Development of Physical Simulation Experiment Technology for Blast Furnace Coal Injection Ironmaking

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Abstract: The coal injection process of blast furnace has certain particularity. Including gas movement, material movement, coal gasification process, coal combustion and other phenomena. However, the actual conditions of the laboratory are limited, and these phenomena need to be simplified. The key of physical simulation is to design the experimental model correctly. The basic theory of the correct design of the experimental model is the principle of similarity, that is, to establish the experimental model satisfying the main similarity conditions. So as to ensure that the main physical phenomena in the model and prototype are similar. A series of measurements were carried out during the experiment. Get the knowledge of the corresponding change law of the prototype. In the process of experiment, it is necessary to make sure that the model has the same number, material balance and heat balance. Otherwise, it is difficult to achieve the equilibrium state in the experimental process and obtain meaningful experimental results.

1 Background

After injecting pulverized coal into blast furnace, part of pulverized coal is burned in front of tuyere, which changes the original operation conditions of blast furnace and has a significant impact on furnace condition. At the same time, unburned pulverized coal will also have a significant impact on the permeability of block zone, soft melt zone and dropping zone. So the researchers studied the influence of pulverized coal combustion and unburned pulverized coal distribution. Research methods include physical simulation and mathematical simulation [1].

Fig.1 Coal injection structure of blast furnace tuyere
In order to study the influence of coal injection process on blast furnace ironmaking by physical simulation method, based on the actual production data and the calculation results of static regional model, the physical model is established according to the similarity theory. The results of the coal injection area model show that the tuyere area and the packed bed area have an important influence on the gas generation, heat supply, slag iron generation and other metallurgical processes. On this basis, the main phenomena of the prototype are selected, the secondary phenomena of the prototype are simplified, and the physical model is established.

Physical simulation is a method to simulate real physical process through laboratory physical experiment. The main characteristics of the real physical process are studied in the laboratory on the basis of reducing the design model according to the actual geometric size and satisfying certain similarity conditions. Compared with the field experiment, the physical simulation experiment is easy to control the experimental conditions, high reproducibility of the experimental results, and save a lot of human, material and financial resources. It can be more convenient to carry out research in many aspects, and can obtain the experimental results with certain regularity. It is an important means of laboratory research.

Due to the lack of research on blast furnace ironmaking process, the COREX physical simulation method is used as the theoretical basis of this study. The key to evaluate the physical simulation is the physical model. The physical model to simulate the blast furnace ironmaking process has inherent limitations. It is impossible to fully satisfy all the similar conditions. We should select the appropriate similarity criterion according to the specific requirements. Physical model of blast furnace based on similarity theory.

2 Block zone

In 1952, Sabri Ergun [2] proposed a semi empirical formula for the pressure difference of packed bed (similar to the block belt structure) on the basis of previous work and a large number of experimental facts, which is the famous Ergen equation.

$$\frac{\Delta P}{L} = k_1 \frac{(1 - \varepsilon)^2 \mu_m V_m}{\varepsilon d_p^2} + k_2 \frac{(1 - \varepsilon) Gv_m}{\varepsilon d_p^3}$$

In the equation, the first term on the right represents viscous resistance, and the second term represents inertial resistance. It is considered that the factors that determine the pressure difference in the packed bed include the fluid velocity, the viscosity and density of the fluid, the void ratio of the packed bed, the size, shape and surface roughness of the particles.

C e Schwartz [3] experiments were carried out to investigate the distribution of air flow in the packed bed to verify whether the air flow rate through the uniform packed bed section was uniform. The height of the packed bed is 4 feet and the diameter is 2 to 4 inches. The results show that the air velocity in the packed bed is not uniformly distributed, and the maximum value of the airflow appears at a particle size away from the tube wall. Moreover, with the decrease of the ratio of the diameter of the tube to the diameter of the ball, the non-uniform phenomenon is more obvious.

Ying Weifeng et al. [4-5] through the physical simulation experiment of COREX pre reduction shaft furnace half cycle cold state model, it is found that the reduction rate of iron ore in the inner diameter of the furnace is quite different, the gas-solid reaction process in the furnace is accelerated with the increase of gas flow rate, and the reaction process is uneven in axial and radial direction.

Chen et al. [6] obtained the solid viscosity PA ÷ s through the experimental study of two-dimensional cold model of blast furnace. The model can simulate the solid flow in the cold model experiment of blast furnace. However, this model can not describe the phenomena such as sloughing, suspension and channel flow in the furnace. The equation is complex and varies with the furnace charge.

From the above experimental research on packed bed, because the flow rate in the bed is not easy to be measured and the pressure value is easy to be measured, the gas in the packed bed is mostly measured by the method of bed pressure, etc., which has achieved good experimental results.
3 Cohesive zone

Chen Shichao and [7] set up a cold flat plexiglass model to simulate coke and ore with soybeans and mung beans. The soft melting zone was made of light foam brick, and the outlet was cold wind. The influence of the position and shape of the melted zone on the distribution of air flow, the permeability of the material column and the pressure loss was studied.

Wu Wenhua and [8] set up a cold model with a geometric ratio of 1:30 to the original, simulating the coke and ore with soybeans and mung beans, and simulating the soft melting zone with light foam plastic blocks. The variation of static pressure and pressure drop strength of the furnace body under different shapes of the soft melting zone in the process of blast furnace ironmaking was studied experimentally, and the shape and position of the soft melting zone in the production of an ironmaking plant were speculated according to the experimental results.

Du Hegui et al [9-10] established a two-dimensional model, whose section geometry size is 1 / 30 of 1500 blast furnace. A temperature and pressure measuring device is set up on the model to simulate coke with a diameter of 3-5 mm for ore and 7-11 mm for coke. The inverted V-type, W-type and V-type soft melt zones were studied experimentally. The distribution of gas flow in different position and shape of soft melt zone was measured, and the gas flow direction and isobaric line were described. The research results show that on the basis of ensuring the fine material and smooth flow, it is beneficial to reduce the height of the soft melt zone properly, to improve the utilization of gas and to reduce the coke ratio; the suitable position of the soft melt zone should be determined according to the comprehensive smelting conditions, generally starting from the lower part of the furnace body; the air flow distribution of the inverted-V structure is reasonable, the hearth is active, the central air flow is open, it is easy to stabilize the edge air flow, protect the furnace wall, and lift. When the top layer of the inverted V-shaped soft melting zone appears at a high position, the pressure difference in the furnace will be reduced, which is conducive to the enhancement of air supply, but the indirect reduction area will be reduced.

Gongfeng [11] et al. Established a three-dimensional physical model of blast furnace in cold state. There are eight pressure taps on the model. The model can accurately express the influence of some practical operation conditions of industrial production on mixed charging effect. The results show that the pressure difference of blast furnace block zone can be reduced by replacing layer charging smelting with mixed charging smelting under appropriate conditions; the larger the batch of materials used in blast furnace, the more obvious the mixed charging effect; the greater the powder content of sinter, the better the permeability of mixed charging.

4 Dropping zone and tuyere zone

Below the soft melt zone is a packed bed of coke and semi coke. A large number of slag iron melts continuously in the soft melting zone. When slag iron passes through this zone, it will drop like...
rain. This zone is called dropping zone. In blast furnace, this area is mainly composed of semi coke, which is called semi coke bed. Due to the complex physical conditions in the dropping zone, the previous studies on the dropping zone are limited.

The tuyere is located in the middle of the dropping belt. A large amount of oxygen is blown into the tuyere. Oxygen, coke and semi coke are burned to generate a large amount of gas, forming a combustion belt. Because it is difficult to study the combustion zone directly, a lot of research results have been obtained.

The ironmaking process of COREX melting gasifier is very similar to that of blast furnace, and its physical simulation has certain reference significance. Luo Zhiguo [12-16] et al. Based on the actual size and operation parameters of COREX, assuming that there are only gas and solid phases in the raceway, according to the similarity criterion, established the COREX Melting Gasifier model to study the raceway. In the experiment, polyethylene particles were used as the filling material of the model to study the formation process of the raceway. Through the boundary of the raceway determined by the particle velocity field, the effects of wind speed, discharge speed, material layer height and other factors on the size of the raceway were analyzed.

Hatano [17] et al. Simulated the pressure field and velocity field in the raceway of tuyere by using soybean, millet, wheat and sand with different particle sizes instead of coke particles in the cold model. They pointed out that when the raceway is completely in turbulence state, the flow streamline is approximately constant, the static pressure distribution coefficient tends to be stable, and the raceway depth reaches the maximum value.Hiroshi et al. [18-19] studied the movement of solid particles in the raceway of blast furnace and the size and shape of dead material column through two-dimensional and three-dimensional cold model. They pointed out that the lower part of blast furnace mainly consists of three characteristic areas: fast flow area, dead material column keeping still and quasi retention zone above the dead material column, and described the characteristics of each area accordingly.

Durnoff et al [20] established a fan-shaped physical model. The fan-shaped model represents the tuyere area of blast furnace. One wall of the model is glass. The raceway area was directly observed visually, and the effects of wind speed and tuyere inclination angle on the raceway depth and air flow distribution were obtained.Morimasa et al. [21] made a detailed study on the coal injection combustion in the tuyere raceway of blast furnace by using a three-dimensional physical model, and finally found that the coal injection rate and the size of coal powder particles have an impact on the charge drop and gas permeability.Nakamura et al. [22] measured the shape of the raceway in the model experiment. According to the experimental results, it is considered that the raceway is an ellipse which takes the depth as the long axis and is connected with the blast jet area. The relationship between the width of the raceway and the depth of the raceway is proposed.

Chen Juhua et al [23-24] established a three-dimensional cold model of the tuyere raceway of blast furnace based on the similarity theory. For the first time, the three-dimensional velocity, particle size and flux of gas and particle were measured by using the three-dimensional phase Doppler Analyzer PDA under different air pressure, air velocity and different simulated particle conditions. The relationship between the condition and the structural parameters of the raceway.

5 Conclusion

The key of physical simulation is to design the experimental model correctly. The basic theory of the correct design of the experimental model is the principle of similarity, that is, to establish the experimental model satisfying the main similarity conditions. So as to ensure that the main physical phenomena in the model and prototype are similar. A series of measurements were carried out during the experiment. Get the knowledge of the corresponding change law of the prototype. During the experiment, the material balance and heat balance of the model must be ensured. Otherwise, it is difficult to achieve the equilibrium state in the experimental process and obtain meaningful experimental results. The coal injection process of blast furnace has certain particularity, including gas movement, temperature drop process and combustion process, material movement, heating, melting process, coal gasification process, coal combustion and other phenomena. However, the actual conditions of the laboratory are limited, and these phenomena need to be simplified.
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References
[1] Ding Zhimin, Jiang Xin, Wei Guo, Shen Fengman. Numerical simulation of the influence of soft melt zone type on the distribution of unburned pulverized coal in blast furnace [J]. Journal of Northeast University (NATURAL SCIENCE EDITION), 2018, 39 (09): 1242-1247
[2] Ergun S. Fluid flow through packed columns [J], Chemical Engineering Progress, 1952, (2): 89.
[3] Schwartz C E, Smith J M. Flow distribution in packed beds [J], Industrial and Engineering Chemistry, 1953, (6): 1209.
[4] Ying Weifeng, Sun Ye, Luo Zhiguo, et al. Numerical physical simulation of COREX shaft furnace [J], Journal of process engineering, 2009, 9 (S1): 292-295.
[5] Ying Weifeng, Sun Ye, Luo Zhiguo, et al. Physical simulation of COREX pre reduction shaft furnace reaction process [J], Journal of materials and metallurgy, 2010, 9 (1): 1-6
[6] Chen J Z, Akiyama T. Modeling of solid flow in moving beds [J], ISIJ International, 1993, (6): 664.
[7] Chen Shichao, Li Wenzhong, Du Rongshan, et al. Experimental study on gas mechanics model of blast furnace soft melting zone [J], Anshan Iron and Steel Institute, 1981, (3): 29-38
[8] Wu Wenhua, song Jiancheng, Jia Yinlong. Cold simulation of gas mechanics in the soft melting zone of blast furnace [J], steel research, 1993, (6): 38-42
[9] Du hegui, Che chuanren. Effect of soft melt zone on blast furnace strengthening smelting [J], steel, 1980, 15 (4): 21-27
[10] Du hegui, Che chuanren. Study on the influence of blast furnace soft melt zone on air distribution [J], Journal of Northeast Institute of technology, 1980, (1): 74-84
[11] Gong Feng, Du hegui, Yu zhengxia. Laboratory research on mixed charging of blast furnace ore and coke [J], ironmaking, 1989, (2): 6-10
[12] Di Zhanxia, Han lithao, Luo Zhiguo. Physical simulation of factors affecting the tuyere raceway of Melting Gasifier [J], Journal of materials and metallurgy, 2011, 10 (1): 6-18
[13] Luo Zhiguo, Sun Ye, Zou Zongshu. Digital image processing method of tuyere raceway [J], Journal of iron and steel research, 2011, 23 (1): 7-10
[14] Luo Zhiguo, Sun Ye, Liu Honghua, et al. Determination of the boundary of tuyere raceway by using particle velocity scalar field [J], Journal of process engineering, 2009, 9 (2): 228-232
[15] Sun Ye, Luo Zhiguo, Zou Zongshu, et al. Determination of the boundary of tuyere raceway by high-speed camera image processing [J], Journal of Northeast University, 2009, 30 (10): 1458-1461
[16] Sun Ye, Liu Honghua, Luo Zhiguo, et al. Physical simulation of the tuyere raceway of COREX Melting Gasifier [J], Journal of process engineering, 2009, 9 (S1): 254-358
[17] Hatano M, Fukuda M, Takeuchi M. An experimental study of the formation of raceway using a cold model [J], Tetsu-to-Hagane, 1976, 1: 25-32.
[18] Hiroshi T, Nobuyuki K. Cold model study on burden behaviour in the lower part of blast furnace [J], ISIJ International, 1993, 33 (6): 655-663.
[19] Hiroshi N T. Cold-model experiments on deadman renewal rate due to sink-float motion of hearth coke bed [J], ISIJ International, 2004, 44(12): 2127-2133.
[20] Rasmussen M R. Comparison of two different methods for evaluating the hydrodynamic performance of an industrial-scale fish-rearing unit [J], Aquaculture, 2004, 24(2): 397-416.
[21] Morimasa I. Behavior of fines in the blast furnace [J], ISIJ International, 1992, 32(4): 505-513.
[22] Nakamura M, Sugiyama T, Uno T, et al. Configuration of the raceway in the experimental furnace [J], Tetsu-to-Hagane, 1977, 63(1): 28-37.

[23] Chen Juhua. Mechanism analysis and 3D numerical simulation of blast furnace raceway [J], Journal of Shandong University (Engineering Edition), 2005, 35(1): 27-31

[24] Guo Shuyi, Chen Juhua. Phase Doppler analysis experiment of cold model in BF Raceway [J], Journal of iron and steel research, 2004, 16(4): 21-24