Analysis of flow field of before and after slag-pig form accumulation in blast furnace

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Citation

Abstract
The flow of hot metal in blast furnace hearth has the wall shear on the BF hearth and furnace bottom, which results in erosion. Based on the theory of fluid mechanics, a three-dimension mathematical model was found for erosion of hot metal in blast furnace hearth, and model was built after slag-pig form accumulation. Using CFX software researches in hearth’s wall shear in different periods and the streamline diagram on different positions. The results indicate that the largest wall shear presents near the taphole in hearth; and wall shear increases after slag-pig form accumulation; the hot metal ‘s velocity decreases slag-pig form accumulation.

1. Introduction
The wear of hearth refractories is widely recognized as the main limitation for a long campaign of blast furnace life, the flow induced shear stress on the wall of the blast furnace hearth have important effect upon the erosion in the hearth. Peters et al. and Gauje et al. have studied the flow pattern in the hearth experimentally and numerically, respectively, without paying much attention to the stress distribution on the wall [1]. Although Venturini et al. and Torrkulla et al. have carried out computational fluid dynamics studies of the blast furnace hearth, they do not discuss the effect of flow induced stresses on the wall of the furnace [2]. Vats and Dash have computed the wall shear stress by solving the flow field and have concluded that there exists an optimum taphole length for minimum wall shear stress [3]. The research on the furnace of 1750 m³ in certain factory is done. The research is based on the related theory of the hydromechanics, and the three-dimensional mathematical model is established. According to different periods of the blast furnace hearth’s different situations of erosion, mathematical model of deadman and different sizes of the hearth are constructed and analyzed.

With the existence of hot metal circuiting flow around deadman, when blast furnace hearth drainage, the hot metal flow along deadman in circuiting flow. Especially when the depth of deadman shallows, the permeability of it deteriorates, and the deadman sits on the bottom of hearth, the erodent effect will increase, where is circuiting flow on the sidewall of hearth, the junction of the hearth sidewall and the hearth bottom. It presents severe erosion liking the elephant’s foot, where are the sidewall lining of hearth and the wall lining of the junction. After the slag-pig form accumulation, it has influence of blast furnace hearth wall shear. So the paper compares the wall shear and flow field to two conditions, which are after and before slag-pig form accumulation.
2. Model Description

Fig. 1 and fig. 2 is the external contour model, those are a blast furnace hearth before and after formation of slag. The size of hearth will be certainly changed. The reason is that the erosion in different degrees and periods is not same. Hot metal flow in hearth to the steady state method, and in hearth there is a deadman, the deadman link up the whole hearth and different periods have different radius. The remaining area in hearth is the coke free zone. The internal structure of hearth will change in periods of before and after the formation of slag, and the degree of clay brick erosion is not same in different time.

3. Assumed Conditions

(1) The speed of inflow of hot metal should vertical the entrance.
(2) Hot metal in hearth is incompressible fluid.
(3) Ignore the physical and chemical reaction between the refractory and hot metal.

4. Mathematical Model

The governing equations for fluids flow used in the three-dimensional mathematical model are based on the equation (1)–(6).

Continuity Equation:

\[
\frac{\partial (p u_j)}{\partial x_j} = - \frac{\partial p}{\partial x_j} + \frac{\partial}{\partial x_j} \left( \frac{u}{x_j} \frac{\partial v_j}{\partial x_j} + \frac{\partial v_j}{\partial x_i} \right) + S_n
\]

Momentum conservation equation:

\[
\frac{\partial (v_j v_j)}{\partial x_j} = - \frac{\partial p}{\partial x_j} + \frac{\partial}{\partial x_j} \left( \frac{u}{x_j} \frac{\partial v_j}{\partial x_j} + \frac{\partial v_j}{\partial x_i} \right) + S_n
\]

Where, \(v_j, v_j\) is speed in i, j direction (m/s); \(x_j, x_j\) is coordinate value in i, j direction(m); \(u\) is effective viscosity coefficient; \(S_n\) is resistance of hot metal flow through dead-man.

\[
S_n = 150 \left( \frac{1 - \varepsilon^2}{\varepsilon} \right) \frac{u v_j}{d} + 1.75 p \left( 1 - \frac{\varepsilon}{d} \right) \frac{u v_j}{d}
\]

5. Boundary Conditions

The entrance velocity is the reducing rate of the liquid level, the velocity is calculated daily production and time of hot metal. Taphole angle is 10 degrees, the two tapholes are symmetrical distribution. Therefore, only need to simulate a taphole tapping position. The application of numerical simulation is ANSYS-CFX fluid simulation tool, it provides Navier-Stokes equation based on finite element method, the computational domain is marked off three-dimensional tetrahedral mesh, and mesh number is about 200 thousand.

deadman in hearth is set in the porous medium, considering the flow of molten iron in the simulation process, and the temperature of molten metal is constant. Taphole has only hot metal and not coke. The temperature of hot metal is set at 1450°C, all walls are set to no slip. Calculation of fluid near the wall in the viscous sublayer uses wall function method, the viscosity coefficient is 0.00715 Pa *s. The porosity is 0.45, the heat capacity is 850J/kg-K. The heat conduction coefficient is 33W/m-K.
6. Results and Discussion

6.1. Analysis Simulation of Normal Blast Furnace Hearth

From fig.3 to fig.6 we can know, when the invasion depth of hearth brick is changed, the velocity vector in the level of taphole will change in different degree, and the circulation phenomenon can be seen. When depth of erosion changes in hearth, the size of deadman will change. The reason of circulation phenomenon is that coke porosity distribution is not uniform, hot metal tends to flow into the larger porosity of the region, and then flow into the taphole, resulting in hot metal circulation phenomenon. As shown in Fig.4 and Fig.5, the circulation phenomenon of hot metal tends to a side. The reason is that the change with the invasion depth, it has influence on the middle deadman, resulting in hot metal’s side of circulation.

Fig. 3. The velocity distribution of horizontal section through the center line of taphole

Fig. 4. The velocity distribution of horizontal section through the center line of the first layer of clay brick invasion taphole

Fig. 5. The velocity distribution of horizontal section through the center line of the second layer of clay brick invasion taphole

Fig. 6. The velocity distribution of horizontal section through the center line of the third layer of clay brick invasion taphole

Fig. 7. The velocity distribution in vertical plane
From fig.7 to fig.10 we can know, flowing to the taphole in hearth do not have obviously mixed flow phenomenon. When the erosion of clay brick degree unceasingly changes, central position of hot metal flow appears arched streamline.

From fig.11 to fig.14 we can know, the depth of clay brick invasion in hearth is different, hearth streamline chart also shows the circulation phenomenon in different degree, more invasion and more fuzzy circulation phenomenon. In the central deadman position also appears flow of hot metal, the reason is that the upper deadman has big porosity, so the retention effect is not strong for the hot metal.
From fig.15 to fig.18 we can know, in the case of different erosion, hearth wall shear gradually decreases, because there is a certain influence erosion clay bricks for hot metal flow and flow velocity, more invasion and hot metal sidewall erosion is small, so the hearth erosion degree is reducing continuously.
From fig.19 to fig.22 we can know, before the third layer of clay brick invasion, the bottom wall shear increases gradually near taphole position, because of existence of central hearth deadman the hearth is far from the taphole iron down along a small gap of deadman and furnace wall and deadman between the narrow space flow, and flow to the bottom then bypass the porosity smaller deadman to taphole, the distal bottom which is far from taphole has small erosion. At the proximal bottom of blast furnace, hot metal from upper deadman, which it goes through deadman porosity and then the taphole, increases the erosion of hearth. After the invasion of the third layer of clay brick, the most severe wall shear appears to the distal bottom sides.

From fig.23 to fig.26 we can know, formation of slag has influence on flow of hot metal in the blast furnace, circulation phenomenon appears on condition of no clay brick erosion. After the invasion of clay brick, hot metal tends to flow one side, and more depth of invasion, more obvious.
tends to upward flow. It can increase erosion of hearth, what is the mixed flow of hot metal flow area to "panning" effect on the furnace bottom corner.

From fig.27 to fig.30 we can know, hot metal flows directly to outlet near the taphole, while the distal hot metal flows to taphole near the hearth wall region, and bottom corner exists of mixed flow. This is because the center of deadman’s edge loose, the porosity is large, however the center is dense, the porosity is small, hot metal bypass the poor areas of permeability, so as to form the edge of circulation. And deadman is in a sink condition, the distal bottom’s hot metal

Fig. 26. The velocity distribution of horizontal section through the center line of the third layer of clay brick invasion of formation of slag taphole

Fig. 27. The velocity distribution in vertical plane of formation of slag

Fig. 28. The velocity distribution in vertical plane of formation of slag and the first layer of clay brick invasion

Fig. 29. The velocity distribution in vertical plane of formation of slag and the second layer of clay brick invasion

Fig. 30. The velocity distribution in vertical plane of formation of slag and the third layer of clay brick invasion

Fig. 31. The level streamline chart of formation of slag hearth
From fig. 31 to fig. 34 we can know, the level streamline of generating slagging hearth changes with the invasion depth of clay brick, it tends to be very chaotic phenomena, more deep of invasion, more chaos of erosion degree, those will result in progressively larger of hearth.

**Fig. 32.** The level streamline chart of the first layer of clay brick and formation of slag hearth

**Fig. 33.** The level streamline chart of the second layer of clay brick and formation of slag hearth

**Fig. 34.** The level streamline chart of the third layer of clay brick and formation of slag hearth

**Fig. 35.** The distribution of wall shear of formation of slag hearth

**Fig. 36.** The distribution of wall shear of the first layer of clay brick invasion and formation of slag hearth

**Fig. 37.** The distribution of wall shear of the second layer of clay brick invasion and formation of slag hearth
The distribution of wall shear of the third layer of clay brick invasion and formation of slag hearth

From fig.35 to fig.38 we can know, the invasion depth is gradually deepening in formation of slag hearth wall, the wall shear will increase near the taphole, other partial hearth’s wall shear do not obviously changes.

The wall shear distribution of formation of slag bottom

From fig.39 to fig.42 we can know, the wall shear increases gradually as invasion depth, but the time is the third layer of clay brick invasion, the wall shear distribution is different from the other cases, the maximum of wall shear appears to both sides of the bottom in the longitudinal section of the taphole parallel bits.

The wall shear distribution of the third layer of clay brick invasion and formation of slag bottom

7. Comparison of before and after Formation of Slag Blast Furnace Hearth

(1) Comparison of the level velocity vector of before and after formation of slag taphole center line: Two cases of velocity distribution difference is the invasion of the first layer of clay brick, the normal hearth has normal circulation. Another case tends to flow to one side, after flows to outlet.

(2) Comparison of the vertical section velocity vector of before and after formation of slag taphole center line: The velocity vector is compared in different periods, there is circulation phenomenon and the path changed in the formation.
of slag hearth, the other is not.

(3) Comparison of the level streamline of before and after formation of slag hearth: The normal hearths appear obviously circulation phenomenon and a part of hot metal flows in the center. But the formation of slag hearths do not appear obviously circulation phenomenon and the path of hot metal is confusion.

(4) Comparison of wall shear stress of before and after formation of slag hearth: The two cases of wall shear are increased with the depth of invasion. Formation of slag hearth’s wall shear is larger than normal hearth.

(5) Comparison of bottom wall shear of before and after formation of slag hearth: The side of taphole’s wall shear increases with the increasing of invasion depth, before bottom hearth is eroded the third layer of clay brick. But after it, two different bottom wall shears’ maximum appears in two sides of bottom hearth.

8. Conclusion

(1) Before and after formation of slag the furnace bottom and hearth’s wall shear increases with the increasing depth of erosion.

(2) The level velocity vector’s circulation phenomenon in the before and after formation of slag center hearth with the increasing depth of erosion is not obvious.

(3) The vertical velocity vector has mixed flow phenomenon in the before and after formation of slag hearth, the path of hot metal changes.

(4) The slag adhering to hearth has buffer effect on hot metal’s erosion of hearth sidewall, and reduces erosion on the hearth of hot metal.

References