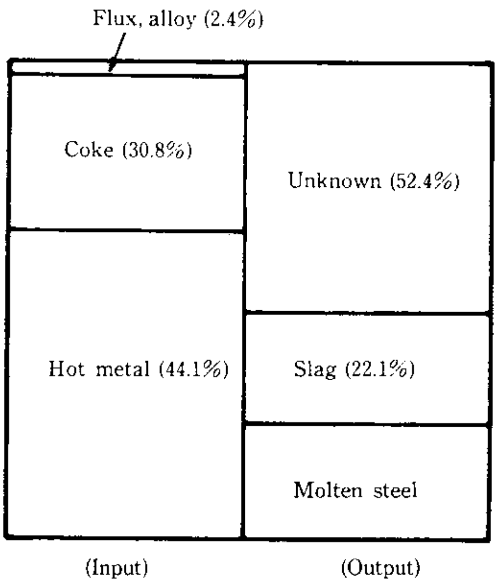


Fig. 9 Comparison of sulfur balance at blow-end

is considered that a desulfurization reaction between slag and metal easily progresses with the help of low oxygen potential, high-basicity slag, and the powerful stirring force of bottom blowing. It is also hypothesized that sulfur which has been absorbed in the slag is affected by the oxygen potential in the gaseous phase which increases as a result of soft-blown oxygen by the top lance, and thus the oxidization-desulfurization reaction between slag and the gaseous phase progresses. Consequently, this phenomenon is peculiar to K-BOP and has not been experienced in Q-BOP and LD converters.

Through this desulfurizing in the gaseous phase, the desulfurization workload in the reduction period is markedly reduced, and with a very small amount of slagging material and short-time reduction treatment, [S] in molten steel drops to 0.005% or below. The condition of

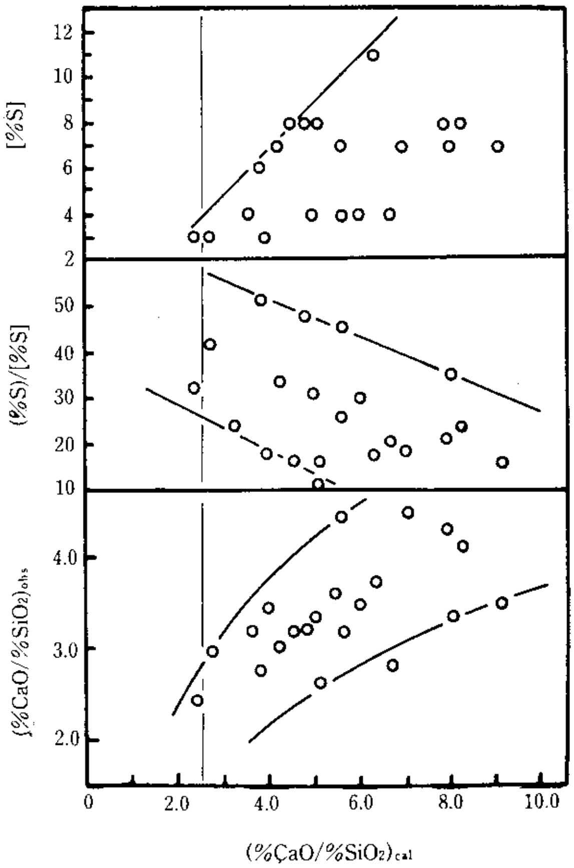


Fig. 10 Relations between calculated basicity and actual basicity, S distribution and S content in reduction period

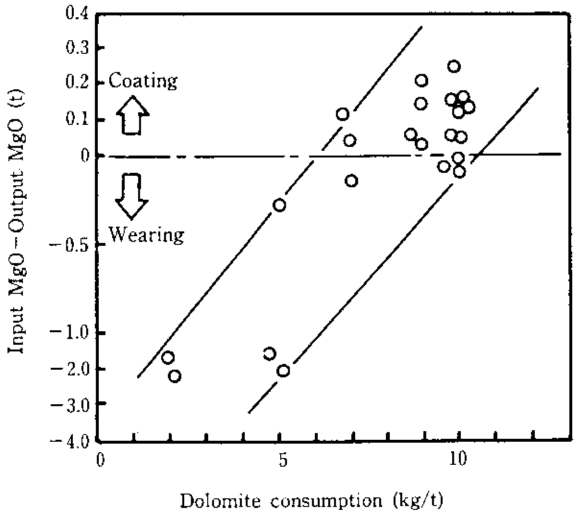


Fig. 11 Influence of dolomite consumption on refractory wearing

the desulfurizing reaction during the reduction period is shown in **Fig. 10**. What is important here is to control slag basicity at 2.5. It is generally considered that high basicity of slag is advantageous to desulfurization, but that the accompanying rise in the melting point of slag slows the reaction speed. Conversely, in this process, a high fluid slag forming ratio and high sulfur distribution ratio are shown at the low basicity side, where a low [S] value in the molten steel is obtained. However, if the slag basicity is set below 2.5, the desulfurizing capacity of the slag drops, and satisfaction of sulfur specifications sometimes becomes impossible.

The unit consumption of slag-forming material is determined by the amount of lime necessary for maintaining a basicity of 2.5, which is required for this desulfurization, and the amount of a burned dolomite necessary for protecting converter refractories, as shown in **Fig. 11**; consumption remains low at about 15 kg/t.

3.4 Decrease in Dust Loss

In general when blowing is performed in the nearly slagless condition as in this process, a problem is posed in the increase in dust loss due to fume generation. To suppress fume generation, soft blowing of the top lance has proved effective. Changes in dust concentration in the OG dust collection water during blowing are shown in **Fig. 12**. The adoption of soft blowing by the top lance which is installed for secondary combustion has decreased dust concentration by half, and reached the level of the conventional process. Through improvement of the top lance, and owing to the fact that nearly 100% of metal in slag can be reduced and recovered, steel yield has shown an increase of 3.4% compared with that by the conventional process, as shown in **Fig. 13**.

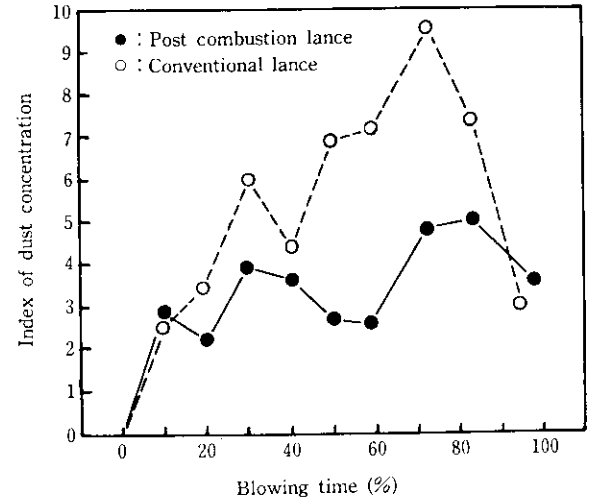


Fig. 12 Influence of post combustion lance on dust loss into exhaust gas

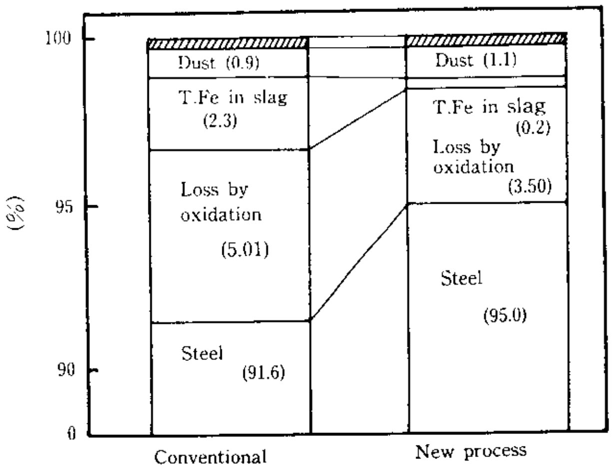


Fig. 13 Comparison of material balance between conventional and new processes

3.5 Economic Benefits

Application of this process has brought about a saving of 8.2% in the production cost of high carbon steel, as shown in **Fig. 14**, as well as the following benefits:

(1) Decreases in consumption of recarburizing materials and alloys such as FeMn and Al

(2) Improvement in steel yield

(3) Decrease in slagging material consumption

What must not be forgotten here is the effect on refractories. In the conventional process, the tap temperature of high carbon steel was high at about 1 670°C. The reasons for this were the necessities of securing sufficient tap time for decreasing the slag out-flow with the aim of preventing rephosphorization after tapping and of adding recarburizing materials and alloys such as

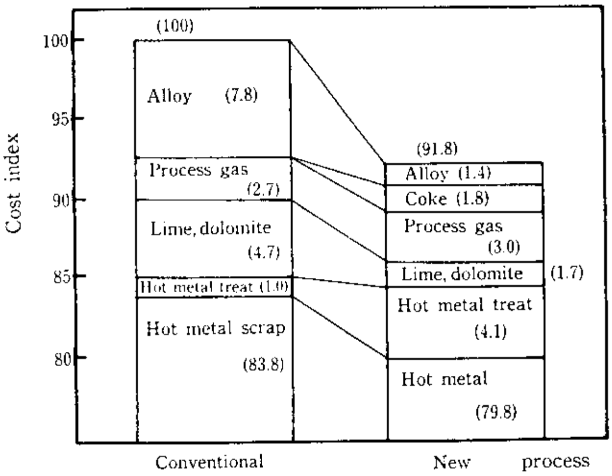


Fig. 14 Cost comparison between conventional and new processes

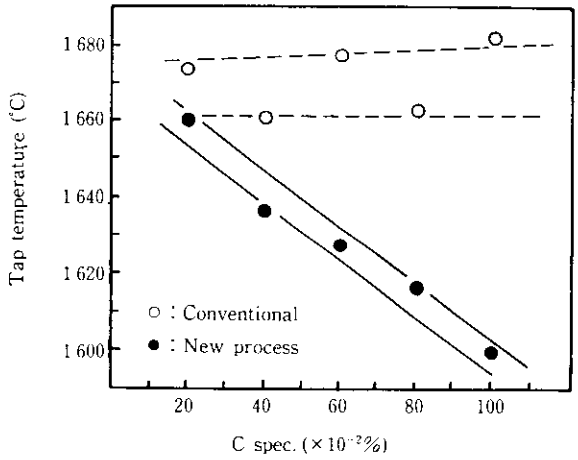


Fig. 15 Comparison of tap temperature between conventional and new processes

FeMn to the ladle for chemical adjustment. In this process, such necessities have been completely eliminated, and a marked decrease in tap temperatures has become possible, as shown in **Fig. 15**. Tap temperatures are nearly proportional to solidification temperatures and become lower as the target carbon value of the steel becomes higher. Lowering the tap temperature has brought about an inestimably great benefit in terms of converter refractories.

In terms of quality too, [O] drops to about 50 ppm under the deoxidation by silicon in the converter. As a result, Al recovery after tapping is very high and the quantity of deoxidization products is small. With a simultaneous contribution from low-level [S], it has become possible to easily blow high carbon steel of very high cleanliness.

4 Conclusions

The authors have been able to establish a highly rational high carbon steel manufacturing process which combines the hot metal dephosphorizing technique and combined-blowing technique. Outstanding features of the process are: first, phosphorus is removed in the hot metal stage, thereby eliminating the dephosphorization load in the converter; and secondly, reduction refining is incorporated in the converter, thus permitting chemical adjustments in the converter. This process has been put into practical application for about 90% of high carbon steel and has brought about not only remarkable economical benefits but also improvement in quality.

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