NUMERICIAL SIMULATION OF GAS-FLOW IN BALL MILL

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ABSTRACT

The present paper performs the numerical simulation of the gas flow in the coal ball mill with two-way inlet and two-way outlet according to the practical condition of 40.53 type mill. The velocity of inlet gas and the fill ratio of steel balls are studied emphatically. Results obtained provide beneficial reference for milling, drying, choosing and transporting coal powder in the practical product.

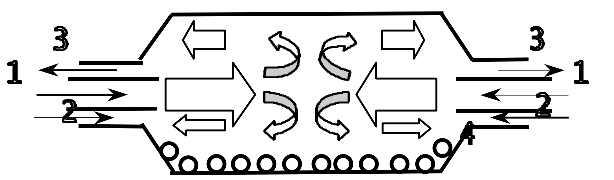
INTRODUCTION [1,2]

Direct combustion coal ball mill with two-way inlet and two-way outlet has a unique gas-solid two-phase field inside, which leads to its efficiency of powder milling, drying higher than that of mill with single-way inlet and single-way outlet. The gas-solid two-phase flow structure and power characteristic of such mill play an important role in drying, milling and transporting powder. In recent years, the theoretical and experimental research in terms of gas-solid two-phase flow of the mill has not developed as rapidly as that of boiler although investment has been strengthened in both fields, which will greatly limit the development of coal powder combustion technology. The present paper contributes to describe the gas field in the mill by numerical simulation.

PHYSICAL MODEL OF TWO-PHASE FLOW [1,2,3]

(1) Axial flow

Two stream of thermal gas spurt into the mill from the center pipe at its both ends respectively. They will meet at the mill center, dash against each other and then return of opposite direction, flow along the mill wall, and last, go out through the ring-shape outlet. (Fig.1) The pre-dried coal enters the mill from the center pipe, and will mix with thermal gas fully under the effect of rolling and milling of the machine. The dried and fined coal particle will rise toward the thermal gas and apart from the steel balls located at the bottom of the roller and develop into gas-solid two-phase flow at axial direction. In stable case, the flow of the two stream of thermal gas at opposite direction is almost equal and the development of the two-phase flow is equal too.



1- thermal gas, 2- pre-dried coal
3- gas-solid mixture, 4- steel balls
Fig.1 The configuration of gas-solid two-phase axial flow

(2) Circular flow

Several spiral ribs are wielded on the wall of thermal-gas-inlet-pipe in order to make both the thermal gas at the mill center and gas-solid flow near the wall move with little spinning (Fig.2). Therefore, two-phase flow stability and its mixing efficiency are improved. Such mill has symmetrical and spherical structure, which will be destroyed at some degree by the steel balls because they occupy 15~20 percent space of the mill. The balls piled up at the bottom may roll and slide along the wall with the mill movement. The cross section of the piling balls appears as crescent moon shape. In the present paper, the steel balls are supposed to fix at the bottom of the mill and their shape and density are assumed to be constant because the rolling speed of the mill is fairly low.

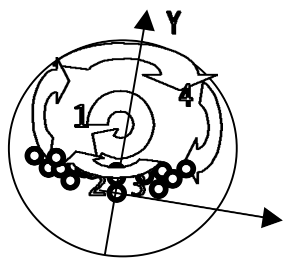


Fig.2 The configuration of gas-solid two-phase circular flow

(3) Assumption

Gas-solid flow in the mill is practically a three-dimension flow with very complex conditions. In the present paper, assumptions are made as follows:

1). No-rotating
The rotating motion of both fluid and mill are ignored in the present research because the circular motion is much weaker than the axial motion, not only for thermal gas but also for gas-solid flow in the mill.

2). Symmetrical gas-field
The thermal gas field and the gas-solid field are assumed to be symmetrical about Y-axis according to the coordinate system set up as Fig.2. The assumption is much close to the practical case when the milling system is operated at stable condition.

NUMERICAL METHOD AND MODEL

(1) Governing equations

For a steady two-dimensional incompressible turbulent flow, if the volume fraction of the solid particles is very small, the modeled transport equations in Cartesian coordinates can be written in a common form as:

$$\left[\frac{\partial}{\partial x}(\rho U\phi)+\frac{\partial}{\partial y}(\rho V\phi)\right]-\left[\frac{\partial}{\partial x}(\Gamma_{\phi,eff}\frac{\partial\phi}{\partial x})+\frac{\partial}{\partial y}(\Gamma_{\phi,eff}\frac{\partial\phi}{\partial y})\right]=S_{\phi}$$

In the above equation, ϕ is the dependent variable and may be used to stand for the velocity components U, V in the x, y directions respectively, the kinetic energy of turbulence k or the dissipation of turbulent kinetic energy ε. The latter two quantities pertain to the k-ε turbulence model, employed to simulate turbulence transport effects. The term $\Gamma_{\phi,eff}$ in the equation is the “effective” exchange coefficient for ϕ, whereas S_{ϕ} stands for the source or sink of variable ϕ. The particular expressions for $\Gamma_{\phi,eff}$ and S_{ϕ} pertaining to each variable are summarized in Table 1, with the appropriate empirical constants listed.

Table 1 Diffusion and source terms

Parameter ϕ	Diffusion $\Gamma_{\phi,eff}$	Source S_{ϕ}
1	0	0
U	μ_{eff}	$-\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}(\mu_{eff}\frac{\partial U}{\partial x})+\frac{\partial}{\partial y}(\mu_{eff}\frac{\partial V}{\partial x})$
V	μ_{eff}	$-\frac{\partial p}{\partial y}+\frac{\partial}{\partial x}(\mu_{eff}\frac{\partial U}{\partial y})+\frac{\partial}{\partial y}(\mu_{eff}\frac{\partial V}{\partial y})$
K	$\frac{\mu_{eff}}{\sigma_k}$	$G_k-\rho\varepsilon$
ε	$\frac{\mu_{eff}}{\sigma_{\varepsilon}}$	$C_1G_k\frac{\varepsilon}{k}-C_2\rho\varepsilon^2/k$

Where

$$G_k=2\mu_{eff}\left[(\frac{\partial U}{\partial x})^2+(\frac{\partial V}{\partial y})^2\right]+\mu_{eff}(\frac{\partial U}{\partial y}+\frac{\partial V}{\partial x})^2,\ \mu_{eff}=\mu+\mu_t,$$

$\mu_t=C_{\mu}\rho k^2/\varepsilon$, $C_{\mu}=0.09$, $C_1=1.14$, $C_2=1.92$, $\sigma_{\varepsilon}=1.3$, $\sigma_k=1.0$

(2) Prediction conditions

The prediction conditions in the present paper are sampled from the 40.53 type mill. Prediction conditions of the machine are listed in Table 2.

(3) Numerical method

The above equations are solved with a finite-difference procedure, namely, the SIMPLER algorithm that was developed by Patankar. A grid of 90×48 is used in the work and grids are distributed unevenly according to practical requirement. The boundary conditions are implemented by using the source terms, and the modification of the convection and diffusion derivatives. The boundaries of the solution domain are shown in Fig.1. In the inlet profile, velocities, k and ε are prescribed and the pressure is determined through solving the continuity equation. The outlet boundary condition of a fully developed flow is implemented by pre-setting values for the velocities, and then adjusting these to ensure that continuity of mass is preserved. Normal “non-slip” conditions are applied to the wall. Diffusive fluxes across the wall are calculated for promoting accuracy and economy by using “wall functions”. [4,5,6]

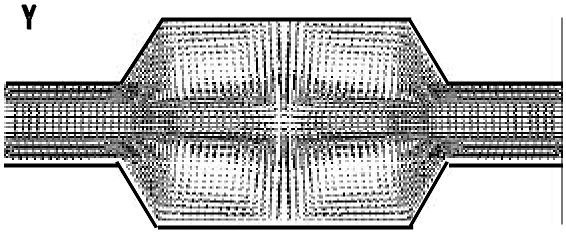


Table 2 Prediction conditions of the 40.53 type mill.

Parameters	Symbol	Prediction range left right
Mass flow of coal inlet	B (kg/s)	7.05, 7.05
Mass flow of gas inlet	m_f (kg/s)	10.00, 10.00
Pressure of gas inlet	p_1 (Pa)	5860, 5910
Gas radial velocity at mill axis	u_{rf}	0
Uniform variable radial variation at axis	$\partial\phi/\partial r$	0
Gas density at outlet	ρ_2 (kg/m^3)	1.09
Pressure of gas outlet	p_2(Pa)	3870, 3900
Mass flow of coal outlet	m_p(kg/s)	8.33, 8.33
Average particle diameter	d_p (μm)	75
Particle density	ρ_p(kg/m^3)	970
Tangent velocity at wall	u^{τ}(m/s)	0
Normal velocity at wall	u^n(m/s)	0
Uniform variable axial variation ratio at outlet	$\partial\phi/\partial z$	0

RESULTS AND DISCUSSION

(1) Gas field analysis

In the present paper, six cases with different fill ratio R and different gas inlet velocity U are taken account of. The fill ratio is 0, 15% and 20% respectively and the gas inlet velocity is 15m/s, 20m/s and 25m/s respectively. When the fill ratio is equal to 0, the gas field inside the mill will be symmetrical about both X-axis and Y-axis (Fig.3). However, if the steel balls are located at the bottom of the mill, the gas field inside the mill will appear much differently (Fig. 4, Fig. 5). When the gas enters a mill with certain fill ratio, it will flow toward the steel balls, close to the bottom, and is divide into two streams, little one and large one. The little stream of gas will return quickly and go out of the mill. The vortex flow produced by the little one is weak and located at the lower part of the mill. The large stream of gas will extend forward and collide against the opposite flow at the mill axis and go along the up-wall until out of the machine. The vortex flow formed by the large one is so strong that fully filled the whole space of the inside mill.

Fig.3. Configure of the gas field (U=25m/s, R=0%)

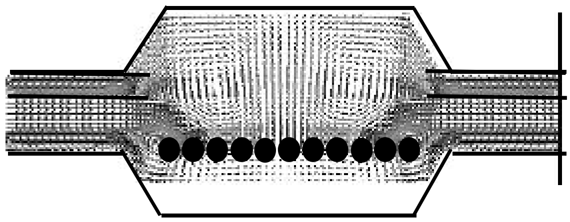


Fig.4. Configure of the gas field (U=25m/s, R=15%)

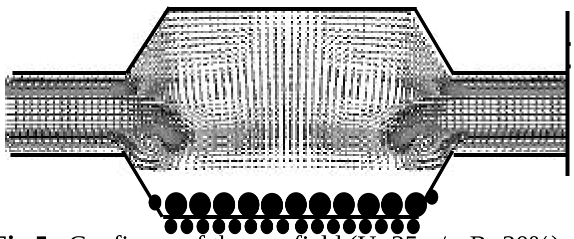


Fig.5. Configure of the gas field (U=25m/s, R=20%)

From the results of simulation and configures of gas fields, the large vortex flow at the higher part of the mill is fairly stable but the lower one will be variable with the fill ratio. In order to find the relationship between the gas field inside of mill and the inlet gas velocity (the fill ration), vortex flow center is cited here, and the variation of vortex flow center position is taken account of in the following paper.

(2) Effect of inlet gas velocity

According to the simulation results, if the fill ration is equal to 0, the position of vortex flow center will not vary with the inlet gas velocity. For the cases with a constant fill ratio, the position of vortex flow center (both up vortex and below vortex) will almost not vary with the inlet gas velocity either.

(3) Effect of fill ratio

When the fill ratio is greater than 0, in comparison with the case with fill ratio 0, the up-vortex center moves little toward the outlet. On the other hand, the below-vortex moves toward outside and upside quickly with the fill ratio increasing. Consequently, the more fill ratio, the less below-vortex flow and the more up-vortex flow, which contributes to enlarge the moving zone of thermal gas in the mill, extend the moving distance and time in the mill, and enhance the efficiency of heat transmitting, powder drying and mixing.

CONCLUSIONS

The present paper performs the numerical simulation of gas field in the mill, provides configures of gas fields and pays more attention on studying gas field variation with the gas inlet velocity and fill ratio. From the results and analysis above, conclusions can be obtained as follows.

1). In comparison with the case with zero fill ratio, the cases with positive fill ratio have more complex gas field in the mill. There are two vortex flows inside the mill, the large one and the little one. The large vortex flow locates at the higher part of mill inside, with long routine and large circular movement zone. On the contrast, the little one locates at the lower part of mill inside, with short routine and very small circular movement zone. Obviously, the large one plays the main role in heat transmitting, powder drying and mixing.

2). The position of vortex flow and the gas field structure inside of mill will almost keep constant with the variation of gas inlet velocity, although the gas inlet velocity has much effect on heat transmitting, powder drying and transporting.

3). The position of vortex flow will vary with the variation of the fill ratio. The more fill ratio, the less below-vortex flow and the more up-vortex flow, which contributes to enlarge the moving zone of thermal gas in the mill, extend the moving distance and time in the mill, and enhance the efficiency of heat transmitting, powder drying and mixing. In the present paper, the largest fill ratio is 20% and its work efficiency is the highest.

REFERENCES

[1] G. Q. Wang, X. Zhu, G. Z. Li and etc, Probing into the Optimized Air Feeding Parameters of BBD Mills, Power Engineering, 1994.(4), 58-62.

[2] Z. Y. Ren, Z. D. Wang, G. Q. Wang and etc, Determination of the Main Parameters of BBD Coal Mills, Power Engineering, 1995.(6), 49-55.

[3] V. S. Patankar, Numerical Heat Transfer and Fluid Flow, McGraw-Hill, 1980.

[4] K. F. Cen and J. R. Fan, Theory and Simulation of Gas-Solid Flows, Zhejiang University Publisher, Hangzhou, 1990, (in Chinese)

[5] L. X. Zhou, Theory and Numerical of Turbulent Gas-Solid Flows and Combustion, Science Press and CRC Press, Beijing, 1993. (in Chinese)

[6] B. E. Launder and D. B. Spalding., Mathematical Models of Turbulence, Academic Press, London, 1972.