Size Segregation of Sinter in Top Bunker of a Bell-less Type Blast Furnace*

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Synopsis

The size segregation of sinter in a top bunker of a bell-less type blast furnace was experimentally investigated by the use of a full scale model as well as a 1/10 scale model and the following results were obtained.

The size variation during discharging from the bunker was significantly reduced by the installation of a simple stone box of suitable size at the suitable vertical position in the bunker for the restraint of the size segregation during charging of burden into the bunker. On the other hand, the installation of an insert to regulate solid flow in the bunker during discharging resulted in the meager reduction of the size variation during discharging. Accordingly, it is proved that the restraint of the size segregation in the bunker is of prime importance for the reduction of the size variation during discharging.

The increase of the charging rate of burden into the bunker decreased the size segregation in the bunker and, as a result, the size variation during discharging was reduced.

In case of bunkers in series, the size variation during discharging from the lower bunker significantly depends on the re-segregation of burden in the lower bunker during discharging from the upper bunker.

Key words: ironmaking; blast furnace process; bell-less top bunker; size segregation.

I. Introduction

The control of the radial burden size distribution is as important as that of the radial ore to coke weight ratio distribution in respect of the control of gas flow distribution, chemical reactions, and heat and mass transfer in a blast furnace.

For a bell-less type blast furnace, the size segregation in a top bunker during charging of burden into the bunker and the size variation during discharging from the bunker, which significantly affect the radial size distribution in a blast furnace, have been already partly investigated.¹⁻⁶⁾

However, the influences of factors affecting the size segregation in the bunker during charging and the size variation from the bunker during discharging have not yet fully investigated. Especially, although the charging rate of burden into the bunker can have the significant influence on the size segregation in the bunker during charging and the size variation from the bunker during discharging, no research has been performed under varied charging rate conditions.

Secondly, studies on the practical countermeasure for the size segregation in the bunker and the size variation from the bunker are also insufficient. Okumura *et al.*¹⁾ reported that the change of the location

of a stone box in the bunker so as to certify the complete collision of burden against the stone box could result in the improvement of the gas utilization ratio by 1.5 %. The effect of the installation of inserts and/or filling chute in the bunker was investigated by Fukutake *et al.*³⁾ However, neither of these two reports was concerned with the change of the size segregation in the bunker during charging and the solid flow in the bunker during discharging in case of the installation of inserts. Consequently, an effective and simple countermeasure which can restrain both the size segregation and the size variation has not yet been established.

Recently, so called center-feed (CF) type bell-less top, in which two bunkers are vertically arranged in series in contrast to the conventional horizontally arranged parallel-type bunkers (PB), was developed to improve both the initial installation cost and the circumferential imbalance in the conventional PB type bell-less charging.

The size variation during discharging from the lower bunker in the CF type bell-less may be different from that of the conventional PB type bell-less, since the size segregation in the lower bunker apparently depends on the size variation from the upper bunker. In spite of this, the research on the size variation in the CF type bell-less was restricted to the case of one separate bunker.²⁾

Therefore, in this report, the researches were performed by the use of a full scale model as well as a 1/10 scale model to clarify the before-mentioned three items on the size segregation and size variation in the bell-less top bunker, that is, the influence of the charging rate, the establishment of the effective and simple countermeasure, and the size variation in case of the CF type bell-less bunker.

II. Experimental Method

The experimental apparatuses used were both the 1/10 scale model shown in Fig. 1 and the full scale model described in the former report.⁴⁾

The similarity condition of the 1/10 scale model was determined considering the predominant forces acting in the system.⁷⁾ During the charging of burden into the bunker, the predominant forces are the inertia force caused by the conveyor transportation (F_b), the impact force on the burden surface caused

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Fig. 1. Experimental apparatus of 1/10 scale model.

by the gravity fall (F_g), the reaction force caused from the burden surface (F_s), and the friction force reacted on the burden surface (F_f). During the discharging of burden from the bunker, the predominant forces are F_g , F_s , and F_f . By omitting the constants, these forces are expressed as follows.

$$F_b = \dot{m}V \dots\dots\dots(1)$$

$$F_g = \dot{m} \sqrt{gD} \dots\dots\dots(2)$$

$$F_s = \rho g D^3 \dots\dots\dots(3)$$

$$F_f = f(\phi_i, F_b, F_g, F_s) \dots\dots\dots(4)$$

where, $\dot{m}$: mass flow rate (kg/s)
 V : velocity of conveyor (m/s)
 D : representative length (m)
 g : gravity acceleration (m/s²)
 f : function (—)
 ϕ_i : angle of internal friction (deg)

When the burdens of nearly the same ϕ_i are used, the following two dimensionless numbers for the 1/10 scale model should accord with those for the actual one.

$$\Pi_1 = \frac{F_b}{F_g} = \frac{V}{\sqrt{gD}} \dots\dots\dots(5)$$

$$\Pi_2 = \frac{F_g}{F_s} = \frac{\dot{m}}{\rho g^{0.5} D^{2.5}} \dots\dots\dots(6)$$

Therefore, the velocity of the conveyor and the mass flow rate in the reduced model should be selected as follows.

$$V' = V \left(\frac{D'}{D} \right)^{0.5} \dots\dots\dots(7)$$

$$\dot{m}' = \dot{m} \left(\frac{D'}{D} \right)^{2.5} \dots\dots\dots(8)$$

The experimental conditions determined are summarized in Table 1. The burden used for experiments was exclusively sinter, since the size segregation in the bunker and the size variation from the bunker were observed to be more significant for sinter than coke.⁴⁾ The size distribution of sinter for the 1/10 scale model was 10 % of 1~2 mm diameter, 45 % of

Table 1. Experimental conditions.

	Full scale model	1/10 scale model
Kind of burden	Sinter	Sinter
Diameter of bunker	6 000 mm	700 mm*
Effective volume of bunker	95 m ³	120 L*
Amount of charging	148 t/ch	260 kg/ch
Charging belt conveyor speed	120 m/min	38 m/min
Charging rate	0.04, 1.1 t/s	0.076, 2.1, 4.4 kg/s
Discharging rate	1.41 t/s	3.7 kg/s

* 1/10 scale of an actual bunker

3~5 mm diameter, and 45 % of 7~10 mm diameter.

III. Experimental Results

1. Influence of Charging Rate

Among factors affecting the size segregation and the size variation, one of the important factors which have not yet been fully investigated was the charging rate.

In the full scale model experiments in the former report,⁴⁾ the charging rate of sinter into the bunker was restricted to 0.04 t/s due to the use of a bucket conveyor. This value corresponds to about 1/30 of the commercial value of 1.1 t/s to be applied at Kashima No. 2 BF of Sumitomo Metals. The large difference in the charging rate seemed to cause the change of the size segregation in the bunker. Therefore, a 20 m³ feed hopper was installed at the end of the bucket conveyor above the bunker to achieve the commercial charging rate by the intermittent charging of sinter into the bunker.

Figure 2 shows the size variation from the bunker in the full scale model experiments under the different charging rate conditions. When the charging rate was increased, the sinter size in the initial stage of discharging increased and that at the final stage decreased. As a result, the size variation from the bun-

Fig. 2. Influence of charging rate on the size variation during discharging in the full scale model experiment.

ker was suppressed under high charging rate. The same phenomenon was observed in the 1/10 scale model experiments as shown in Fig. 3.

The agreement of the size variation shown in Figs. 2 and 3 certifies the applicability of the use of the 1/10 scale model.

Since the solid flow in the bunker during discharging is considered to be unaffected even in case of high charging rate, the reason of the decrease of the size variation seemed to be attributed to the change of the size segregation during charging of sinter into the bunker. Therefore, the radial size distribution in the bunker was investigated. As shown in Fig. 4, the increase of the charging rate in the full scale model resulted in the decrease in the size segregation in the bunker. The radial size distribution in the bunker was measured when 1/3 of the burden was charged into the bunker ("lower level") and the whole burden was charged into the bunker ("upper level"). Similar result was also obtained in the 1/10 scale model.⁸⁾

In addition, the increase of the charging rate caused about 3° decrease of the deposit angle as was reported for blast furnace charging.⁹⁾ This phenomenon decelerates the sieving on the burden surface and also was contributed to the suppression of the size segregation.

Accordingly, in case of high charging rate, the size segregation during charging into the bunker is restrained and at the initial stage of discharging, sinter of a bit smaller size above the discharge hole and in the apex of burden pile is discharged first because of the funnel flow in the bunker, while at the final stage of discharging, sinter of a bit larger size near the bunker wall is discharged. As a result, the size variation for the higher charging rate is restrained as shown in Figs. 2 and 3.

Fig. 3. Influence of charging rate on the size variation during discharging in the 1/10 scale model experiment.

Fig. 4. Change of the size segregation in the bunker under different charging rate in the full scale model experiment.

2. Countermeasures for Size Segregation in the Bunker and Size Variation from the Bunker

1. Fundamental Concept of Countermeasures

It is obvious that the controlling factor of the radial size distribution in the blast furnace is the size variation during discharging from the bunker, that is, from the distributing chute, and is not the size segregation during charging of sinter into the bunker. However, the size variation from the bunker during discharging is determined by the preceding two steps, that is, the size segregation during charging of sinter into the bunker and the solid flow in the bunker during discharging.

Therefore, firstly, the influence of each step on the size variation from the bunker will be evaluated and then a concrete countermeasure for the step of prime importance will be considered.

2. Effect of the Control of Solid Flow in the Bunker during Discharging

As reported before,⁴⁾ the solid flow in the bunker is almost funnel flow, which causes the early discharge of fine sinter deposited near the apex of burden pile and the late discharge of coarse sinter deposited near the bunker wall. It is familiar to install an insert in the bunker to establish plug flow. However, it is also well-known that the insufficient size of the insert results in the meager improvement of solid flow.

Therefore, according to the research by Johanson,¹⁰⁾ a suitable cone type insert was designed as illustrated in Fig. 5 and was installed in the bunker of the full scale model. In designing, the 42° inner friction of sinter of 18~20 mm diameter was adopted from the data with a three axial shear test rig. Then, the half top angle of the cone (θ_2) was determined to satisfy the partial plug flow condition proposed by Johanson¹⁰⁾ using the measured inner friction angle. Next, the angle was calculated by the following equation.

$$\alpha = \tan^{-1} \{ \tan \theta_1 / (1 + W/R) \} \dots\dots\dots(9)$$

where θ_1 , W and R are defined as shown in Fig. 5 and W/R is evaluated using a figure proposed by Johanson.¹⁰⁾ Using the values of θ_2 and α , the size and the position of the appropriate cone type insert was geometrically determined as shown in Fig. 5. The change of the size variation from the bunker by the introduction of the cone type insert is shown in Fig. 6. The low charging rate condition was so selected that the significant change of the size variation could be observed. Against the expectation, the size variation from the bunker was not significantly improved by the installation of the cone type insert of diameter as large as 2 000 mm. Small size sinter was discharged in the initial stage and coarse size sinter was discharged in the last stage to exhibit still monotonous increase of size during discharging.

The reason for this was thought to be that the improvement of the funnel flow in the bunker by the installation of the insert was small and could not compensate the size segregation during charging of sinter into the bunker. When the insert was moved further downwards, the tendency of the plug flow might be intensified. However, the formation of bridge near the insert might cause unstable discharge of sinter. Therefore, in the practical operation, the downwards movement of the insert is difficult.

3. Effect of the Control of Size Segregation in the Bunker during Charging

Although the installation of a distributing chute above the bunker can be possible in order to restrain the size segregation in the bunker during charging, it has restrictions both in the installation space and the investment. Therefore, a stone box was selected as one of the candidates for the effective and simple countermeasure against the size segregation during charging and was investigated by using both the 1/10 scale and the full scale model.

First of all, the influence of the size and the shape of the stone box was investigated by using the 1/10 scale model. (Fig. 7) The stone box was placed at

θ_1 : Hopper angle ($=30^\circ$)
 θ_2 : Half top angle of cone ($=45^\circ$)
(θ_2 and α were determined according to Johanson.¹⁰⁾)

Fig. 5. Design method of the suitable cone type insert in the bunker in the full scale model experiment.

Fig. 6. Effect of the installation of the cone type insert on the size variation during discharging in the full scale model experiment.

440 mm above the discharge hole for each case. The ordinate ($\sigma_{dp}/\bar{d}_p$) in Fig. 7 is the quotient of the standard deviation of sinter size during discharging (σ_{dp}) divided by the average size of charged sinter ($\bar{d}_p$).

When part of sinter charged into the bunker does not collide with the stone box due to its small size, the reduction of $\sigma_{dp}/\bar{d}_p$ is insufficient.

On the contrary, as long as all of sinter charged into the bunker collides with the stone box, $\sigma_{dp}/\bar{d}_p$ is significantly reduced irrespective of its shape and size.

Secondly, the effect of the vertical position of the stone box was investigated in the 1/10 scale model experiment. The relationship between the vertical

Fig. 7. Effect of size and shape of the stone box on the standard deviation of size during discharging in the 1/10 scale model experiment.

Fig. 8. Effect of vertical position of the stone box on the standard deviation of size during discharging in the 1/10 scale model experiment.

position of the stone box and the size variation ($\sigma_{dp}/\bar{dp}$) is shown in Fig. 8. The higher vertical position of the stone box results in the more reduced size variation. This fact is mainly attributed to the reduction of the size segregation during charging, and is not attributed to the improvement of solid flow during discharging. One of the verification is shown in Fig. 9 which shows the funnel flow in the bunker in the 1/10 scale model even in the installation of the stone box. The burden deposited above the stone box (designated as ● in Fig. 9(b)) was discharged in the early stage of discharging. This phenomenon can be expected from the results in Fig. 6, in which even the installation of the large cone type insert failed in enhancing plug flow. The other evidence was the restraint of the size segregation in the bunker by the installation of the stone box at higher vertical position. (Fig. 10)

The restraint of the size variation by the installation of the stone box in the bunker was also proved in the full scale model experiment as shown in Fig. 11.

3. Size Variation of CF Type Bell-less

As mentioned earlier, the size variation during discharging from the lower bunker in the CF type bell-less may be different from that of the PB type bell-less, since the size segregation in the lower bunker apparently depends on the size variation from the upper bunker.

In the practical operation, the most interesting point is whether the size variation from the bunker of the CF type bell-less is accelerated by that from the upper bunker or not.

Therefore, two extreme cases were selected in the experimental condition of the 1/10 scale model experiment. The one is that the size variation from the upper bunker is significantly large, corresponding to the case without the stone box in the upper bunker.

Fig. 9. Effect of the installation of the stone box on the discharge behavior in the 1/10 scale model experiment.

Fig. 10. Effect of vertical position of the stone box on the size segregation in the bunker in the full scale model experiment.

The other is that the size variation from the upper bunker is small, corresponding to the case with the stone box at the highest vertical position in the upper bunker. In each case, no stone box was installed in the lower bunker to observe the enhanced difference in the size variation.

The experimental results on the size variation for the two cases are shown in Fig. 12. When the size variation from the upper bunker is large, that is, no stone box is installed in the upper bunker, the size variation from the lower bunker is slightly reduced. The dimensionless standard deviation of size during discharging was reduced from 0.14 to 0.11. The reason is that the size segregation occurs in the lower bunker as shown in Fig. 13. In the initial stage of charging into the lower bunker, the sinter of small size charged into the lower bunker is deposited near

the bunker wall as well as near the center, while in the final stage of charging, the charged sinter of large size is deposited near the apex of burden pile as well as near the wall. As a result, the size segregation in the lower bunker is reduced to result in the reduction of size variation in spite of the funnel flow during discharging.

When the size variation from the upper bunker is small, that is, a stone box is installed at the highest position in the upper bunker, the size variation from the lower bunker is increased. The reason is that the size segregation occurs in the lower bunker as shown in Fig. 14. During the charging into the lower bunker, the sieving of the sinter occurs on the slope of the burden pile to result in the increase of the size segregation in the lower bunker. The size variation from the lower bunker is increased because of the funnel

Fig. 11. Effect of the installation of the stone box on the size variation during discharging in the full scale model experiment.

Fig. 13. Size segregation in the lower bunker in the 1/10 scale model experiment without installation of the stone box in the upper bunker.

Fig. 12. Size variation during discharging from CF type bell-less bunkers in the 1/10 scale model experiment.

Fig. 14. Size segregation in the lower bunker in the 1/10 scale model experiment with installation of the stone box in the upper bunker.

flow of solid with the increased size segregation in the lower bunker. Thus, although the former research¹¹⁾ reported the reduction of the size variation in case of multiple bunkers in series, the size variation from the following bunker does not always decrease when the size segregation in the following bunker becomes the determining process, as is the latter case in the experiment.

In order to decrease the size variation from the lower bunker for the latter case, a stone box was installed in the lower bunker and the size segregation in the lower bunker and the size variation from the lower bunker was reduced as low as those in the upper bunker.

Accordingly, in the CF type bell-less, the installation of a stone box or equivalent countermeasure in the lower bunker is necessary to maintain the size variation of the low level from the lower bunker.

IV. Conclusion

The size segregation and size variation of sinter in a top bunker of a bell-less type blast furnace was investigated using a 1/10 scale model and a full scale model and the following results were obtained.

(1) The increase of the charging rate of sinter into the bunker decelerates the size segregation in the bunker to result in the decrease of the size variation during discharging from the bunker.

(2) Aiming at the restraint of the size variation from the bunker, it is difficult to change the solid flow into plug flow during discharging by the installation of an insert in the bunker.

(3) For the restraint of the size variation from the bunker, the control of the size segregation during charging into the bunker is effective and one of the

simple countermeasures is the installation of a stone box.

(4) The suitable size of the stone box was determined such that all of the sinter can collide with the stone box. The suitable position of the stone box was selected close to the upper surface of burden pile.

(5) The size variation from the lower bunker of the CF type bell-less depends on the size segregation during charging into the lower bunker. Therefore, the installation of a stone box or an equivalent in the lower bunker is necessary to restrain the size variation from the lower bunker.

REFERENCES

- 1) K. Okumura, T. Kawai, H. Marushima, H. Takahashi and J. Kurihara: *Tetsu-to-Hagané*, **66** (1980), 1956.
- 2) T. Nagai, Y. Okuno, N. Yazaki, J. Hasegawa, M. Sawa and E. Chikamatsu: *Tetsu-to-Hagané*, **68** (1982), S694.
- 3) T. Fukutake, T. Fujita and Y. Tanaka: *Kawasaki Steel Giho*, **14** (1982), 405.
- 4) Y. Kajiwar, T. Jimbo, T. Joko, Y. Aminaga and T. Inada: *Trans. Iron Steel Inst. Jpn.*, **24** (1984), 799.
- 5) H. Otsuka, S. Ichinoseki, T. Sawai, Y. Hara, Y. Nakagawa, A. Suzawa and H. Kimura: *Tetsu-to-Hagané*, **72** (1986), S6; *Trans. Iron Steel Inst. Jpn.*, **26** (1986), B290.
- 6) K. Okuda, S. Matsukura, H. Yamada, K. Kurihara, Y. Mizuno and A. Sato: *Tetsu-to-Hagané*, **72** (1986), S917.
- 7) R. I. Emori and D. J. Schuring: *Mokeyjikken no Riron to Oyo*, (in Japanese), Gihodo, Tokyo, (1973).
- 8) K. Sato, Y. Aminaga, Y. Kajiwar, T. Inada, T. Iba and Y. Nakamura: *Tetsu-to-Hagané*, **72** (1986), S913.
- 9) K. Okimoto, S. Inaba and K. Narita: *Tetsu-to-Hagané*, **68** (1982), S104; *Trans. Iron Steel Inst. Jpn.*, **22** (1982), B318.
- 10) J. R. Johanson: *Powder Technol.*, **1** (1967/68), 328.
- 11) S. Kawai: *Kanazawa Daigaku Kogakubu Kiyo (in Japanese)*, **2** (1959), 187.