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Inner Profile and Burden Descent Behavior in the Blast Furnace

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Abstract

The blast furnace inner wall profile exerts a large influence on not only the descent velocity distribution of the burden but also the layer structure of the burden and the gas flow. Then, it was clarified that the furnace wall brick erosion and the scaffolding made the solid flow and the gas flow unstable in the upper part of the shaft and the furnace wall erosion changed the shape of cohesive zone greatly in the lower part of the furnace based on the finding of the three-dimensional half-section blast furnace model experiment of 1/10-1/20 reduced scales concerning the optimization of the blast furnace inner wall profile seen from the viewpoint of the stabilization of the solid flow and the gas flow. The problem of the lower part profile of the large-scale actual blast furnace was discussed at the end.

1. Introduction

The blast furnace, except at its hearth, is basically a passage for gases and burden particles that flow in opposite directions. The basic requisite for stable operation of the blast furnace is to maintain a moving layer of burden which does not fluctuate much. Specifically, it is to form a stable gas flow and a burden layer structure free of mixed burden layer. These are closely related to each other: the stability of the gas flow depends almost entirely on the burden permeability, which is determined by the burden packing structure (particle size, particle size distribution, fine particles ratio, etc.), and the burden descent behavior, that is, the solid flow. As shown in **Fig. 1**, the mechanism for the descent velocity distribution involves the disappearance of ore and coke through their reaction, melting and combustion, the motion of burden particles at the top of the burden layer and near the furnace wall, the infiltration of fine-grained raw material into a coarse-grained layer, etc. As factors that influence the descent velocity distribution, the condition of the raw materials (particle size, strength, burden distribution – ore/coke ratio), the raceway condition (auxiliary fuel injection), and the furnace inner wall profile, etc. are all considered.

In the present study, paying particular attention to the blast furnace's inner wall profile (wall erosion, scaffolding, etc.), which significantly influences not only the descent velocity distribution but also the burden layer structure, experiments were conducted using 3D half-section blast furnace models of 1/10 to 1/20 scales on optimization of the blast furnace's inner wall profile from the standpoint of stabilizing the solid and gas flows in the blast furnace. This paper describes the knowledge obtained from these experiments, and gives an example of application of the knowledge to an actual blast furnace.

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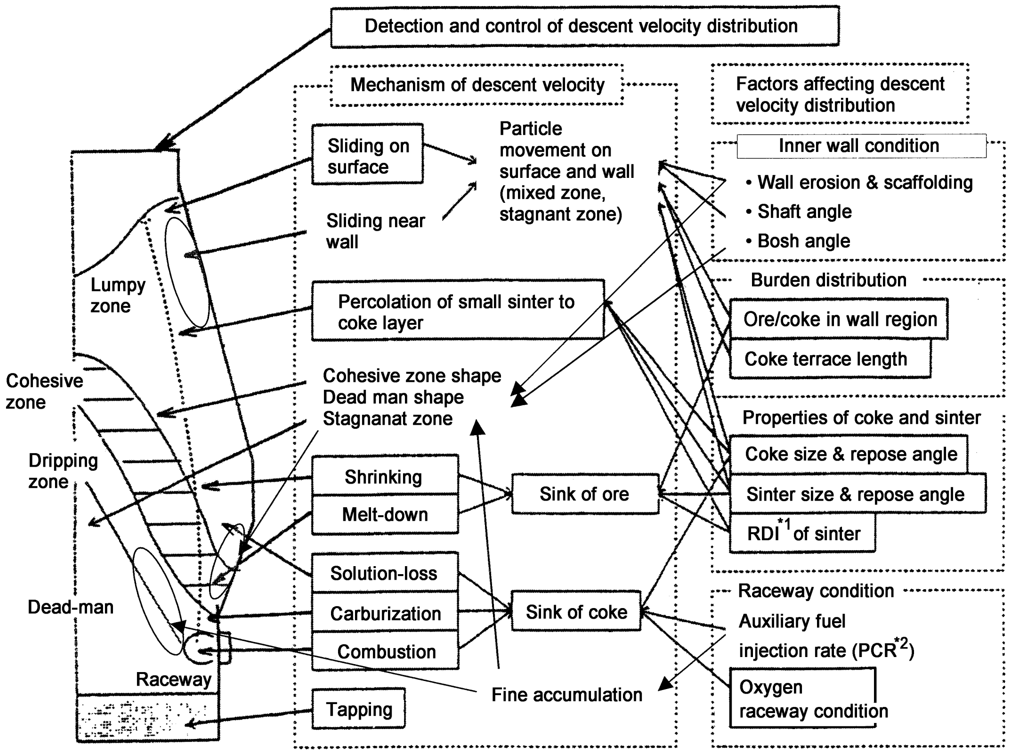


Fig. 1 Mechnism of descent velocity radial distribution and factors affecting its distribution

2. Particle Descent Behavior in Shafts

2.1 Particle descent behavior near furnace top

Concerning the descent of burden in the shaft of a blast furnace, Nishio et al.[1)] have explained via their uniform descent model that the burden descends in such a manner that the burden layer thickness uniformly decreases in a radial direction. On the other hand, the profile meter that permits measurement of the burden layer surface profile was introduced into the blast furnace top, making it possible to measure the burden descent velocity distribution at the top of the burden layer. According to results of measurements in an actual blast furnace[2)], the burden descent velocity near the furnace wall is about 1.5 times higher than that at the center of the furnace. The velocity ratio (1.5) is much higher than the calculated values (1.1 to 1.2) obtained with the uniform descent model mentioned above. This suggests that the burden descent behavior at the top of the layer cannot be explained by the uniform descent model. Clarifying the burden descent mechanism at the top of the layer is necessary from the standpoint of improving the accuracy of comprehensive blast furnace models and burden distribution models.

According to the results of an experiment using a cold blast furnace model[3)], the burden particles near the layer surface at the furnace top do not descend uniformly in a radial direction. Although the particles near the furnace wall descend along the flow line of the uniform descent model of Nishio et al.[1)], the particles in the intermediate and central parts of the furnace descend vertically (**Fig. 2**). This phenomenon is especially conspicuous in the case of free surface descent (Fig. 2a) in which the new burden is not charged onto the existing burden to simulate the behavior of particles near the layer surface at the furnace top. An image of non-uniform particle descent based on the above experimental results is shown in **Fig. 3**. It is

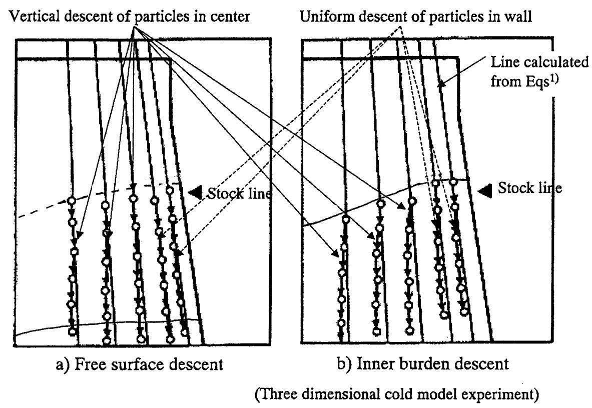


Fig. 2 Particle stream line with burden descent in V type burden profile (solid line:calculated from Eqs.[1)] (sinter 1-3mm)

conjectured that during non-uniform particle descent, the particle descent velocity near the furnace wall is higher than that near the furnace center because the burden layer thickness near the furnace wall decreases selectively. According to the results of measurements by profile meters in Tobata No. 1 BF of Nippon Steel Yawata Works[1)], the relative descent velocity near the furnace wall measured for the first time is higher than that measured for the second time (**Fig. 4**).

This result suggests that close to the furnace top, only particles near the furnace wall are rearranged in a relatively short time with the extension of shaft section, and that the descent behavior of particles near the burden layer surface at the furnace top is easily influenced by the profile of the upper shaft's inner wall. With a large blast

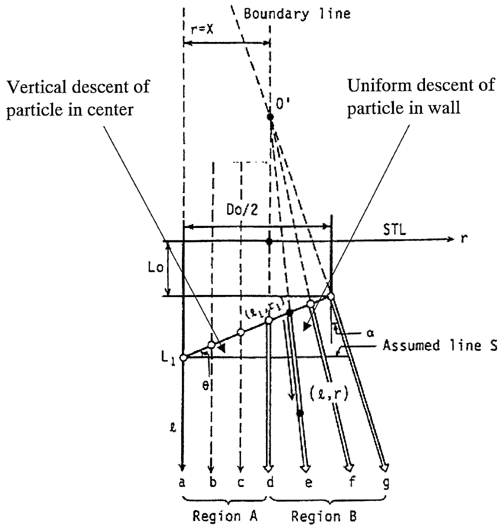


Fig. 3 Image of nonuniform descent of particle in upper part of shaft

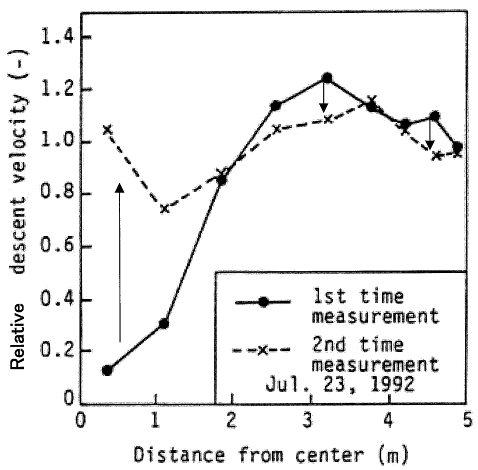


Fig. 4 Radial distribution of relative descent velocity at burden surface measured by profile-meter in Tobata No. 1 BF

furnace (inner volume: 5,000 m[3] or more) having a small shaft angle and a large cross-sectional area variation rate per unit height of the shaft (**Fig. 5**), it is expected that the phenomenon of particle rearrangement near furnace walls with extension of shaft section will become conspicuous even without erosion of the furnace wall.

2.2 Particle descent behavior when furnace wall is eroded

According to the results of an experiment using a cold blast furnace model[4)], when the upper part of the shaft is free of eroded wall brick (shaft angle: 81 degrees), the burden particles descend while maintaining the ore and coke layer structures (**Fig. 6**a). However, in the case of wall erosion in which the cross-sectional area variation rate (i.e., the rate of change in radius per unit height) of the eroded part is as large as 1.4 (local shaft angle: 36 degrees) (Fig. 6c), the particles near the furnace wall move locally toward the wall as described in 2.1 and form a mixed layer, thereby causing the gas flow velocity near the furnace wall to increase (indicated by Δ in **Fig. 7**). When the eroded part of the furnace wall is located close to the stock line, it is conjectured that the burden surface profile is influenced to

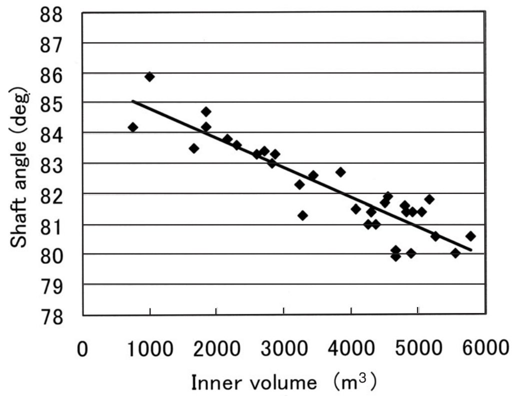
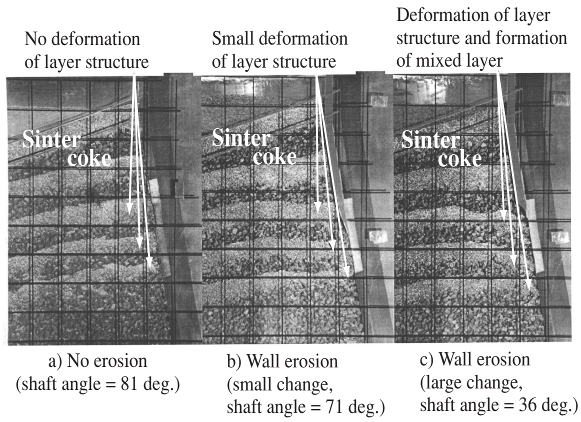
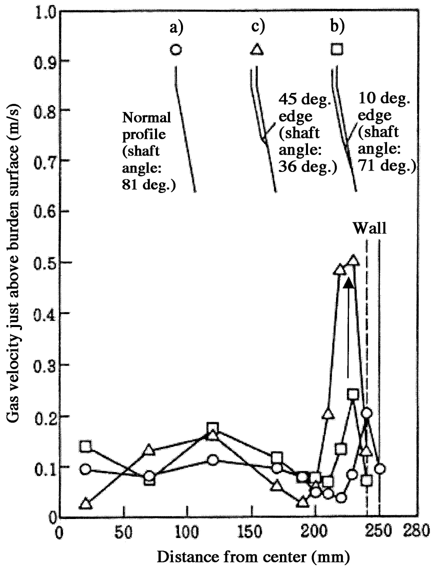


Fig.5 Relationship between inner volume and shaft angle



(Three dimensional cold model experiment)

Fig. 6 Relationship between wall erosion condition and particle descent behavior at the upper shaft (sinter: 1-3mm / 0.5-1mm = 80/20, coke: 4-6mm)



(Three dimensional cold model experiment)

Fig. 7 Relationship between wall erosion condition and gas flow distribution at the upper shaft (sinter: 1-3mm / 0.5-1mm = 80/20, coke: 4-6mm)

such an extent that the accuracy of burden distribution control decreases markedly. On the basis of the above experimental results, Nippon Steel repaired the upper shaft wall of the No. 2 blast furnace at Kimitsu Works[4)] during a shutdown by applying a water-cooled iron casting panel to the wall brick, the erosion of which had extended over 7 m right under from the bottom of the fixed armor (**Fig. 8**).

After these repairs, the variation in the gas utilization rate (η co) around the upper shaft probes decreased to about 60% (**Fig. 9**) and the gas utilization rate in the entire blast furnace increased 1.5%. In addition, the consumption of reducing agent rate decreased by 10 to 15 kg/t and the productivity coefficient increased from 2.23 (t/d•m^3) to 2.41 (t/d•m^3). All this is considered attributable to the stabilization of the peripheral gas flow that was achieved by restraining the formation of a mixed layer near the wall. In view of the above results, water-cooled iron casting panels have been installed between the fixed armor and shaft stave for the blast furnaces at Nippon Steel as standard procedure.

2.3 Particle descent behavior when scaffolding is formed

According to the results of an experiment using a cold blast furnace model[4)], when scaffolding is formed in the upper part of the shaft (**Fig. 10** (2)), the particle descending behavior right under the scaffolding replicates that in the case of wall erosion: particles close to the furnace wall move locally toward the wall and form a mixed layer, causing the gas flow velocity near the wall to increase (indicated by ▲ in **Fig. 11**). This phenomenon is conspicuous when the

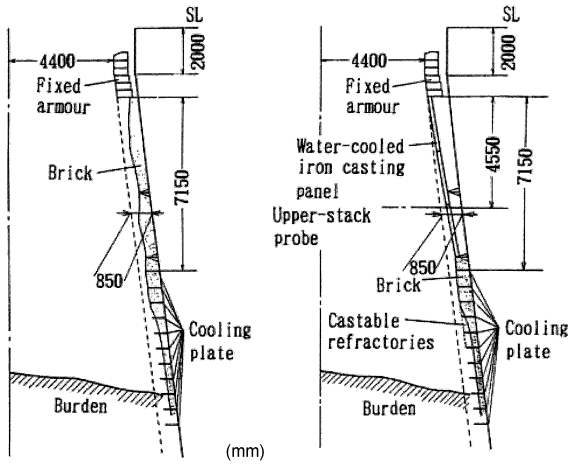


Fig. 8 Repair of upper shaft wall in actual BF (Kimitsu No. 2 BF: 1990.5.28 - 6.4)

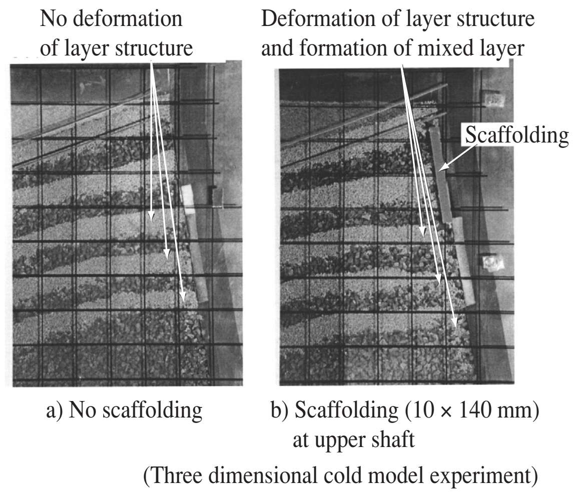


Fig. 10 Relationship between formation of scaffolding and particle descent behavior (sinter: 1-3mm, coke: 4-6mm)

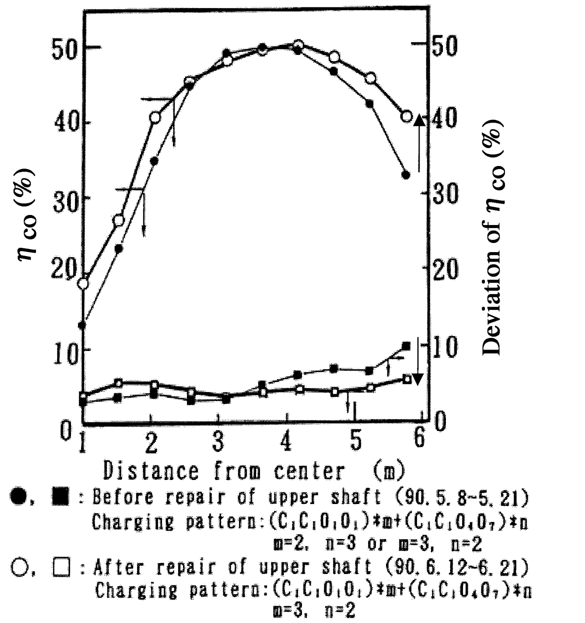


Fig. 9 Comparison of η_{co} and its deviation of upper shaft probe between before and after repair of upper shaft (Kimitsu No. 2 BF: 1990.5.28 - 6.4)

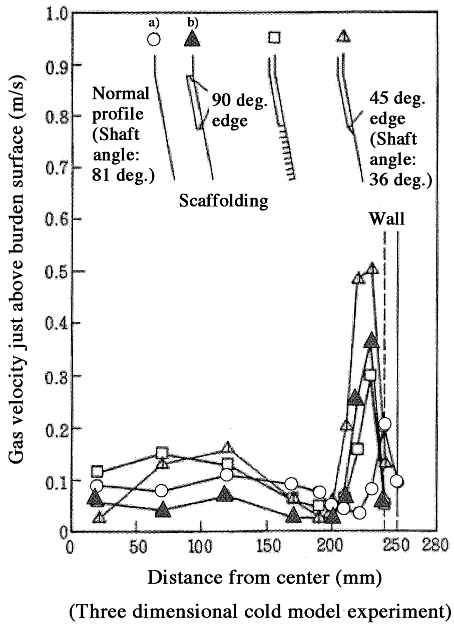


Fig. 11 Relationship between wall condition and gas flow distribution at the upper shaft (sinter: 1-3mm / 0.5-1mm = 80/20, coke: 4-6mm)

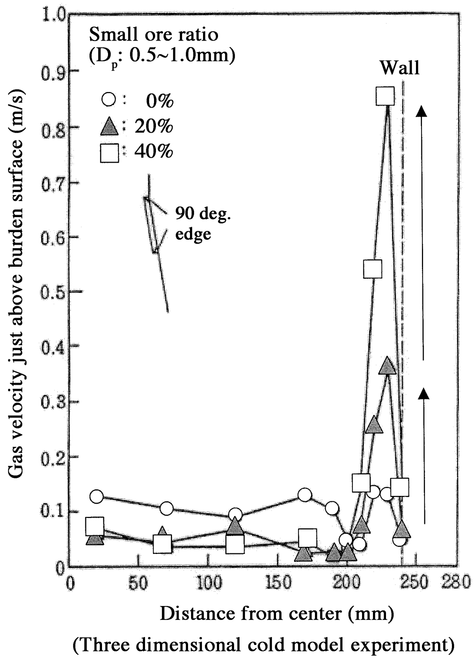


Fig. 12 Relationship between sinter fine (0.5-1mm) ratio and gas flow distribution (sinter: 1-3mm, coke: 4-6mm) in case of scaffolding profile

fine particles ratio is high (indicated by □ in **Fig. 12**). In this case, there is the fear that stock hanging might occur. At present, in order to prevent the formation of scaffolding, such measures as limiting the entry of zinc into the burden from raw materials and preventing excessive increase in gas flow velocity near the furnace wall are implemented.

3. Particle Descent Behavior in Lower Part of Blast Furnace

3.1 Change of particle descent behavior due to wall erosion

In the lower part of the blast furnace, due to erosion of the bosh brick, the stave inner surface is exposed to become a working face within around one year after blowing-in of the furnace (**Fig. 13**). This change in working face profile at the lower part of the furnace is greater than the change in bosh angle with the increase in furnace inner volume (**Fig. 14**) and has a significant influence on the particle descent behavior in the lower part of the furnace. According to the results of an experiment using a warm blast furnace model, when the bosh brick is eroded, a stagnant layer is formed near the wall at the lower part of the bosh (**Fig. 15**b)) and the particle descent velocity in the inner part of the furnace (indicated by □ in **Fig. 16**) becomes much higher than when the furnace is blown in (Fig. 15a)). As a result, the cohesive zone hangs down, causing the furnace temperature right above the raceway to drop (Fig. 15b). These experimental results suggest that a change in the inner wall profile at the lower part of the furnace caused by wall brick erosion, etc. can change the cohesive zone profile at the lower part of the furnace, thereby complicating the method of blast furnace operation. Nippon Steel aims to design a new inner wall structure for the lower part of the blast furnace so that the working face profile hardly changes.

3.2 Particle descent behavior when block assuming scaffolding is installed

According to the results of an experiment using a warm blast furnace model[5], a stagnant layer is formed near the furnace wall (**Fig. 17**) when a block (protruding length: 15 mm (corresponding to 300 mm in an actual furnace), height: 15 mm (corresponding to 300 mm in an actual furnace)) is installed in the lower part of the furnace. The thickness of the stagnant layer varies according to the installation position of the block: the thickness is large when the block is installed at the belly bottom where the horizontal stress in a passive stress state is large (Δ in **Fig. 18**), whereas it is small when the block is installed at the bosh bottom right above the raceway where the horizontal stress is small (□ in Fig. 18).

3.3 Change of particle descent behavior with increase in inner furnace volume

With the increase in the inner blast furnace volume, the ratio of effective hearth cross-sectional area (EHA: $\pi \times (\text{hearth diameter}/2)^2 - \pi \times (\text{hearth diameter}/2 - \text{raceway depth (assumed to be 1.5 m)})^2 / (\pi \times (\text{hearth diameter}/2)^2)$) that is used as an index of the area occupied by the raceway space at the level of the tuyere center is decreasing[6] (**Fig. 19**). The above phenomenon can cause the burden melting ability to decline and the heat transfer to become insufficient due to a relative shrinkage in the burden descent region at the lower part of the furnace. In this case,

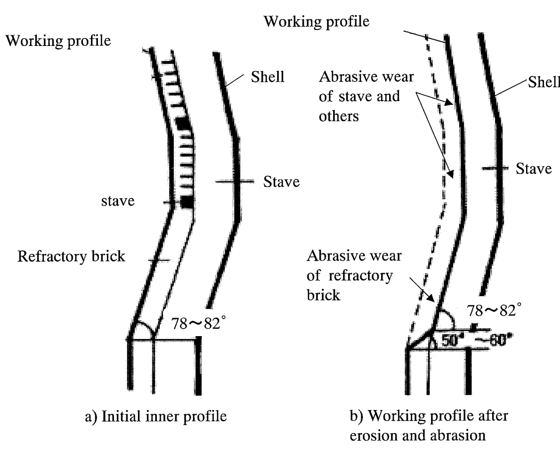


Fig. 13 Change of inner profile of blast furnace due to abrasive wear of refractory brick and "stave and others"

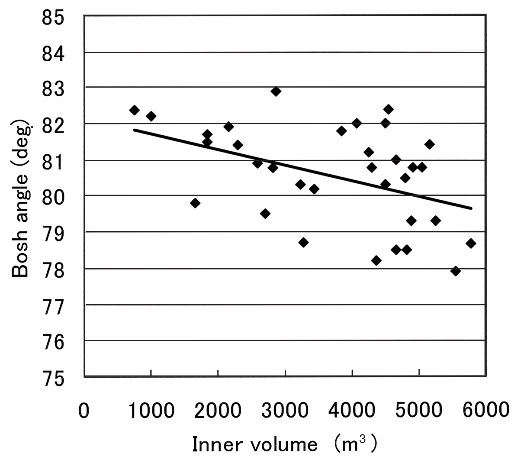


Fig. 14 Relationship between inner volume and bosh angle of BF in Japan

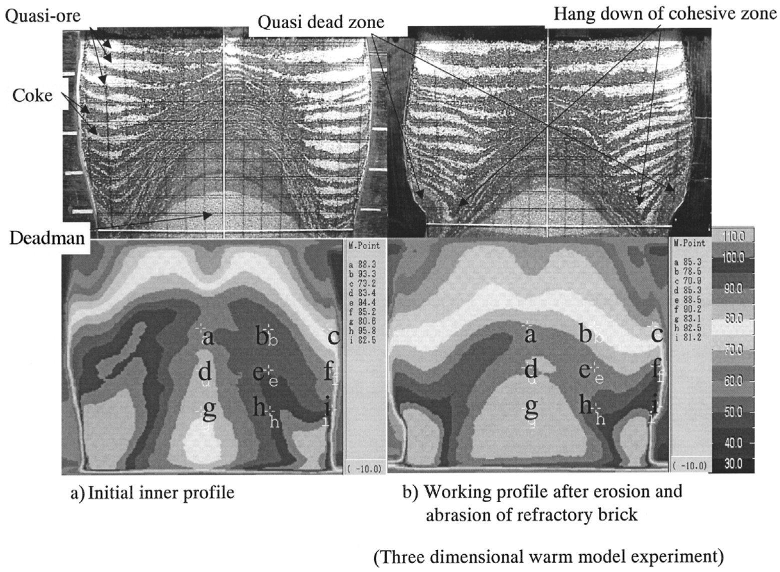


Fig. 15 Particle descent behavior under working profile after erosion and abrasion of refractory brick (white: quasi-ore (0.5-5mm), black: coke (2-4mm))

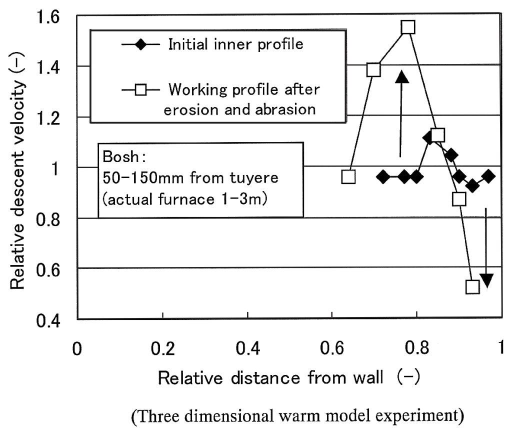


Fig. 16 Relative descent velocity distribution of particle in the lower part under working profile after erosion and abrasion of refractory brick

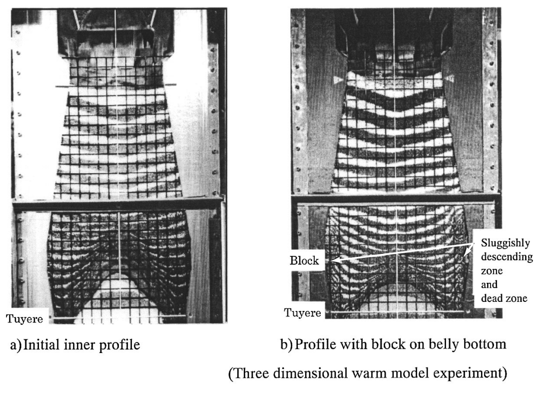


Fig. 17 Relationship between block and particle descent behavior at the lower part (white: quasi-ore 0.5-5mm, black: coke 2-4mm)

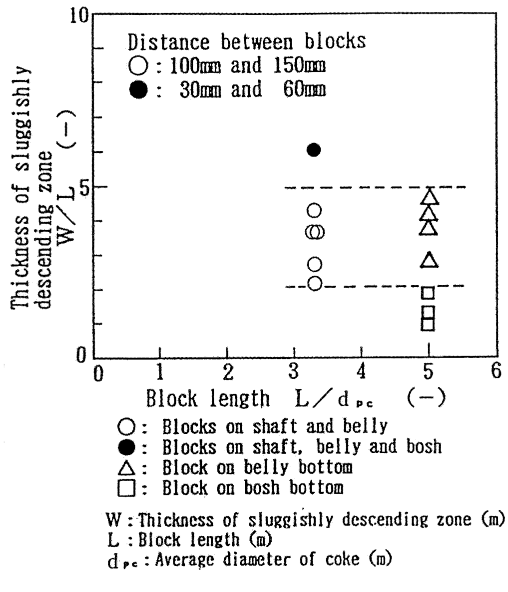
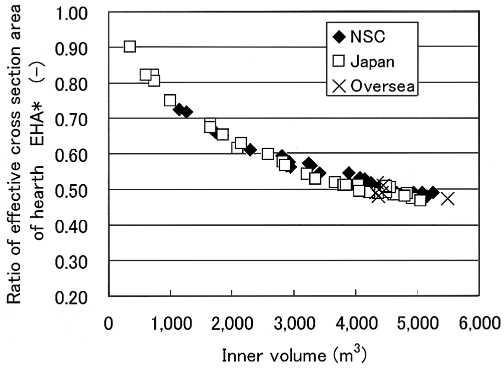


Fig. 18 Relationship between block setting condition and thickness of sluggishly descending zone

there is the fear that the deadman might become inactive.

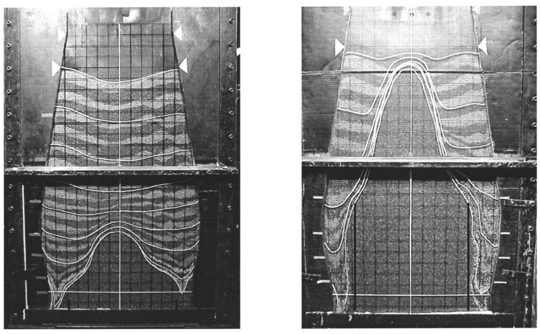
In order to restrain the above phenomenon, it is necessary to reduce the dead space by increasing the raceway depth. As a means of increasing the raceway depth, raising the tuyere velocity can be considered. However, excessive tuyere velocity promotes the disintegration of coke in the raceway[7]. The disintegrated coke accumulates on the deadman surface and nearby furnace wall, causing the burden descent region at the lower part of the furnace to narrow[8].

According to the results of an experiment using a cold blast fur-



* EHA=(π × (Hearth diameter/2)^2 – π × (Hearth diameter/2 – Raceway depth (=1.5))^2) / (π × (Hearth diameter/2)^2)

Fig. 19 Relationship between inner volume and ratio of effective cross section area of hearth



a) Deadman start point : −50mm under tuyere center

b) Deadman start point : +350mm over tuyere center

(Three dimensional cold model experiment)

Fig. 20 Influence of deadman shape on particle descent behavior

nace model, when the deadman start-up position is significantly raised above the tuyere level (350 mm above tuyere in the model, or 7 m in an actual furnace) assuming excessive accumulation of disintegrated coke on the deadman surface, the burden descent region at the lower part of the furnace shrinks markedly and at the same time, the particle descent behavior of the layer surface at the furnace top is significantly influenced as compared with when the deadman start-up position is set 50 mm (1 m in an actual furnace) below the tuyere level (**Fig. 20**).

The above behavior of disintegrated coke accumulating in the lower part of the furnace and the experimental results shown in Fig. 20 suggests that the inevitable widening of the deadman region with the increase in inner blast furnace volume cannot be dealt with effectively simply by raising the tuyere velocity and thereby increasing the raceway depth. In order to improve the burden descent behavior in the lower part of a large blast furnace, it is necessary to take comprehensive measures, including the improvement of coke quality to restrain coke disintegration[9] and optimization of the inner wall structure at the lower part of the blast furnace. In particular, optimizing the inner wall structure of the lower part of the blast furnace so as to stabilize the working face profile right above the tuyere is an important future task.

4. Conclusion

Paying particular attention to the blast furnace's inner wall profile that significantly influences not only the burden descent velocity distribution but also the burden layer structure, the authors experimented with 3D half-section blast furnace models of 1/10 to 1/20 scales on optimization of the blast furnace's inner wall profile from the standpoint of stabilizing the solid and gas flows in the furnace. The experimental results and examples of application thereof in actual blast furnaces are summarized below.

(1) Particles near the burden surface at the furnace top do not descend uniformly in a radial direction: the descent velocity of particles near the furnace wall is higher. This suggests that in the neighborhood of the furnace top, only particles near the furnace wall are rearranged in a relatively short time with the extension of shaft section.

(2) Furnace wall erosion and scaffolding in the upper part of the shaft cause a mixed layer to be formed as particles near the furnace wall move locally toward the wall. The mixed layer thus formed causes the gas flow velocity near the furnace wall to increase, thereby destabilizing the furnace operating condition. On the basis of this knowledge, Nippon Steel has made it a standard procedure to install a water-cooled iron casting panel between the fixed armor and shaft stave of every blast furnace.

(3) The change in the working face profile at the lower part of the furnace due to bosh brick erosion significantly influences the particle descent behavior in the lower part of the furnace. On the basis of this knowledge, Nippon Steel aims to design a new inner wall structure for the lower part of the blast furnace in which the working face profile hardly changes.

(4) When a block is installed at the lower part of the furnace, a stagnant burden layer is formed near the furnace wall. The thickness of the stagnant layer varies according to the installation position of the block.

(5) With the increase in inner furnace volume, a relative shrinkage of the burden descent region in the lower part of the furnace occurs, causing the melting capacity to decrease and rendering the heat transfer insufficient. In this case, there is the possibility that the deadman may become inactive. In order to restrain the above phenomenon, it is necessary to reduce the dead zone by increasing the raceway depth. However, excessive increase in the tuyere velocity promotes disintegration of coke in the raceway.

(6) In order to improve the burden descent behavior in the lower part of a large blast furnace, it is necessary to take comprehensive measures, including the improvement of coke quality to restrain coke disintegration and the optimization of inner wall structure at the lower part of the furnace. In particular, optimizing the inner wall structure so as to stabilize the working face profile right above the tuyere is an important future task.

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