BEHAVIOR OF COKE IN BLAST FURNACE AND ITS EVALUATION

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1. Introduction

Coke quality is an important factor for the stable operation of the blast furnace. In the past, coke production has been mainly controlled according to cold strength. Dissections of quenched blast furnaces in recent years have attached importance to the hot properties of coke. Nippon Steel has adopted coke strength after reaction with carbon dioxide or CO_2 (CSR) as an important coke quality control item. This CSR cannot be fully explained by the behavior of coke in the blast furnace alone. Here are reported the study results of the behavior of coke at high temperatures in the blast furnace and the quality required of coke for use in the blast furnace.

2. Behavior of Coke in Blast Furnace

Blast furnace coke is required to combine functions of a heat source, reductant, gas transfer medium and liquid transfer medium. To make clearer the properties required of blast furnace coke, it is necessary to know the behavior of coke in the blast furnace.

The dissection work of blast furnaces, which started in the 1960s, has made it possible to know the changes in the properties of various burden materials in the blast furnace. Nippon Steel dissected Higashida No.5 furnace, Hirohata No.1 furnace and Kukioka No.4 furnace in succession. With new information from the dissection of Nagoya No.1 furnace, coke is known to change in properties in the blast furnace as shown in Fig.1. According to these results of investigation, coke increases in reactivity and decreases in cold strength and mean size as it descends into the high-temperature, high-pressure region in the lower part of the furnace. Simulation tests were repeated under conditions close to those in the furnace, making it feasible to predict the behavior of coke in the furnace to a considerable extent.

(Fig. 1)

The changes in the shape of the cohesive zone and raceway with the quality of coke are schematically shown in Fig.2.

(Fig. 2)

Coke of poor quality decreases in size as it is charged into the blast furnace and moves down the lumpy zone. This increases gas flow resistance in the middle shaft with increasing top gas pressure. In the cohesive zone, fine coke increases in slit layers and causes the locally uneven gas flow to the slit layers and the fluidization of the coke in those portions. The gas flow resistance increased by the fine coke particles reduces the upward gas flow in the dripping zone and increases the gas flow through the lower slit layers toward the wall of the furnace. In the raceway zone, the size deterioration increases further, decreasing the raceway depth and increasing the gas flow toward the wall. In the hearth zone, the fine coke and ash produced in the raceway zone cause dripping iron and slag to fall locally and discharge unevenly through the taphole.

The aforementioned behavior of coke in the blast furnace indicates that strength in the upper part of the furnace, resistance to degradation by reaction at high temperatures of over $1,000^{\circ}C$ in the shaft and resistance to degradation by combustion in the raceway are important properties required of blast furnace coke.

3. Properties Required of Blast furnace Coke

3.1 Basic Considerations

As far as the behavior of coke in the blast furnace is concerned, the first quality requirement of coke is cold strength. The behavior of coke at high temperatures is considered here on condition that coke is maintained at a certain level of cold strength.

As high-temperature properties required of blast furnace coke, it is important to clarify how the coke degrades in strength and size in the blast

furnace. This coke degradation results from thermal action and chemical reaction with carbon dioxide (CO_2), and the effects of these two factors must be taken into account.

This section describes reactivity and reaction temperature concerning the reaction of coke with CO_2 that has a large influence on high-temperature degradation of coke and indicates the relationship between the CSR index and the coke degradation behavior in the blast furnace.

3.2 Coke Degradation at High Temperatures

The degradation of coke when treated at high temperatures and tested in an I-type tumbler drum is shown in Fig.3. When coke is not reacted with CO_2 (reactivity index or RI = O), is declines little in strength after the heat treatment at 1,500°C. The change in the porosity of coke is shown in Fig.4. A slight rise in porosity is observed for both of lump coke subjected to the I-type drum test and that not subjected to the I-type drum test, and actual strength reduction is very small. The coke reacted with CO_2 significantly decreases in strength as the RI increases, as evident from Fig.3. When the reaction temperature exceeds 1,100°C, however, the rate of strength reduction diminishes and the coke varies little in strength in the vicinity of 1,500°C when the RI is changed from 20 to 40%. The porosity of coke similarly increases as the RI increases in magnitude, but the rate of increase in porosity decreases with increasing temperature and the effect of porosity change decreases.

(Fig. 3)

(Fig. 4)

The following can be known from the above results.

Coke does not degrade significantly when treated at high temperatures. The CO_2 reaction greatly accelerates the degradation of coke in direct proportion to the amount of reaction. As the temperature rises, however, the effect of the CO_2 reaction diminishes.

The effect of reaction history on the reduction degradation of coke was investigated next.

The degradation of coke was investigated by keeping the reactivity (weight loss) of coke constant at 1,400°C and varying the reactivity between 1,300°C and 1,500°C (Fig.5). Coke samples 1 and 2 in Fig.5 were given the same thermal history to meet the heat pattern in the blast furnace (10°C/min from ambient temperature to 800°C, 2°C/min from 800°C to 1,200°C and 7°C/min from 1,200°C to 1,500°C). Coke sample 1 was treated in an atmosphere of 1.5 Nl/min of CO_2 and 3.5 Nl/min of N_2 from room temperature to 1,500°C. Coke sample 2 was treated in an atmosphere of 0.5 Nl/min of CO_2 and 4.5 Nl/min of N_2 from room temperature to 1,300°C, atmosphere of 3.75 Nl/min of CO_2 and 1.25 Nl/min of N_2 from 1,300°C to 1,400°C and atmosphere of 1.0 Nl/min of CO_2 and 4.0 Nl/min of N_2 from 1,400°C to 1,500°C.

(Fig. 5)

The cumulative weight loss up to 1,400°C being the same in the reaction during the heating process, the post-reaction strength at 1,400°C decreases with increasing weight loss to 1,300°C. The change in weight loss between 1,400°C and 1,500°C produces only a slight change in strength. The strength difference between these two cases is the same as the strength reduction effected by the reaction to the neighborhood of 1,300°C. The variation in coke degradation with the reaction history in this way suggests the possibility that the reaction of coke with CO_2 in the blast furnace may be controlled by reducing the carbon solution

loss to near 1,300°C.

3.3 Coke Degradation Pattern

The reaction process of coke was studied by a single-coke particle model according to the variation of coke porosity with the reaction shown in Fig.4. Assume a spherical coke particle as illustrated in Fig.6 and let　be the thickness, G_i be the gasification rate and RI_i (RI_i = RI) and　be A, B and C. Then, the parameters listed in Table 1 are obtained for the three portions of the single coke particle.

(Fig. 6)

(Table 1)

The following values are obtained from the experimental values of the entire coke particles in each experiment:

W　= sample weight (200 grams)

n_o　= number of coke particles before reaction

n　= number of coke particles after reaction

ΣIW_C　= weight of portion C after I-type drum tumbling

$\Sigma (RW_B + RW_C)$ = weight of portions B and C after reaction

The values given in Table 1 can be calculated from the above values and from the initial coke particle diameter n_o and apparent specific gravity.

The results with a reaction index (RI) of 30% are shown in Fig.7. In this schematic illustration, A is a portion that is lost by gasification due to reaction with CO_2, B is a portion that is reduced in size to -10mm after 600 revolutions of the I-type drum and C is a portion that remains intact after 600 revolutions of the I-type drum. The numbers given for the three portions in Fig.7 signify the gasification rates (G_i) of the respective portions. As evident from Fig.7, the

gasification rate is about 30% and 20% for portions B and C, respectively, at 1,000°C. The gasification rate of portion C decreases with increasing temperature and falls below 5% at temperatures of over 1,400°C. The critical gasification rate at which the size reduction to -10mm takes place after 600 revolutions of the I-type drum is indicated for portion B. The critical gasification rate decreases with increasing reaction temperature. This may be attributed to coke embrittlement at high temperatures.

(Fig. 7)

The above analysis demonstrates that as the reaction temperature rises, coke lumps intensely react with CO_2 on the surface and remain unreacted in the bulk.

Next, the selective reactivity of optical anisotropic textures of coke with CO_2 was investigated at temperatures of 1,000°C and 1,600°C. According to the results, the isotropic texture and fine mosaic texture are selectively reacted with CO_2 at 1,000°C and the coarse mosaic texture and leaflet texture are reacted with CO_2 at 1,600°C.

The above results may be classified by reaction type and temperature as follows:

1   Reaction up to 1,300°C: The selective reaction of anisotropic texture with CO_2 proceeds to the core of lump coke and the strength reduction of coke is thus affected by the weight loss.

2   Reaction between 1,300°C and 1,600°C: The coke lump uniformly reacts with CO_2 on the surface, the reacted portion is lost by gasification and the coke lump remains unreacted inside. The high-temperature treatment raises the microstrength and lowers the porosity of coke, so that the weight loss does not exert a direct influence on the strength reduction of coke.

3.4 Significance of Coke Strength after Reaction with CO_2 (CSR)

Nippon Steel uses coke strength after reaction with CO_2 (CSR) as one coke control item. The strength of coke after reaction with CO_2 at 1,100°C is measured and adopted as the CSR. The significance of this index was studied.

Based on the strength reduction of coke with reaction with CO_2 on heating up to 1,500°C, the drop in post-reaction strength ΔI_{10}^{600}; for example, $I_{10}^{600}(AT) - I_{10}^{600}$ (1,100°C) was related to the weight loss ΔRI; for example, $RI = RI(1,100°C) - RI(AT)$ in three temperature regions of ambient temperature (AT) to 1,100°C, 1,100°C to 1,300°C and 1,300°C to 1,500°C, as shown in Fig.8. With the CO_2 reaction in the temperature regions of AT to 1,100°C and 1,100°C to 1,300°C, I_{10}^{600} increases with increasing weight loss (ΔRI). With the CO_2 reaction in the temperature region of 1,300°C to 1,500°C, on the other hand, no correlation is observed between ΔI_{10}^{600} and ΔRI.

(Fig. 8)

The relationship between ΔI_{10}^{600} and CSR in each temperature region is shown in Fig.9. ΔI_{10}^{600} is inversely proportional to the CSR up to 1,300°C but is independent of the CSR in the temperature region of 1,300°C to 1,500°C. The relationship between the post-reaction strength (I_{10}^{600}) and CSR on heating to 1,300°C was obtained as shown in Fig.10. The following correlation was noted between the two indexes:

$$I_{10}^{600} = 33.7 + 67.3CSR$$

(Fig. 9)

(Fig. 10)

These results of analysis indicate that CSR, though measured at the reaction temperature of 1,100°C, is a good indicator of the strength reduction of coke in

the temperature region of up to 1,300°C in the blast furnace.

The effect of CSR at high temperatures was investigated using the raceway combustion furnace illustrated in Fig.11. Coke lumps were charged into the raceway combustion furnace, air preheated to 800°C was introduced into the furnace and the coke was lighted by the tuyere nose burner. A maximum flame temperature of about 1,000°C can be obtained with this setup. coke was charged through the top of the reaction furnace and burned until the furnace temperature reached the specified level. When the desired furnace temperature was achieved, the air blast was switched to nitrogen gas and the furnace was left to stand one night. After the furnace cooled to ambient temperature, all coke was removed from the furnace and investigated for such quantitative properties as percentage of fines and particle size. The furnace was divided into 108 blocks, and the particle size and percent fines of the coke sampled from each block were measured. Coke 3mm or less in size is defined as fine coke. The percentage of fine coke in each block is shown in Fig.12.

(Fig. 11)

(Fig. 12)

As the CSR increases from 53 through 57 to 64, the amount of fine coke at the tuyere nose decreases and indicates that the gas more readily flows toward the center of the furnace.

As described above, the CSR closely agrees with the strength reduction of coke by reaction with CO_2 up to 1,300 °C in the blast furnace but why the CSR affects the generation of coke fines in the vicinity of the raceway is not fully known. It may, however, correspond to the finding described in 3.2 above that the reaction weight loss of coke in the temperature region of up to 1,300°C affects the strength degradation of coke at higher temperature.

4. Conclusions

The properties required of blast furnace coke have been discussed above, based on the results of dissection work and other studies. Several experiments were run to simulate the behavior of coke in the blast furnace. It may not be grossly wrong to infer from the results of the experiments that coke is reduced in strength in approximate accord with the CSR in the presence of a CO_2 atmosphere. The furnace atmosphere at higher temperatures is reducing and mechanical degradation of coke must be considered in that case.

From an economic viewpoint, Japan must use inexpensive coal of poor coking quality in large amounts. In terms of coke manufacture, studies have been made of the largest volume of poorly coking coal that can be used without lowering the DI and CSR, two important coke quality control items. As far as blast furnace operation is concerned, attention has been also focused on the possibility of operating the furnace stably with coke of lower DI and CSR.

Reference

1) T.Nishi, H.Nakama and Ida: Tetsu-to-Hagane, 59 (1973) p.S8.

2) T.Nishi, H.Haraguchi and Y.Miura: Tetsu-to-Hagane, 73 (1987) p.S14.

3) H.Haraguchi, T.Nishi and T.Okuhara: Tetsu-to-Hagane, 73 (1987) p.S14.

4) H.Haraguchi, T.Nishi and T.Okuhara: Tetsu-to-Hagane, 71 (1985) p.S91.

5) H.Haraguchi, T.Nishi and T.,Okuhara: Tetsu-to-Hagane, 73 (1987) p.S17.

6) K.Tamura, M.Ichida, Y.Hayashi, T.Nishi and H.Haraguchi: Tetsu-to-Hagane, 73 (1987) pp.S15 and S16.

7) Y.ishikawa, M.Kose, Y.Abe, K.Ono, M.Sugata and T.Nishi: Ironmaking Proceedings, Volume 42, Atlanta, Georgia, ISS-AIME (1983).
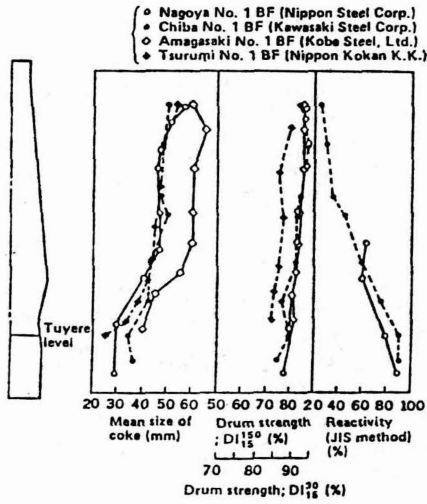
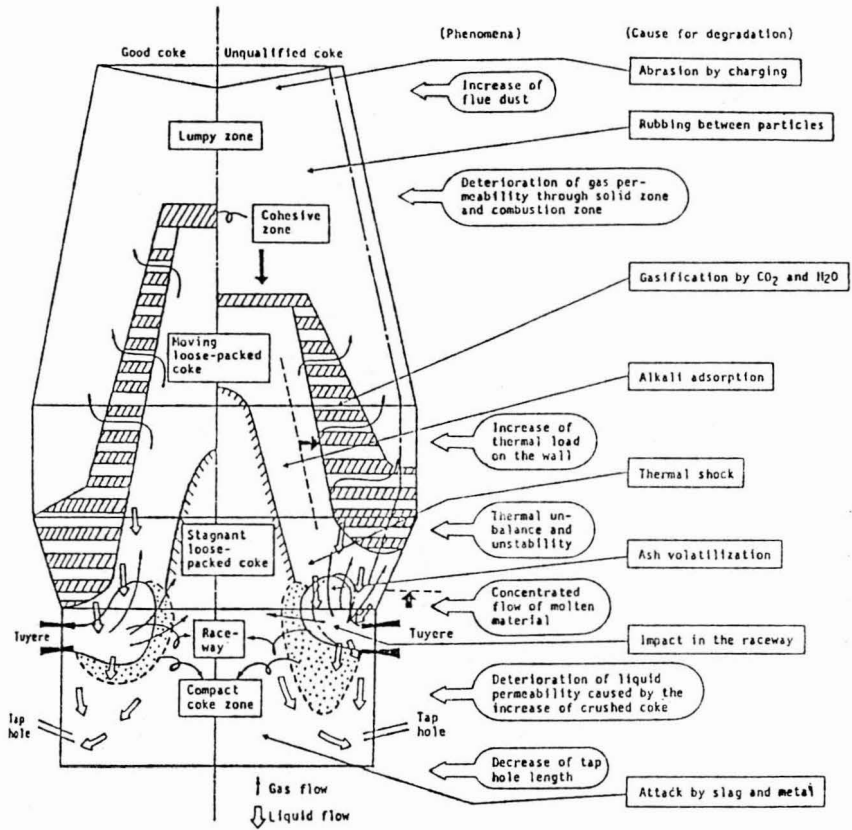Fig. 1.   Changes in properties of coke.
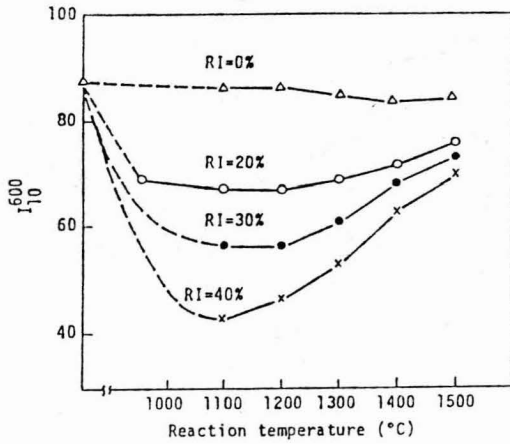
Fig. 2. Behavior of coke in blast furnace.

Fig. 3.   Relationship between reaction temperature and post-
          reaction strength of coke.

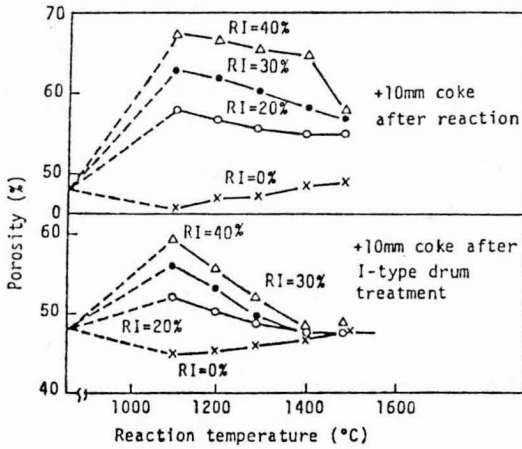Fig. 4.   Relationship between reaction temperature and
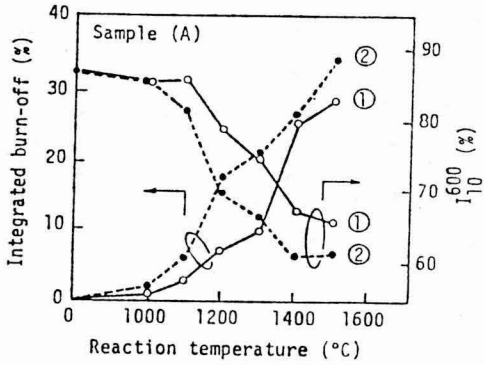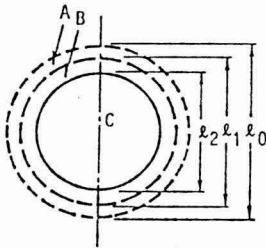   porosity of coke.

Fig. 5. Change in post-reaction strength with gasification
rate on heating.

A: Disappeared part by gasification
at surface

B: Disintegrated part -9.52mm by
drum treatment after gasification

C: Residual part +9.52mm by drum
treatment after gasification

ℓ_0 Particle diameter before gasifi-
cation (=20mm)

ℓ_1 Particle diameter after gasifi-
cation (observed, mm)

ℓ_2 Particle diameter after drum
treatment (observed, mm)
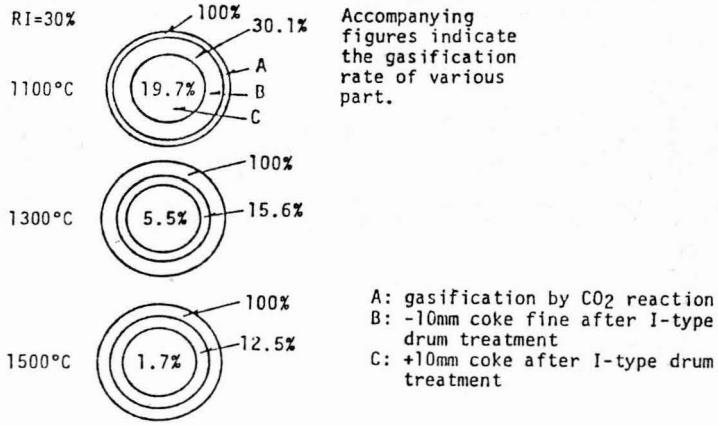

Fig. 6. Reaction model of single coke particle.

RI=30%   100% 30.1%   Accompanying
                         figures indicate
                         the gasification
1100°C 19.7% A   rate of various
               B   part.
               C

               100%

1300°C 5.5%   15.6%

               100%   A: gasification by CO_2 reaction
                                 B: -10mm coke fine after I-type
1500°C 1.7%   12.5%   drum treatment
                                 C: +10mm coke after I-type drum
                                    treatment

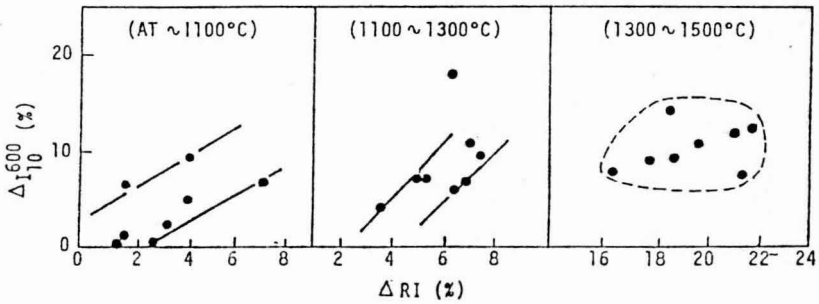Fig. 7. Reaction models of coke particles by CO_2.

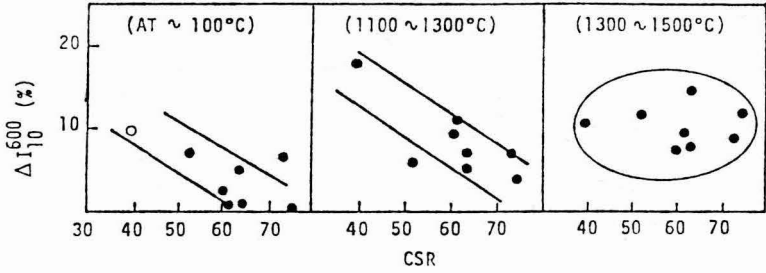Fig. 8. Relationship between ΔRI and ΔI_{10}^{600}.

Fig. 9.   Relationship between CSR and ΔI^{600}_{10}.
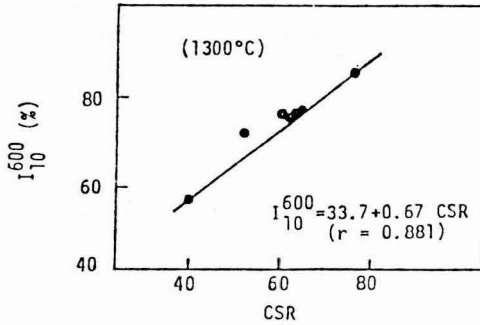

Fig. 10.   Relationship between CSR and post-reaction strength
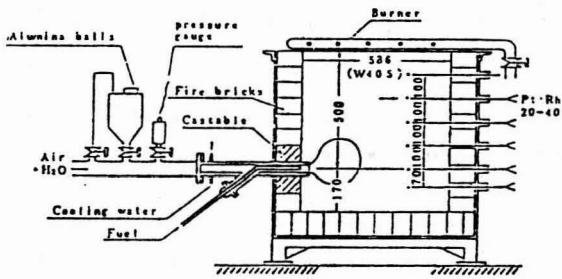up to 1,300°C on heating.
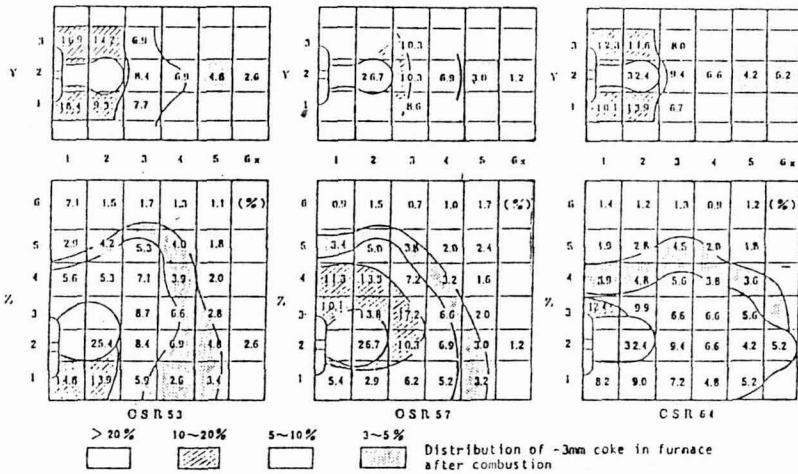
Fig. 11.　Raceway model combustion furnace.

Fig. 12.   Difference in CSR and percentage of fine coke in
raceway (raceway combustion test).

Table 1.   Analytical parameters for CO_2 reaction of coke particles

Item / Zone	Thick-ness (mm)	Weight before reaction (g)	Weight after reaction (g)	Weight after I type drum treatment (g)	Gasified amount (%)	Reaction Index (%)
A	t_A	W_A	-	-	G_A	RI_A
B	t_B	W_B	RW_B	-	G_B	RI_B
C	t_C	W_C	RW_C	IW_C	G_C	RI_C