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The body can be viewed from the next page.

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A three-parallel bunker bell-less top was installed at Mizushima Works No. 3 blast furnace for the third campaign in order to realize highly sophisticated burden distribution control techniques. These control techniques make it possible to increase the ratio of small sinter in multi-batch charging using two-size fractional charging of coarse and fine sinters and vertical coke charging. The authors also introduced a new type of top bunker which has strengthened the radial size distribution of coke and ore, and a real-time control system which ensures a uniform flow of materials. These burden distribution measures have greatly improved the charging function and enhanced controllability, making it possible to stably charge small sinter at a high rate of 17%.

1 Introduction

Japan's first 3-parallel bunker (3PB) bell-less top was introduced as part of the revamp for the third campaign of No. 3 BF at Kawasaki Steel Corp.'s Mizushima Works. This type of equipment was adopted because furnace-top charging equipment offers higher performance than the conventional two-parallel bunker or center feed type, and because it is advantageous in multi-batch charging of multiple raw materials of varying size and quality, allowing charging to arbitrarily selected radial positions. Considering the fact that, in the behavior of materials discharged from top bunkers, fine material is discharged in the first stage of charging and coarse materials in the latter stage, which is an advantage for controlling the gas flow distribution, an off-center top bunker design with the discharge gate located toward the furnace center was adopted. Two-size fractional charging was also adopted, and a technique was developed for using high-ratio charging of small sinter by positively charging small material toward the furnace wall.

This report describes a burden distribution control technique for high-ratio blending of small sinter (S_S) using the 3 PB bell-less top.

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2 Outline of Charging Equipment at No. 3 BF

2.1 Features of 3-Parallel Bunker Bell-less Top

The three-parallel bunker bell-less top adopted for the 3rd campaign at Mizushima Works No. 3 BF is shown in schematically in **Fig. 1**. Because this furnace has a rotating chute length of 4.5 m and three top bunkers (85 m^3) in combination with a throat 10.6 m in diameter, a charging chute was installed at the top of the bunkers. Features of the bunkers at No. 3 BF include an off-center bunker configuration in which the discharge gates are located near the furnace center so that the discharge behavior of material is characterized by the discharge of fine material in the earliest stage and coarse material in the late stages of charging. Segregation control gates which can be adjusted to the required angle are also provided to control the shape of the material accumulation in the top bunkers and strengthen the radial size distribution of materials.[1,2]

Changes over time in the arithmetical mean particle diameter of coke charged from the top bunkers are shown in **Fig. 2**. Discharge of fine particles in the early stage of rotation and coarse particles later, which is characteristic of the parallel bunker type, can be confirmed from this figure.

Flow control gates (FCG) were installed in the lower

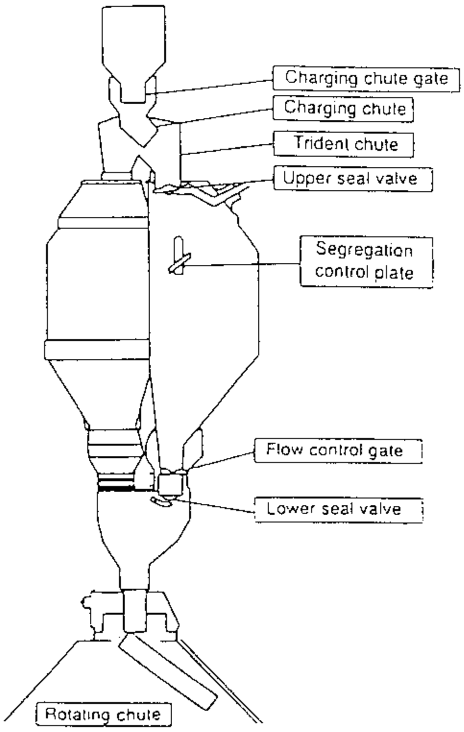

Fig. 1 Outline of discharging equipment of Mizushima Works' No.3 blast furnace

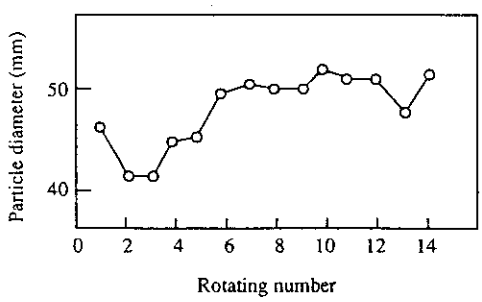

Fig. 2 Discharging behavior of coke from the bunker

part of the bunkers for control of the rate of material charging.

2.2 Adoption of Raw Material Charging Rate Control

At No. 3 BF, the rate of raw material charging is gradually reduced by uniform FCG opening control during charging in order to strengthen the radial size distribution and secure the discharge of fine particles early in charging and coarser particles in the later period. We therefore developed a charging rate control method which makes it possible to control the degree of FCG opening in real time during charging, ensuring a set material discharge rate during charging and enabling end-point control, under which the discharge operation is completed after a specified number of

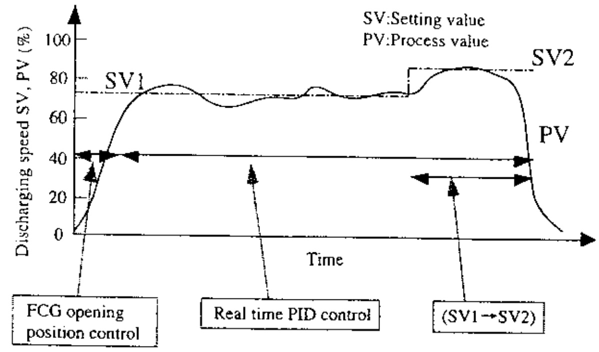

Fig. 3 Discharging behavior on discharging speed control system

chute rotations.

Real-time control of raw material charging makes it possible to guarantee accuracy in the number of chute rotations required to complete raw material charging regardless of material weight deviations from batch to batch, even when size distribution and moisture variations occur in a given batch.

Figure 3 shows the set value (SV) of the raw material charging rate and changes over time in the actual performance values (PV) in one batch when uniform charging rate control was applied. The degree of FCG opening in the initial period of raw material charging is a set value calculated from the weight of the material in the top bunkers. After PV and SV1 calculated from the number of charging rotations and the weight of the charge fall within a specified difference, PID feedback control begins and the degree of FCG opening is adjusted so that the rate of charging is uniform. The target charging rate set value SV2 is reviewed to ensure that charging is completed in the target number of rotations, considering the residual weight of the raw material in

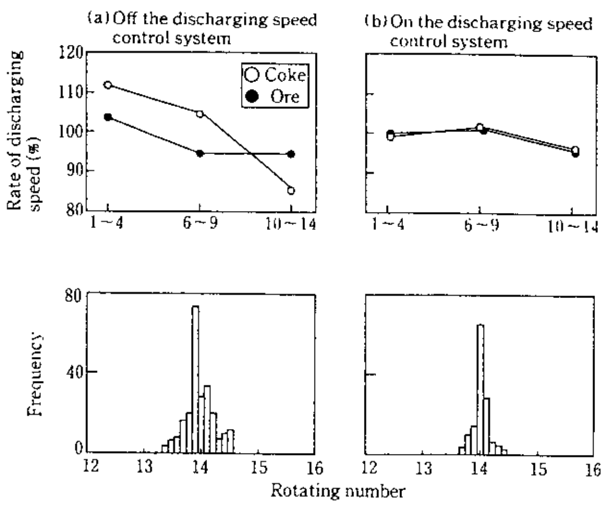

Fig. 4 Comparison of variation of discharging speed and frequency of rotating number in relation to the discharging speed control system

the bunkers in the final period of charging and the remaining number of rotations. Changes over time in the rate of charging and the success rate for the target number of charging rotations before and after the introduction of the charging rate control system are shown in **Fig. 4** (a) and (b) respectively. With the introduction of this technology, variations in the rate of charging have been reduced from 10–20% to under 5%, and the accuracy of the number of rotations for charging, targeted at 14 ± 0.4, has improved from 88.1% to 98.4%.

3 Burden Distribution Control Using Parallel Bunker Type Bell-less Top

3.1 Concept of Burden Control in High-Ratio Use of Small Materials

To reduce the cost of raw materials, it is necessary to increase the use of low-grade fine materials, namely, small sinter and small coke. However, the problems with this practice include increased gas flow resistance due to the decreased average diameter of the material particles and reduced central gas flow due to the accumulation of fine material at and near the center of the furnace. The latter is particularly a problem when fine materials are used in large quantity and flow into the center of the furnace when an ore layer collapse occurs. Multi-batch charging using excellent top-charging equipment such as the 3-parallel bunker top is essential to prevent ore layer collapse and control the radial distribution of the ore layer thickness and particle size.

Figure 5 shows a type diagram of four-batch charging and a representative bell-less pattern for $C_1C_2C_LC_S$ charging, which is the representative charging method used at No. 3 BF. In this pattern, C_1, which comprises about 90% of the total amount of coke, is charged inward from the furnace wall to create a terrace. Together with this operation, C_2 is charged vertically to the furnace center in two rotations, with the rotating chute set at a tilting angle of 13.5 degrees. Sintered ore classified as coarse, together with submaterials, is charged as O_L in the third batch, and sintered ore classified as fine is charged as O_S in the fourth batch with small-sized material. (These last two steps are referred to as "two-size fractional charging.")

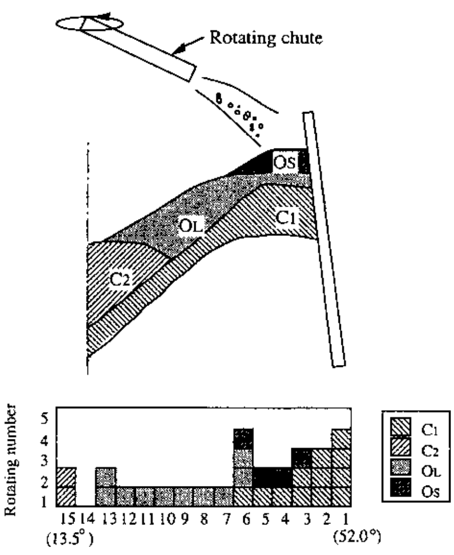

Fig. 5 Typical charging pattern of No.3 blast furnace

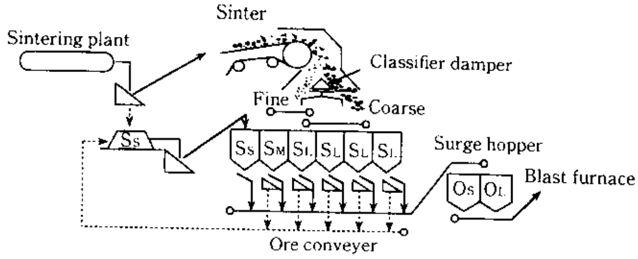

Fig. 6 Outline of two size segregation equipment of sinter at the top of ore bins

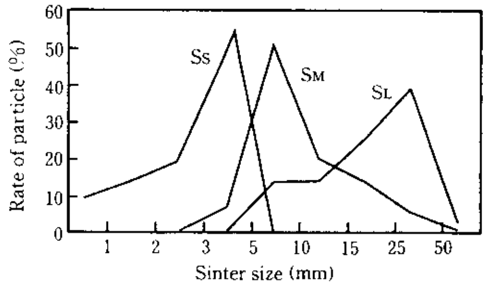

Fig. 7 Particle size distribution of small sinter

Figure 6 shows the size classification equipment for sinter. This equipment is mounted at the top of the ore bins and is used to classify sintered ore into coarse and fine sizes. The figure also shows the flow of S_S recovery by which undersize sinters are rescreened and recovered. **Figure 7** shows the particle size distribution of sintered ore classified as coarse, medium, and small. The average diameter of coarse sinter (S_L) is 24.1 mm, while the average diameter of medium sinter (S_M) is 13.4 mm and that of S_S is 3.3 mm.

The problems in high-ratio blending of small sinter using the method of fractional charging described above are (1) the length of the coke terrace and (2) the order of charging small materials. These two points are discussed below.

3.2 Control of Coke Terrace Length

Figure 8 shows a comparison of the ore profile in a typical bell-less pattern for two-batch charging obtained using a simulation model. In this model, close consideration is not given to coke layer collapse during ore charging, but when the coke terrace is long (case a), the larger part of the ore shifts from the furnace wall to the

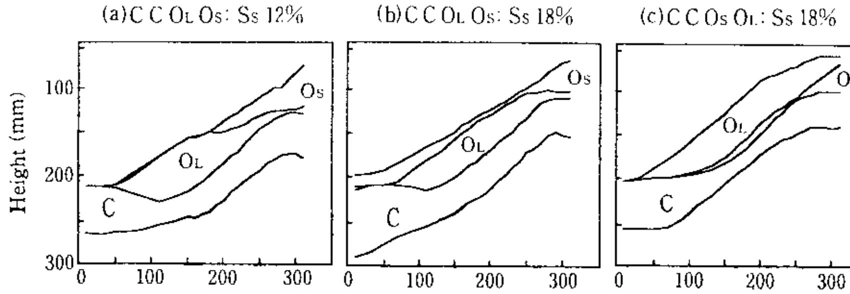

Fig. 9 Results of burden distribution by 1/16.5 model

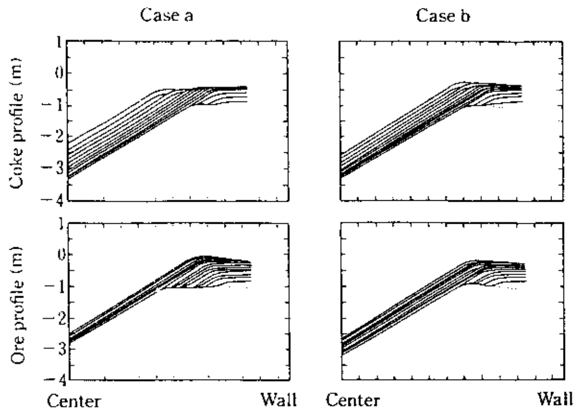

Fig. 8 Comparison of variation of length of coke terrace

intermediate area. The thickness of the ore layer from the intermediate area to the furnace center can be adjusted in only four of the fourteen rotations, and for this reason, the central gas flow tends to assume a strengthened distribution. When the position of the ore charging device is moved toward the center during rotation and the thickness of the ore layer in the intermediate area is increased as a method of achieving uniformity in the thickness of the ore layer, the thickness of the ore layer deposited in each rotation becomes excessive because changes in the tilt angle during charging must cover a wide range, from the furnace wall to the center. Consequently, the gas flow distribution changes considerably when the accuracy of material charging burden cutoff fluctuates due to changes in material characteristics.

On the other hand, when a short coke terrace is indicated (case b), it is possible to adjust the thickness of the ore layer from the furnace wall to the center with the present range of tilt angles (29-47 degree), and because the material is shifted from the furnace wall to the center, where it accumulates, the distribution tends not to be affected by the bell-less notch. In a commercial blast furnace, when the length of the coke terrace was reduced from 2.5 m to 1.5 m, the central flow was suppressed and the peripheral gas flow secured, and fluctuations in the top gas were eliminated. It is therefore a fundamental principle that, even in high-ratio blending of small material, extending the length of the coke terrace on which small material is laid should be avoided, and the coke terrace should be controlled to 1.5 m.[3)]

3.3 Prevention of Inflow of Small Material

A scale-model experiment was conducted to determine the burden distribution required to suppress the inflow of ore to the furnace center due to high-S_S operation.

In **Fig. 9** (a), ore inflow does not occur in $C_1C_2C_LO_S$ charging at S_S blending ratio of 12%, but at 18% S_S, as shown Fig. 9 (b), O_S flowed in on top of the vertically charged coke at the furnace center. As a countermeasure, the charging order of O_L and O_S was reversed, and charging using a $C_1C_2O_SO_L$ pattern was studied. The results are shown in Fig. 9 (c). The reversed order was chosen with the aim of suppressing O_S collapse to the center by charging O_S directly onto the coke terrace, allowing the S_S to pack into the spaces between lumps of coke. Some O_S inflow occurred in spite of this "packing" strategy, but inflow to the furnace center was prevented by the vertically charged coke, and it was considered possible to secure the central gas flow.

In view of the fact high-ratio blending of S_S is generally accompanied by a decrease in the central flow, we therefore decided to create the conditions for a more appropriate gas flow distribution by changing the ore charging pattern to $C_1C_2O_SO_L$.

4 Operational Results

In October 1992, the order of ore charging was changed from $C_1C_2O_LO_S$ to $C_1C_2O_SO_L$, and S_S blending ratio of 16–18% was adopted on a continuing basis. Operational conditions with this high-S_S ratio are shown in **Fig. 10**. The representative burden distribution patterns following the adoption of this practice can be broadly divided into three periods.

4.1 First Period (Oct. 1992 to Jan. 1993)

Changes in the gas flow distribution before and after the implementation of high-S_S operation are shown in

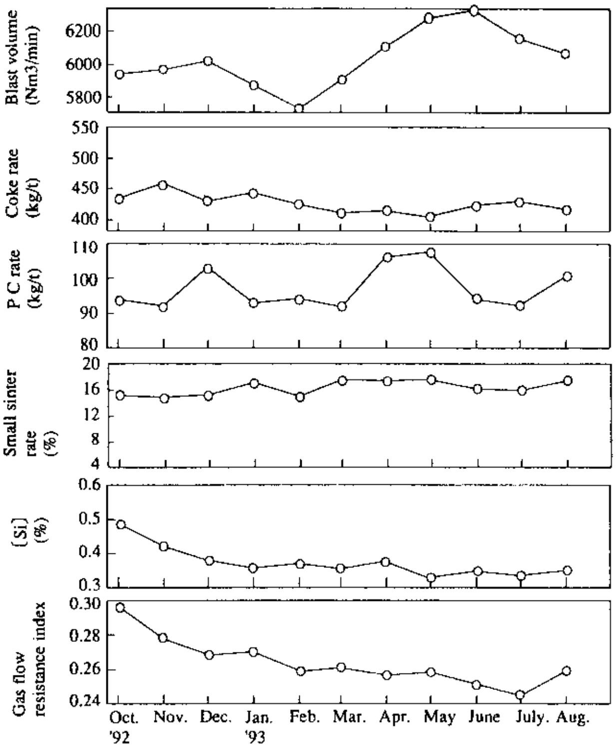

Fig. 10 Transition of operation at Mizushima No.3 blast furnace

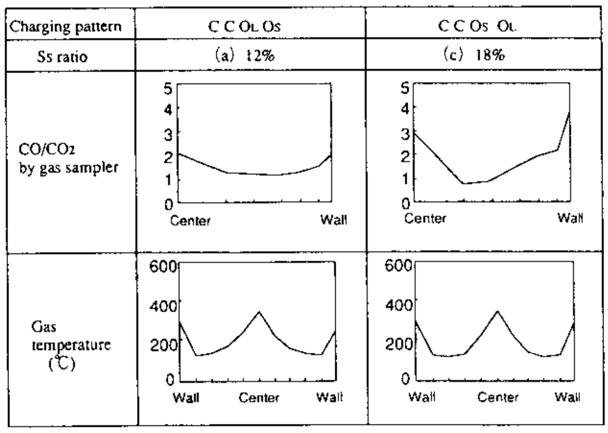

Fig. 11 Transition of gas distribution by small sinter ratio and charging pattern

Fig. 11. As features of gas flow distribution during high-S_S operation, the central gas flow was secured by $C_1C_2O_SO_L$ charging, but the gas flow near the furnace center showed an extreme decrease, and the CO/CO_2 ratio detected by the gas sampler decreased to 0.5 or 0.6.

Figure 12 shows the radial ore layer thickness ratio $L_O/(L_O + L_C)$ obtained from the top gas composition using an ore layer thickness ratio estimation model.[4] In comparison with charging at an S_S ratio of 12% using

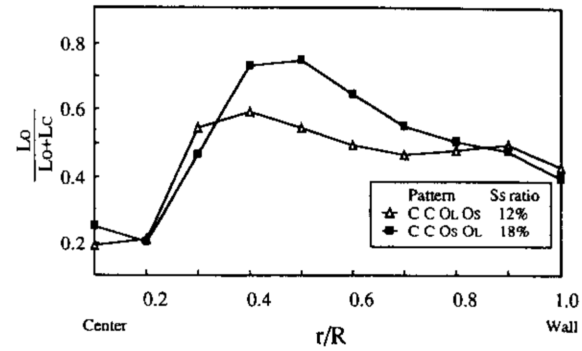

Fig. 12 Radial $L_O/(L_O + L_C)$ distribution calculated by a model

the $C_1C_2O_LO_S$ pattern, the ore layer thickness ratio in $C_1C_2O_SO_L$ charging at 18% S_S increased at the position where the radial r/R value was between 0.4 and 0.6. In other words, the value of $L_O/(L_O + L_C)$ increased in the intermediate area because S_S flowed in as far as the edge of the vertically charged coke, where it stopped. The distribution of $L_O/(L_O + L_C)$ thus showed a considerable change from the flat ore layer thickness ratio in $C_1C_2O_LO_S$ charging.

4.2 Second Period (Feb. to July 1993)

Because the inflow of small material to the intermediate area seen in the first period should be avoided, the O_S bell-less pattern was shifted toward the furnace wall in the second period. **Figure 13** shows an example of the state of operation in this period. The gas flow resistance index showed a sudden increase with this burden distribution pattern. This change was attributed to the fact that the thickness of the layer of small material near the furnace wall became excessive, abruptly suppressing the peripheral flow, and as a result, fluidization of the small materials took place, causing layer collapse and irregular descent of the burden. In short, extreme concentration of the thickness distribution of the small

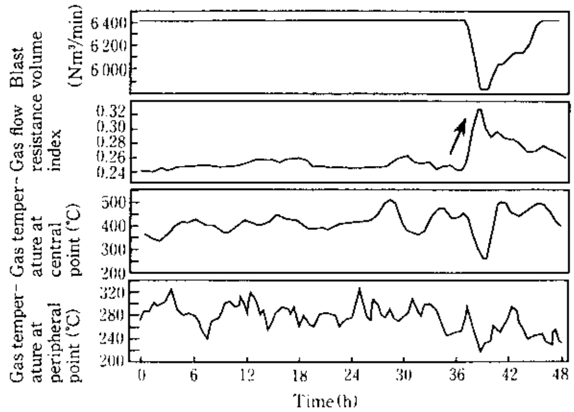

Fig. 13 Example of unstable operation at second period

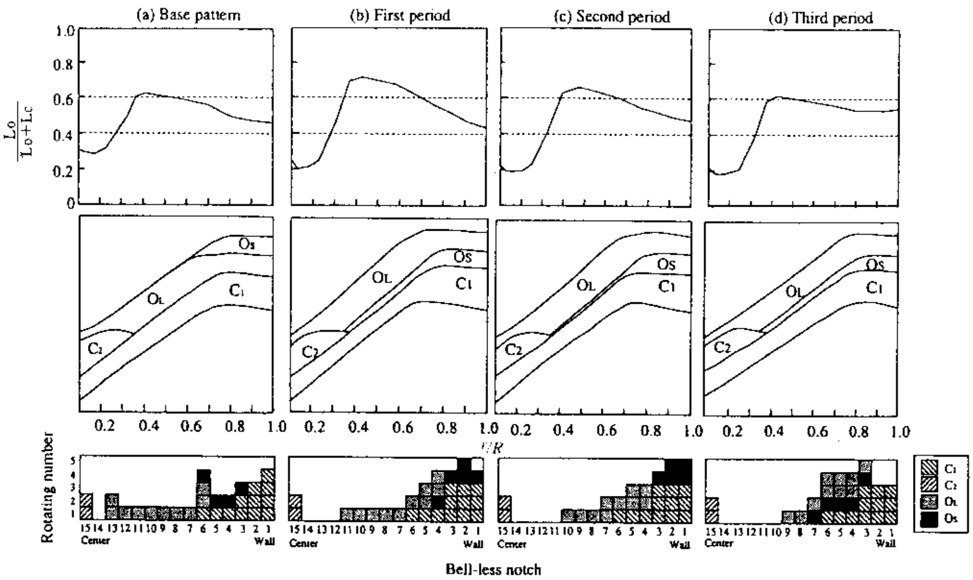

Fig. 14 $L_O/(L_O + L_C)$ and charging pattern of No.3 blast furnace

material layer at either the furnace center or the furnace wall is not desirable, and on the contrary, it is essential to maintain uniformity in the radial direction.

4.3 Third Period (July 1993 to Present)

Based on the operational results in the first and second periods, a burden distribution study was made with the aim of obtaining a radially uniform O_S and ore layer thickness distribution. A burden distribution model was used in this study. The target pattern was a flat distribution of ore layer thickness ratios, of the type seen when the $C_1C_2O_LO_S$ charging pattern is used without high-ratio S_S blending. The ore layer thickness ratio when high-ratio S_S blending is not used, shown in **Fig. 14** (a), is approximately 0.4 to 0.6, except in the vicinity of the center, and overall has a flat distribution, but in the first and second periods, when the high-ratio S_S blending was used, as shown in Fig. 14 (b) and (c), the ore layer thickness ratio in the intermediate area rose to 0.7. To achieve a uniform ore layer thickness ratio, the O_S charging position was moved from the pattern in the second period toward the furnace center and the O_S layer thickness at the wall was decreased, in the pattern in Fig. 14 (d), in which each batch is charged over a wide area during each rotation. As a result, the amount of O_L coming to rest near the wall increased, and it was possible to obtain a flattened ore layer thickness ratio distribution.

After the bell-less pattern was modified on the basis of these calculation results, the previously mentioned extreme drop in CO/CO_2 in the radial intermediate area and sudden gas flow abnormalities did not recur, and stable high-S_S operation was realized on a continuing basis.

5 Conclusions

This report has described a burden control technology for high-ratio blending of small sinter using the 3-parallel bunker bell-less top introduced at Mizushima Works No. 3 BF. The results are summarized below.

(1) Adoption of a 3-parallel bunker bell-less top and improvement of the configuration of the furnace-top bunkers made it possible to strengthen the radial size distribution of materials.

(2) Real-time control of the charging rate made it possible to reduce deviations in the charging rate to 5% or under, and to achieve a stable burden distribution.

(3) Multi-batch charging based on two-size fractional charging has made it possible to achieve uniformity in the ore layer thickness ratio in the BF radial direction simultaneously with high-ratio blending of small sinter, allowing stable high-volume use of small sinter at a blending ratio of 17%.

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