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Modeling of Critical Carbon Content in Decarburization in BOF And Its Application to Dynamic Control Model

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Abstract: We developed the critical carbon content estimation model using the sequential quadratic programming method (SQP method) so that the standard critical carbon content obtained from the conventional knowledge matches the calculated critical carbon content in satisfying the balance equation of oxygen. We made use of the calculated critical carbon content in the estimation of carbon content at the end point. The accuracy of carbon content was improved compared to the dynamic control model which used the fixed critical carbon content. *Copyright ©2008 IFAC*

1. INTRODUCTION

In steelmaking, BOF(Basic Oxygen Furnace) is the main process of making steel from iron, and decarburization in BOF is the most important reaction governing the productivity.

Critical carbon content is defined as the value that the oxygen efficiency when the decarburization begins to decrease the last stage of blowing, which characterizes the change of decarburization in the last stage of blowing. It depends on the operational conditions of the BOF such as the oxygen gas flow-rate (Higuchi *et al*., 2000) or the amount of slag (Kimura *et al*., 1983).

On the other hand, in order to control decarburization in the last stage of blowing, most steel companies have introduced the blowing control system which consists of the sublance measuring equipment and the dynamic control model on the process computer. The accuracy of the dynamic control model depends on the correct estimation of the variation of the oxygen efficiency for decarburization. Therefore, critical carbon content is the effective information for the development of the dynamic control model which withstands change of operational condition. However, it is difficult to accurately measure critical carbon content in blowing of BOF.

We developed the critical carbon content estimation model using the sequential quadratic programming method (SQP method) so that the standard critical carbon content obtained from the conventional knowledge matches the calculated critical carbon content in satisfying the balance equation of oxygen. We made use of the calculated critical carbon content in the estimation of carbon content at the end point, hence the accuracy of carbon content was greatly improved compared to the dynamic control model which used the fixed critical carbon content.

2. OUTLINE OF BLOWING CONTROL SYSTEM

The blowing control system in BOF consists of sublance measuring equipment and the dynamic control model. This model consists of the balance equation of oxygen and the balance equation of heat in order to express the oxygen consumption and the temperature increase in the blowing process. The amounts of the oxygen and the coolants to attain the aimed carbon content and temperature at the end point can be calculated by solving the balance equations. In this work, only the balance equation of oxygen is examined.

3. MODELING OF CRITICAL CARBON CONTENT

3.1 Balance Equation of Oxygen Using Critical Carbon Content

The carbon content decreases in according to the progress of blowing. At the critical carbon content the oxygen efficiency for decarburization begins to decrease as shown Fig.1. As described in the introduction, the critical carbon content is a key data for obtaining the balance equation of oxygen appropriately. So, we formulated the relation between oxygen efficiency for decarburization and carbon content with (2) using critical carbon content directly.

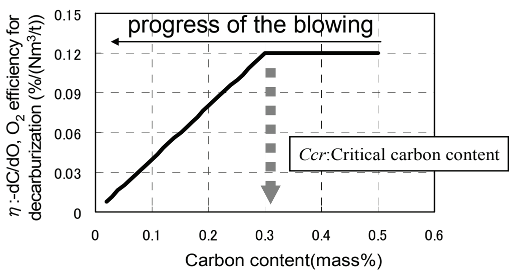

Fig.1. A relation between oxygen efficiency for decarburization and carbon content

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The balance equation of the oxygen shown (3) is obtained by integrating (2) for the carbon content.

$$\frac{dC}{dt} = -\eta \frac{dO_2}{dt} \tag{1}$$

$$\eta = -\frac{dC}{dO_2} = \begin{cases} k_1 \times C^n & (C < C_{cr}) \\ k_1 \times (C_{cr} - C_L)^n = k_2 & (C \geq C_{cr}) \end{cases} \tag{2}$$

$$\Delta O_2 = \frac{1}{k_1} \times \left(\frac{1}{1-n} \left((C_{cr} - C_L)^{1-n} - (C_{EP} - C_L)^{1-n} \right) \right) + \frac{1}{k_2} \times (C_{SL} - C_{cr}) \tag{3}$$

η : *Oxygen efficiency for decarburization* $[\%/(Nm^3/ton)]$
C_{cr} : *Critical carbon conent* $[\%]$, C : *Carbon content* $[\%]$
k_1 : *Decarburization rate* $[\%^{1-n}/(Nm^3/ton)]$
k_2 : *Maximum* O_2 *efficiency for decarburization* $[\%/(Nm^3/ton)]$
n : *reaction order* $[-](n<1)$, C_L : *Lower limit carbon conent* $[\%]$
C_{SL} : *Sub−lance measurement carbon conent* $[\%]$
C_{EP} : *Carbon content at the end point* $[\%]$, O_2 : *Oxygen consumption* $[Nm^3/ton]$

3.2 Identification of the Critical Carbon Content

If critical carbon content were accurately measured on real time the calculated carbon content at the end point by (3) would correspond with the actual carbon content. However, it is difficult to measure critical carbon content in blowing of BOF. Therefore, we identify the critical carbon content for a heat using the SQP method which is one of the effective methods for nonlinear programming problems. The problem is formulated as the following: The decision variables are the critical carbon content C_{cr} and the decarburization rate k_1. The objective function to minimize is defined by (4), which is the weighted squares sums of the differences in calculated values of critical carbon content, decarburization rate and maximum oxygen efficiency for decarburization from their standard values. In this problem, constraints are the balance equation of oxygen and the theoretical upper limit of maximum oxygen efficiency for decarburization and are written in (5) and (6). By solving this problem using the SQP method, the most appropriate critical carbon content is calculated.

$$f = W_1(k_1 - k_1')^2 + W_2(C_{cr} - C_{cr}')^2 + W_3(k_2 - k_2')^2 \tag{4}$$

subject to

$$\Delta O_2 = \begin{cases} \frac{1}{k_1} \times \left(\frac{1}{1-n} \left((C_{cr} - C_L)^{1-n} - (C_{EP} - C_L)^{1-n} \right) \right) + \frac{1}{k_2} \times (C_{SL} - C_{cr}) & (C_{cr} < C_{SL}) \\ \frac{1}{k_1} \times \left(\frac{1}{1-n} \left((C_{SL} - C_L)^{1-n} - (C_{EP} - C_L)^{1-n} \right) \right) & (C_{cr} \geq C_{SL}) \end{cases} \tag{5}$$

$$k_2 \leq K_{max} \tag{6}$$

W_1, W_2, W_3 : *weighting factors*
k_1', k_2', C_{cr}' : standard *values* K_{max} : theoretical value of k_2

3.3 Application to Dynamic Control Model

For every heat, the critical carbon content is calculated by using the proposed identification method, and it is stored with other actual operational data in a database. Because the critical carbon content is influenced by such operational conditions as the oxygen gas flow-rate or the amount of slag, therefore the prediction model of critical carbon content can be expressed by (7). The model parameters α_i in (7) can be determined by the regression analysis of the actual operational data stored in the database.

$$C_{cr} = \sum \alpha_i \times X_i \tag{7}$$

α_i : *model parameters* X_i : *operational conditions*

On the actual operations the critical carbon content of each heat is predicted, and by applying this value to (3) the carbon content at the end point is calculated on line.

3.4 Discussion

On the experimental result, the oxygen gas flow-rate and the amount of slag changed greatly. However, the critical carbon content was calculated corresponding to the change as shown Fig.2. As a result, the carbon content at the end point was calculated accurately as shown Fig.3.

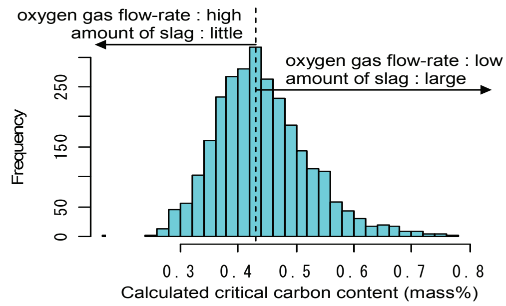

Fig.2. A Histogram of the calculated critical carbon content

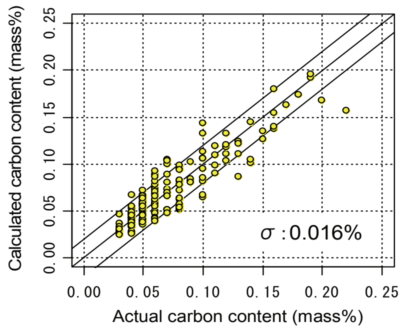

Fig.3. Accuracy of carbon content estimation

4. CONCLUSION

We developed the critical carbon content estimation model using the SQP method. We made use of the calculated critical carbon content in the estimation of carbon content at end of the blowing. The accuracy of carbon content was improved compared to the dynamic control model which used the fixed critical carbon content.

REFERENCES

Higuchi, Y. and Y. Tago (2000). Effect of Top and Bottom Blowing Conditions on Metallurgical Characteristics in Converter. *Tetsu-to-Hagane*, **Vol.86**, 654-659.

Kimura, M., H. Matsui, S. Ito, T. Saito, T. Soezima and M. Kitamura (1983). Characteristics of Refining Process with a Little Quantity of slag in the Top and Bottom Blowing Converter. *Tetsu-to-Hagane*, **Vol.69**, 1986-1900.