Uneven Distribution of Burden Materials at Blast Furnace Top in Bell-less Top with Parallel Bunkers

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In the blast furnace operation equipped with parallel bunker-type bell-less top, the uneven charging of materials in circumferential direction is an important issue to be avoided. This unexpected circumferential imbalance is caused by dynamics of burden materials in charging system. Full analysis is necessary for overcoming this problem.

In this paper, on-site measurements such as charging rates of coke at different flow control gate openings, burden falling trajectories in the air, height distribution of burden stock surface at furnace peripheral and at orthogonal two diameter directions, were done during the filling-up stage. Dislocation of center point was found in this measurement.

Mechanical equations of burden materials flow are derived for three successive regions such as bunker-to-chute colliding point, materials motion on the chute and free falling in the air. Influence of operational factors such as flow control gate opening, rotating speed and tilting angle of chute, and stock line on circumferential weight and falling point distribution was investigated. By making use of the mathematical model, H value and K value are introduced to quantitatively evaluate the circumferential height and ore/coke distribution in several charges. Measured results and simulation results matched well. Observed dislocation of center point was explained well by the mathematical simulation.

It is concluded that change of rotation direction is thought to be much effective in correcting the unevenness of circumferential height distribution. On the other hand, application of bunker change in turn at coke and ore charging is effective to realize circumferential even distribution of ore/coke.

KEY WORDS: uneven burden charging; circumferential distribution; parallel bunker-type bell-less top.

1. Introduction

Based on extensive dissection surveys after blow-out of blast furnace operation, it has been well recognized that the radial distributions of the coke and ore layer are basically maintained until the ore layer melts down in the lower part of the furnace. And the control of ore/coke ratio distribution in the radial direction is significant in forming the gas passage and resultant gas permeability in the furnace operation. Since then, many efforts such as operational experiments and analyses on site, small-scale laboratory experiments, 1-to-1-scale cold model experiments, and mathematical model simulations and so on, were done on radial distribution control of burden materials throughout the world. BF engineers realized that the radial distribution change of burden materials at the blast furnace top could result in a big difference in operation. Consequently, blast furnace performance was greatly improved both in stability and in a lower fuel operation.

On the other hand, there were some reports on the uneven charging of materials in circumferential direction in the blast furnace equipped with parallel bunker-type bell-less top.

That unexpected circumferential imbalance is caused by dynamics of burden materials in charging system, but not fully analyzed and overcome yet. Due to the parallel configuration of two bunkers at the blast furnace top, the burden flow from a bunker deviate from the center line in vertical chute and the flow path is tend to peculiar one for each bunker if the flow rate remains constant. During one revolution of the chute, the deviation results in different velocity and collision point on the chute and leads to uneven charging of materials at stock surface, for example, uneven ore/coke ratio, in circumferential direction. The change in ore/coke ratio in circumferential direction causes the difference in silicon content and hot metal temperature along the direction which draws much attention of BF operators. But during the normal operation, the operators can hardly get the imbalance signals. So, it is essential to construct a mathematical model to inform blast furnace operators quantitatively how much unevenness occurs in the circumferential distributions of both burden height and ore/coke ratio.

In the past decades, a few mathematical models were established to simulate the uneven burden distribution in the circumferential direction. Kondoh et al.1) presented a mathematical simulation model to clarify the materials charging rate distribution in circumferential direction and

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showed numerically that burden flow deviation in vertical tube caused unevenness of material charging on the stock surface in the blast furnace. Nomura et al. calculated the local coke rates distribution in circumferential directions at the furnace top by detecting the top gas composition, from each quadrant region. They showed that it could be changed by selecting charging pattern of bell-less top to achieve its uniform distribution as well as that of hot metal temperature by selecting charging pattern of bell-less top to achieve its each quadrant region. They showed that it could be changed by detecting the top gas composition, from local coke rates distribution in circumferential directions at different bun- lands on the stock surface at the furnace throat. In this operation of an actual blast furnace. Burden surface height measurement on top of burden materials movement of particles flow, it was assumed that shape of flow was represented as continuous medium, but that equation of motion was represented by the mathematical model. The circumferential distributions of both burden falling point on stock surface and of burden layer thickness were investigated by making use of the mathematical simulation model. Circumferential imbalance of burden height and volume-metric ore/coke distributions was investigated under the conditions of various combinations of bunker usage and burden materials, and chute rotating direction in different overall ore/coke ratios. A plant experiment of surface height measurement on top burden surface was also done before the blowing-in operation of an actual blast furnace. Burden surface height distributions were measured not only in circumferential direction at wall-side but also on two rectangular cross diameters. The results measured at wall side were in good coincidence with simulated one. The radial dislocation of actual center point, minimum height point of the burden in the experiment could be explained by the simulation model too.

2. Mathematical Model Construction

2.1. Description of Overall Burden Flow at Charging in Bell-less Top

As shown in Fig. 1, burden material flows down from the flow control gate of a bunker in bell-less top, and passes through the vertical tube, then collides with the surface of rotating chute, and moves to the lower tip end of the chute. After falling from the chute tip end into the air, it finally lands on the stock surface at the furnace throat. In this mathematical model, equations of burden flow are given by dividing the investigating region into three parts, above-chute, on-chute and bellow-chute. The part “above-chute” covers the area from the flow control gate to the collision point on rotating chute surface, “on-chute” from collision point to the chute lower tip end and “bellow-chute” from chute tip end to the stock surface, respectively. In treating the burden materials movement of particles flow, it was assumed that shape of flow was represented as continuous medium, but that equation of motion was represented by the movement of a particle which had the same dimension of particle in motion.1,3,4) The dimensions of the bell-less top charging system in our investigation, used as input in the simulation model, are listed in Table 1.

2.2. Burden Movement in the Region above the Chute

The correction factor $K_f$ in equation of motion, Eq. (1), is introduced to get the burden velocity $v_{in}$ when it gets to the surface of rotating chute,5) where $v_0$ is an initial burden velocity at the flow control gate(here, $= 0$), $H$ is an effective height from the flow control gate to the surface of rotating chute, $K_f$ is employed for correcting both the inter-particles collision and the friction between particles and wall of the flow path. $K_f$ is 0.28 and 0.26 respectively for coke and ore in this calculation.

$$v_{in} = \left[v_0^2 + 2gH\right]^{1/2} - K_f$$

![Fig. 1. The overall burden flow at charging in bell-less top.](image)
The volumetric flow rate of burden material, \( V \), in the vertical tube is the function of flow control gate opening \( fcg \) as shown in Eq. (2). The function is got from the onsite measurement of Hongfa No.1 2500 m³ BF in Shasteel, as shown later in Fig. 7. Assuming that the cross-section of the burden flow forms a crescent shape in the vertical tube as depicted in Fig. 2 and the burden flow velocity is uniform in it, the burden flow centroid \( G \) can be given by making use of Eqs. (1), (2) and bulk density of the burden. The symbol \( T \) represents the angle of crescent of the burden flow from the center axis of the tube.

\[ V = f(fcg) \]  

### 2.3. Burden Movement on the Chute

By decomposing the particle velocity \( v_0 \) and coordinates of burden centroid \( G \) into the chute longitudinal direction \( i \), namely parallel to the center line of the chute and the tangential direction of the chute bottom surface in rectangular cross section to the center line \( j \), we can get those components of initial values such as particle location \( z_0 \), velocity \( u_0 = (dz/dt)_0 \), deviation angle \( \theta_0 \) and angular velocity \( \beta_0 = (d\theta/dt)_0 \). And \( v_k \) is always zero during this motion. Here \( k \) is the direction rectangular to the chute bottom surface (See Fig. 3).

A particle motion in the 3-dimensional equation on the chute can be expressed as Eq. (3),

\[ m\ddot{u} = \overrightarrow{F}_s - m[\omega \times (\omega \times r)] - 2m(\omega \times \dot{v}) - \overrightarrow{F}_n \]  

(3)

By decomposing these vectors in Eq. (3) into three directions, we can get equations of motion in 3-components, \( i \), \( j \) and \( k \) as shown in Fig. 3. As the result, equations of particle motion can be given by Eqs. (4), (5), (6) and (7) as shown below. The variables used in Eqs. (3)–(7) are listed in Table 2.

\[ \frac{d^2z}{dt^2} = g\cos\alpha + \omega^2(z\sin\alpha - R\cos\theta\cos\alpha + R\cos\alpha)\sin\alpha - 2\omega R\sin\alpha\cos\theta \frac{d\theta}{dt} - \eta \frac{dz}{dt} \frac{N}{mv} \]  

(4)

\[ R\frac{d^2\theta}{dt^2} = -g\sin\alpha\sin\theta + \omega^2(z\sin\alpha\cos\alpha + R\sin^2\alpha\cos\theta)\frac{dz}{dt} - \eta \frac{Rd\theta}{dt} \frac{N}{mv} \]  

(5)

\[ N = m\left[ g\sin\alpha\cos\theta + \omega^2 R\cos^2\alpha - \omega^2 R\cos\theta\cos^2\alpha + R\cos^2\alpha\sin^2\theta - 2\omega R\cos\alpha\frac{d\theta}{dt} + 2\omega\sin\alpha\sin\theta\frac{dz}{dt} \right] \]  

(6)

\[ v = \left[ \left( \frac{dz}{dt} \right)^2 + \left( R\frac{d\theta}{dt} \right)^2 \right]^{1/2} \]  

(7)

Here, \( N \) is the normal force from the particle to the chute wall, \( v \) is absolute value of particle velocity on the chute. The fourth order Runge-Kutta method is applied to solve these ordinary differential equations and get the final location \( z_n \), velocity \( u_n \), rising angle \( \theta_n \) and angular velocity \( \beta_n \) at the chute tip end. Finally, the total travelling time of the particle on the chute, \( t \), is calculated by the increment of the time in motion.

### 2.4. Burden Movement in the Section Below the Chute

The effect of gas flow on particle motion is ignored because a drag effect of gas flow is small enough. Equations
of free fall motion of a particle in three rectangular coordinates system, shown in Fig. 4, are solved to get the particle trajectory. In the figure variables are; \( \gamma = \alpha + \alpha' \), \( \alpha' = \tan^{-1}(R(1-\cos \theta)/z_{n}) \), \( r_{n} = \{z_{n}^{2} + 2R^{2}(1-\cos \theta)\}^{1/2} \), respectively.

The travelling time of the particle in the air, \( t_{a} \) is calculated by using vertical component of the particle velocity as shown in Eqs. (8) and (9). Here, symbol \( v \) is vertical component of initial particle velocity at chute tip end. \( h \); the height from chute tip end to the stock surface and \( v_{w} \); the height from chute tip end to the stock surface.

\[
t_{a} = \frac{1}{g} \left[ \sqrt{(v_{w})^{2} + 2gh - v_{w}} \right] \quad \text{(8)}
\]

\[
v = u_{w} \cos \alpha + R\beta_{n} \sin \theta_{n} \cos \alpha + r_{w} \omega \sin \gamma \sin \varphi \quad \text{.... (9)}
\]

2.5. Calculation of Unevenness of Burden Charging Rate in Circumferential Direction and of Falling Point Deviation in Radial Direction during a Rotation of the Chute

At first, definition of circumferential direction is important in this analysis. As depicted in Fig. 5, two bunkers of bell-less top are located in a horizontal plane and on a line, which crosses with center axis of the furnace. Here, the direction of the east side bunker is assumed as 0 degree and the chute direction is defined as 0 degree if the chute tip end faces to the east. If the rotation of the chute is clock-wise as shown in the figure, the chute direction shifts from 0 to \( \pi \) and then \( \pi, (3/2)\pi \) and \( 2\pi \), and angular velocity vector, \( \delta \), points to the downward perpendicular to the paper plane is defined as positive in this case. For a calculation of burden charging rate on stock surface in circumferential direction, we assume a definite amount of burden materials which falls down on the chute between the chute angles of \( \xi \) and \( \xi + d\xi \). Then we can calculate and identify the directions of distribution of falling points of burden materials between \( \lambda \) and \( \lambda + d\lambda \) by making use of burden movement simulation. If the calculation results of \( d\xi \) and \( d\lambda \) are not the same, burden distribution rate per unit circumferential length differs from the average value during one rotation of the chute because that burden amounts of falling down on the chute and of distributing on stock surface should be the same. If \( d\xi > d\lambda \), the distribution rate of the circumferential part is more than average, and if \( d\xi < d\lambda \), the distribution rate of the part is lower than average. The calculation of \( d\xi \) and \( d\lambda \) are actually put into practice as followings. When the chute rotation angle is \( \xi \), the burden collides with the surface of the rotating chute, when the chute direction moves to \( \xi + \alpha_{n} \), the burden leaves from chute tip end, and after the free falling time \( t_{a} \) from Eq. (8) when the particle position is rotation angle of \( \lambda \), the burden materials loads on the stock surface. \( \lambda \) is given by Eqs. (10) and (11).

\[
\lambda = \xi + \alpha_{n} - \varphi + \delta \quad \text{(10)}
\]

\[
\delta = \tan^{-1}\left\{v_{w}t_{a} / (v_{w}t_{a} + r_{n} \sin \varphi)\right\} \quad \text{(11)}
\]

where, \( v_{w} \) is a velocity component of the particle in rotating direction of the chute when it leaves the chute tip end. Symbol \( r_{n} \) denotes the length from center axis of the furnace to particle position at lower tip end of the chute. \( \gamma \) is the angle between \( r_{n} \) and the vertical line.

In the next step, when the circumference angle is \( \xi + d\xi \), the burden collides with the surface of the rotating chute, and a series of calculations are the same likewise just mentioned above. In this case, \( t'_{a} \) and \( t'_{c} \) are also given by burden travelling time on the chute and in the air respectively. Resultant equation for the case of angle, \( \lambda + d\lambda \), is given by Eqs. (12) and (13). Symbol \( \Psi \) is a normalised flow rate distribution ratio at the circumferential angle \( \lambda \).

\[
\lambda + d\lambda = \xi + d\xi + \alpha_{n} - \varphi + \delta' \quad \text{.... (12)}
\]

\[
\delta' = \tan^{-1}\left\{v_{w}t'_{a} / (v_{w}t'_{a} + r_{n} \sin \varphi')\right\} \quad \text{.... (13)}
\]

\[
\Psi = \frac{d\xi}{\lambda + d\lambda} = \frac{d\xi + (t'_{a} - t_{a}) \cdot \omega + \delta' - \delta - (\varphi' - \varphi)} {d\xi} \quad \text{.... (14)}
\]

In addition to the burden charging rate distribution in circumferential direction, radial distribution of burden falling point, FP, during a rotation of the chute at definite chute tilting angles can be calculated at the same time. FP value denotes the distance from the furnace center axis to impact point of falling material on stock surface. When we get \( \lambda \) or \( \lambda + d\lambda \), falling trajectory of a burden particle is also got in the same calculation process.
3. Methods and Data of Preliminary Experiments in Actual Blast Furnace

3.1. The Relationship between the Flow Control Gate Opening and Flow Rate at Different Bunker-material Combinations

It is easily thought that the flow control gate opening will affect the centroid of burden flow in the vertical tube as depicted like in Fig. 2 and that it results in change of the charging rate distribution on stock surface in the circumferential direction. A ball-type flow control gate is equipped in bell-less top charging system in Hongfa No.1 BF of Shasteel as shown in Fig. 6. During the material filling for blow-in operation, the weight and discharging time were recorded for coke and ore under different flow control gate openings. From the results, linear fitting method was used to get correlation function in Eq. (2) between flow control gate opening and burden flow rate from a bunker as shown in Fig. 7. This equation is applied as input to the simulation model to investigate the influence of flow control gate opening in west bunker on coke charging rate distribution on the stock surface in the circumferential direction.

3.2. Burden Trajectory Measurement in the Freeboard of Furnace Top at Various Tilting Angles of the Chute

While the burden height near the wall in circumferential direction is considered to be affected not only by the circumferential burden charging rate distribution but also by the distance between the burden impact point and the wall, the calculation of burden falling trajectory from the rotating chute is needed to determine both the circumferential flow rate distribution and the impact point at the stock surface. The calculation procedure is shown later in section 3. Here, burden trajectory measurement data in actual blast furnace are mentioned. Figure 8 represents the results of center position of burden flow measured by crossed laser beam method during the material filling for blow-in, which is in comparison with the simulation result as shown in the figure. The computed and measured results agreed well with each other in a constant inlet velocity at chute surface and constant friction factors for coke and ore with the chute except for the small tilting angle, which is the same with that reported by Yamamoto et al. That means the burden falling trajectory can be simulated by the mathematical model except small tilting angle.

3.3. The Burden Height Measurement at the Top Stock Surface

During the material-filling-up, the burden stock surface is assumed to be flat before the last 4 charges due to the large kinetic energy of falling materials at deep stock line level. As shown in Fig. 9, the last 4 charges consist of one coke (with flux) charge and 3 alternative coke and ore charges. The composition and physical property of the last 4 charges of burden are listed in Table 3 and the charging pattern setting is listed in Table 4.

For verification of the mathematical simulation model, the circumferential burden height distribution at wall side and radial burden height distribution were measured after filling-up of Hongfa No. 1 BF. The measurement methods are sketched in Fig. 10. Cross-circle denotes the measure-

Fig. 6. The geometry of the flow control gate.

Fig. 7. The relationship between charging rate and flow control gate opening. (a) Coke from west bunker, (b) Ore from east bunker.

Fig. 8. Comparison of measured falling trajectories and simulation results in Hongfa No.1 BF of Shasteel. (a) Burden trajectory of coke, (b) Burden trajectory of ore.

Fig. 9. The Burden structure of the last 4 charges.
As results of the measurements, measured burden profiles in radial direction at the top of Hongfa No.1 BF of Shasteel are shown in Fig. 11. Small deviation to south and to west directions was observed in this measurement. For measurement results of circumferential direction, data are discussed in section 3.

4. Simulation Analysis and Discussion

4.1. The Influence of Operational Parameters on Distribution of Variables in a Single Layer

Ψ value as expressed in Eq. (14) denotes the normalized charging rate distribution of coke or ore in circumferential direction. The influence of such items, flow control gate opening, chute rotating speed and height of stock level on the distribution ratio and radial distance of falling point (FP) of coke under the condition of charging from west bunker is investigated under counter-clockwise rotation of the chute as follows.

Distribution of ψ value with a rotation of chute has a maximum and minimum value as pointed out by Kondoh et al. and Xu et al. Here, rotating direction of the chute in counter-clockwise proceeds from 360° to 0° (right hand side to left hand side) on horizontal axis in Fig. 12. The difference between maximum and minimum value of both ψ value and FP significantly changes with the flow control gate opening. When the flow control gate opening is larger, angle γ of the crescent of burden flow depicted in Fig. 2, becomes bigger, which means the centroid of burden flow in vertical tube comes closer to the center of vertical tube, and both ψ value and FP distribution becomes more uniform. When the chute rotates from east→north→west, Ψ value decreases gradually but increases rapidly during rotation from west→south→east. This asymmetric change of Ψ value is due to synthesizing both transfer speeds of specific motion of centroid, G point, and of burden materials flow down on the chute.

Distributions of the circumferential charging ratio ψ value and of the falling point FP are also thought to be influenced by the chute rotating speed. The difference between maximum and minimum value of ψ value and FP changes in the same tendency with Xu et al. Here, rotating direction of the chute in counter-clockwise proceeds from 360° to 0° (right hand side to left hand side) on horizontal axis in Fig. 12. The difference between maximum and minimum value of both ψ value and FP significantly changes with the flow control gate opening. When the flow control gate opening is larger, angle γ of the crescent of burden flow depicted in Fig. 2, becomes bigger, which means the centroid of burden flow in vertical tube comes closer to the center of vertical tube, and both ψ value and FP distribution becomes more uniform. When the chute rotates from east→north→west, Ψ value decreases gradually but increases rapidly during rotation from west→south→east. This asymmetric change of Ψ value is due to synthesizing both transfer speeds of specific motion of centroid, G point, and of burden materials flow down on the chute.

When stock line changes from 0 to 2 meter which was in the range of normal operation in actual blast furnace, there is little change in the distribution curve of ψ value as shown in Fig. 13. With respect to FP value, the value itself increased as a whole with the increase in rotating speed.

When tiltling angle changes from 25° to 45°, the difference between maximum and minimum point values of ψ value becomes a little bit smaller and the distribution curve shifted to counter-clockwise direction (See Fig. 15). The reason why the difference between maximum and minimum values becomes smaller may be attributed to the velocity of burden materials on the chute becomes smaller.
with increased tilting angle. The distribution curve of FP value shifts a little to counter-clockwise direction shown in Fig. 15 when tilting angle increases.

It is found from Figs. 12 and 14 that the respective minimum directions both in falling point and in mass charging rate differ with each other by almost 90 degree which is the same with Xu’s simulation result.\(^4\) This 90-degree shift can be explained by the difference of mechanisms between mass charging rate and falling point of particles, namely acceleration and deceleration motion of particles on the rotating chute and the change in effective length of the chute. On the other hand respective maximum directions, however, both angular positions look like almost the same in Fig. 12 and in Fig. 14. Factors forming the maximum direction may somewhat change in the case of falling point distribution.

4.2. Control of Stock Height and Ore/Coke Ratio Distribution in Circumferential Direction

Based on \(\Psi\) value distributions of coke and ore layers for one charge, \(H\) and \(K\) values are introduced, which denote stock height and ore/coke ratio distribution in circumferential direction. Figure 12 shows the circumferential charging ratio and falling point distributions of coke and ore layers for one charge. Figure 13 shows circumferential charging ratio distribution of coke from west bunker at different chute rotating speeds. Figure 14 shows circumferential charging rate distribution and radial distance of falling point on stock surface when charging from west bunker at different stock lines. Figure 15 shows circumferential charging rate distribution and radial distance of falling point on stock surface when charging from west bunker at different tilting angles.

Fig. 12. Circumferential charging ratio and falling point distributions of coke in circumferential direction at different flow control gate openings in west bunker. (a) Circumferential flow ratio distribution, (b) Circumferential falling point distribution, (c) Crescent angle of the burden flow in vertical tube.

Fig. 13. Circumferential charging ratio distributions of coke from west bunker at different chute rotating speeds.

Fig. 14. Circumferential charging rate distribution and radial distance of falling point on stock surface when charging from west bunker at different stock lines.

Fig. 15. Circumferential charging rate distribution and radial distance of falling point on stock surface when charging from west bunker at different tilting angles.

Fig. 16. The stock height and ore/coke distribution in circumferential direction under equal \(V(O)\) and \(V(C)\). (a) Circumferential stock height distribution, (b) Circumferential ore/coke distribution.

Fig. 17. Comparison of falling point lines of coke and ore at the largest tilting angle.
the total dimensionless stock height distribution of the coke plus ore layer and ore/coke height ratio distribution in a charge respectively in circumferential direction. \( H \) and \( K \) values are given by Eqs. (15) and (16).

\[
H_j = [V(C) \cdot \psi_j(C) + V(O) \cdot \psi_j(O)] / [V(C) + V(O)]
\]

\[
K_j = [V(C) \cdot \psi_j(O)] / [V(O) \cdot \psi_j(C)] \quad \ldots \ldots \ldots \ldots \ldots (15)
\]

\[
i = 1, \ldots, N
\]

Where, \( N \) is the total number of the circumferential sections. \( V(C) \) and \( V(O) \) are the average volumetric charging rate of coke and ore respectively.

Four patterns of burden charging sequence are defined concerning the bunker-material combination and chute rotation as shown in Table 5.

From Fig. 16(a), it is found that unevenness of circumferential burden height distributions remains even if coke and ore are charged from different bunkers in a charge with an equal volume and when bunker-material combination is changed in turn, such as from charging pattern (1) to (3) or from (2) to (4), the distribution does not change, and when the chute rotating direction is changed in turn, from charging pattern (1) to (2) or from (3) to (4), distributions of \( H \) value will not become fully uniform by adding both curves. In \( K \) volumetric ore/coke distributions in circumferential direction are different in all of four cases but have some regularity. When bunker-material combination is changed, such as from (1) to (3) or from (2) to (4), both distributions in before and after change are almost reverse during a rotation. When the chute rotating direction is changed, such as from (1) to (2) or from (3) to (4), both distributions are somewhat different but not so big during a rotation. This behaviour mentioned above was basically in the same tendency when \( V(O)/V(C) \) is changed from 0.5 to 1.5. Therefore, two important things are concluded in this section as follows;

i) As for the unevenness in circumferential surface height distribution of burden materials, the uneven height distribution occurs in the ordinary operation of parallelltype bell-less top and the distribution can not be made fully uniform by making sequential use of these four patterns, (1)–(4). However, change of rotation direction is thought to be much effective in correcting the unevenness.

ii) In case of the circumferential unevenness of volumetric ore/coke distribution, application of bunker-material combination change in turn, (1) to (3), or, (2) to (4), is an effective method to realize circumferential even distribution of ore/coke.

### 4.3. Analysis and Discussion on Experimental Data from Actual Blast Furnace

From Fig. 11, it is observed that the burden surface profile is typical “V” shape, which means the charged material at the largest tilting angle comes near to the wall side, leading to the largest height in the wall side. From Table 4, the maximum tilting angle was 40.5° for coke and 37° for ore. The estimated falling point lines of coke and ore during a chute rotation calculated from simulation model are shown in Fig. 17. The distance from falling point of coke to wall is around 0.45–0.9 m, but 0.9–1.35 m for ore. Therefore, burden distribution of \( V \) shape was thought to be attained in case of coke charging.

For the comparison of measured plant data with computed result, the plant data are converted to dimensionless form firstly as shown below.

The \( H^{(4)} \) value for the last 4 charges are adopted as sum of each circumferential section value and represented by Eq. (17), \( V_j \) is the average volume flow rate of charging material at charging in jth stock line. This equation is used to calculate the dimensionless circumferential height distribution of the stock surface at wall side after filling-up.

\[
H^{(4)}_j = \sum_{i=1}^{4} \left[ \psi_j(C) \cdot V_j(C) + \psi_j(O) \cdot V_j(O) \right] / \sum_{i=1}^{4} \left[ V_j(C) + V_j(O) \right] \quad \ldots \ldots \ldots \ldots \ldots (17)
\]

\[
i = 1, \ldots, N
\]

There are two cases in assumption, one is ore-ignored case that means charged ore at maximum tilting angle didn’t contribute to the burden height at wall side, which is plotted in Fig. 18(a), and the other is ore-considered case that means charged ore at maximum tilting angle contributes to the burden height at wall side, which is plotted in Fig. 18(b). The dots represent the measured data and are approximated by the dashed lines in fourth-order polynomial in both Figs. 18(a) and 18(b). The simulated results given in solid lines represent a case ore-ignored and ore-considered respectively in Figs. 18(a) and 18(b). It is clearly observed that the ore-ignored case is in good accordance with the plant measurement results. The reason why the contribution of charged
ore to burden height could be ignored at wall-side is because the layer thickness of coke charge at wall was thought to be superior to that of ore charge after the mechanism mentioned above. We are now going to develop a cylindrically symmetric burden distribution model of BF and will make the point more clear in the future.

From Fig. 18, materials charged in the South-West direction are minimum in the circumferential direction, and it is thought that it leads to a dislocation of minimum height position at top surface to South-West side. This can explain the dislocation of center point to South-West side as measured in Fig. 11.

5. Conclusion

In Hongfa No.1 blast furnace, 2 500 m³ in capacity, of Sha-steel, measurements on circumferential imbalance at the furnace top were done in burden materials filling process before the blow-in. A mathematical simulation model was built to make clear the obtained results quantitatively. The results obtained are as follows:

1) The relationships between the flow rate and the flow control gate opening were measured under different bunker-material combinations, and they are used as input for mathematical model on circumferential imbalance at the blast furnace top. It is found that smaller flow control gate opening leads to eccentric burden centroid in vertical tube, as a consequence the circumferential imbalance of both distributions in charging rate and falling point on the stock surface occurs.

2) The burden trajectory was measured in the blast furnace during the filling-up of burden before blow-in by using cross laser beam method and compared with simulation results. They are in good agreement with each other except small tilting angle of the chute.

3) From simulation results, influence of such factors as flow control gate opening, chute rotating speed, the height of stock line and tilting angle was quantitatively investigated on the distributions of materials charging rate and falling point.

4) As for the unevenness in circumferential surface height distribution of burden materials, the uneven height distribution occurs in the ordinary operation of paralell-type bell-less top, and the distribution can not be made fully uniform by making sequential use of bunker change for coke and ore charge or change in chute rotation direction. However, change of rotation direction is thought to be much effective in correcting the unevenness.

5) In case of the circumferential unevenness of volumetric ore/coke distribution, application of bunker change in turn at coke and ore charging is an effective method to realize circumferential even distribution of ore/coke.

6) The distributions of burden heights both at wall side in circumferential direction and in radial direction at the furnace top were measured after the filling-up for blow-in. The results coincide well with the simulation results and dislocation of the center point at the burden surface was explained by simulation results of circumferential height distribution.

REFERENCES