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EFFECTS OF PACKED STRUCTURE AND OPERATION CONDITIONS ON LIQUID FLOW BEHAVIOR IN BLAST FURNACE HEARTH

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Abstract: The circulating flow of molten iron is an important reason that results in the erosion of blast furnace hearth. In order to prolong the campaign life of blast furnace, it is necessary to analysis the flow state of molten iron. The three-dimensional mathematical model at steady state which takes the standard k-e and porous zone model into consideration is applied to simulate the flow field under different conditions. The results showed that floating of the deadman did strengthen molten iron circulating flow. Increasing the deadman diameter will increase the erosion of hearth and bottom. Deepen the depth of the taphole and reduce the taphole diameter can reduce the circulating flow. Effect of the taphole angle from 10° to 15° is not significant. The results can be used to provide guidance for protecting the blast furnace hearth.

Introduction

Blast furnace longevity has become an important symbol and component of the modern ironmaking technology progress. The circumferential flow of molten iron in the blast furnace hearth is the main reason of the hearth erosion.[1-2] The flow of molten iron in blast furnace hearth cannot be directly measured, therefore, it is necessary to use mathematical simulation method [3-6] to analyze the reasons and influencing factors of the circumferential flow of molten iron, so as to master the control measures and reduce the circumferential flow, in order to prolong the service life of blast furnace hearth.

With the development of computational fluid dynamic, numerical simulation has become a powerful method that can provide detailed information on liquid iron flow in the hearth. In this paper, a 1780 m^3 blast furnace in China is taken and a three-dimensional flow mathematical model is built, aimed at analyzing more details of molten iron flow under different conditions, including sinking and floating deadman, different size of deadman, different deadman depth, taphole diameter and taphole angle. Furthermore, the calculation results were compared and analyzed, so as to provide reference for production and optimum tapping operation conditions.

Model description

Mathematical model

The flow phenomena in the blast furnace hearth are extremely complex, the following assumptions are necessary in order to establish the model: (1) Assuming the hearth and deadman are cylindrical; (2) Only liquid iron is considered, while slag is ignored, and the flow is steady state; (3) The surface of liquid iron remains at a constant level; (4) Ignoring chemical reactions and solidification. Many governing equations are applied to describe the model, including the conservation equations of continuity and momentum, turbulent kinetic energy equation and turbulent kinetic energy dissipation equation. The flow resistance force through the coke bed is described by Ergun's equation. The dropping speed of the liquid iron level is applied as the entrance velocity.

Boundary conditions

The boundary conditions are: (1) The inlet is velocity entrance condition according to the blast furnace production rate; (2) The outlet is pressure-outlet, while the pressure at the taphole exit is set at 1 atm; (3) The hearth wall is no-slip condition using the standard wall function in FLUENT ; (4) The deadman is taken as porous medium, flow resistance force is described by Ergun's equation [5].

Physical model and simulation parameters

The physical model of the hearth is shown in Figure 1. The hearth diameter is 10 m with a height of 3 m. The taphole diameter is 0.055 m with a 10° angle to the horizontal. The molten iron production rate is 200 t/h, molten iron density is 7000 kg/m^3 and viscosity is 0.0067 Pa•s. The porosity of deadman is 0.4. Numerical simulation parameters and values are listed in Table I.

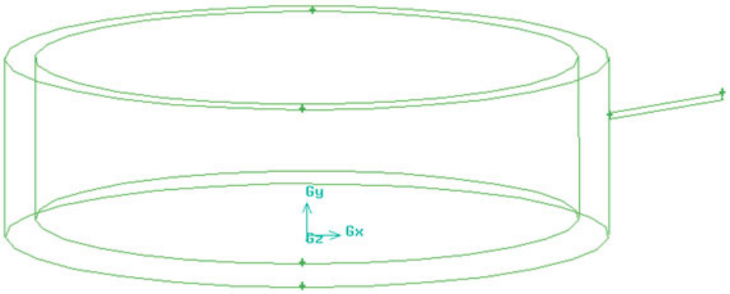


Figure 1. Physical model of blast furnace hearth

Table I. Simulation conditions

Item	Value		
Taphole angle /°	10	15	-
Taphole diameter /m	0.055	0.070	-
Deadman depth /m	1.5	2.0	2.5
Deanman floating height /m	0	0.3	-
Proportion of deadman diameter	50	70	90

Results and discussion

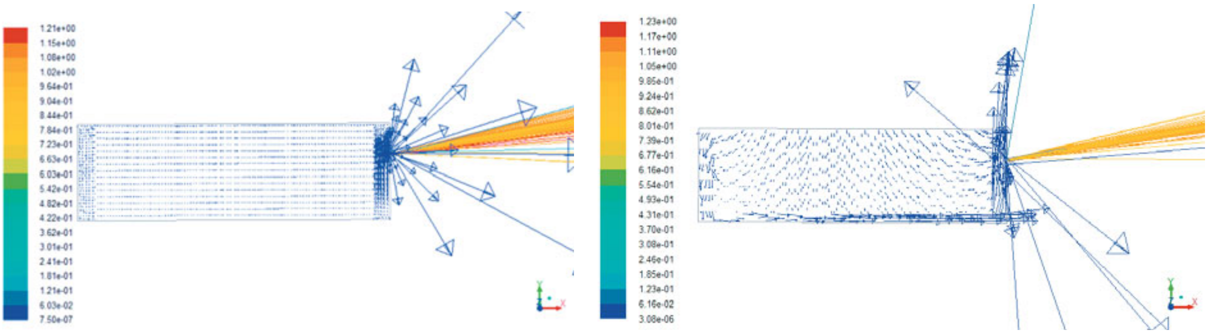
Effect of deadman sitting and floating

The practical production shows that during one tapping cycle, the coke bed sinking on the hearth bottom at the later stage instead of floating on the liquid iron at the earlier stage of tapping. In this study, two different cases are considered, as shown in Figure 2. Case (a) stands for the sitting deadman, and case (b) represents the floating deadman, the floating height is 0.3 m.

(a) Sitting deadman (b) Floating deadman

Figure 2. Schematic diagram of deadman state

The velocity vectors of liquid iron in the symmetry plane for case (a) and case (b) are described in Figure 3. As can be seen, the velocity of liquid iron in the fine coke region is extremely low owing to the poor permeability. For case (a), it can be found that the flow velocity in the lower region of coke bed is very slow, while for case (b), when the deadman is floating, forming a free region, the velocity of liquid iron in the coke free region is higher and more chaotic owing to the smaller flow resistance, which means a more serious mechanical erosion of hearth bottom. Meanwhile, the velocity of liquid iron near the sidewall at the taphole side is higher than that at the opposite side of the taphole, which means a higher mechanical erosion rate of the refractory at the taphole side.



(a) Sitting deadman (b) Floating deadman

Figure 3. Velocity vectors of molten iron with deadman sitting and floating

For further comparison of hot metal flow, selecting a straight line distance of 0.1 m to the hearth bottom(See Figure 1, y=0.1,z=0,-5＜x＜5). The hearth bottom liquid iron flow velocity comparison is shown in Figure 4. It can be obviously seen that the velocity of liquid iron with the deadman floating is significant higher than that with the deadman sitting in the hearth bottom, which means more serious erosion of hearth bottom.

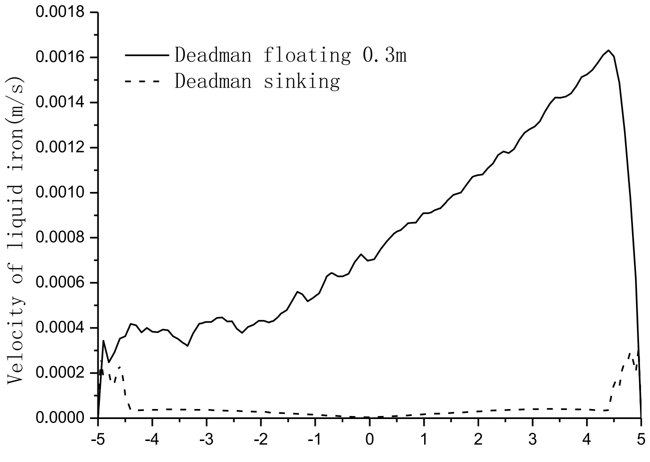


Figure 4. Effect of deadman position on flow field of molten iron

Effect of deadman size

The velocity of liquid iron comparison under different deadman sizes is shown in Figure 5. As can be seen, with the increase of the deadman diameter, the velocity of liquid iron in the hearth bottom increases rapidly. In the practical production of blast furnace, low coke strength and longtime blowing-down will cause the deadman increase in size and decrease in porosity, leading to more liquid iron flow through the hearth side wall and hearth bottom free coke region, thereby aggravating the erosion of blast furnace hearth and bottom.

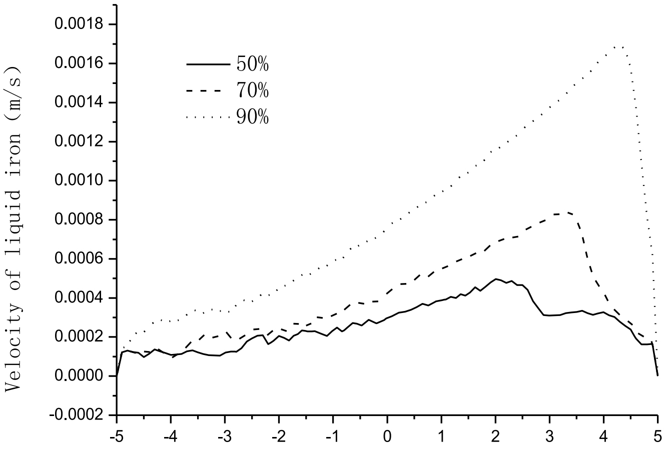


Figure 5. Effect of deadman size on flow field of molten iron

Effect of salamander depth

The velocity of liquid iron under different salamander depth is shown in Figure 6. As can be seen, the velocity of liquid iron in the hearth bottom decreases with the increase of the salamander depth, which indicates that deepening the salamander depth can protect the blast furnace hearth and bottom.

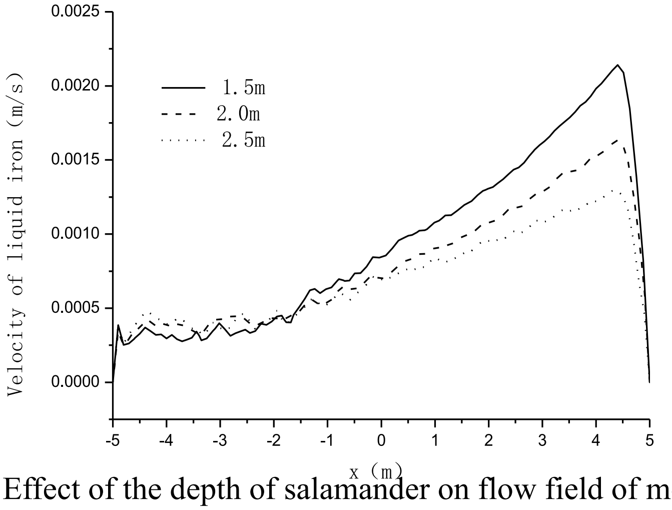


Figure 6. Effect of the depth of salamander on flow field of molten iron

Effect of taphole diameter

Assuming the flow rate of liquid is 200 t/h when the taphole diameter of 0.055 m while the flow rate of liquid iron is 300 t/h when the taphole diameter of 0.070 m. Effect of taphole diameter on flow velocity of liquid iron is shown in Figure 7. As can be seen, reducing the taphole diameter, the velocity of liquid iron decreased, which means the erosion of hearth bottom reduced. In addition, the taphole diameter is too large could easily lead to excessive flow, causing an overflow of iron slag or other accidents, and also affect the stability of the blast furnace conditions.

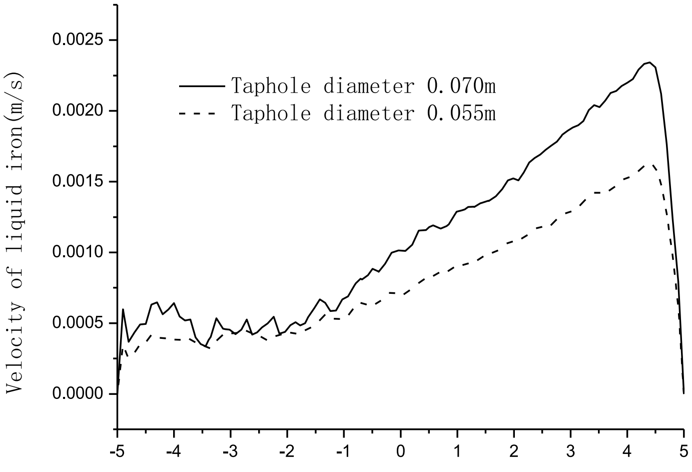


Figure 7. Effect of taphole diameter on flow field of molten iron

Effect of taphole angle

Effect of taphole angle on flow velocity of liquid iron is shown in Figure 8. As can be seen, the taphole angle changed from 10° to 15° has little effect on the flow velocity of liquid iron. However, in the actual production of blast furnace, the taphole angle should be stable, shall not be arbitrarily changed.

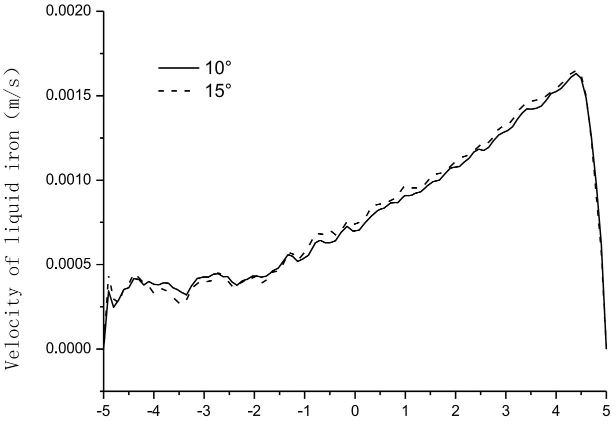


Figure 8. Effect of taphole inclination angle on flow field of molten iron

Conclusions

1) The velocity of liquid iron in the coke free region is higher and more chaotic when the deadman is floating, which means more serious mechanical erosion of hearth bottom. Increasing the deadman diameter will increase the velocity of liquid iron in the hearth and bottom rapidly.

2) The velocity of liquid iron in the hearth bottom decreases with the increase of the salamander depth, which indicates that deepening the salamander depth can protect the blast furnace hearth and bottom.

3) Reducing the taphole diameter, the velocity of liquid iron decreased. Effect of the taphole angle from 10° to 15° is not significant. However, in actual production of blast furnace, the taphole angle should be stable, shall not be arbitrarily changed.

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