https://doi.org/10.20965/jaciii.2015.p0269

Paper:

Modeling of High Temperature Gas Flow 3D Distribution in BF Throat Based on the Computational Fluid Dynamics

Jian Qi An*,†, Kai Peng, Wei Hua Cao*, and Min Wu***

*School of Automation, China University of Geosciences
No.388 Lumo Road, Wuhan 430074, China
E-mail: anjianqi@cug.edu.cn
**School of Information Science and Engineering, Central South University
Changsha, Hunan 410083, China
†Corresponding author

[Received June 20, 2014; accepted December 12, 2014]

This paper aims at building a Computational Fluid Dynamics (CFD) model which can describe the gas flow three dimensions (3D) distribution in blast furnace (BF) throat. Firstly, the boundary conditions are obtained by rebuilding central gas flow shape in BF based on computer graphics. Secondly, the CFD model is built based on turbulent model by analyzing the features of gas flow. Finally, a method which can get the numerical solutions of the model is proposed by using CFD software ANSYS/FLUENT. The proposed model can reflect the changes of the gas flow distribution, and can help to guide the operation of furnace burdening and to ensure the BF stable and smooth production.

Keywords: blast furnace (BF), gas flow field, 3D distribution model, computational fluid dynamics (CFD)

1. Introduction

Iron and steel industry is a fundamental industry of national economy, which has significant influence on the strategy of sustainable development. Blast furnace (BF) is the most important equipment in steel industry and its steady running has the influences on the economic benefits of steel enterprises [1]. In the BF process, reasonable control of the gas flow distribution is a crucial factor of high production, low consumption and superior quality. However, it is difficult to detect the gas flow directly because of the adverse reaction environment in BF throat. Therefore, an appropriate soft measure method is essentially needed for the detection of the gas flow distribution [2, 3].

In the past, many works have been done for the fluid model of BF. Since the early ’60s, scholars have built several mathematical models about the thermal state. Then, some researchers proposed a concept of the multi-fluid model. H. Nogami and M. Chu put forward a multiphase dimensional transient mathematical simulator and a numerical simulation of innovative operation respectively in [4] and [5] based on multi-fluid and kinetic theories. The multiphase reacting flow model and the gas-solid flow model in the BF based on computational fluid dynamics (CFD) has become a hot issue in recent years. According to discrete particle simulation (DPS) and CFD, Z. Y. Zhou et al. proposed a method which can investigate the gasCsolid flow in a BF [6]. A CFD model which includes gas flow dynamics, burden movement, chemical reactions, heat and mass transfer between the gas phase and burden phase was developed to simulate the multiphase reacting flow in BF shaft [7]. D. Fu et.al proposed a new methodology which can efficiently simulate the gas and solid burden flow in the counter-current moving bed in BF shaft [8]. Those results are useful in developing a comprehensive understanding of gasCsolid flow within BF. However, BF is a huge and very complicated multiphase-flow system, and affected by many related issues. Those current studies can’t reflect the state of whole BF accurate, because there are too many assumptions to simply the model. Compared with the extremely complex BF shaft, gas flow distribution in BF throat is relatively simple. So the gas flow distribution can be accurate described with the fewer assumptions.

There are two main forms to describe the gas flow 3D distribution, one is temperature field and the other is velocity field. For the temperature field, many subjects have been proposed. J. Q. An and M. Wu did some research on burden surface temperature distribution based on contacted crossing temperature device in [9] and designed a measuring system for burden surface temperature field of BF in [10]. In [11], Y. Wu et.al proposed a temperature system based on two-color imaging in adaptive optics of CCD. However, the velocity field of gas flow in BF throat has not been described in the previous models. Because of the important of velocity field of gas flow, which is directly related to the carbon monoxide utilization ratio and the stability of BF [12], a model of gas flow in the BF throat is proposed in this paper.

In order to build the accurate model of the gas flow 3D velocity distribution in BF throat for guiding the BF operation, a CFD method for high temperature gas flow 3D distribution in BF throat base on the top camera is proposed in this paper. Firstly, the boundary conditions are obtained by rebuilding central gas flow shape in BF based on computer graphics. Secondly, the CFD model is built based on turbulent model by analyzing the features of gas flow. Finally, a method which can get the numerical solutions of the model is proposed by using CFD software ANSYS/FLUENT. The simulation results show that the proposed model can give good and visible measuring for gas flow velocity filed, which would provide an efficient way to guide burden operation.

2. The Central Gas Flow 3D Shape in BF Throat

The 3D high temperature gas flow shape in BF throat is an important status parameter of BF iron-making process. In this section, we extract the edge features of image, and then build the relationship between images and the gas flow by computer graphics. Based on this, we can rebuild a 3D shape of BF throat high temperature gas flow, and furthermore we can get the boundary conditions for CFD of gas flow 3D distribution model.

2.1. Image Preprocessing and Edge Feature Extracting

In order to get the coordinate information of edge feature point of the gas flow shape, we need to preprocess the image and extract the edge feature of the image.

2.1.1. Image Preprocessing

In order to get more features of the gas flow images, weighted average method and median filter are used for image graying and filtering the noise. Then the foreground of image can be distinguished from background by the method of image binarization [13].

2.1.2. Edge Feature Extracting

In order to extract the edge feature of the image at the real-time request of industrial field, a feature edge detection algorithm is presented based on Canny [14] and director chain code tracking. First, using the Canny operator algorithm to extract the edge feature points in the binary image of the gas flow shape. Then, we apply a method based on director chain code tracking to get the coordinate of edge feature points. The method has low computational complexity and rapid running speed.

By this method, the coordinates of edge feature points in the gas flow shape image, which provides foundation of calculating the 3D coordinate.

2.2. The 3D Coordinate of the Central Gas Flow Shape in the BF Throat

In order to get the relationship between images collected by the top camera and the real gas flow shape, the internal parameters of the camera should be calculated

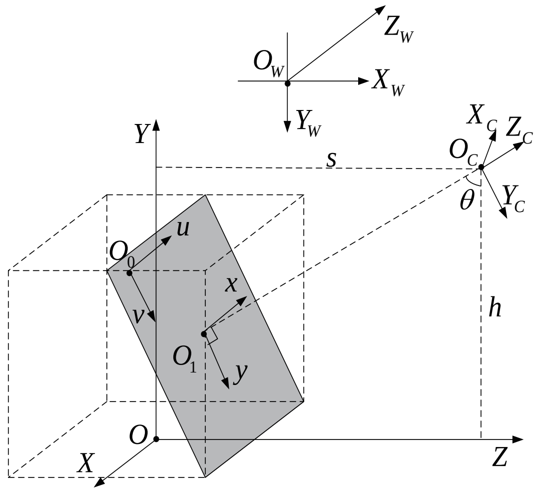


Fig. 1. The imaging model of gas flow detection.

by calibration method firstly. Through edge extraction to gain the two dimensions (2D) information of the edge feature points, the 3D space coordinate of the feature points can be calculated by the linear camera model. In this way, the gas flow 3D shape in BF throat can be build.

2.2.1. Camera Calibration

In order to reconstruct the gas flow 3D shape in BF throat, we need to calibrate the parameters of the camera. In this paper, we apply the linear camera model to build the transfer relationship between image and entity. Then apply the least square method based on corner detection coordinates from different points to calibrate the parameters of camera [15].

2.2.2. The 3D Space Coordinate of the Central Gas Flow in BF Throat

The camera used to detect the gas flow is installed at the top edge of BF. The parameter model of detection of BF gas flow is shown as **Fig. 1**.

In order to gain the 3D coordinate of gas flow shape, we need to rebuild the 3D imaging model. Axis X_c, Y_c, Z_c and origin O_c constitute the camera coordinate. Axis X_w, Y_w, Z_w and origin O_w make up the world coordinate system (WCS). Axis x, y and origin O_1 make up the image coordinate system (ICS) in millimeter. Axis u, v and origin O_0 make up the pixels coordinate in millimeter. Axis X, Y, Z and origin O make up the original coordinate system (OCS). θ stands for the cameras angle of roll, h stands for the distance between camera and BF burden surface, s stands for the cross range between camera and the central point at the circular high-temperature region of the BF burden surface.

Considering the transfer relationship between WCS and OCS making the calculation of coordinate in OCS easier, we regard the OCS as WCS directly.

According to the coordinate of the edge feature points and the linear imaging model obtained by camera calibration, we can calculate the physical coordinate of edge feature coordinate of gas flow shape. And then the coordinates (X_w, Y_w, Z_w) in WCS of edge feature points can be obtained. The transfer relationship between OCS and WCS can be shown as the following Eq. (1):

$$Z_C\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} a_x & 0 & u_0 & 0 \\ 0 & a_y & v_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}\begin{bmatrix} \mathrm{R} & \mathrm{t} \\ 0 & 1 \end{bmatrix}\begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix} \quad . \quad (1)$$

where a_x, a_y, u_0, v_0 is the parameters of the camera which calculated by the calibration method; R and t can be computed by the transfer relationship between OCS and WCS. So, if we can get the parameter ZC, the coordinates (X_W, Y_W, Z_W) in OCS corresponding the coordinate (u, v) in ICS will be obtained.

In order to compute Z_C, the central (h, s) should be knew. In this paper, Cross-thermocouples are used to ascertain the central point position of gas flow 3D shape. The Cross-thermocouples is above the burden surface. Its temperature data can reflect the temperature distribution of gas flow [15]. The point which has the highest temperature is considered the central axis of gas flow 3D shape the coordinate of the highest temperature point can be confirmed through the installing position of Cross-thermocouples. According to the coordinate, we can calculate Z_C.

2.3. The Boundary Velocity of Gas Flow Edge in BF Throat

The distribution of gas flow in BF throat always changes. It gets stronger after each burden operation. Through the image shot by the camera and the method mentioned above, the shape of gas flow in the central point is built. According to the variation of this shape, we can calculate the initial speed and ultimate speed of gas flow in the central of BF.

After coordinate transformation, the 3D shape of central gas flow can be described as the following equations[15].

$$\begin{cases} x^2+y^2 = R_i^2,\ z=0 \\ x^2+y^2 = \left(\dfrac{R_i'-R_i}{H_i}z+R_i\right)^2,\ z\in(0,H_i) \\ x^2+y^2 = R_i'^2,\ z=H_i \end{cases} \quad . \quad (2)$$

The R_i, R_i', H_i in the equations can be obtained through images detected by the top camera.

It is supposed that the delay between the successive two images (*img i* and *img* $i+1$) collected by the camera is Δt after burden operation. When the Δt is small enough, the movement of flow shape on the edge can be regarded as velocity of gas flow on burden surface. And the top and bottom direction of the gas flow velocity is perpendicular to the XOY in **Fig. 1**. Therefore, the gas flows velocity $\boldsymbol{v}_i(x,y,z)$ on the region Ω of burden surface within Δt can be obtained.

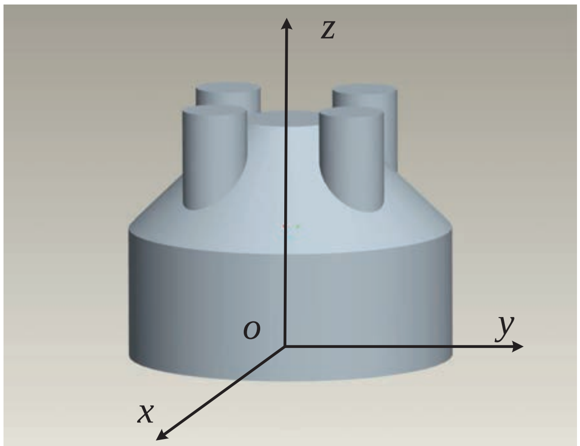


Fig. 2. The 3D model of BF throat.

$$\begin{aligned} &\boldsymbol{v}_i(x,y,z) = V_i = \frac{H_{i+1}-H_i}{\Delta t} \quad (\Delta t = t_{i+1}-t_i) \\ &\Omega: \quad x^2+y^2 \le R_i^2,\ z=0 \end{aligned} \quad (3)$$

where t_i and t_{i+1} is the detecting time of *img i* and *img* $i+1$. H_i, H_{i+1}, R_i can be obtained by *img i* and *img* $i+1$. And the $\boldsymbol{v}_i(x,y,z)$ can be regarded as the boundary velocity of burden surface at time t_i.

According to this method, the gas flow boundary velocity on burden surface can be obtained at any time. And the velocity field would be used as boundary conditions of gas flow distribution model based on CFD in BF throat.

3. Modeling of Gas Flow 3D Distribution in BF Throat

According to the gas flow 3D shape in BF throat central, we can detect the central gas flow distribution in BF throat. But we don't know the comprehensive gas flow distribution in BF throat. In order to obtain the distribution situation of the whole throat area, the governing equation of fluid mechanics and 3D turbulent model are introduced in this paper. By utilizing the boundary conditions from gas flow 3D shape in BF throat calculated in Section 2.3, the distribution model of the BF throat gas flow field can be built based on CFD, and then the numerical solution for the built model can be achieved through the CFD software. Thus, the condition of velocity filed of gas flow in the whole throat area can be reflected by these numerical solutions.

3.1. The Gas Flow 3D Distribution Model in BF Throat

To build the 3D model of BF throat gas flow, the entity model of the throat area must be built at first. In order to simplify the entity model, it is assumed that the burden surface is plat and it is regarded as the bottom of the throat. The built model of the throat area is shown in **Fig. 2**.

In this model, the coordinate system is built at the conditions that the center of the burden surface is the origin, burden surface is the XOY surface, and z axis is perpendicular to the XOY surface at origin. The flow field in this model is described by Euler description. The method considers the physical variables vary with the space point. And it is assumed that a fluid particle is at the position (x,y,z) in its own coordinate system, thus the physical variables can be described by the function of x, y, z. For example, the velocity of the particle can be described as $\boldsymbol{v} = \boldsymbol{v}(x,y,z)$.

To obtain the gas flow distribution of the whole BF throat, the governing equations of gas flow in this model should be built at first. Then, the equations should be deal with by using discretization method. Finally, the boundary conditions of the model can be derived and the numerical solutions of the flow field distribution can be obtained by numerical modeling method.

3.1.1. The Governing Equations of the Throat Fas Flow

BF is a relatively closed airtight reactor. There is some mixed gas of CO, CO_2, N_2 and dust which is leaded by the burden operation in the reaction. To simply the governing equations of gas flow, the following assumptions are given.

1) The gas flow in BF throat considered in this paper is an ideal gas which satisfies the continuity equations, the motion equation and the energy equation of fluid mechanics. Only the continuity equation and motion equation are considered in this paper because this paper only studies the throat gas flow velocity distribution and ignores the temperature change of the gas flow.

2) The gas flow distribution can be regarded as constant speed flow as it is the state within a certain time in this paper. What is more, the top pressure is a controlled variable and the boundary top pressure can be regarded as a constant.

3) The throat area is shape irregularity and the gas velocity exists in the chamber. Besides, the stratification of the gas is not obvious and there is not only mass transfer but also momentum transfer between layer and layer. So the gas flow is the turbulent flow and the turbulent flow model should be added to the governing equation.

4) The influence of the gas gravity for the gas movement can be ignored, when calculating the gas flow distribution.

Based on the assumptions above, the continuity equation of the flow field under the Euler method satisfies the following Eq. (4).

$$\rho\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)=0 \quad \ldots\ldots\ldots \quad (4)$$

where u, v, w is the component at x, y, z axis of the velocity, vector $\vec{v}$ respectively. ρ is the density of the mixed gas flow as shown in Eq. (5).

$$\rho = \rho_{CO}\eta_{CO} + \rho_{CO_2}\eta_{CO_2} + \rho_{N_2}(1-\eta_{CO}-\eta_{CO_2}), \quad (5)$$

where ρ_{CO} is the density of CO at the top pressure of the moment, ρ_{CO_2} is the density of CO_2 and ρ_{N_2} is the density of N_2, η_{CO} and η_{CO_2} are the content of CO and CO_2 at the real time.

From the assumptions, the throat gas flow on unit volume satisfies the following motivation equation based on the theorem of momentum.

$$\begin{cases} \mathrm{div}(u\vec{v}) = \mathrm{div}(\mu\,\mathrm{grad}u) + F_x \\ \mathrm{div}(v\vec{v}) = \mathrm{div}(\mu\,\mathrm{grad}v) + F_y \\ \mathrm{div}(w\vec{v}) = \mathrm{div}(\mu\,\mathrm{grad}w) + F_z \end{cases} \quad \ldots\ldots \quad (6)$$

where F_x is the component of mass force unit at x axis, F_y is the component of mass force unit at y axis and F_z is the component of mass force unit at z axis. And μ is the kinematic viscosity which can be calculated from the proportion with normal viscosity.

The closed solvable differential equations cannot be constructed based on the continuity equation and the motivation equation mentioned above. The $k-\varepsilon$ two equation model of the turbulent which include turbulent kinetic energy equation and turbulent dissipation rate equation should be added. According to Eqs. (4), (5), and $k-\varepsilon$ two equation, we can obtain the velocity field in BF throat by CFD software Fluent.

3.1.2. Boundary Conditions and Initial Velocity of the Model

In order to obtain the velocity field in BF throat by CFD, the boundary velocity is necessary. According to the method in Section 2.3, it is obvious that the boundary velocity field on the burden surface can be derived from the obtained 3D shape of the gas flow can be described as the following equations.

$$\begin{cases} \mathrm{v}_i(x,y,z) = V_i \quad x^2+y^2 \le {R_i}^2,\ z=0 \\ \mathrm{v}_i(x,y,z) = V_0 \quad R_i < x^2+y^2 \le {R_0}^2,\ z=0 \end{cases} \quad (7)$$

where v_i is the velocity of gas flow on burden surface at time t_i. R_0 is the radius of the models undersurface in **Fig. 1**. Therefore, we can calculate the velocity at any point on burden surface according to Eqs. (7).

Next, we must set boundary conditions of the top of BF throat. There are four gas rising pipes on the model. They are the outlet of the flow, and its boundary conditions are set as free outflow at the top pressure. The wall conditions of the model are set as it can stand any pressures.

At last, the initial velocity in BF throat should be set. The problem considered in this paper is the transient state of gas flow distribution. It belongs to transient problems in which the initial conditions should be given firstly. But the final solutions do not vary with the initial conditions when the results converge. Only the number of iteration is affected by the initial conditions. Therefore, the initial conditions of the velocity field inside the throat area are set as zero.

3.2. The Solving of the Gas Flow Distribution Model in BF Throat

The gas flow distribution can be calculated from the model and the boundary conditions. The solving process includes three steps: governing equations discretization, boundary conditions discretization and the discrete equations solving.

3.2.1. Governing Equations and Boundary Conditions Discretization

When using the numerical methods to solve equations, the control equations should be discretized in the determining space before solving the discrete equations. The meshing technique is indispensable for getting the discrete equations.

According to the various discretizing principles, the methods of CFD numerical solving can be divided into three classes, i.e., finite difference method, finite component method and finite volume method. In this paper, we use the FVM to get the discrete equations. The FVM has a direct physical interpretation. The physical meaning of the discrete equation is that variables are constant in the finite volume. So the finite volume method is always adopted to discretize differential equations of air fluid. Firstly, the computational region is divided into a series of non-redundant volume. Then each grid is assigned an associated control volume. At last the differential equation need to be solved is integrated on each volume to get a group of equations.

To get the 3D meshes, hexahedral model, tetrahedral model, pyramid, wedge and polyhedral cells can be used. And different model decides different numerical precision. In this paper, to get the throat flow distribution, the brief flow field is preferred to the precision solution of each grid in the throat. Taking account of the computation ability and real time requirements in the industry field, the tetrahedral model is adopted as the basic grid due to its low cost in this paper. The meshing model is shown in **Fig. 3**.

By utilizing numerical method, the dependent variables of the unit volume node in the throat area can be just regarded as the unknown variables. Then a group of algebraic equations about these variables can be attained. The values of the nodes can be achieved by solving these equations and the values of other positions are decided by these values.

3.2.2. Solving Discrete Equations

After obtaining the discrete equations by finite volume method, the values of the boundary meshing nodes in the given boundary continuity equations can be calculated. And the initial condition values of other remaining nodes are set as 0. The gas flow is comprised of CO, CO_2 and N_2 according to the given ratio. And the control precision of iterative accuracy and the experience parameters of 3D turbulent model are also given. By utilizing Semi-Implicit Method for Pressure Linked Equations as the solver, the velocity field distribution in the throat can be achieved by appropriate number of iteration.

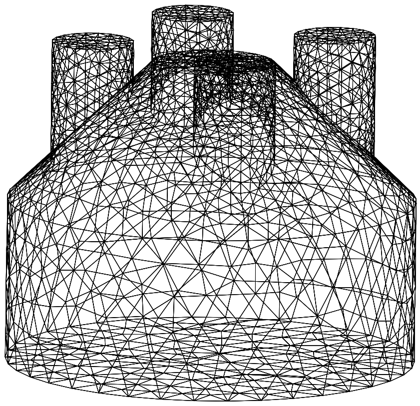


Fig. 3. The meshing model of BF throat.

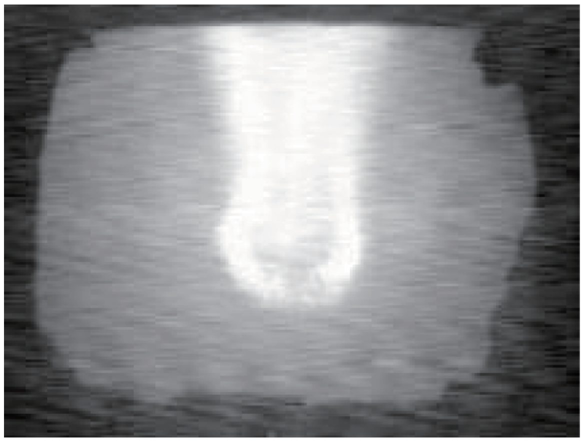


Fig. 4. The detection image central gas flow in the BF throat.

4. Simulation and Result Analysis

In this paper, we analyzed the data of a large steel companys 3200 m^3 BF, the simulation results are shown as follows.

The central gas flow image detected by the camera in BF is shown in **Fig. 4**.

The 3D shape coordinates of gas flow are calculated by using the calibrated internal parameter, external parameters and the linear imaging model. Calculated by the calibration method, the internal parameters of the camera are $a_Y = 762.82$, $a_v = 785.46$, $u_0 = 411.94$, $\upsilon_0 = 241.2$. The installation angle of the top camera detecting the gas flow images is $\theta = 18$; the distance between the top camera and BF burden is $h = 1500$ mm (obtained by calculating the tape data); the horizontal distance between the top camera and the central point of the BF burdens high temperature

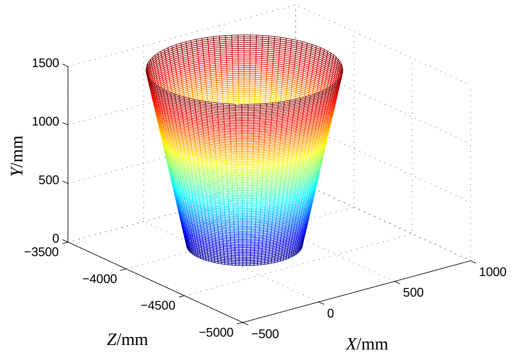


Fig. 5. The central gas flow 3D shape ($y = 0 : 1500$ mm).

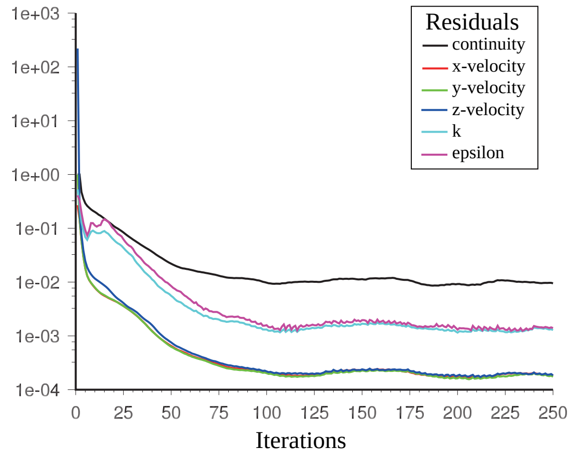


Fig. 6. Iterative curve.

Table 1. The parameters in $k-\varepsilon$ model.

C_1	C_2	C_3	σ_k	σ_ε
1.44	1.92	0.09	1.0	1.3

Table 2. Physical parameters of the gas flow.

The type of gas	CO	CO_2	N_2
dynamic viscosity μ (μ Pa $\cdot s$)	17.649	14.932	17.805
kinematical viscosity v (mm^2/s)	15.614	8.369	15.752

circle is $s = 4500$ mm (obtained by calculating the distribution of cross temperature device). Based on the above research, the 3D central gas flow shape in BF throat is finally established in the Matlab environment, as shown in **Fig. 5**.

According to the simulation result, the 3D central gas flow shape in BF throat can be established. The radius of the top gas flow circle is 513.7 mm.

According the 3D central gas flow shape, we can calculate the velocity of the gas flow by the methods in Section 2.3, which is regarded as the boundary conditions. Next, we will obtain the numerical solution of gas flow 3D distribution in BF throat by using the ANSYS/FLUENT module.

(1) The establishment and meshing of the 3D model

The established BF 3D model is shown in **Fig. 2**, the model is meshed by tetrahedral mesh, the result is shown in **Fig. 3**.

(2) Physical properties of the central gas flow in the BF throat

This paper assumes that the central gas flow in the BF throat is an ideal gas flow which is constant, steady and non-compressible. The model parameters which are used in this paper are shown in **Table. 1**.

When BF top pressure is 2.37105 Pa, the dynamic viscosity and kinematic viscosity of BF gas are shown in **Table. 2**. According to the viscosity coefficients, the mixed gas viscosity can be calculated.

(3) Boundary conditions

We can build the 3D model by sampling a large number of continuous camera images of the furnace throat. The velocity distribution of the BF burden gas flow between two consecutive sampling times can be obtained by using the method illustrated in Section 2.3. In order to calculate conveniently, the velocity of the gas flow in initial BF burden is assumed perpendicular to the burden. The conditions of outlet are set as the free outflow boundary under the top pressure.

(4) Calculation and simulation

In the ANSYS/FLUENT, according to the fluid characteristics, the definition of physical properties are defined, the solving control options (SIMPLE) is set, the definition of physical properties and the solving control precision are set. The number of iterations is 250.

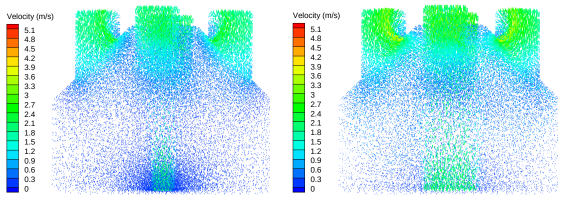
Figure 6 shows the iterative curve, the abscissa represents the cumulative number of iterations, the ordinate represents the normalized variation ratio of variables. The convergence of turbulent kinetic energy, dissipation coefficient and velocity components in all directions are illustrated in the image. As can be seen from the chart, when the number of iterations is around 100, those observation precision can reach one percent. Many experiments show that if the number of iterations is between 100 and 200, the precision can reach within one percent.

(5) Simulation results and analysis

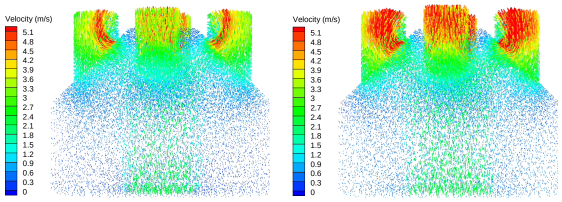
In the reference [15], the change of the gas flow shape after the BF burdening can be inferred in simulation by comparing the variations of 3D shape in four development stages of the central gas flow distribution.

Corresponding to that, the result of gas flow distribution in the BF throat, which is solved by CFD software, is shown in **Fig. 7**. The change of gas flow distribution can be divided into four periods: primeval stage, early stage, middle stage and late stage.

Figure 8 shows the gas flow developing process after the burden operation in BF. As we can see from this picture, the central region of gas flow is increasing gradually along with its velocity. If the central region of gas flow

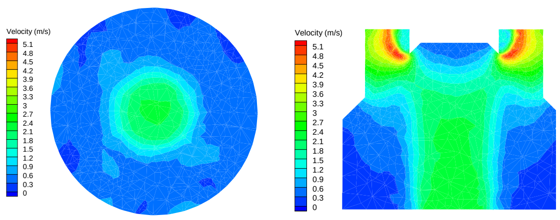


(a) Primeval (b) Early



(c) Middle (d) Late

Fig. 7. Development process of throat gas flow.



(a) Cross section (b) Longitudinal section

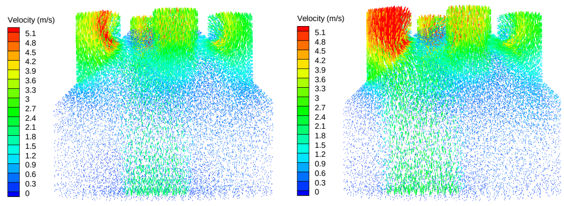
Fig. 8. The velocity contour of gas flow in BF throat.

isn't skewing, the gas flow field is symmetric in whole throat. And it is an ideal distribution.

To illustrate the distribution of gas flow more clearly, **Fig. 8** shows the velocity contour which gives the cross section and longitudinal section speed components along the Z axis direction in the middle stage of gas flow distribution. It can be seen from the velocity contour that the velocity of gas flow along the Z axis direction is symmetrical distribution in the whole BF throat when central gas flow shape has no offsets from the center of burden, namely, the distribution of BF throat gas flow is normal. On this occasion, its distribution is not harmful to the next burdening to keep the balance of burden surface.

Figures 7 and **8** show the normal distribution of the gas flow, we can see that a back flow down along the wall comes up when the center air has reached the top of the throat, because the rising gas pipeline is not located exactly above the BF throat. So a small vortex flow, which distributes symmetrically when the gas flow does not deviate from the center of the burden, forms in the edge region. **Fig. 9** shows the situation when the gas flow deviates from the center position.

When the center gas flow is deviates, the deviation will become increasingly serious as the gas flow develops. The reason is that when the center flow deviates to one side, the velocity of the flow in the rising gas pipe of this side



(a) The early stage (b) The late stage

Fig. 9. The gas flow distribution in BF throat when middle throat gas flow has offsets.

will be get accelerated, which leads to lower gas pressure in this pipeline compared with others. Consequently, the gas flow of this side will be more vigorous, which will bring adverse impacts on the next operation of burden distribution. When the flow velocity along the Z axis in the throat is asymmetry, uneven burden is likely to exist. The lower the burden is, the stronger the central gas flow is, which deteriorates the deviation of the center gas flow. Without human intervention, serious production accidents will happen, such as uneven charge level. So, if the uneven distribution of gas flow can be detected through flow field analysis, it is necessary to adjust the burden operation according to the specific distribution of the flow field. Thus, the balance of the burden is ensured and the distribution of the gas flow in the BF throat can be adjusted appropriately.

According to the accurate velocity field distribution of gas flow in BF throat, we can know the central of gas flow and the distribution of burden surface, which can guide BF operation.

5. Conclusion

In this paper, we have obtained the 3D coordinate of central gas flow in BF throat based on computer graphics firstly. Then, according to calculate the position change of central gas flow in a short period of time, we have got the boundary condition of gas flow 3D distribution model in BF throat. Next, we have built a 3D mathematical model of gas flow, based on fluid control equation and turbulent model. And we have designed a method which can get the numerical solutions of the model by the FVM. Finally, we simulate the gas flow 3D distribution in the ANSYS/FLUENT, so we can get the gas flow 3D dynamic distribution model and the velocity field in BF throat.

The simulation results confirm that the approach can build the accurate model of gas flow 3D distribution in BF throat. The results are very useful in developing a more comprehensive understanding of gas flow distribution in BF throat. And the model can guide burden operation which is critical to smooth and stable BF operation.

Acknowledgements

This work was supported in part by the National Natural Science Foundation (NNSF) of China under Grant 61203017 and 6133302 and was also supported by the Fundamental Research

Funds for the Central Universities of China University of Geosciences (Wuhan) (Grant Nos.2015349120).

References:

[1] L. Wei-Guo, "Review and Look Forward of the Development of Iron Making in China Since 21st Century," China Metallurgy, Vol.22, No.11, pp. 4-10, 2012.

[2] X. F. Dong, A. B. Yu, J. I. Yagi, et al., "Modelling of Multiphase Flow in a Blast Furnace: Recent Developments and Future Work," ISIJ Int., Vol.47, No.11, pp. 1553-1570, 2007.

[3] M. S. Chu, X. F. Yang, F. M. Shen, et al. "Numerical Simulation of Innovative Operation of Blast Furnace Based on Multi-fluid Model," J. of Iron and Steel Research Int., Vol.13, No.6, pp. 8-15, 2006.

[4] H. Nogami, M. Chu, and J. Yagi., "Multi-dimensional Transient Mathematical Simulator of Blast Furnace Process Based on Multi-fluid and Kinetic Theories," Computers and Chemical Engineering, Vol.29, No.11, pp. 2438-2448, 2005.

[5] M. Chu, X. Yang, F. Shen, et al., "Numerical Simulation of Innovative Operation of Blast Furnace Based on Multi-fluid model," J. of Iron and Steel Research, Int., Vol.13, No.6, pp. 8-15, 2006.

[6] Z. Y. Zhou, H. P. Zhu, A. B. Yu, et al. "Discrete Particle Simulation of GasCsolid Flow in a Blast Furnace," Computers and Chemical Engineering, Vol.32, No.8, pp. 1760-1772, 2008.

[7] D. Fu, Y. Chen, Y. Zhao, et al. "CFD Modeling of Multiphase Reacting Flow in Blast Furnace Shaft with Layered Burden," Applied Thermal Engineering, Vol. 66, No. 1, pp. 298-308, 2014.

[8] D. Fu, C. Q. Zhou, Y. Chen, "Numerical Methods for Simulating the Reduction of Iron Ore in Blast Furnace Shaft," J. of Thermal Science and Engineering Applications, Vol.6, No.2, pp. 1-9, 2014.

[9] J. Q. An, M. Wu, Y. He, et al., "Intelligent Modeling Based on Expert Evaluation and Information Fusion for Burden Surface Temperature Field of Blast Furnace," Computers and Applied Chemistry, Vol.25, pp. 782-786, 2006.

[10] J. Q. An, B. Wang, M. Wu, et al., "A measuring System for Burden Surface Temperature Field of Blast Furnace," Proc. of the 18th IFAC World Congress, Milano, Italy, Vol.8, pp. 12102-12107, 2011.

[11] Y. Wu, Y. Hu, and F. Jiang, "Design of Temperature Measurement System Based on Two-color Imaging in Adaptive Optics of CCD," Proc. of SPIE-The Int. Society for Optical Engineering, pp. 7656-76564E, 2010.

[12] C. S. Xue, W. H. Cao, M. Wu, et al., "Recognition Method for Determining Gas Flow Distribution along Blast Furnace Burden Surface," Tsinghua Science and Technology, Vol. 48, pp. 1785-1789, 2008.

[13] J. Sauvola, and M. Pietikainen, "Adaptive Document Image Binarization," Pattern Recognition, Vol.33, No.2, pp. 225-236, 2000.

[14] S. Kiranyaz, M. Ferreira, and M. Gabbouj, "Automatic Object Extraction over Multi-scale Edge Field for Multimedia Retrieval," IEEE Trans. on Image Processing, Vol.15, No.12, pp. 3759-3772, 2006.

[15] J. Q. An, Y. Liu, M. Wu, et al., "Reconstruction of Gas Flow Distribution in Blast Furnace Throat," J. of Control Theory and Application, Vol.31, No.5, pp. 624-631, 2014.

Name:
Jian Qi An

Affiliation:
School of Automation, China University of Geosciences

Address:
No.388 Lumo Road, Wuhan 430074, China

Brief Biographical History:
2011-2007 Ph.D. student, Central South University
2012-2013 Associate Professor, Central South University
2014- Associate Professor, China University of Geosciences

Main Works:
- Complicated metallurgical process detection, information fusion, virtual reality simulation and implementation

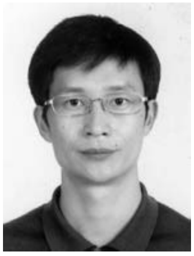
Name:
Kai Peng

Affiliation:
School of Information Science and Engineering, Central South University

Address:
Changsha, Hunan 410083, China

Brief Biographical History:
2009-2013 Undergraduate student, Central South University
2013- Master student, Central South University

Main Works:
- Control science and engineering, blast furnace, information fusion



Name:
Wei Hua Cao

Affiliation:
School of Automation, China University of Geosciences

Address:
No.388 Lumo Road, Wuhan 430074, China

Brief Biographical History:
2007-2008 Visiting Scholar, University of Alberta
2009-2013 Professor, Central South University
2014- Professor, China University of Geosciences

Main Works:
- Control science and engineering, information fusion, process control

Name:
Min Wu

Affiliation:
School of Automation, China University of Geosciences

Address:
No.388 Lumo Road, Wuhan 430074, China

Brief Biographical History:
1996-1999 Guest Professor, Tokyo Institute of Technology
1994-2014 Professor, Central South University
2014- Professor, China University of Geosciences

Main Works:
- Control science and engineering, robust control and applications, process control, intelligent control