Dynamic Refining Control by Analysis of Exhaust Gas from LD Converter*

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Synopsis

The possibility of blowing control based on exhaust gas data was studied. The amount of oxygen accumulated in LD converter (O_S), which is calculated from the oxygen balance by using exhaust gas data, corresponds to the amount of FeO, Fe_2O_3 *and* MnO *in the slag during blowing.*

When the refining reaction was controlled by O_S control, the carbon, phosphorus and manganese contents of steel and the total iron content of slag at blow end were controlled at preferable levels and the fluctuaticns of levels were remarkably reduced. Namely, O_S is an effective parameter representing the progress of the reaction and can be used to control the blowing at an optimum level.

Key words: oxygen converter; gas blow; computer control; refining reaction; optimum control of oxygen.

I. *Introduction*

Nearly 30 years have passed since LD converters went into operation. Recently, many of these LD converters have been modified to be equipped with bottom blowing nozzle in Japan.[1] In the meantime, LD converter refining control has been improved with the spread of computerization.

The ways of LD converter refining control can be divided into two major groups: static control based on the information obtained before the start of the blowing and dynamic control based on the process signals representing the state of refining during the blowing.

Static control is unable to adjust the course of refining following the variations in the reactions during the blowing and is limited in the achievable accuracy level. Static control is usually utilized to define initial condition of the raw material charging and oxygen blowing as auxiliary to dynamic control.

Various techniques have been proposed for dynamic control. The progress of the sublance dynamic control process[2] enhanced the accuracy of blow-end temperature and carbon content control.

The sublance process, however, gives only the instantaneous bath carbon content and temperature during the blowing and can not provide continuous information after the in-blow measurements.

Recently, for a wide application of the continuous casting process and especially the CC-DR process,[3,4] in which a continuous caster is directly linked with a rolling mill and cast slabs are delivered at the rolling mill without conditioning, rearrangement and reheating, slabs with a lower phosphorus content are required. This requirement intensified the need for closer phosphorus control.

The sublance measurement is not sufficient for the control of phosphorus and manganese contents that are deeply related to the slag formation reactions during the blowing.

It has been well known that the total iron content of slag (T.Fe) is closely related to blow-end chemical composition of steel, the phosphorus and manganese contents in particular,[5] and the total iron content of slag has been frequently used as a practical parameter of refining. The present authors thought that the phosphorus and manganese contents of steel at blow end could be more closely controlled if a suitable slag oxidation parameter could be found to replace the conventional parameter, the total iron content of slag, and a means to control the new parameter would be developed.

The present study focused on the utilization of the data obtained from exhaust gas, some of which had been already available through previous studies on the methods[6-8] of controlling the OG system.[9]

It was expected that the amount of oxygen that gradually accumulates in a slag could be calculated as a parameter to represent the oxidation degree of the slag based on data on exhaust gas and the amount of fluxes charged during blowing. The parameter was studied for use in the dynamic control of the refining reactions. Prior to application to the practical operation of the LD converter, the accuracy of the data on exhaust gas and the effective usage of the information were studied basically. It was found that the parameters based on data on exhaust gas were applicable to LD converter refining control and that the LD converter blowing process could be accurately controlled by using the parameters. The findings obtained are reported in the following.

II. *Experiment*

1. *Data on Exhaust Gas*

1. Measuring System for Exhaust Gas

The experiment was conducted on a 170-t top-blown LD converter. The main specifications of the LD converter and the converter gas recovery system (OG) are tabulated in Table 1.

The measuring system for exhaust gas is shown in Fig. 1. The chemical composition of exhaust gas was continuously analyzed for eight components by a mass spectrometer,[10] the specifications of which are given in Table 2.

The exhaust gas flow rate was measured by a venturi tube installed in the horizontal duct of the

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OG system.

2. Difference in Composition of Exhaust Gas throughout OG Duct

The exhaust gas was sampled at the top of the radiation cooling section ahead of the primary dust collector where the exhaust gas is sprayed with scrubbing water. The uneven flow of exhaust gas throughout a sectional area of OG duct was studied to determine the optimum sampling position that gives the representative composition of exhaust gas.

For the study, exhaust gas was continuously sampled during the blowing at three positions in the OG duct of the radiation cooling section as shown in Fig. 2. Gas compositions were compared to each other.

3. Response against Changes in Composition of Exhaust Gas

While air was drawn into the OG duct by an induced-draft fan (IDF), argon (purity of 99.995 %) was added as tracer gas, into the air stream through the mouth of the converter. The air was sampled by a gas sampler installed at the top of the radiation cooling section, and analyzed by the gas spectrometer. The changes in argon content were followed to evaluate the capability of sampled of the gas to respond to incoming gases. The argon injection conditions are given in Table 3.

2. *Definition of Amount of Oxygen Accumulated in LD Converter (O_s)*

The amount of oxygen accumulated in the converter was continuously calculated from the difference between the amount of oxygen input into and output from the LD vessel (the latter is the amount of oxygen in the exhaust gas). The value at every moment, thus calculated as a change in the amount of oxygen accumulated in the converter, was defined as dO_s. The amount of oxygen accumulated in the converter was considered to be the value after subtracting the amount of oxygen consumed in the oxidation of silicon and phosphorus and accumulated in the slag as SiO_2 and P_2O_5 from an integrated value of dO_s.

Table 1. Main specifications of LD converter and OG system.

Equipment	Item	Specification
BOF	Capacity	170 t/heat × 3 vessels
Oxygen equipment	Blowing capacity	40 000 Nm^3/h max.
OG	IDF capacity	102 000 Nm^3/h max.
	Main dust collector	Pease-Anthony venturi scrubber

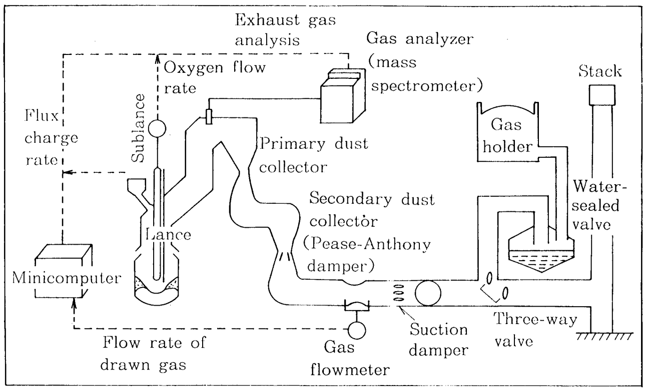


Fig. 1. Exhaust gas data measuring system.

The amount of oxygen in the form of SiO_2 and P_2O_5 was subtracted, because the amount of oxygen fixed as SiO_2 did not participate in the oxidation reaction of carbon as the oxidation potential of the slag and the amount of oxygen fixed as P_2O_5 were thought to be almost constant.

As the phosphorus content can not be continuously determined, the total amount of oxygen accumulated in the converter (O_s) was defined as calculated by the following equations (1) and (2) where only the amount of oxygen as SiO_2 was subtracted for convenience.

The expression of dO_s and O_s can be given by Eqs. (1) and (2), respectively, in terms of the oxygen flow rate, flux charge rate, and exhaust gas flow rate.

Table 2. Main specifications of mass spectrometer.

Item	Specification
Mass spectrometer	MG-1200 of Perkin-Elmer Corp., USA
Analysis	Simultaneous analysis for 8 components (CO, CO_2, O_2, N_2, H_2, Ar, CH_4, He)
Response time	1 s
Accuracy	±0.1% over full scale

Table 3. Argon injection conditions.

Test	Flow rate of drawn air (Nm^3/h)	Argon injection condition	
		Argon flow rate (N*l*/min)	Argon injection position
A	53 400	500	P_1 (around converter mouth)
B	53 800	500	P_2 (at center of converter)
C	109 600	500	P_2 (at center of converter)

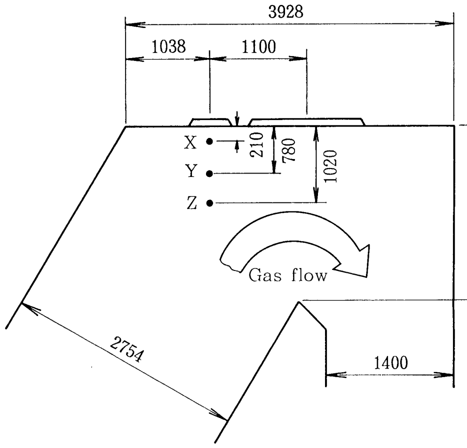


Fig. 2. Gas sampling positions in the top part of radiation cooling section.

Corrections are to be made for the combustion of exhaust gas at the converter mouth and delay in the analysis of the exhaust gas. Accumulated oxygen O_s is expressed in units of Nm^3 for convenience.

$$dO_s = \{F_{O_2} + \sum(\alpha_i+\beta_i)W_i + 1/2V_{H_2}\} -(1/2V_{CO}+V_{CO_2}) \quad \cdots\cdots(1)$$

$$O_s = \int_t (dO_s)dt - K\cdot[\mathrm{Si}]_{HM}\cdot W_{HM} \quad \cdots\cdots(2)$$

where, dO_s: change in amount of oxygen accumulated in LD converter $(=dO_s/dt)$

O_s: total amount of oxygen accumulated in LD converter

F_{O_2}: oxygen flow rate

α_i: coefficient for generation of oxygen from flux

β_i: coefficient for generation of carbon dioxide from flux

W_i: flux charge rate

i: type of flux

V_{H_2}: flow rate of hydrogen gas generated in LD converter

V_{CO}: flow rate of carbon monoxide gas generated in LD converter

V_{CO_2}: flow rate of carbon dioxide gas generated in LD converter

k: coefficient for conversion of Si into SiO_2, $Si+O_2=SiO_2$

$[\mathrm{Si}]_{HM}$: silicon content in hot metal

W_{HM}: weight of hot metal

3. Steel and Slag Sampling and Analysis

Steel and slag samples were picked out by the sublance.[2] The steel samples were analyzed by arc discharge spectrometry and the slag sample were analyzed by fluorescent X-ray spectrometry. Of the slag analysis, the value of CaO represents the value exclusive of free lime.

III. Results and Discussion

1. Data on Exhaust Gas

1. Difference in Composition of Exhaust Gas throughout OG Duct

Figure 3 shows the differences in the CO and CO_2 content among the exhaust gas sampled at different positions, with reference to the contents in the sample obtained at the center of OG duct.

The CO and CO_2 contents near the top wall of the duct (position X, Y) were not significantly different from those at the center of the duct (position Z). This might be a natural result, since the Reynolds Number of the exhaust gas flow in the duct is always above 3×10^5. Based on the above result indicating that the exhaust gas composition was uniform across the duct section, samples of the exhaust gas were taken by the gas sampler at the point X shown in Fig. 2 for the total period of the experiment.

2. Response against Changes in Composition of Exhaust Gas

Data on exhaust gas can not be used for the blowing control of LD converters in practical operation if it takes too long to obtain the data because of rapid variations in the reactions taking place in the converter within a short period.

An example of response to change in argon content with argon injection is shown in Fig. 4 and the results of response in analysis are given in Table 4.

The response delay shown in Fig. 4 may be attributed to the following factors:

① Gas transport time through the OG duct (from the converter mouth to the sampling position) and concurrent gas mixing

② Gas sample transport time through the gas sampling line and simultaneous gas mixing

③ Analysis time by the mass spectrometer.

The response delay phenomenon can be studied by comparing the difference of delay time among conditions A to C in Table 4, and may be understood as described below.

(1) Delay Time

The differences in delay time between the conditions A and B, and C may be attributed to the effect of the transport times ① and ②. The transport time ① of the air flow through the OG duct is equal to the time during which the inner volume (197.3 m^3) from the converter mouth to the radiation cooling section top is replaced by the drawn air if the mixing of the air flow in the direction of flow is ignored. Replacement times at different gas flow rates are shown in Table 5.

The difference between the calculated replacement

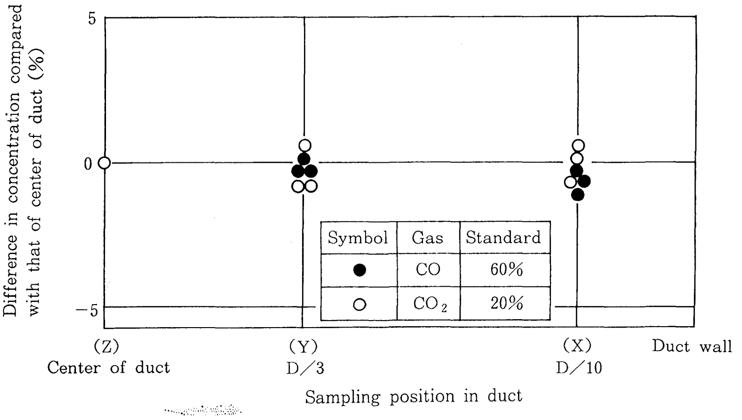


Fig. 3. Relationship between exhaust gas sampling position and differences in CO and CO_2 concentrations.

times A and B and time C is 6.3 s, whereas the difference between the mean of the argon response times A and B and the argon response time C was 5.2 s. As these figures are practically the same, transport time of the sample gas through the sampling line, the factor ②, should be close to the total delay time and less than the replacement time, which is 8.4 s for the conditions A and B and 9.5 s for the condition C.

The above results are those obtained with air at room temperature. The temprature of the exhaust gas is high during the blowing. When corrected for the blowing condition, the transport time of the exhaust gas through the OG duct (from the converter mouth to the radiation cooling section top) should be 2.6 s for the conditions A and B, and 1.3 s for the condition C as shown in Table 5. The total delay time is thus estimated at 11.0 for conditions A and B where the flow rate of the exhaust gas is low and 10.8 s for the condition C where the flow rate of the exhaust gas is high.

(2) Time Constant

The difference in the time constant arises due to the influence of mixing of the exhaust gas in the direction of flow for the factors ① and ②.

As the gas flow rate increases, the time constant decreases as shown in Table 4 thereby decreasing the mixing of the exhaust gas. During the blowing, the time constant is probably less than 3 s because the high temperature of the exhaust gas increases the actual gas velocity.

The factor ③ or analysis delay is consequently included in the delay time and time constant.

The above results suggest that the total analysis delay time of the exhaust gas is 14 s; that is, the transport delay time of 11 s plus the time constant of 3 s. This fixed time was used in the calculation of dO_s and O_s.

Since the exhaust gas flowmeter is of the differential pressure type, the lag time in pressure propagation and flow rate detection are taken to be O_s.

Summarizing the above, it was found that the total time required to obtain data on exhaust gas was 14 s. This is short enough to be applied to the refining control of an LD converter on a production basis.

3. Decomposition of Moisture in Flux

The flow rate of the exhaust gas measured in the venturi tube is converted into the corresponding value on a dry basis. In the calculation of O_s and dO_s, described above, the amount of oxygen that enters and accumulates in the converter in the form of H_2O can be calculated if H_2 in the gas before the spray zone can be obtained. The decomposition rate of moisture in the flux needs not to be taken into account.

2. *Relationship between O_s and Refining Characteristics*

1. Relationship between Change of O_s and Oxidation Potential of Slag during Blowing

Figure 5 shows typical changes in the bath composition, amount of oxygen accumulated in the slag and O_s (O_s pattern) during the blow. The value of O_s was obtained by Eq. (2) from the continuous processing of data on exhaust gas. The change in O_s closely agrees with the actual change in the amount of oxygen accumlated in the slag and determined by slag analysis.

The amount of oxygen accumulated in the slag at blow end (excluding oxygen as SiO_2) was composed of about 50 % of FeO and Fe_2O_3, about 25 % of P_2O_5 and about 25 % of MnO. The amount of oxygen dissolved in the steel bath was about 2 % of O_s, when determined by equilibrium calculation, and was at a level that could be ignored for the refining control.

The relationship between the amount of oxygen accumulated in the slag (excluding oxygen as SiO_2)

Table 4. Results of analysis response.

Argon injection condition	Number of heats	Item: Argon concentration (%)		Equivalent delay (s)	
		Ar_i	Ar_f	Delay time	Time constant (100 % response)
A	3	0.900	0.943	20.2	4.5
B	3	0.900	0.944	21.2	4.0
C	4	0.899	0.921	15.5	3.0

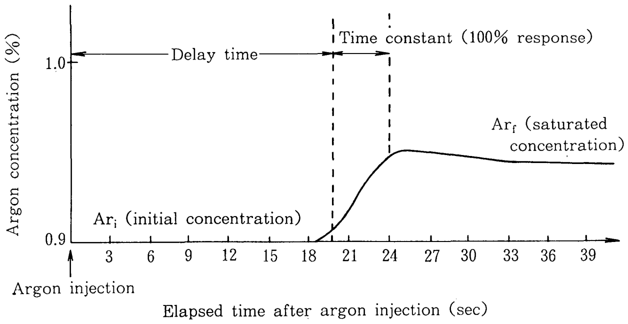


Fig. 4. Analysis response curve against step-like injection of argon gas.

Table 5. Replacement time of inner volume of radiation cooling section.

Aron injection condition	Flow rate of drawn air (Nm³/h)	Calculated replacement time of inner volume of radiation cooling section: Not blowing (20°C)		Blowing (1 100°C)	
		Flow rate of exhaust gas (m³/s)	Replacement time (s)	Flow rate of exhaust gas (m³/s)	Replacement time (s)
A, B	53 600	16.0	12.3	75.0	2.6
C	109 600	32.7	6.0	153.1	1.3

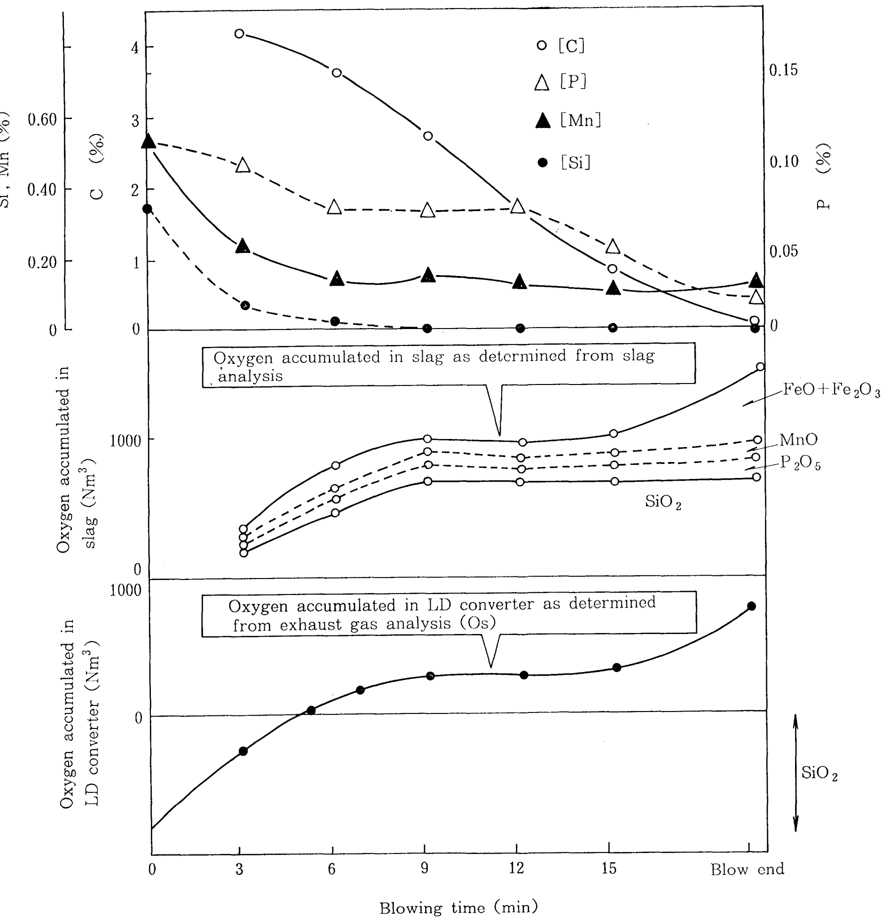


Fig. 5. Typical example of changes in LD converter reaction parameters during blowing.

as determined from the slag analysis at blow end and O_s determined from the exhaust gas analysis is shown in Fig. 6. The calculated O_s closely agrees with that obtained from slag analysis at blow end as well.

These results indicate that O_s, an item of information that can be continuously obtained during blowing, corresponds to $FeO+Fe_2O_3+MnO$ and is an index of the progress of the blowing reactions.

2. Relationship between Change of O_s and Chemical Composition of Bath

The selection of O_s as an index may be made in six forms as shown in Fig. 7. The form most closely correlated with the bath composition at blow end, the phosphorus and manganese contents in particular, was studied. The single correlation coefficients for each form with the phosphorus and manganese contents in steels at blow end are listed in Table 6.

The characteristics of O_s as an index can be classified into the following three groups:

(1) Initial Stage of Blowing (① and ②)

The O_s is not considered to exert a large effect on the phosphorus and manganese contents of the steel at blow end.

(2) Middle Stage of Blowing (③)

The manganese content of the steel at blow end is practically independent of O_s and the phosphorus content tends to drop, while O_s tends to increase throughout the middle stage of blowing.

(3) Final Stage of Blowing (④, ⑤ and ⑥)

The phosphorus and manganese contents of the steel at blow end are most strongly correlated with O_s. As O_s (⑥) and the increasing rate of O_s (④) towards blow end increase, the phosphorus and manganese contents decrease. This tendency is more evident for the manganese content.

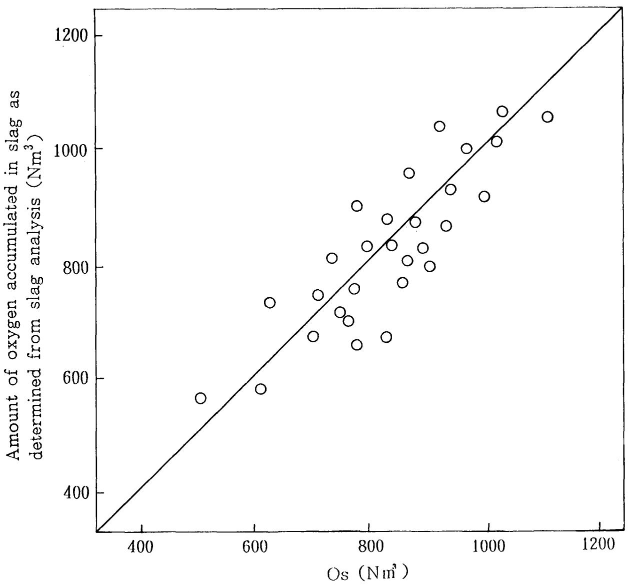
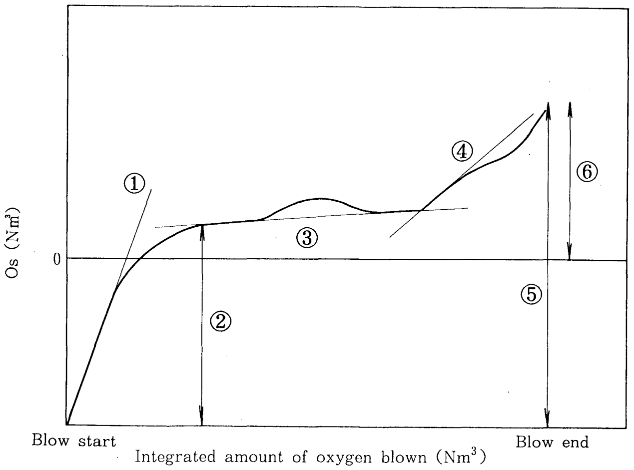


Fig. 6. Relationship between O_s and amount of oxygen accumulated in slag as determined from slag analysis.

It is presumed statistically from the above results that the adoption of O_s in pattern A (Fig. 8) results in higher manganese and lower phosphorus contents than O_s in pattern B. The O_s in pattern A corre-

Table 6. Coefficients of single correlation between phosphorus and manganese contents of steel at blow end with process parameters.

Composition	Parameter									
	O_s						Basicity charged	Hot metal [Si]	Blow end temperature	Blow end [C]
	①	②	③	④	⑤	⑥				
Blow end [P]	−0.05	0.05	−0.22	−0.34	−0.35	−0.45	−0.27	0.07	0.08	0.30
Blow end [Mn]	−0.20	−0.05	0.01	−0.45	−0.37	−0.51	−0.05	−0.03	0.13	0·49



① Average dO_s for 3 min after blow start
② Maximum value of O_s or O_s at inflection point for 7 min after blow start
③ Average dO_s at middle stage of blowing
④ Average dO_s at final stage of blowing
⑤ Oxygen in SiO_2+O_s
⑥ O_s

Fig. 7. Quantitative representation of O_s.

sponds to the blowing practice in which O_s is increased during the middle stage of blowing, the increasing rate of O_s is lowered during the final stage of blowing and the optimum value of O_s is obtained at blow end. This means that O_s must be controlled within an optimum range after the middle satage of blowing.

3. Relationship between Blowing Conditions and Change of O_s

It was studied to see if O_s could be changed by manipulating the two blowing conditions (lance height and oxygen flow rate). For this study, one condition was fixed while the other was changed.

The relationship between the manipulated amount of the blowing conditions and the rate of change in O_s is shown in Fig. 9. The lance height was varied in the range of 1.6 to 2.2 m and the oxygen flow rate in the range of 22 000 to 32 000 Nm^3/h.

The amount, ΔdO_s, changed ±300 to 600 Nm^3/h with the change of the lance height by ±100 mm or the oxygen flow rate by $\mp$1 000 Nm^3/h. Namely, O_s increased when the agitation of the bath was weakened by increasing the lance height or decreasing the oxygen flow rate and O_s decreased when the aigtation of the bath strengthened by decreasing the lance height or increasing the oxygen flow rate.

It was thus proved that O_s could be controlled by manipulating the blowing conditions.

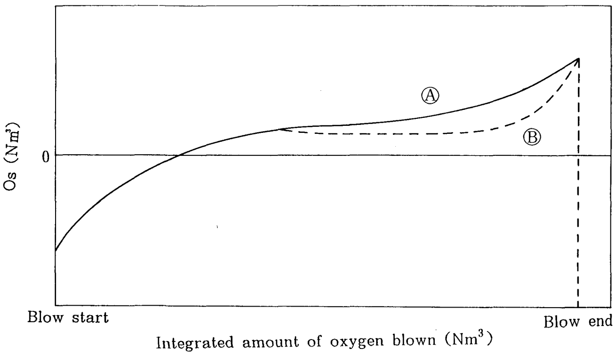
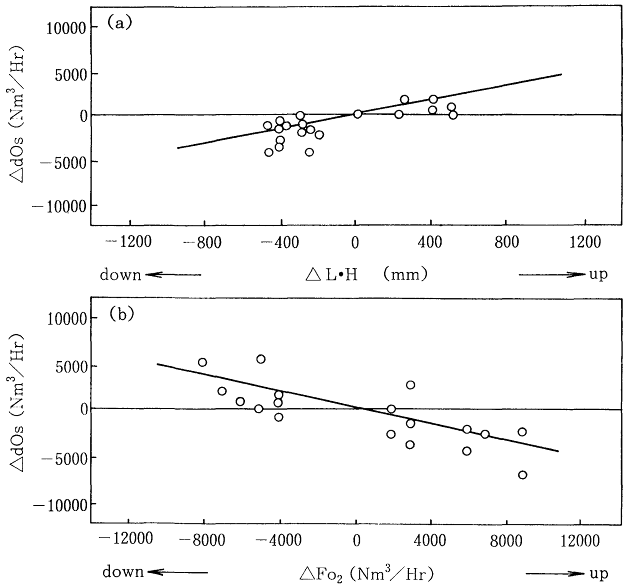


Fig. 8. Example of two O_s patterns.



(a) Relationship between lance height and O_s
(b) Relationship between oxygen flow rate and O_s

Fig. 9. Relationship between blowing condition and rate of change in O_s.

4. Determination of Optimum O_s Pattern

It was considered from the above study that the O_s pattern, based on the past heats which were successfully blown, could adequately simulate the blowing reaction process and provide good blowing results of the subsequent heat.

The following procedure was tried to determine the O_s pattern suitable for some specific heat.

(1) The O_s pattern of every heat had been calculated and recorded, and the O_s pattern of one heat of the same grade with low phosphorus content together with high manganese content at blow end was selected from the preceding blowing results of

recent heats. (This O_s pattern was supposed to correspond to the case in which the steel and slag at blow end were close to equilibrium at blow end and the slag formation degree was high.)

(2) The O_s pattern described in (1) above, was corrected to fit for the aiming amount of oxygen and aiming O_s of the heat concerned.

(3) The above two steps were performed for several of the past heats and the optimum aiming O_s pattern was selected based on the results.

3. Control of O_s in Practical Operation

Blowing control of LD converter by O_s was tested by manipulating the blowing variables noted above.

1. Method of O_s Pattern Control

The actual procedure to control the O_s pattern of the subsequent heat to achieve the aiming O_s pattern is described below. An example of the change in the actual O_s pattern is shown in Fig. 10.

(1) Aiming O_s (O_s^A) was compared with actual O_s (O_s^R) at intervals of T_0.

$$\Delta O_s = O_s^R - O_s^A$$

(2) When ΔO_s deviated from the allowable range of ±100 Nm³, the blowing condition was manipulated. The lance height was first changed and, if the lance height exceeded the upper or lower control limits, the oxygen flow rate was changed.

(3) After this, the O_s pattern was monitored without any manipulation for the time T_1.

(4) If ΔO_s increased after the time T_1, no controlling action was made and the procedure moved to step (5). On the contrary, if ΔO_s did not decrease, the procedure returned to step (2).

(5) The procedure returned to step (1) after the time T_2 from the manipulation step (2).

In this test, T_0, T_1 and T_2 were 8, 56 and 80 s, respectively.

2. Changes in Carbon, Phosphorus and Manganese Contents of Steel at Blow End with O_s Control

The relationships between the carbon, phosphorus and manganese contents at blow end and the total iron content of slag corresponding to them and the same between the phosphorus and manganese contents of the steel are shown in two separate groups with and without O_s control in Figs. 11 to 14, respectively.

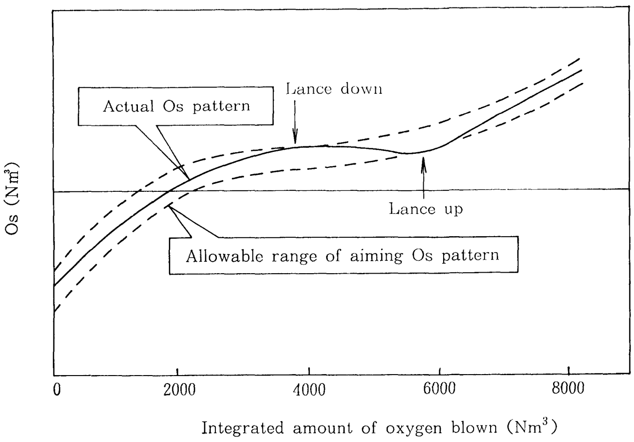


Fig. 10. O_s control method.

As shown in these figures, O_s control reduced the fluctuation of the total iron content of slag with the carbon content of steel and provided the high manganese content with the low phosphorus content for the same total iron content compared with the group without O_s control. These indicate that the refining reaction was satisfactorily controlled by O_s control in following the aiming O_s pattern with low phosphorus and high manganese content at blow end.

4. Effect of O_s Control on Metallurgical Reaction

The phosphorus and manganese removal reactions in LD converter are not necessarily stable among

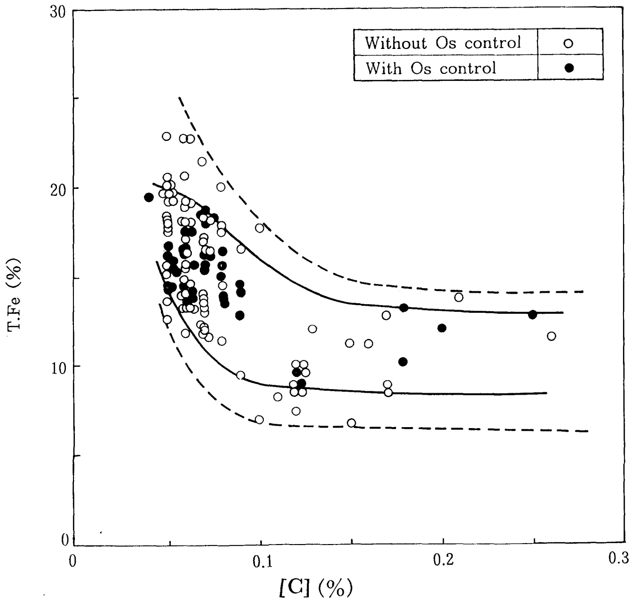


Fig. 11. Relationship between carbon content and total iron content of slag at blow end.

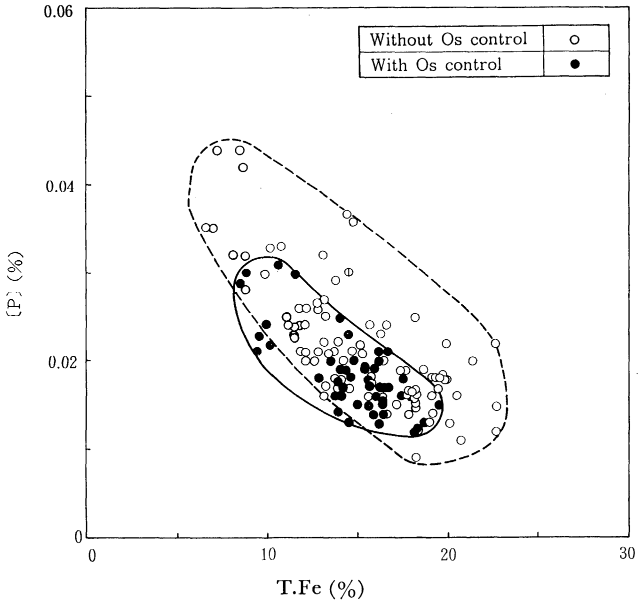


Fig. 12. Relationship between phosphorus content of steel and total iron content of slag at blow end.

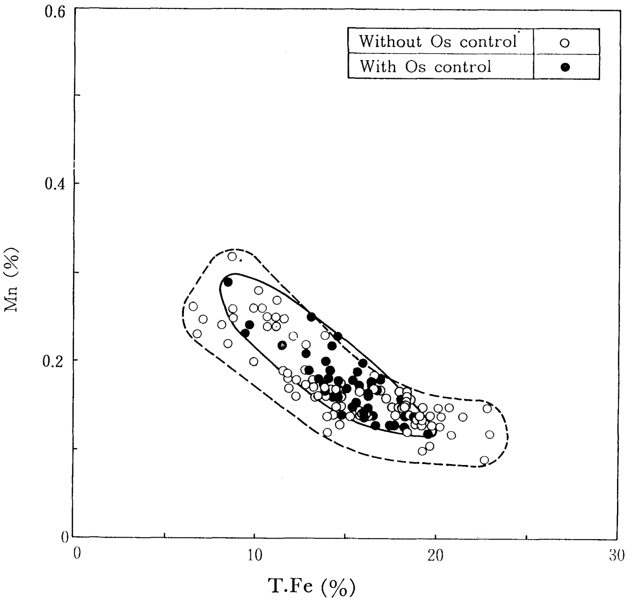


Fig. 13. Relationship between manganese content of steel and total iron content of slag at blow end.

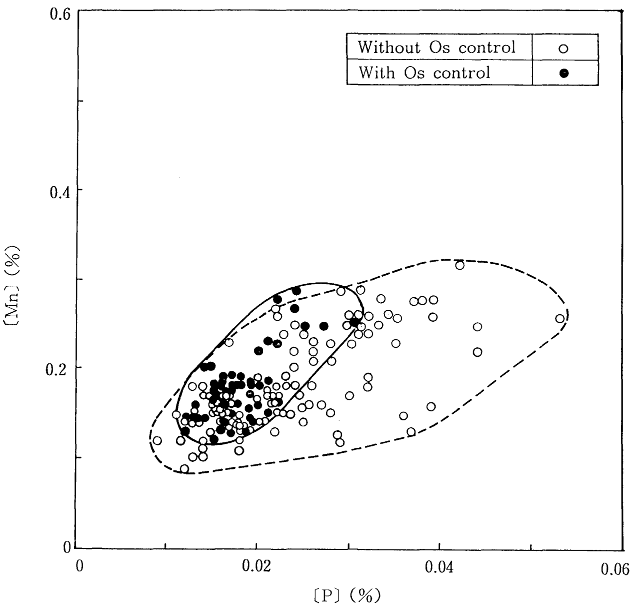


Fig. 14. Relationship between phosphorus and manganese contents of slag at blow end.

the subsequent heats. The main reason is that these reactions depend strongly on the total iron content of slag and the slag formation reaction of burnt lime and tend to fluctuate from heat to heat.

As mentioned above, the fluctuation of the total iron content of slag with carbon content was reduced by the operation aiming at the same value of O_s. The fluctuations of the phosphorus and manganese contents with the total iron content in slag were reduced as shown in Fig. 13. The phosphorus content could be decreased with the high manganese content as shown in Fig. 14. The reason for these could be understood that the progress of the refining reaction was effective to accelerate the slag formation reaction of burnt lime with the relatively low iron content of slag, when O_s control was applied.

The effect of O_s pattern control in controlling the phosphorus content and improving the degree of phosphorus removal was studied from the equilibrium point of view. Figure 15 shows the relationship between the calculated equilibrium phosphorus contents of the steel at blow end by the modified Healy equation,[11] and the actual contents.

$$\log [P] = 21.876 - 22\,350/T - 5.6 \log(\%CaO) - 2.5 \log(\%T.Fe) + \log(\%P) \quad \ldots\ldots\ldots\ldots\ldots(3)$$

Figure 15 indicates that phosphorus in the slag and metal was not in complete equilibrium at blow end. Blowing control by the optimum O_s pattern, however, made the phosphorus content in the steel at blow end to approach the equilibrium that gives better dephosphorization.

The reasons for this were studied by the slag formation reaction of burnt lime. In the case of a production scale LD converter, the chemical composition of steel bath at blow end is not only related with that of the slag, but also depends on the slag formation of burnt lime in the early stage of blowing. Controlling of O_s by following the optimum and identical pattern would mean to control the oxidizing potential of the slag within higher and narrow range. This is closely related to the melting of burnt lime, namely, the acceleration of the slag formation, thereby reducing the fluctuation and improving the reproducibility of the blowing performances.

The relationship between the total iron content of slag and slag formation ratio (actual basicity at blow end/calculated basicity from charged fluxes) is shown for two groups with and without O_s pattern control, in Fig. 16.

As the total iron content of slag increased, the slag formation ratio increased, accompanying a large fluctuation without O_s control. When O_s was controlled in the optimum pattern, the slag formation ratio was increased with high accuracy.

From the above, it can be concluded that this stabilization of the slag formation is one of the important reasons for the improvement of phosphorus and manganese contents.

IV. *Conclusions*

(1) It was studied whether in-blow data on LD converter exhaust gas can be properly applied for the blowing control to improve the refining reaction. The following findings were obtained:

(i) The exhaust gas sample, taken at the top of the radiation cooling zone of OG system, can represent the total LD converter exhaust gas as it was found that the exhuast gas flowed uniformly in the top part.

(ii) Response against a change in exhaust gas chemical composition is divided into delay time and time constant. A delay of 14 s is to be considered adequate for processing exhaust gas data.

(2) The amount of oxygen accumulated in the LD converter (O_s), which was calculated form the oxygen balance by using exhaust gas data, corre-

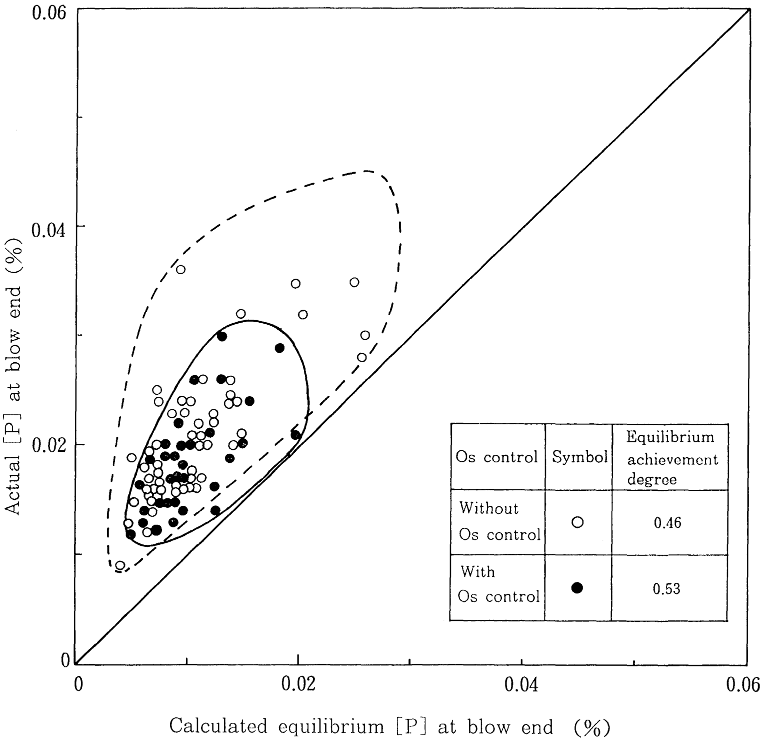


Fig. 15. Relationship between calculated equilibrium and actual phosphorus content of steel at blow end.

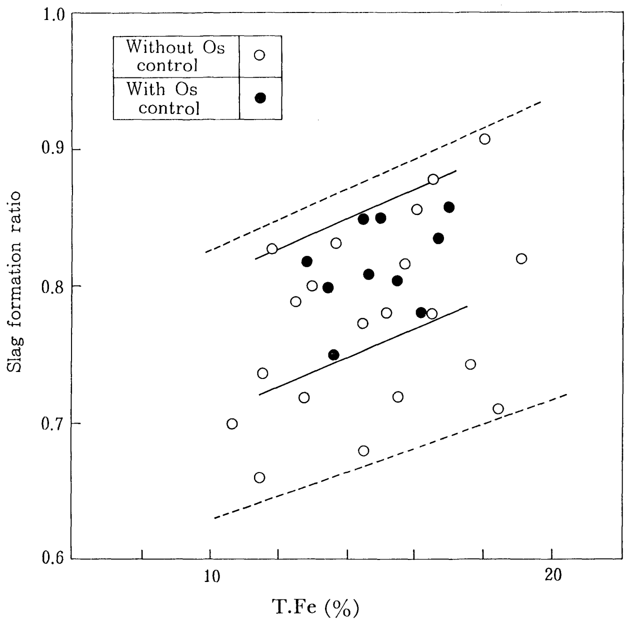


Fig. 16. Relationship between total iron content of slag and slag formation ratio (actual basicity at blow end).

sponds to the amount of FeO, Fe_2O_3 and MnO in the slag during blowing. Its change is closely correlated with the refining reaction procedure.

The amont of O_s can be controlled to a desired level if the blowing conditions, such as lance height or oxygen flow rate, are optimally controlled.

(3) When the refining reaction was controlled by O_s control, the carbon, phosphorus and manganese contents of steel and the total iron content of slag at blow end were controlled at preferable levels and their fluctuations were remarkably reduced.

These may be ascribed to the improvement in the slag formation ratio of burnt lime and the stabilization of the oxygen potential. As a result, the equilibrium achievement degree was improved as well. Finally, O_s is proved to be an effective index representing the progress of the reaction and can be used to control the blowing of an LD converter to keep the progress of the reaction in the optimum level.

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