Effects of Coke Charging Pattern on Burden Distribution and Normal Force Distribution in COREX Melter Gasifier

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Abstract. Based on the principle of discrete element method (DEM), a 2D slot model of COREX Melter Gasifier (MG) being used to study the burden movement under different coke charging patterns has been established. Two kinds of coke charging patterns were introduced to be used to analyze the burden movement in MG. The burden distribution and normal force distribution were analyzed by using the proposed model at a microscopic level. The results show that the burden movement under different coke charging patterns presents different burden movement phenomenon.

1. Introduction

The COREX developed by VAI is a smelt reduction iron-making process, that the lump ore or pellet would be served as the raw materials and the non-coking coal would be served as the reducing agent or fuel [1]. The first set of COREX 3000 at Bao steel began production in November 2007. The development thought of COREX process is iron-making with coal, but it has found that it was not possible to smelt iron without certain proportion coke [2]. The coke proportion of COREX 2000 at India and South Africa is about 20% and 40%, separately. With the development of the COREX process, its furnace hearth diameter extends from 7.5 m to 9.4 m, then this process has higher demand of gas permeability of the burden column. Therefore, the coke proportion in COREX 3000 is increased to about 25%. In addition, the whole COREX was moved to Bayi steel. In order to adapt to the resource of Xinjiang, some scholars put forward a project that using the semi-coke with high strength performance and low pulverization ratio instead of lump coal [3].

The COREX unit is made up of pre-reduction shaft furnace and MG, and the function of MG is similar to the lower half of blast furnace, that the gas formed in furnace would experience redistribution to be discharged. In the raceway, the high-temperature gas generated by oxygen and semi-coke forms the initial distribution, and the gas going through the burden bed forms the secondary distribution. In the actual production of blast furnace, the furnace status would suffer abnormal conditions if the gas permeability and liquid permeability of lump zone and deadman can not be assured on account of low coke quality. The blast furnace employs the coke charging pattern [4, 5] to
improve the permeability of burden column and ensure the central gas flow smoothly. Unlike the BF, the cause of bad gas and liquid permeability of burden as well as without central gas channel may relate to the factors such as mixed charging pattern employed by the MG, the tuyeres blowing pure oxygen and the expansion of hearth diameter and so on [6, 7, 8], thus affects the gas efficiency. Unfortunately, there are fewer researches of burden charging in MG, so the study focuses on the experience of blast furnace. In this paper, the effects of different coke charging patterns on burden movement were discussed based on the DEM and some interesting results such as which can provide references for further calculation of gas distribution were obtained.

2. Mathematical model

2.1. Introduction of simulation method

DEM [9] started relatively late in China, and its originally research subjects are mainly focus on the mechanical behavior such as rock and discontinuous media. The interaction force between two particles represented by spring-damper-friction plate is shown in Figure 1.

![Spring-damper-slider-roller model](image)

**Figure 1. Spring-damper-slider-roller model**

Figure 2 shows the depiction of interaction forces between two particles that the particle $i$ bears two kinds of forces which are gravity $m_i g$ and the contact force between particle and particle, as well as particle and wall. In addition, the particle $i$ bears two kinds of torques which are tangential torque and rolling friction torque. Based on the Newton’s second law of motion, the governing equations for the translational and rotational motion of particle $i$ can be written as

$$m_i \frac{d\mathbf{v}_i}{dt} = \sum_{j=1}^{k} (F_{\text{cn},ij} + F_{\text{dn},ij} + F_{\text{ct},ij} + F_{\text{dt},ij}) + m_i g \tag{1}$$

$$I_i \frac{d\omega_i}{dt} = \sum_{j=1}^{k} (T_{ij} + M_{ij}) \tag{2}$$

Where, $m_i$, $I_i$, $v_i$, $\omega_i$ represent mass, rotational inertia, translational velocity and rotational velocity of particle $i$, respectively. $m_i g$ represents the gravity of particle $i$. $F_{\text{cn},ij}$, $F_{\text{ct},ij}$, $F_{\text{dn},ij}$, $F_{\text{dt},ij}$, $T_{ij}$, $M_{ij}$
represent the normal and tangential contact force, normal and tangential damp force, tangential and rolling friction torque acting on \( i \), respectively. \( k_i \) denotes the particle numbers contacting with particle \( i \).

**Figure 2.** Depiction of interaction forces between two particles

The computational equations about the contact force between particle-particle and also particle-wall adopted in this paper were taken from available literature [10].

### 2.2. Simulation conditions

**Figure 3.** Computation geometry domain

The laboratory has been equipped with IBM P55A workstation and its computing power can achieve 0.5 million particles; nevertheless, it cannot accomplish the calculation that there are millions and millions particles in industrial production. Consequently, according to the study of B. Wright [11] and to simplify the calculation, a 1/30 slot model was established on the basis of MG’s prototype of
COREX 3000. The raceway was assumed to be sphere and the cohesive zone was set as inverse V shape. The transient diameter of DRI particles in the cohesive zone is determined by equation (3) [12]. The computational geometry domain is shown in Figure 3. The simulation conditions adopted for the burden movement of DEM model are listed in Table 1.

**Table 1. Physical properties of burden and simulated conditions**

| Variables                        | Coke | DRI  |
|----------------------------------|------|------|
| Particle shape                   | Sphere |      |
| Particle number, $N$ (-)         | 16000 |      |
| Particle density, $\rho_p$ (kg·m⁻³) | 1100 | 4000 |
| Particle diameter, $d_p$ (mm)    | 10   | 10   |
| Particle-particle sliding frictional coefficient, $\mu_{s, pp}$ | 0.5 | 0.3 |
| Particle-particle rolling frictional coefficient, $\mu_{r, pp}$ | 0.0005 | 0.00005 |
| Young’s modulus of particle, $E_p$ (Pa) | 2160000 |  |
| Young’s modulus of wall, $E_w$ (Pa) | 2160000 |  |
| Poisson’s ratio of particle, $\nu_p$ | 0.3 |  |
| Poisson’s ratio of wall, $\nu_w$ | 0.3 |  |
| Time step, $\Delta t$ (s)       | $1.0 \times 10^{-5}$ |  |

Where $d_{0,DRI}$ is the critical diameter of DRI particles when leaving the cohesive zone (set to 0.4$d_{0,DRI}$ and $d_{0,DRI}$ is the original diameter of DRI particles), and $Z_{top}$, $Z_{bot}$ and $Z_p$ are vertical distances to the hearth bottom wall as shown in Figure 4.

$$d_{DRI} = d_{0,DRI} - \left( d_{0,DRI} - d_{c,DRI} \right) \left( Z_{top} - Z_p \right) \left( Z_{top} - Z_{bot} \right)$$

(3)

Where $d_{c,DRI}$ is the critical diameter of DRI particles when leaving the cohesive zone (set to 0.4$d_{0,DRI}$ and $d_{0,DRI}$ is the original diameter of DRI particles), and $Z_{top}$, $Z_{bot}$ and $Z_p$ are vertical distances to the hearth bottom wall as shown in Figure 4.

**Figure 4. Cohesive zone with inverse V shape**

2.3. **Presentation of coke charging pattern**

Two kinds of coke charging patterns including center coke charging and intermediate coke charging were introduced in this study. Coke charging is that a small amount of coke should be added to certain region in order to form coke column, then the ore to coke ratio in this region would be decreased to improve the gas permeability of burden column via more gas. The amount of center coke charging refers to the blast furnace and the width of center coke charging is set as 3 cm. Via the volume calculation of furnace profile, center coke charging accounts for 8.7 percent of the total amount of coke. Currently, it is in lack of researches related to intermediate coke charging in MG as well as in BF so far. Therefore, the amount of intermediate coke charging is the same as the amount of center...
coke charging. Figure 5 shows the schematic of coke charging position in which the gray area represents the center coke charging and the black area represents the intermediate coke charging. Figure 6 and Figure 7 show the coke charging patterns in DEM simulation.

![Figure 5. Schematic of coke charging position](image)

![Figure 6. Schematic of center coke charging pattern in DEM simulation](image)

![Figure 7. Schematic of intermediate coke charging pattern in DEM simulation](image)

3. Results and discussion

3.1. Effect of coke charging pattern on burden distribution

Figure 8 and Figure 9 show the burden distribution under different coke charging patterns. The position of center coke charging and intermediate coke charging is shown as black lines in Figure 8 and Figure 9, separately. As shown in Figure 8 and Figure 9, unlike the mixed charging pattern, the cohesive zone formed by the white solid line appears to break phenomenon at the coke charging location no matter what kinds of coke charging patterns adopted in COREX. For the center coke charging pattern, the range of center coke column widens with the descending of burden. The reason is
that the descending rate of center burden could be slow and the coke moves to both sides presenting decentralised movement, as shown in Figure 8 formed by the blue solid line. While for the intermediate coke charging, the range of intermediate coke column narrows with the descending of burden caused by the squeezing action among burden. Also, some DRI particles enter the coke column and then move inside. When the DRI particles reach cohesive zone, the diameter of particles could change according to the equation (3).

**Figure 8.** Burden distribution under center coke charging pattern

**Figure 9.** Burden distribution under intermediate coke charging pattern

### 3.2. Effect of coke charging pattern on normal force distribution

Figure 10 and Figure 11 show the normal force distribution under different coke charging patterns. As can be seen from the figures, the particles located in lower-center zone experience stronger normal force. With the addition of center coke column and intermediate coke column, the cohesive zone appears breakage in the coke charging location, and causing different normal force distribution in MG.
4. Conclusion

Based on the principle of DEM, a 2D slot model of MG being used to study the burden movement has been established. The burden distribution and normal force distribution were analyzed by using the proposed model at a microscopic level. The following results were obtained.

1. For the mixed charging pattern adopted now by MG and greatly developed study methods, there are few researches about the gas distribution under different coke charging patterns nowadays. A method that charging coke column to MG was firstly put forward to improve the gas permeability. And the burden movement under different coke charging patterns was analyzed by DEM.

2. For the center coke charging pattern, the range of center coke column widens with the descending of burden. While for the intermediate coke charging, the range of intermediate coke column narrows with the descending of burden caused by the squeezing action among burden.

3. With the addition of center coke column and intermediate coke column, the cohesive zone appears breakage in the coke charging location, and causing different normal force distribution in MG.

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