Research on Influence of the Internal Parameters of V-Type Separator on the Separation Efficiency

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Abstract. The performance of the grinding system is affected by the performance of the separator. It is significant to study the efficiency of the milling system for reducing the energy consumption of the whole grinding system. By changing the baffle plate parameters, the Distribution Law of the flow field inside the separator was analyzed, and the most reasonable structure parameters of the separator were obtained. By using the gas-solid two-phase model and the DPM discrete phase model, the classification efficiency and the total efficiency of the separator are calculated. It is verified that the parameters of the baffle plate are important factors to improve the efficiency of powder separation.

1. Introduction
In the cement manufacturing industry, scholars at home and abroad mainly study how to reduce the unit energy consumption by improving the grinding efficiency. At present, most of the v-type separator used in China are imported from abroad\textsuperscript{11}, but the internal structure of the relevant separator is seldom designed and analyzed. It is necessary to study the internal flow field and gas-solid two-phase flow in order to study the classification characteristics of the separator. The gas distribution in the internal flow field has a direct effect on the particle trajectory, which affects the classification efficiency of the separator.

In this paper, the flow field and gas-solid two-phase flow in the separator are analyzed by finite element method by changing the parameters of the baffle plate, the effect of changing the parameters of the baffle plate on improving the grinding efficiency, reducing the unit energy consumption and reducing the production cost is verified.

2. Particle motion analysis
The particles in the separator are affected by gravity, drag force and buoyancy. The particles settle under gravity, following the Newton's second law of motion, or equation 1.

\[
\frac{d}{dt}(m_p \frac{dq}{dt}) = F_i
\]

In the equation, \(m_p\) is the particle mass, kg; \(q\) is the displacement vector of the particle, m; \(F_i\) is the net force or the total force acting on the particle.
For a moving particle in the air, the total force is the sum of $F_g$ and $F_D$ minus its own buoyancy $F_b$, as in equation 2:\[2\].

\[
F_g = \rho_p - \rho \cdot m_p g \\
F_D = 3 \pi \mu d_p (u - v) \\
F_b = \rho_p \frac{\pi}{6} d_p^3 g \\
F_i = F_g + F_D - F_b
\]

In this equation, $\rho_p$ is the density of the particle, kg/m$^3$; $\rho$ is the density of the fluid around, kg/m$^3$; $g$ is gravity acceleration, m/s$^2$; $\mu$ is the dynamic viscosity of the surrounding fluid, Pa·s.

The term $\rho_p - \rho$ in the gravity expression represents buoyancy. When a particle has the same density as the surrounding fluid, its value approaches zero. In this case, the particle is called a suspended particle.

The drag force expression is derived from stokes law of drag, which is more applicable when the relative Reynold number of particles is very small. Smaller particles are more effective.

\[
R_v = \frac{\rho d_p |u - v|}{\mu} \leq 1
\]

Assuming that the particles do not change size ($d_p$ and $m_p$ are constants), the mass of the spherical particles is given in equation 3.

\[
m_p = \frac{\pi}{6} \rho_p d_p^3
\]

In this equation, $d_p$ is the particle size, m; $u$ is the velocity of the surrounding fluid, m/s; $v$ is the velocity of the particle ($v = dq / dt$), m/s.

Combined with equation 1-3, we obtain a simplified expression for the equation of motion of the particle, such as equation 4, $\tau_p$ is the Lagrange time scale or the particle velocity response time.

\[
\frac{d^2 q}{dt^2} = \frac{\rho_p - \rho}{\rho_p} g + \frac{1}{\tau_p} (u - v)
\]

\[
\tau_p = \frac{\rho_p d_p^2}{18 \mu}
\]

3. Numerical simulation and result discussion

3.1. Analysis of gas flow field of separator

3.1.1. Boundary condition

(1) The entrance boundary condition

The entrance includes the air inlet and the material inlet, and the material inlet is set as the wall condition for the model which only calculates the internal flow field and does not consider the motion state of the solid particles. The setting of the air inlet is based on the calculation of the designed air volume and the inlet area, and the wind speed is 15.4 m/s. The air inlet is set as the velocity inlet. Taking into account the actual production situation, the air flow direction of the air inlet is uniform and perpendicular to the inlet boundary.

(2) The outlet boundary condition
There are two outlets in the model, one is the outlet and the other is the coarse material outlet, which includes the fine powder outlet. The outlet flow and pressure at both outlets are unknown, so the outlet type is set as the pressure outlet[3].

(3) Wall setting
The air flow inside the separator in actual use is high Ren number turbulence, except the inlet and outlet boundary, all other surfaces are set as a solid wall and non-slip wall.

3.1.2. Mesh generation
The flow field inside the separator was calculated and the fluid field was meshed by finite element software. The fluid field model divided about 7.75 million structured tetrahedral grids. Mesh quality directly affects the numerical results.

3.1.3. Parameter setting and solver
The implicit method based on steady state and pressure solver is chosen. Using the pressure-velocity coupling equation of the SIMPLEC algorithm with the default relaxation factor, the standard pressure gradient, the convection term of the upwind discrete quadratic equation, and the RND turbulence model. The initialization is done before the computation begins, and then the iterative computation begins.

3.1.4. Results of model optimization analysis
Only the internal flow field simulation is considered, and the motion state of solid particles is not considered.

(1) The influence of different baffle angle in the dispersion zone and in the classification zone on the internal flow field
The spacing of baffle plates in the grading area is set to 343 mm, the angle of baffle plate in classification area is 40°, under the condition of this separator structure, the influence of the baffle angle in the dispersion zone on the internal flow field is analyzed when the baffle angle in the dispersion zone is 30° and 35°.

On the basis of this research, the optimum value of the baffle angle in the classification zone is found, and the structure parameters of the separator with more reasonable pressure, streamline distribution and better powder selection effect are obtained. The specific structural parameters are shown in table 1.

| Serial number | Angle of baffle in dispersion zone | Angle of baffle in grading area |
|---------------|----------------------------------|--------------------------------|
| 1             | 30°                              | 40°                            |
| 2             | 35°                              | 40°                            |
| 3             | 30°                              | 50°                            |

Table 1. Structural parameters

Figure 1. Pressure and velocity distribution diagram of serial number 1
Figure 2. Pressure and velocity distribution diagram of serial number 2
The analysis of figures 1 and 2 shows that the pressure distribution and velocity distribution in figure 1 are obviously better than figure 2 when the angle of the baffle plate is 30° and 35° respectively. Therefore, the angle of the baffle in the dispersion zone is 30°. When the angle of baffle plate is 30°, the angle of baffle plate is changed, by comparing the figures 1 and 3, it is found that there is a large pressure difference between the dispersion area and the classification area, and it is advantageous to the material carries on the separation in the classification area. Therefore, through the comparison and analysis of the structural parameters of the above model, it is concluded that the angle of the baffle plate in the dispersion zone of the optimized separator is 30°, the velocity distribution figure 3 is more uniform than figure 1, and the pressure distribution in the upper part of the air distribution zone is better than figure 1, the pressure distribution in the air distribution area is reasonable and the airflow is uniform.

The pressure distribution at the baffle angle of 50° in the classification area is more uniform and reasonable than that at the baffle angle of 40° in the classification area of the pre-optimized separator, the velocity and pressure distribution of the separator with 30° baffle angle in dispersion zone and 50° baffle angle in classification zone are more favorable for powder selection.

### 3.2. Analysis of gas-solid two-phase flow in separator

Lagrange method and Euler method are commonly used in gas-solid two-phase flow analysis. Discrete particle model DPM, is the Euler-Lagrange method. The discrete phase is the particle and the continuous phase is the gas, and the volume fraction of the particle is less than 12%. Steady-state analysis is used for both continuous and discrete phases.

#### 3.2.1. Boundary condition setting

Gas phase boundary condition as mentioned above, in solid phase boundary condition, material inlet is set as injection surface, air outlet is set as escape surface, coarse powder outlet is trap surface, others are set as reflect wall. The entrance mode of particles is plane injection. The direction of injection is perpendicular to the entrance, and the particles are tracked by random mode. When calculating the classification efficiency, the particle distribution is uniform. According to the type of powder separator, the inlet air velocity is 15.4 m/s, the equal particle diameter is 2 mm, the incident velocity is 5 m/s, and the feeding velocity is 611 kg/s, when calculating the total efficiency, the particle size distribution was chosen to satisfy the Rosin-Rammler distribution.

The particle size of the Rosin-Rammler distribution assumes the following relationships:

\[ Y_d = e^{-\left(\frac{d}{\bar{d}}\right)^n} \]  \hspace{1cm} (5)

\[ n = \ln(-\ln Y_d) / \ln\left(\frac{d}{\bar{d}}\right) \]  \hspace{1cm} (6)

In the equation, \(d\)—the particle size, mm; \(Y_d\)—the mass fraction of particle size larger than particle size \(d\), \(n\)—propagation coefficient, \(\bar{d}\) — average particle size.

When the particle size range is 75-26500 um, the mass fraction of the corresponding particle size is calculated according to the sieve residue, and the mass fraction larger than the particle size \(d\) is
calculated according to equation 5. The average particle size is 1526 μm according to the curve fitting of \( Y_d \) data. According to equation 6, the propagation coefficients \( n \) of different particle sizes is calculated. The final \( n \) value, \( n = 0.503 \), is obtained by averaging the \( n \) of different particle sizes.

### 3.2.2. Calculation of particle classification efficiency

The classification efficiency of particles is calculated and the equation is satisfied\(^4\):

\[
\text{Classification efficiency (Overall efficiency)} = \frac{\text{Number of particles in the outlet}}{\text{Total particle number}} \times 100\% \tag{7}
\]

Based on the analysis of the above parameters, the uniform distribution of particles of the same diameter of 2mm before and after optimizing the structure of \( \text{v-type separator} \) is calculated. The number of particles tracked is 48 before optimizing, the number of particles in the air outlet is 28, the number of particles in the coarse powder outlet is 20, the particles are completely trapped. After optimization, the number of particles is 50, the number of particles in the air outlet is 48, the number of particles in the coarse powder outlet is 2, and the particles are completely trapped. The movement of particles in the separator is shown in figures 4 and 5.

The classification efficiency of pre-optimization and post-optimization \( \text{v classifier} \) was calculated. The classification efficiency of pre-optimization and post-optimization \( \text{v classifier} \) was respectively 58.3\% and 96\%.

It is concluded that the change in the structural parameters of the separator has an important effect on the classification efficiency of the separator by comparison.

![Figure 4](image1.png)  
**Figure 4.** Trajectories of 2 mm equal-diameter particles before optimization

![Figure 5](image2.png)  
**Figure 5.** Optimized trajectories of 2 mm equal-diameter particles

### 3.2.3. Calculation of total efficiency of the separator

In order to study the gas-solid separation characteristics of the separator, the particle size range of 75-26500 μm was selected to calculate the total efficiency of the separator. The total efficiency was 57.4\% before optimization and 81.4\% after optimization. The total efficiency of the optimized model is 24\% higher than that before optimization. It is proved that the efficiency of the separator can be improved effectively by optimizing the angle parameters of the baffle plate.

### 3.2.4. Analysis of internal flow field of separator

The reasonable structure parameters of pressure and velocity distribution were obtained by gas phase analysis of the separator, and the classification efficiency and total efficiency were calculated by the structural parameter model, which verified the correctness of gas phase analysis. DPM discrete phase analysis of the separator, particle size model for Rosin-Rammler distribution\(^5\), is getting the following internal flow field analysis results, analysis results as showed in figure 6.
Optimized pressure distribution  Optimized velocity distribution  Pressure distribution before optimization  Velocity distribution before optimization

Figure 6. Pressure and velocity distribution of the internal flow field

It can be seen from the diagram that the pressure at the dispersed area of the optimized baffle is higher, and there is a larger pressure difference. The pressure difference is evenly distributed, which is beneficial to the separation of particles. At the same time, the pressure difference distribution of the optimized model is more reasonable at the baffle of particle inlet. The velocity distribution of the optimized structure in the whole separator is more reasonable than before optimization structure. The optimized structure enables the particles to be separated efficiently under the action of gravity, air resistance and wind force, which meets the experimental requirements.

4. Conclusion
Through the fluid analysis, the calculation of the internal flow field and the track of particle movement of the separator is completed, and the better gas flow velocity and pressure distribution can be realized by changing the angle parameters of the baffle plate of the separator, to effectively improve the classification efficiency and the total efficiency of the separator, it is of great significance for the improvement of the overall performance of the grinding system.

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