All Pellets Operation in Kobe No. 3 Blast Furnace under Intensive Coal Injection

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(Received on July 26, 2002; accepted in final form on September 19, 2002)

In Kobe No. 3 blast furnace (third campaign) (inner volume: 1 845 m³; blown in on April 5, 1983), the use of pellets was begun as a result of suspended operation of the sintering plant in the end of May 1999 and Kobe 3BF began all pellets operation (pellet: 73%; lumpy ore: 27%) in the end of September 2001. This is dedicated to the advancement of all pellets operation under intensive coal injection with the bell-less blast furnace. A study has been made of the deepening of understanding on the phenomena of softening and melting properties by using the mixture of dolomite-fluxed pellets and low basicity pellets. In order to prevent the growth of cohesive zone root by using of low basicity pellets, the charging technique of time-series discharging based on model experiments was developed and applied to an actual furnace. To achieve the high accurate burden distribution control, the change of ore falling trajectory by filing-up of pellets inside the rotation chute was monitored and corrected. With respect to slag and metal chemistry under the low slag ratio operation with use of low basicity pellets, securing the slag fluidity and desulfurizing efficiency was designated as control points.

KEY WORDS: blast furnace; preliminary-treated ores; pellets; sinter; high temperature properties; burden distribution control; fluxed pellets; bell-less charging; cohesive zone; slag chemistry; desulfurizing ratio; dolomite.

1. Introduction

In Kobe No. 3 Blast Furnace (third campaign) (inner volume: 1 845 m³; blown in on April 5, 1983) (hereinafter called “Kobe 3BF”), preliminary-treated ores were totally changed over to externally supplied products as a result of suspended operation of the sintering plant at the end of May 1999 and Kobe 3BF began all pellets operation (pellet: 73%; lumpy ore: 27%) in the end of September 2001. This paper reports the transition process to all pellets operation (pellet: 73%; lumpy ore: 27%).

Kobe Steel has achieved satisfactory results in the high-percentage pellet ratio operations including 80% ratio test operation¹ on Kobe 1BF (first campaign) in 1967 and 70% ratio test operation⁵ on Kakogawa 2BF (second campaign) under intensive coal injection in 1991. This paper reports the transition process to all pellets operation under intensive coal injection in a bell-less blast furnace based on the relationship between changes of various phenomena and blast furnace controllability with a hope to contribute to further improvement of operational flexibility.

2. Concept of Shifting from Sinter Operation to Pellet Operation

2.1. Comparison of Pellet and Sinter

Table 1 compares properties of sinter and pellet. Since pellets are of agglomerated sized ore whereas sinter is of crushed sized ore, their shapes are different and have markedly great influences on burden distribution at the time of charging into a blast furnace.¹² In addition, since pellets have drawbacks in high temperature properties as compared to the sinter, Kobe Steel has been making efforts to improve the hot properties by adding dolomite for improvement in the pellet quality.³

For the control of the cohesive zone, the melting properties become important along with the softening properties. Presently, desirable burdens are assumed to be those which

Table 1. Comparison of pellets and sinter for blast furnace burden.

|                  | Advantages            | Disadvantages         |
|------------------|-----------------------|-----------------------|
| Sinter (Crushed sizing) | High inclination angle | Wide size range       |
|                  | High reducibility     | High reduction degradation |
| Pellets (Pelletizing) | Low slag rate         | Low inclination angle  |
|                  | Low reduction degradation | Retardation of reduction |
hold a lumpy packed structure to as high temperature as possible, that is, it is desirable to have burdens which provide good softening properties under load and achieve a narrow temperature range from start of softening to melting. From the viewpoint of holding the lumpy packed structure to high temperature, Kobe Steel adopts 1 100°C reduction contraction under load for controlling pellet high temperature properties. Figure 1 shows the correlation between composition of various commercial pellets and reduction contraction under load and Fig. 2 the melting temperature under high-temperature load. The experiment was carried out at a heating rate of 10°C/min (up to 1 000°C) and 5°C/min (1 000°C or over) with CO/N₂ (30/70) used for reducing gas. The dolomite-fluxed pellets fabricated in-house (K in the drawing) provide a low contraction as compared to imported pellets (A, B, C in the drawing), and have been improved to maintain the lumpy packed structure up to high temperature and at the same time to achieve a high melt-finishing temperature.

For pellets used for shifting to the all pellets operation, dolomite-fluxed pellets fabricated in-house were used together with imported pellets, which were used partly. Consequently, when pellets are mixed and used, influences of mixture ratio of both must be taken into account in addition to the properties of individual brands of pellets. Figure 3 shows changes in softening and melting characteristics when low-basicity pellets (B) are mixed to dolomite-fluxed pellets (K). The experiment was carried out at a heating rate of 7°C/min (holding temperature at 950°C: 150 min) to simulate the peripheral region, and CO/CO₂/N₂ (950°C: 33/12/55) was used for reducing gas. Dolomite-fluxed pellets (K) provide a narrow temperature range from start of melting to end of dripping, however the temperature range is enforced to be expanded as the low-basicity pellet mixing ratio increases. Figure 4 shows the relationship between the melt-down starting temperature and the calculated melting temperature of pellet gangue (CaO–SiO₂–MgO–Al₂O₃), since it has a linear relation, it can be said that the expansion of the temperature range from start of melting to end of dripping depends on the slag composition when the fluxed pellet mixture ratio is 30% or more.

2.2. Concept of Shifting to All Pellets Operation

Figures 5 and 6 show changes of in-furnace phenomena and their control and the basic concept of burden distribution control for a blast furnace under intensive coal injection, respectively, in shifting to all pellets operation. In Kobe 3BF bell-less system, both ore and coke are allowed to form flat part in the peripheral region, and by suppressing the layer collapse, the O/C distribution is smoothed out from the middle to the peripheral region, and the formation of the inverse V-type cohesive zone is aimed at by center charging of coke.

Figure 7 predicts changes of direct reduction ratio (relative value) distribution in the radial direction in the furnace as the pellets ratio increases. Because the ore inclination angle lowers as the pellets ratio increases, ore flows into the central region and the direct reduction ratio rises. In addi-
tion, because the ore flat part shrinks as the ore inclination angle lowers, it was foreseen that the direct reduction ratio in the vicinity of peripheral region would increase. For these changes, it was aimed at maintaining the inverse V type cohesive zone at the time of all sinter operation by increasing the amount of center charged coke at the central region and maintaining the ore and coke flat section at the peripheral region respectively.

On the other hand, the width and thickness of the cohesive zone are subject to the melt-down properties. Consequently, radial distributions of pellets and sinter of different melt-down properties must be taken into account, too. From the viewpoint of comparison of properties of sinter and pellets (Table 1) and effects\(^2\) of improving retardation of reduction reaction by the presence of thermal reserve zone from the middle section to peripheral section under intensive coal injection, it was assumed appropriate to locate dolomite-fluxed pellets from the middle region to the peripheral region. However, as shown in Fig. 8, in the bell-less charging, pellets are flung up to the upward in a
rotating chute because pellets provide a small coefficient of friction with the chute wall surface. Consequently, in the vicinity of the peripheral region, pellets are likely to form lumps, and particularly, in the case of low basicity pellets, the expansion of the temperature range from start of melting to end of dripping (growth of cohesive zone root) results.

Consequently, in order to prevent the growth of cohesive zone root in the mixture use of low basicity pellets, it was assumed desirable to keep the pellet concentration in the peripheral region to 30% or lower at the pellet blending ratio up to 50% and to keep the low basicity pellet concentration in the peripheral region to 30% or lower at the pellet blending ratio of 50% or higher based on the softening and melting characteristics (Fig. 3) with reference to the other bell-less operation. The discharge control method for this will be discussed later in Chap. 3.

From the viewpoint of circumferential balance, monitoring of ore falling trajectory was reinforced because it was concerned that the discharge deviation due to discharge characteristics of parallel two-stage furnace top hoppers would be promoted by fling-up of pellets inside the rotation chute.

With respect to slag and metal chemistry, it was anticipated that the slag ratio would lower to 220 kg/thm as pellets ratio increases. In low slag ratio operation, it was feared that the buffering capacity against slag viscosity variations resulting from [%Si] variations would lower as well as slag desulfurizing efficiency would lower. In particular, under the use of low basicity pellets, securing the slag fluidity and desulfurizing efficiency was designated as control points.

3. Radial Direction Concentration Distribution Control by Time-series Discharge of Pellets

The discharge behavior from the furnace top hopper presents a funnel flow and varies in time-series in accord with the concentration distribution of the height in hoppers. Making the best of this, the concentration distribution in furnace hoppers was varied in accord with the material weighing and charging sequence and investigation was made on the control of pellet concentration distribution in the furnace radial direction by time-series discharge.

3.1. Discharge Characteristics from the Furnace Top Hopper and Accumulation Conditions in Furnace Radial Direction

Figure 9 shows time-series change of pellet concentration in accord with the pellet charging position in the furnace top hopper. Experiments were made using sinter and pellets as materials in bell-less three-dimensional charging equipment (scale: 1/5). The pellet discharge pattern varies in accord with the pellet charging positions (A, B, C) in the hopper and the material at upper part of the furnace top hopper (position A) is discharged early. Figure 10 shows the concentration distribution at the time of V-type discharging in accord with discharge patterns. As pellets are discharged earlier in the process for forming the ore layer, the burden flowing into center is further promoted and non-uniform distribution is formed in the radial direction.

3.2. Ore Weighing and Charging Sequence and Discharge Characteristics from Furnace Top Hoppers

Figure 11 shows changes in time-series concentration distribution at the time of discharge from furnace top hop-
pers in accord with the material weighing and charging sequence from ore bins. Experiments were carried out using alumina beads (mean particle size: 0.75 mm) simulating pellets as materials and sinter (mean particle size: 0.75 mm) in a reduced model (1/20) covering ore bins to furnace top system. As compared to pellet head end discharge (case B), the maximum concentration is obtained in the midst of discharge by a funnel flow in the furnace top hopper in the case of pellet rear end discharge (case A).

Consequently, by formulating time-series discharge characteristics from ore weighing and charging to the furnace top hopper, it is possible to estimate pellets discharging characteristics from ore bins.

The estimated values plotted in the figure well coincide with the experimental values.

**Figure 12** shows the radial distribution of pellet concentration by in-service furnace top sampling. By formulating time-series discharge characteristics from ore weighing and charging to the furnace top hopper, it is possible to estimate pellets discharging characteristics from ore bins to radial distribution in the furnace. The radial distribution of pellet distribution nearly coincides with the estimate from model experiments, and the controllability of radial distribution by time-series discharging was confirmed and applied to an actual furnace on May, 1999.

4. Results of Shifting to All Pellets Operation

**Figure 13** shows operational results of Kobe 3BF when all pellets operation is achieved. As a result of suspended operation of sintering plant in the end of May 1999, pellets began to be used, and the blast furnace was completely

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Fig. 13. Operation results of Kobe No. 3 blast furnace.
shifted to all pellets operation in the end of September 2001. As the countermeasure to the degradation of sinter in the transportation process, coal injection rate was decreased from 200 kg/thm to 170 kg/thm on May, 1999. As the furnace heat was adjusted by blast temperature, so the fuel rate after shifting to all pellets operation nearly coincided with that on start of using pellets.

Figure 14 shows typical hearth heat drop patterns in the beginning of increasing the pellet ratio in 1999 before the time-series pellet charging control was adopted. With a sudden pressure drop at the lower part of furnace and an increase of thermal load as a turning point, solution loss reaction rapidly increases and molten iron temperature rapidly drops. This is assumed to be attributed to melting reduction of collected lumps with unreduced pellets fused. After the introduction of the time-series pellet discharging control on May, 1999, this hearth heat drop patterns have been dissolved.

4.1. Changes and Control of Ore Falling Trajectory and Burden Distribution

Figure 15 shows changes of ore inclination angle resulting from increased pellet ratio. As the pellet ratio increases, the ore inclination angle rapidly lowers as compared to the bell-less distribution experimental results. This is assumed to be attributed to great influence of furnace throat gas velocity under high O/C operation. On the other hand, at the pellet blending ratio of 45% or more, the ore inclination angle gradually approaches to about 25°, nearly same as bell armor distribution experimental results. This is assumed to be attributed to the rise of ore discharge flux (t/m²/h) at the bell-less flow-regulating gate section as a result of increased pellet ratio and the ore inclination angle.

Fig. 14. Typical furnace working pattern in furnace heat dropping.

Fig. 15. Effects of pellets ratio on inclination angle of ore.
that comes closer to pellet repose angle. Figure 16 shows changes of ore to coke thickness ratio distributions in the radial direction. As the pellet ratio increases, the ore layer thickness ratio in the vicinity of the center increases, and to cope with this change, the center-charged coke amount was increased.

Figure 17 shows changes of trajectory of ore falling from the rotating chute. As the pellet ratio increases, the ore falling trajectory was displaced to the furnace wall side. This is also attributed to the fling-up of pellet inside the rotating chute previously discussed.

4.2. Changes of In-furnace Gas Flow Distribution and Its Control

Figure 18 shows changes of temperature distribution in the furnace resulting from the increased pellet ratio.

At 26% pellets, the south-to-north balance of in-furnace temperature distribution was broken (Fig. 18(b)). This is because the discharge deviation of coke and ore in the south and the north in the discharge characteristics of two-parallel top hopper shown in Fig. 19 is promoted by the fling-up in the rotating chute resulting from increased pellet ratio. To solve this problem, the inside diameter of vertical chute was reduced from 550 to 500 mm on October, 2000. Figure 20 shows changes of ore falling trajectory before and after reducing the vertical chute diameter. The ore falling trajectory is corrected to the furnace inner side and as a result, the
problem of south-north balance of in-furnace temperature distribution was solved (Fig. 18(c)).

When attention is focused on the 900°C isotherm line in changes of temperature distribution in the furnace (Fig. 18), the isotherm position lowers in the vicinity of the center and rises in the peripheral region as the pellet ratio increases. This is because the gas volume in the vicinity of the center is reduced by the rise of ore to coke thickness ratio in the vicinity of the center and reduction of sinter particle size segregation as well as the gas volume in the peripheral region is increased by the drop of ore to coke thickness ratio in the peripheral region, reduction of the fine particle accumulation amount of sinter on falling position, and reduction of degraded fine amount originating from sinter.

Figure 21 shows changes of gas temperature distribution at the furnace-throat. By the increase of center-charged coke amount, the center gas flow can be maintained even in all pellets operation. On the other hand, the furnace-throat gas temperature in the peripheral region shifts to the pattern decreases and the correspondence between furnace-throat gas temperature distribution and in-furnace temperature distribution was markedly changed from that at the time of all sinter operation. Consequently, it is assumed that under all pellets operation, gas flow distribution control not by ore particle size segregation will acquire greater importance.

4.3. Changes Associated with Decreased Slag Ratio and Its Control

Figure 22 and Table 2 show the background of changes in slag chemistry in the process of increasing the pellet ratio. For the beginning of increasing the pellet ratio (period A), the upper limit of basicity setting was trially relaxed from the viewpoint of maintaining slag desulfurizing power and the basicity was increased from 1.26 to 1.28 and (%MgO) was increased from 4.0 to 7.0% (period B).

Figure 23 shows the effects of slag composition and temperature on slag viscosity. Since the slag fluidity was degraded due to upper limit relaxation of basicity setting, the basicity setting was lowered to 1.20 and at the same time, (%MgO) was increased from 7.0 to 9.0% (period C).

Figure 24 shows correspondence between the actual value and estimated value of [%S] advocated by Tamura et al. from the equilibrium study concerning distribution reactions of S between slag and molten iron in the hearth section. As compared to periods A, B, period C has low actual values, though the estimated values are high. Consequently, it is suggested that the slag desulfurizing efficiency in low
5. Conclusion

The process of shifting to all pellets operation under intensive coal injection in a bell-less blast furnace was reported from the viewpoint of relationship between changes of various phenomena and blast furnace controllability. Figure 25 shows the recent pellet shifting process in typical blast furnace ferrous burden constitution. It was able to shift to all pellets operation with a low preliminary treated ore blending ratio maintained. The results of the work carried out allow us to draw the following conclusions.

(1) In order to prevent the growth of cohesive zone root in the mixture use of low basicity pellets, it was assumed desirable to keep the pellet concentration in the peripheral region to 30% or lower at the pellet blending ratio up to 50% and to keep the low basicity pellet concentration in the peripheral region to 30% or lower at the pellet blending ratio of 50% or higher based on the softening and melting characteristics.

(2) The radial distribution of pellet distribution by in-service furnace top sampling nearly coincides with the estimate from model experiments, and the controllability of radial distribution of pellet by time-series discharging was confirmed.

(3) From the viewpoint of circumferential balance, the discharge deviation of ore falling trajectory due to discharge characteristics of parallel two-stage furnace top hoppers was promoted by fling-up of pellets inside the rotation chute. The ore falling trajectory is corrected by reducing the vertical chute diameter and the problem of south-north balance of in-furnace temperature distribution was solved.

(4) The correspondence between furnace-throat gas temperature distribution and in-furnace temperature distribution was markedly changed from that at the time of all sinter operation. And it is assumed that under all pellets operation, gas flow distribution control not by ore particle size segregation will acquire greater importance.

(5) From the equilibrium study concerning distribution reactions of S between slag and molten iron in the hearth section it is suggested that the slag desulfurizing efficiency in low slag ratio operation is susceptible to the slag fluidity.

Furthermore, in order to pursue the molten iron cost reduction with efforts made to extend the blast furnace life, it is necessary to improve the operation flexibility that can follow changes in raw fuel conditions and production, and further sophistication of gas flow control and deepening of understanding on the phenomena at the lower part of furnace are essential.

REFERENCES

1) N. Fujii, S. Tamura, K. Taguchi, K. Kunii and R. Nishida: Tetsu-to-Hagané, 54 (1968), 1241.
2) R. Ono, T. Goto, J. Kiguchi, R. Hori and K. Kuwano: Tetsu-to-Hagané, 78 (1992), 1322.
3) R. Nishida, O. Tsuchiya, T. Uenaka, T. Satoh, K. Aketa and T. Nishida: R&D Kobe Steel Eng. Rep., 34 (1984), 28.
4) Y. Omori and M. Otani: Japan Society for the Promotion of Science Molten Iron 54 Committee, (1979), 1479.
5) T. Tanaka and T. Isida: Neter Sotuketei, 18 (1991), 174.
6) Y. Hida, K. Ono, A. Shigemi and T. Kodama: Tetsu-to-Hagané, 59 (1973), S33.
7) T. Matsu, Y. Kanazuka, K. Hoshino, Y. Yoshida, S. Kitayama and S. Ishiwaki: Ironmaking Conf. Proc., ISS, Warrendale, PA, (1997), 203.
8) S. Inaba, K. Okimoto, T. Nishida, T. Yabata and M. Takada: R&D Kobe Steel Eng. Rep., 34, (1984), 42.
9) A. Tanaka, T. Fukuda, M. Himeda, K. Nishikawa and N. Maekawa: Tetsu-to-Hagané, 65 (1979), S590.
10) E. Schoone, H. Toxopeus and D. Vos: Ironmaking Conf. Proc., ISS, Warrendale, PA, (1995), 465.
11) A. Kasai, Y. Matsui, M. Shimizu, K. Ito, S. Kitayama and N. Nagai: CAMP-ISIJ, 12 (1999), 126.
12) S. Miwa: Powder Technology, Asakura Publishing Co., Ltd., Tokyo, (1972), 206.
13) R. Hori, H. Miyatani, T. Goto, R. Ono, Y. Matsui and M. Arisuka: Tetsu-to-Hagané, 78 (1992), 1330.
14) T. Narita and M. Maekawa: Tetsu-to-Hagané, 63 (1977) No. 9, 1443.
15) K. Tamura, K. Ono and N. Nishida: Tetsu-to-Hagané, 67 (1981), 2635.
16) K. Ishii, S. Kishimoto and C. Yoshii: JIS: Iron Steel Inst. Jpn., 11 (1971), 506.
17) J-M. Steiler: ICSTI/Ironmaking Conf. Proc., ISS, Warrendale, PA, (1998), 161.