

Study on the Influence of Moving Bed with Different Discharge Slope on Discharge Speed

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Abstract: The MP-PIC CPF method was used to numerically simulate the particle flow in a moving bed, and the change of particle outlet flow under different discharge slope of the moving bed was studied, so as to select the appropriate discharge slope of the moving bed. The results show that when the discharge slope is 45 degrees, compared with the discharge slope of 30 degrees, the outlet flow is more stable, and the mass flow of 60 degrees is larger. In the unloading process with a calculated time of 30s, the cumulative discharge quality of the moving bed with a 30 degree and 45 degree discharge slope is similar, while the discharge quality of the moving bed with a 60 degree discharge slope is 116% of that of the other two moving beds. It can be concluded that the discharge slope of the moving bed at 45 degrees can ensure the good flow uniformity of the moving bed and the good flow uniformity of the moving bed. Through the three-dimensional numerical simulation of the moving bed, the theoretical basis for the structural design of the moving bed is provided.

Keywords: Moving bed; Discharge slope; CPF.

1. Introduce

Moving bed is a kind of particle bed between fixed bed and fluidized bed, which is often used as gas-solid reaction equipment and heat exchanger, and is widely used in metallurgy, chemical industry, energy development and environmental protection[1]. The granular material in the moving bed moves slowly downward in a tight packing manner under the action of gravity[2]. In the unloading process of the moving bed, the internal particle material flow is complicated, and the movement between particles is affected by the particle property, the environment in the moving bed, the structure of the moving bed, etc., affecting the residence time and reaction degree of the particles in the moving bed, and the flow rate at the outlet of the moving bed is constantly fluctuating^{[3][4]}. By studying the discharge flow at the outlet, we can deeply understand the complex flow mechanical characteristics of the particles in the moving bed, which is of great significance for the design, optimization and enlargement of the moving bed device.

The main work of this paper is to study the influence of the slope of the moving bed outlet on the discharge flow during the discharge process of the moving bed. The Barracuda Virture Reactor software based on the CPF method conducts three-dimensional numerical simulation of the discharge process of the moving bed, and determines the appropriate slope of the moving bed outlet through the change of the discharge flow. It provides theoretical basis for structural design of moving bed.

2. Mathematical Model

MP-PIC-based CPF method adopts Euler-Lagrange method to solve gas-solid flow characteristics. In this method, fluid is regarded as continuous phase and described by Navier-Stoke equation, particles are regarded as discrete phase and calculated by MP-PIC method under the Lagrange framework. Large eddy simulation (LES) is used for turbulence model. The CPF method packages particles with the same material properties into "computational particles"

during calculation, which can track the motion characteristics of each particle under complex particle size distribution conditions, simplify the particle system, and greatly improve the calculation efficiency. In the solution process, the CPF method interpolates the fluid information into a single particle, and maps the statistical average of the particle information in the Euler mesh back to the Euler mesh, and then realizes the coupling of the continuous fluid phase and the discrete particle through the interphase drag force.

2.1. Gas phase governing equation

Gas phase mass conservation equation:

$$\frac{\partial}{\partial t}(\varphi_g \rho_g) + \nabla(\varphi_g \rho_g u_g) = 0 \quad (1)$$

Formula: φ_g is the gas phase volume fraction, ρ_g is the fluid density, u_g is the fluid velocity vector.

Gas phase momentum conservation equation:

$$\frac{\partial(\varphi_g \rho_g u_g)}{\partial t} + \nabla(\varphi_g \rho_g u_g u_g) = -\varphi_g \nabla p + \nabla \cdot \varphi_g \tau_g + \varphi_g \rho_g g - F \quad (2)$$

Formula: p is the gas phase pressure, g is the acceleration of gravity, F is the source term of gas-solid phase dynamic exchange, τ_g is the vapor viscous stress tensor.

2.2. Particle phase governing equation:

The distribution of particle phases in space is solved by the Liouville equation:

$$\frac{\partial f}{\partial t} + \nabla(f u_p) + \nabla_{u_p} \left(f \frac{du_p}{dt} \right) = 0 \quad (3)$$

Formula: f is a probability distribution function, u_p is the particle velocity vector.

Particle motion equation:

$$\frac{dx_p}{dt} = u_p \quad (4)$$

Formula: x_p is used to calculate the position of the particles.
Particle acceleration equation:

$$\frac{du_p}{dt} = D(u_g - u_p) + \frac{\nabla_p}{\rho_p} - \frac{\nabla \tau_p}{\phi_p \rho_p} + g \quad (4)$$

Formula: D is the phase drag coefficient, ρ_p is the particle density, τ_p is the normal stress of interparticle collision, ϕ_p is the particle phase volume fraction.

2.3. Gas-solid phase drag model

The selection of drag model for gas-solid two-phase mainly depends on the particle and local fluid flow characteristics. In the process of calculation and solution, the particle concentration varies from the minimum to the maximum packing concentration. Therefore, the Wen-Yu & Ergun drag model suitable for a wide particle concentration range is selected. The expression of the drag coefficient D_0 between Wen-Yu & Ergun is as follows:

When $\phi_p < 0.75$,

$$D_0 = D_W \quad (6)$$

When $0.75\phi_{cp} \leq \phi_p \leq 0.85\phi_{cp}$,

$$D_0 = \frac{\phi_p - 0.75\phi_{cp}}{0.85\phi_{cp} - 0.75\phi_{cp}} (D_E - D_W) + D_W \quad (7)$$

When $\phi_p > 0.85\phi_{cp}$,

$$D_0 = D_E \quad (8)$$

Formula: D_W is the drag coefficient of the Wen-Yu phase, D_E is Ergun phase drag coefficient, ϕ_{cp} is the bulk fraction of particles.

The expression of Wen-Yu phase drag coefficient is:

$$D_W = \frac{3}{4} C_d \frac{\rho_g |u_g - u_p|}{\rho_p d_p} \quad (9)$$

Formula: C_d is the drag coefficient.

The expression of Ergun's interphase drag coefficient is:

$$D_E = \left(\frac{180\phi_p}{\phi_g \text{Re}_p} + 2 \right) \frac{\rho_g |u_g - u_p|}{\rho_p d_p} \quad (10)$$

3. Geometric Model and Parameter Setting

3.1. Geometric model

The research objects are moving beds with discharge

gradients of 30°, 45° and 60°. The model structure and its detailed dimensions are shown in Figure 1. The velocity inlet boundary conditions and pressure outlet boundary conditions were defined. Under the initial conditions, particles were uniformly mixed and deposited at the bottom of the moving bed at a height of 1m. Adaptive Cartesian mesh division was carried out on the geometric model adopted in the simulation. After grid independence verification, the number of calculated grids was determined to be 300,000. The grid diagram is shown in FIG. 2.

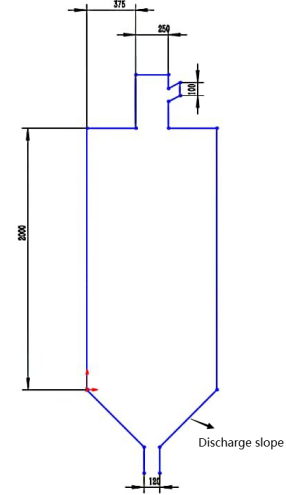


Figure 1. Moving bed structure and detailed dimensions

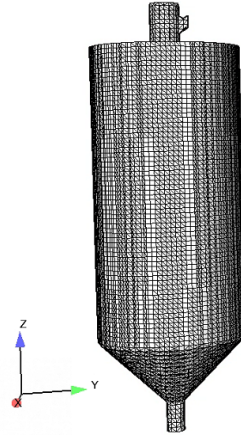


Figure 2. Grid division model

3.2. Simulate the boundary conditions and parameters

Two kinds of solid particles are selected, and the properties of the two kinds of particles are shown in Table 1, and the particle size distribution is shown in Figure 3.

Table 1. Physical properties of particles

Name	Particle size(mm)	True density(kg/m3)	Sphericity ϕ
Circulating ash	0.05-0.11	1400	1
Quartz sand	0.08-0.13	1350	0.88

Table 2. Parameter setting of numerical solution process

Argument	Bulk fraction of particles	Initial bed height/mm	Outlet pressure/Pa	Operating temperature/k	Time step/s
Numerical value	0.6	1000	101325	300	0.001

4. Results and Discussion

4.1. Influence of different discharge slope on outlet mass flow

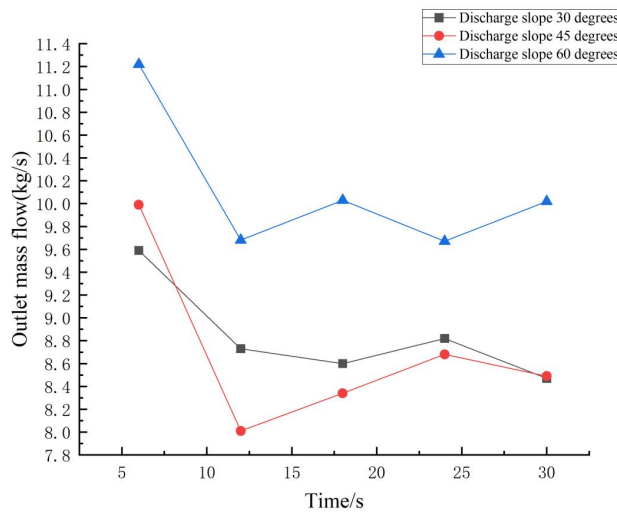


Figure 3. Different discharge gradients on outlet mass flow

As can be seen from Figure 3, when the three discharge gradients are adopted, the mass flow rate at the outlet generally shows a decreasing trend before the first 12s, and the mass flow rate at the outlet fluctuates continuously during the 12-30s. The overall flow trend is similar at the discharge slope of 30 degrees and 45 degrees, but the outlet mass flow rate changes more slowly at the discharge slope of 45 degrees, and the flow uniformity is higher. Compared with the other two discharge slopes, the mass flow at the outlet increases significantly at the discharge slope of 60 degrees, and the mass flow rate changes greatly before 12s.

4.2. Discharge conditions of different discharge slopes during the calculated time

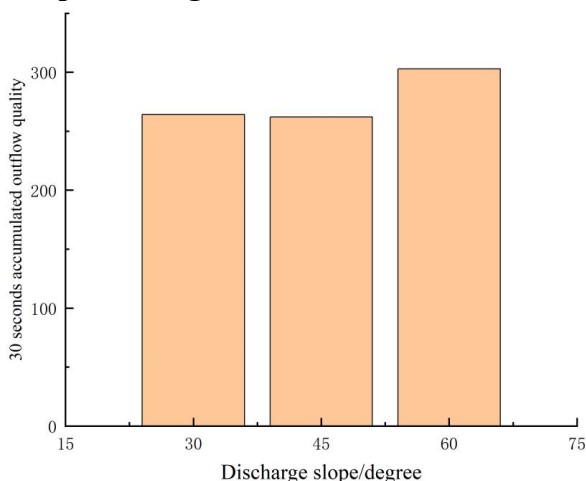


Figure 4. Discharge quality of different discharge slope in calculation time

As can be seen from FIG. 4, during the unloading process of the calculation period of 30s, the cumulative outflow mass under the discharge slope of 30 degrees and 45 degrees is

similar, which is 264kg and 261kg respectively, while the cumulative outflow mass under the discharge slope of 60 degrees is 303kg, which is 116% of the cumulative outflow mass under the other two discharge slopes. This indicates that the moving bed material flows faster and stays shorter at this Angle, which is not conducive to the full reaction of the moving bed material.

5. Conclusions

1. The simulation results show that compared with the discharge slope of 30 degrees, the outlet flow is more stable when the discharge slope is 45 degrees, while the outlet flow is larger when the discharge slope is 60 degrees.
2. In the discharge process of 30 degrees, the cumulative discharge quality of 30 degrees and 45 degrees of discharge slope is similar, and the discharge quality of 60 degrees of discharge slope is 116% of the other two. Therefore, the use of 45 degrees moving bed discharge slope is more appropriate.

References

- [1] Kung K S, Thengane S K, Ghoniem A F, et al. Bulk permeability characteristics in a biomass moving bed and their effects on reactor design and scaling [J]. *chemical Engineering Journal*, 2021, 420:129979.
- [2] Wei H, Ding W T, Li Y, et al. Porosity distribution of moving burden layers in the blast furnace throat [J]. *Granular Matter*, 2021, 23(1): 10.
- [3] Golman B, Shinohara K. Comparison of moving bed reactors for chemical vapor deposition coating of fine particles [J]. *Advanced Powder Technology*, 1999, 10(1): 65-76.
- [4] Lü H, Liu Y X, Dong Y Y, et al. Experimental study on filtration performance of the moving bed granular filter with axial flow [J]. *Particuology*, 2023, 72: 17-28.