Study on Separation Efficiency of Cyclone Separator for 75t/h Circulating Fluidized Bed Boiler

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Abstract: Taking a 75t/h circulating fluidized bed boiler cyclone separator in a boiler manufacturing plant as the research object, this study uses FLUENT fluid calculation software and the balanced orbit and dwell time model to analyze the influence of the particle trajectory tracking, exhausting pipe length and pipe diameter on the separation efficiency. The calculation results show that when the relative diameter is equal to 0.3~0.5, the separation efficiency is already high. If the diameter of the core tube is reduced, the separation efficiency is not improved much. However, this will lead to a sharp increase in pressure loss; The increase of the powder concentration is markedly increased; the larger the particle size is, the higher the separation efficiency is. The separation efficiency is obviously improved after the particle size is larger than 30 μm. The separation efficiency is already high after the particle size is larger than 80 μm, and the increase of the particle size is not significant.

1. Introduction

In the development of circulating fluidized bed combustion technology, since the cyclone separator has no moving parts, the structure is relatively simple and the separation effect is good, and it is applied in engineering. Manufacturers and research institutes in all countries have a set of optimal design parameters, and the separation efficiency is high. Generally, the particle size distribution and operating conditions of the circulating fluidized bed can reach more than 99%. However, since the internal flow field of the cyclone is a three-dimensional turbulent rotation accompanied by gas-solid two phases, and the gas interacts with solid particles, solid particles and solid particles, the internal flow field is extremely complicated [1-5]. At present, through a certain empirical or semi-empirical formula, the combination of theory and practical experience in design is the design idea of the cyclone separator, which is used to obtain the structure and scale of the separator. However, the relationship between the insertion length of the central separator of the cyclone separator and the flow resistance is still insufficient, especially for the influence of the volute inlet and the slit inlet cyclone on the separation performance, which directly affects the influence. The accuracy of the cyclone design, and the traditional design method requires a lot of time and effort, and there are a lot of costs, and through numerical simulation, can shorten the research time and save research funding [6-8].

In this paper, the balance trajectory model and the residence time model are used to calculate the separation efficiency of the cyclone separator. The core tube is extended down to the lower end of the separator to form a CS cylindrical surface, and a balanced orbital model obtained by analyzing the resistance of the outward centrifugal force and the inward flowing airflow is established. Under the action of centrifugal force, the large particles move toward the wall of the cyclone separator and are replenished. The small particles escape and are carried into the exhaust pipe by the airflow. The reason
is that the centrifugal force is proportional to the mass of the particles, that is, proportional to the resistance, that is, the skeletal force is proportional to the particle size, and the cyclone separator or cleavage particle size mainly means that the particle size is in equilibrium. A particle size is representative of a particle with a 50% probability of being captured, which is a measure of separator separation performance. The residence time model assumes that any position of the particles enters the cyclone at the inlet of the cyclone and the residence time is sufficient inside the cyclone to cause the particles to move radially to the wall and trapped at the bottom by the cyclone.

2. Physical model and meshing

2.1 Physical model
In this paper, numerical simulation is carried out for the cyclone separator of a 75t/h circulating fluidized bed boiler. One is to use the volute inlet according to the design drawings and the other is to use the tangential inlet. Figure 1 is a plan view of a design drawing of a volute inlet. 2 is a schematic view showing the structure and dimensions of a cyclone separator. The main geometric parameters are shown in Table 1.
| Separator inlet height \(a\) | Separator inlet width \(b\) | Volute diameter \(D_0\) | Separator diameter \(D_1\) | Exhaust tube outlet diameter \(D_2\) |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| 2600            | 1500            | 3865            | 3400            | 1500            |
| Diameter of ash outlet of separator \(D_2\) | Exhaust pipe insertion depth \(h\) | Separator cylinder height \(h\) | Total height separator \(H\) |
| 1180            | 1100-3000       | 3600            | 6000            |

2.2 Meshing

In this paper, FLUENT’s own Gambit pre-processing program is used to establish a cyclone separator calculation model and generate the required grid for subsequent calculation and comparison. The cyclone separator meshing is shown in Figure 3 and Figure 4.

To carry out the numerical calculation of the flow field, it is first necessary to discretize the region to be calculated. The meshing of the region is to discretize the differential equation and lay the foundation for numerical solution. The way of meshing will directly affect the difficulty of discretization of the equation, affect the calculation speed and the required storage, and affect the convergence and accuracy of the numerical solution. In order to ensure the quality of the grid and improve the calculation accuracy, taking into account the sharpness of the connection between the intake pipe and the cylinder, the partition is used to generate the grid, and the whole model is divided into seven parts: the intake pipe, the annular space, the cylindrical separation space, Conical separation space, ash bucket portion, ash cone portion, and exhaust pipe. The intake pipe adopts a hexahedral unstructured grid, and the other parts adopt a hexahedral structured grid. The total number of calculated grids is controlled by the grid density along the height direction. In order to obtain a solution unrelated to meshing, a grid with a total number of 1 million is divided. The mesh model obtained by the division is shown in Fig. 3 and Fig. 4.

![Figure 3 Schematic diagram of meshing of tangential inlet cyclone separator](image1)

![Figure 4 Schematic diagram of grid division of volute inlet cyclone separator](image2)

3. Mathematical models and calculation methods

3.1 Mathematical model

Adopt RSM turbulence.

3.2 Boundary conditions and calculation methods

(1) Entrance boundary
The inlet airflow is the air at normal temperature. According to the actual flue gas volume and the inlet cross-sectional area, the inlet velocity is calculated to be 18 m/s, the turbulence intensity is set to 10%, and the hydraulic diameter is 1.9.

(2) Exhaust port boundary
The exhaust port boundary is set to a pressure outlet, and the turbulence intensity is set to 10%, and the hydraulic diameter is 1.9.

(3) Particle trap boundary
Since there is almost no airflow flowing from the bottom, the airflow is set to zero.

(4) Solid wall boundary
No slip boundary wall, wall roughness defaults to 0.5.

The wall has a non-slip boundary with a default wall roughness of 0.5. The wall effect is the main source of vortices and turbulence, so the treatment of the near wall region has a significant impact on the accuracy of the numerical solution results. The turbulent diffusion of the laminar flow bottom layer is enhanced and the turbulent diffusion is relatively weakened in the region close to the solid wall surface, so that the turbulent transport equation acting on the high Reynolds number is not strictly effective. In this paper, the standard wall function method is used to treat the boundary turbulence to give the correct wall shear stress.

4. Results and analysis

4.1 particle trajectory tracking
In order to visually show the gas-solid separation process of the cyclone separator, it is necessary to track the movement trajectories of particles of various particle sizes by finding the principle of gas-particle two-phase separation in the separator. In this paper, the discrete phase model is used to analyze the trajectories of particles with different diameters and different incident positions in the cyclone separator.

![Particle Trajectory Tracking](image)
Fig. 5 is particles of three particle sizes, respectively 1 μm, 30 μm, 100 μm, and the incident position of the particles to be studied is the upper left corner of the inlet, see Fig. 5 (a) to (c). The movement of particles with particle sizes of 1 μm and 30 μm is similar, but it can be clearly seen that the 1 μm particle size is more complicated, that is, the motion trajectory is more unpredictable, but the particles of 1 μm and 30 μm particle size eventually escape. The 100 μm particle size is significantly different from the 1 μm and 30 μm particle size particles. It is a particle that can be trapped. After several rotations, it is free to fall to the bottom along the wall.
c) Particle size is 100μm

Figure 6: Particle tracking track at the lower right corner of the incident position (x = -0.2, y = -4, z = 0)

Fig. 6 shows particles having a particle diameter of 1 μm, 30 μm, and 100 μm, but the incident position is different from that of Fig. 6, and the incident position is the lower right corner. It can be seen from the figure that the incidence of the incident particle trajectory in the lower right corner is significantly different from that in the upper left corner. That is to say, the small particles are more affected by the turbulent pulsation, and the larger random particles are stronger, and the larger particles are less affected. Particles with a particle size of 1 μm are incident from the lower right corner. After the rotation, the final particles no longer collide with the inner surface of the wall and eventually escape. Particles with a particle size of 30 μm are incident from the upper left corner and eventually escape, but are incident from the lower right corner, collide with the wall, and are finally trapped by the lower end of the wall.
The incident particle diameter of Fig. 7 is also 1 μm, 30 μm, 100 μm, but the incident position is the middle of the entrance. As can be seen from the figure, the particles having a particle size of 1 μm and 30 μm formed a short circuit, and after the incident, the gas stream escaped from the exhaust pipe, and the particles having a particle diameter of 100 μm were trapped by the wall. It can be seen from Fig. 5 to Fig. 7 that small particles below 30 μm are not easily separated, and even if they are separated, the relationship with the incident position is large, and particles larger than 100 μm are easily trapped, and the relationship with the incident position of the particles is not Big.

In summary, most of the small particles incident from the upper left corner of the inlet will be carried away by the air flow, but there may be a small amount of particles staying near the top cover, forming a so-called "ash-up ring". The small particles injected from the entrance surface parallel to the exhaust pipe are likely to form a "short circuit", which seriously affects the separation efficiency of the cyclone. In addition to the 1 μm particles, the particles injected from the lower right corner of the entrance surface have a better separation effect. It can be seen from the numerical calculation results that the short circuit of the upper ash ring and the exhaust pipe has a great influence on the separation efficiency of the separator. Therefore, in the design process of the cyclone separator, attention should be paid to preventing or minimizing these two phenomena and improving the cyclone separator.

4.2 Influence of exhaust pipe length and pipe diameter on separation efficiency

The abscissa of Fig. 8 is the relative length of the center tube, that is, the ratio of the length of the center tube to the longitudinal length of the inlet, and the ordinate is the efficiency. It can be seen from the figure that as the length of the central tube increases, the separation efficiency increases. When the length of the central tube is about 0.4 to 0.5 times the longitudinal length of the inlet tube, the separation efficiency is the highest, and as the relative length of the central tube increases, the separation efficiency is reduced. Therefore, the influence of the excessive length of the central pipe on the separation efficiency is not conducive to the gas-solid separation. Because the insertion of the center tube is too shallow, it will cause the normal swirl core to bend or even break, resulting in an unstable state, and it is easy to cause gas short circuit to reduce the separation efficiency, and the exhaust pipe inserted is too deep, which will shorten the exhaust pipe. The distance from the bottom of the cone increases the chance of secondary entrainment.
Figure 8 Effect of center tube length on separation efficiency

The abscissa of Fig. 9 is the relative pipe diameter, and the ratio of the diameter of the exhaust pipe to the diameter of the separator, and the ordinate is the separation efficiency of the cyclone. The size of the exhaust pipe affects both the separation efficiency and the pressure drop of the separator, and the two are contradictory. If the separation efficiency is to be increased, the diameter of the exhaust pipe should be reduced. To reduce the pressure drop of the separator, a larger exhaust pipe diameter is required. Therefore, in the design of the actual cyclone separator, it is necessary to comprehensively consider the separation efficiency and the relationship between pressure drop, as can be seen from the figure, when the relative diameter is equal to 0.3–0.5, the separation efficiency is already high. If the diameter of the core tube is reduced, the separation efficiency is not improved much. However, this will lead to pressure loss increase rapidly. Therefore, it is suitable to take a relative pipe diameter of about 0.4.

Figure 9 Effect of relative pipe diameter on separation efficiency

4.3 Effect of particle concentration on separation efficiency of cyclone separator

Figure 10 is a graph showing the variation of the separation efficiency of the tangential inlet cyclone with the powder concentration. In the figure, the abscissa is the solid powder concentration and the ordinate is the total separation efficiency. As can be seen from the figure, the total separation efficiency increases significantly as the powder concentration increases. When the concentration of the powder is 80g per cubic meter of gas, the increase of the total separation efficiency is obvious. The ratio of the concentration of the powder at the outlet of the cyclone core tube to the inlet concentration is only 1/3 of the low concentration. Therefore, although the amount of particles taken out from the cyclone vent is still increased as the powder concentration is increased, the proportion of the powder concentration in the inlet concentration is decreased.
4.4 Effect of Particle Size on Separation Efficiency of Cyclone Separator

Figure 11 is a plot of particle size versus separation efficiency, with the abscissa being the particle size and the ordinate being the separator efficiency. Due to the use and conditions of use of the separator, the overall efficiency of the cyclone separator is only meaningful for a specific particle group, and its performance as a separator is not versatile. It can be seen from Fig. 11 that the larger the particle size, the higher the separation efficiency, but the separation efficiency is obviously improved after the particle size is larger than 30 μm. The separation efficiency is already high after the particle size is larger than 80 μm, and the increase of the particle size is not significant.

5. Conclusions

(1) Most of the small particles incident from the upper left corner of the inlet will be carried away by the airflow, but a small amount of particles will stay near the top cover to form an "upper ash ring". The small particles injected from the entrance surface parallel to the exhaust pipe are likely to form a "short circuit", which seriously affects the separation efficiency of the cyclone. In addition to the 1 μm particles, the particles injected from the lower right corner of the entrance surface have a better separation effect. The short circuit of the upper ash ring and the exhaust pipe has a great influence on the separation efficiency of the separator.

(2) When the relative diameter is equal to 0.3–0.5, the separation efficiency is already high. If the core tube diameter is reduced, the separation efficiency is not improved much. However, this will
cause the pressure loss to rise sharply. A relative diameter of about 0.4 is suitable.

(3) The total separation efficiency increases significantly as the powder concentration increases. When the concentration of the powder is 80g per cubic meter of gas, the increase of the total separation efficiency is obvious. The ratio of the concentration of the powder at the outlet of the cyclone core tube to the inlet concentration is only 1/3 of the low concentration.

(4) The larger the particle size, the higher the separation efficiency, but the separation efficiency is obviously improved after the particle size is larger than 30μm. After the particle size is larger than 80μm, the separation efficiency is already high, and the increase of the particle size is not significant.

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