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RESEARCH ON RELATIONSHIP BETWEEN CHARGING PRINCIPLE AND HEARTH ACTIVITY OF BLAST FURNACE (BF)

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The relationship between charging principle and hearth activity of blast furnace has been clarified in this research. The voidage and diameter of coke in deadman which are related to charging principle serve as two pivotal factors for hearth activity. Discrete element method (DEM) analog simulation illustrates that both central and non-central coke charging result in the stratified structure of coke and ore in BF center. It is suggested to take non-central coke charging to promote central gas flow if the quality of raw materials meets the corresponding requirements. For the BF with poor raw materials, it is reasonable to employ central coke charging to keep the long-term stability of the production.

Key words: blast furnace, charging principle, coke, ore, statistical results

INTRODUCTION

Recent years, ironmaking industry in China was developing rapidly, the main technical and economical indexes of certain BFs represented by Baosteel and Shougang were in world advanced level [1]. To form adaptive and reasonable operation principles, it is necessary to have a deep sight into the core problem of BF production: hearth activity [2]. In the past decades, a series of reduced scale experiments have been performed to explore the peculiarity of burden distribution [3]. The mechanism-based method in which the burden is treated as either discrete moving element or continuous flowing medium is another way to model burden distribution in blast furnace [4]. However, accurate description of burden distribution is still a huge challenge to the above methods due to the complexity of this process, such as the formation of mixed layer and coke collapse.

In this paper, we propose a strategy for the formulation and optimization of coke charging scheme based on the analysis of statistical results derived from BFs in China. The relationship between these factors and charging modes were clarified by DEM simulation and mechanism analysis of particles motion on surface layer.

THEORETICAL ANALYSIS

The flow resistance coefficient of liquid, f_L, can be quantitively described by Eq. (1) [5].

$$f_L = 180 \times \frac{(1-\varepsilon)^2}{\varepsilon^3} \times \frac{1}{\varphi^2 d^2} \times \frac{\mu}{\rho} \times \frac{\upsilon_0}{g} \times (\frac{D}{H})^2 \qquad (1)$$

Where f_L is the flow resistance coefficient; e is the voidage of the deadman coke, f is the shape factor of the deadman coke, d is the diameter of the deadman coke / mm, m is the viscosity of liquid slag and iron in hearth / Pa×s, r is the density of the liquid slag and iron in hearth / t×m^{-3}, n_0 is the average flow rate of liquid slag and iron flowing through the hearth section / m×s^{-1}, g is gravitational acceleration / 9,81 m×s^{-2}, D is the hearth diameter / m, H is the thickness of slag and iron layer as soon as beginning to tap slag and iron / m. It is assumed that both f and r remain unchanged, and the ratios of e_{in} to e_{out}, d_{in} to d_{out}, m_{in} to m_{out} (the subscript 'in' and 'out' represent the states that the burden get into and out of the hearth respectively) all keep constant. Then, for a specific BF, the absolute value difference between $f_{L\text{-}in}$ and $f_{L\text{-}out}$ depends on ein and din which can be expressed as Eq. (2).

$$\left| f_{L-in} - f_{L-out} \right| \propto \frac{(1-\varepsilon_{in})^2}{\varepsilon_{in}^3 d_{in}^2} \qquad (2)$$

This formula reveals that the hearth activity is sensitive to the voidage and diameter of deadman coke which are closely related to the coke charing scheme and coke quality. For the given raw materials, the charging principle contributing to central aggregation of large particles and enhancing central gas flow will efficiently promote the hearth activity.

CHARGING PRINCIPLE

DEM analog simulation

For bell-less BFs in China, central coke charging and non-central coke charging are the two common

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modes for burden distribution [6]. In the view of statistical results, it seems that the performance of a BF with non-central coke charging is better than that with central coke charging. Anyway, the charging principle indeed plays an important role on the hearth activity. In order to clarify the difference between the two charging modes and the effects of charging principle on the voidage of deadman, DEM analog simulations of surface and layer distribution shape by the two charging modes have been conducted in an identical 2 500 m^3 BF, respectively. Table 3 shows the burden distribution matrices of non-central and central coke charging. An obvious difference on burden distribution between the two modes is that some coke is directly placed in the BF center by decreasing gear angle to 14,3 ° during central coke charging while the gear angle always keeps above 26,1 ° during non-central coke charging. The weight of coke batch is 16 t, the weight of ore batch is 59 t, the depth of stockline is 1,3 m, so the the surface shape and layer distribution shape formed by the two modes are respectively simulated by DEM [7].

Table 1 **Burden distribution matrices of 2 500 m^3 BF**

Angle / °	38,7	36,6	34,4	32,0	29,3	26,1	14,3
Coke / Lap	3	2	2	2	2	2	
Ore / Lap	3	2	2	2	2		
Coke / Lap	3	2	2	2	2	1	1
Ore / Lap	3	2	2	2	2		

The vertical section views of burden distribution charged by the two modes are both presented in Figure 1. Clearly, the ore and coke along the horizontal direction are stratified successively in either non-central or central coke charging process. During non-central coke charging, some coke and ore on the layer surface is driven to the BF center along the slope by their own gravity and the impact from falling burden. Meanwhile, the burden layers tend to collapse due to the gravitational force from the continuous burden accumulation. Thus, as shown in Figure 1 - A, the coke and ore in the BF center also distribute layer by layer due to the synergy of the above effects. During central coke charging, the movement of burden from BF edge to center is significantly inhibited because the slope of surface layer becomes flat by putting part of coke into the BF center directly. By contrast, as shown in Figure 1 - B, the upper BF center prefers forming pure coke layers rather than mixed layers. Owing to the collapse of burden layers, the stratified structure of coke and ore inevitably appeared in the center of middle and lower BF.

On the surface, both the two modes can maintain central gas flow by placing some coke in BF center directly and indirectly. In fact, there exists significant difference on the voidage of deadman between the two. To understand this point, it is necessary to have a deep sight into the motion behaviour of coke in the non-central coke charging. As a coke particle falls on the sur-

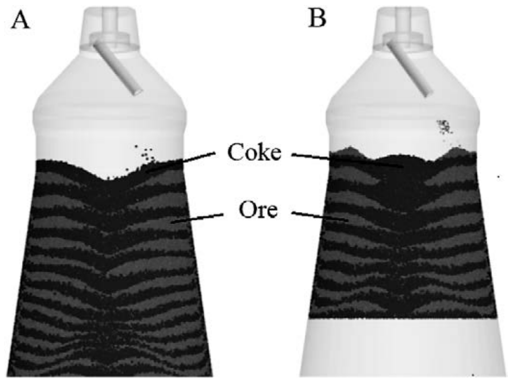

Figure 1 The vertical section views of burden distribution with non-central and central coke charging (A. non-central coke charging, B. central coke charging.)

face layer, part of its kinetic energy loses in the inelastic collisions and the remaining part drives the particle to roll along the slope. At this time, the resistance in particle movement is derived from the frication effect and the collisions with other particles on the slope. The latter may play a major role in impeding particle motion on an uneven slope comprising of varying shape and size of particles. Several diagrams in Figure 2 demonstrate the motion behaviour of coke particles and the coke distribution in a BF with non-central coke charging. As shown in Figure 2 - A, a particle tends to be stopped by the obstacle with similar size. And the particles with large size are much easier to get over a given obstacle (Figure 2 - B). Thus, in the surface coke layer large particles are closer to the BF centerline than small particles (Figure 2 - C). With the burden accumulating on the coke layer, some particles on the surface are pushed to the BF center like those marked with 1, 2, 3, 4 and 5 in Figure 2 - C and 2 - D. Therefore, the average coke granularity in the BF center is generally larger than that in the BF edge. By contrast, the center aggregation of large particles in the BF with central coke charging is insignificant due to the inhibition on horizontal movement of burden. That is to say, it is better to adopt non-central coke charging to develop central gas flow and improve hearth activity.

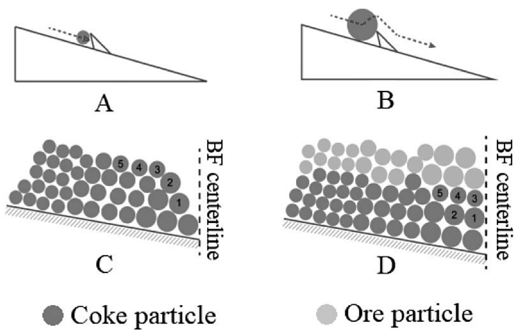

Figure 2 Schematic diagrams of coke distribution in BF with non-central coke charging (A. Motion behaviour of small coke paricle; B. Motion behaviour of big particle; C. Coke distribution in surface layer; D. Coke distribution in the inner layer)

Production practice

According to Eq. (2), hearth activity can be improved by enlarging the voidage of deadman. According to the DEM simulation results and theoretical analysis, the development of central gas flow prefers central coke charging rather than non-central coke charging. To further evaluate the effect of charging principle on hearth activity, the performances of two BFs of both 4 747 m^3 with different charging modes are in detailed contrast. The one with central coke charging is marked as BF A and the other with non-central coke charging as BF B. Their burden distribution matrices are both presented in Table 2 .

Table 2 **Burden distribution matrices of BF A and B**

BF A								
Angle / °	39	37	35	32	29	26	23	13,5
Coke / Lap	2,3	2	2	2	2	1	0	4,2
Ore / Lap	2	3,5	3,5	3	1	0	0	0
BF B								
Angle / °	42	40	37,5	35	32	29	26	
Coke / Lap	3	3	3	2	2	2	1	
Ore / Lap	3	3	3	3	2			

Table 3 shows the main production indexes of the two BFs. The total reductant ratios of BF A and B are 516 and 483 kg/t, respectively. The performance of BF B is obviously better than that of BF A for that the latter consumes more energy. Taking the discrepancy in the quality of raw material into account, we cannot entirely ascribe the performance difference to the charging principle. However, does the transformation of charging principle from central to non-central coke really work on the improvement of hearth activity for a specific BF? A significant attempt has been carried out on BF A to reduce the reductant consumption. The process spanning of two modes comprises of a series of experiments and can be divided into three main stages as follows: firstly, reduce the edge ores gradually; secondly, reduce the central coke and adjust the width of the coke platform; thirdly, completely cancel central coke. Overall, the quality of raw material kept stable throughout the process. During the same period, we consecutively tracked the variations of main production indexes. It was found that as the quantity of feeding central coke was cut down in the second stage, the gas utilization rate increased to 50 % and the reductant ratio decreased to 495 kg/t. In terms of these results, reducing central coke in a BF with central coke charging is indeed conductive to raise hearth activity. However, after canceling the central coke completely in the third stage, BF A became volatile accompanying with frequent slipping and hanging. In particular, the pressure of blast air was forced to increase to supplement the decreased central gas flow. But the blast air volume was insufficient to hold its pressure. In order to keep BF A in stability and safety, the original central coke charging principle was performed again.

Table 3 **Main production indexes of BF A and B**

BF	Output / $t \cdot d^{-1}$	Coke burden	Nut coke ratio / $kg \cdot t^{-1}$	Coke ratio / $kg \cdot t^{-1}$
A	9 950	5,06	53	322
B	10 659	5,84	24	278
BF	Coal ratio / $kg \cdot t^{-1}$	Reductant ratio / $kg \cdot t^{-1}$	Air volume / $m^3 \cdot min^{-1}$	Gas utilization / %
A	141	516	6 500	46,0
B	181	483	6 900	51,5

The reason why non-central coke charging is unsuitable to BF A is that the burden quality does not meet the corresponding requirements. As mentioned above, large particles of coke tend to aggregate in BF center during non-central coke charging. Therefore, the permeability of BF center with non-central coke charging is closely related to the quality of feeding coke, particularly particle size distribution and mechanical strength. Feeding coke with sufficient strength and large size will generate enough channels in BF center and heighten the voidage of deadman. Table 4 shows the main indexes of raw materials fed into BF A and B. The average particle size of coke from BF A is 50,86 mm less than that from BF B (52,73 mm). One hand, the center aggregation of large coke particles in BF A is worse than that in BF B. On the other, according to Eq. (2), the flow resistance coefficient of BF A is less than that of BF B due to that the coke diameter fed into the former is less that fed into the latter. Thus, even though BF A adopts the same burden matrices with BF B, its performance is still inferior to the latter. Besides, the ratio of sinter smaller than 5 mm from BF A is higher than that from BF B. Samll ore particles are prone to enter into the coke layers, resulting in the deterioration of deadman permeability. This might explain why the non-central coke charging is unsuitable for BF A. Placing some coke directly into the center of BF A can hinder the horizontal movement of ore particles so as to maintain the central gas flow. Thus, a combination of central and non-central coke charging, defined as hybrid charging, may promote the hearth activity of BF A.

Table 4 **Main raw materials of BF A and B**

BF	Coke				
	Ash / mas. %	Sulfur / mas. %	M40 / %	M10 / %	CRI / %
A	12,48	0,82	89,1	6,0	22,05
B	11,73	0,64	87,4	5,1	24,26
BF	Coke			Sinter	
	CSR / %	Particle size / mm		TFe / %	<5mm / %
A	67,14	50,86		56,61	7,8
B	68, 60	52,73		58,51	3,5

CONCLUSION

- The voidage and diameter of coke in deadman which are closely related to charging principle serve as two pivotal factors in the hearth activity.
- DEM analog simulation illustrates that both central and non-central coke charging result in the stratified structure of coke and ore in BF center. Owing to the central aggregation of large burden particles, it is suggested to take non-central coke charging to promote central gas flow if the quality of raw materials meets the corresponding requirements, especially the size distribution and mechanical strength of coke particles.
- To keep the long-term stability of the blast furnace production, the charging principle should be projected according to the quality of raw materials.

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Note: Y. ZHAO is responsible for English language, Anhui, China