Study on inertial separation device of the sandy flow

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Abstract. An inertial separation device was designed in order to solve the problem of water-sand separation in the flow. Firstly the trajectories of sand grains were qualitatively analysed, the movement rules in the device were preliminarily grasped. Then the separation efficiency of different sizes of sand was numerically simulated, and the effect of different structural parameters on the separation efficiency was analysed. Finally, a testing rig was set up, the separation efficiency and pressure loss were analysed, and the experimental and numerical results were compared. The numerical and experimental results can guide the further design of separating device.

1. Introduction
Sediment flow is a common transportation in mining, construction, petrochemical, port dredging and other industries. Because of the existence of sand particles, it will cause serious abrasion and low efficiency of moving parts, affect the service life of the pump and reduce the operation quality of the pump. A sand-water separation device added before the intake of the pump, and let the sand separated before the pump is important. It is of great significance to improve the efficiency of the pump and improve the design level of the pump group.

In this paper, based on the principle of inertial separation, a sand-water separating device is designed. Through numerical simulation and experimental analysis, the characteristics of the separation efficiency of the device are analyzed, and the relevant conclusions are obtained. The numerical and experimental results can guide the further design for the separation device.

2. Basic Equation
2.1. Basic hypothesis
To achieve this numerical simulation, the following hypotheses are made: (1) Liquid phase is a continuous incompressible fluid, solid phase is discrete, physical parameters of each phase are constants, and there is no phase transition. (2) The self-rotation, collision and rupture of sand grains are not considered. (3) The effect of temperature changed on the flow field is not considered.

2.2. Numerical Model
The $\kappa-\varepsilon$ turbulence model and the modified $\kappa-\varepsilon$ turbulent combustion model are applied to estimating the time averaged Navies-Stokes equations in this paper.

Fluid phase continuity equation:
Solid phase continuity equation:
\[
\frac{\partial \Phi_f}{\partial t} + \frac{\partial}{\partial x_i} \left( \Phi_f V_{fi} + \varphi_f v_{fi} \right) = 0
\]  
(1)

Fluid phase momentum equation:
\[
\frac{\partial}{\partial t} \left( \Phi_f V_{fi} + \frac{\partial \vec{F}_f}{\partial \vec{x}_k} \right) + \frac{\partial}{\partial x_k} \left( \Phi_f V_{fi} V_{ik} + \frac{\vec{F}_f}{\rho_f} \right) + V_{fi} \frac{\partial \varphi_f}{\partial x_k} + \frac{\partial \varphi_f}{\partial x_k} V_{fi} + \frac{\partial \varphi_f}{\partial x_k} V_{fi} = \frac{1}{\rho_f} \left( \Phi_f \frac{\partial \vec{F}_f}{\partial \vec{x}_i} + \varphi_f \frac{\partial \vec{F}_f}{\partial \vec{x}_i} \right) + \frac{v_f}{\rho_f} \left( \frac{\partial \varphi_f}{\partial x_k} \left( \frac{\partial \vec{V}_{fi}}{\partial \vec{x}_k} \right) + \frac{\partial \varphi_f}{\partial x_k} \left( \frac{\partial \vec{V}_{fi}}{\partial \vec{x}_k} \right) \right) - B
\]  
(2)

Solid phase momentum equation:
\[
\frac{\partial}{\partial t} \left( \Phi_p V_{pi} + \frac{\partial \vec{F}_p}{\partial \vec{x}_k} \right) + \frac{\partial}{\partial x_k} \left( \Phi_p V_{pi} V_{pk} + \frac{\vec{F}_p}{\rho_p} \right) + \frac{\partial \varphi_p}{\partial x_k} \left( \frac{\partial \vec{V}_{pi}}{\partial \vec{x}_k} \right) + \frac{\partial \varphi_p}{\partial x_k} \left( \frac{\partial \vec{V}_{pi}}{\partial \vec{x}_k} \right) = \frac{1}{\rho_p} \left( \Phi_p \frac{\partial \vec{F}_p}{\partial \vec{x}_i} + \varphi_p \frac{\partial \vec{F}_p}{\partial \vec{x}_i} \right) + \frac{v_p}{\rho_p} \left( \frac{\partial \varphi_p}{\partial x_k} \left( \frac{\partial \vec{V}_{pi}}{\partial \vec{x}_k} \right) + \frac{\partial \varphi_p}{\partial x_k} \left( \frac{\partial \vec{V}_{pi}}{\partial \vec{x}_k} \right) \right) - B
\]  
(3)

Volumetric fraction equation:
\[
\Phi_f + \Phi_p = 1, \quad \varphi_f = -\varphi_p
\]  
(4)

Where \( V \) is average velocity, \( P \) is pressure, \( f \) and \( p \) is solid and liquid phases, \( i \) and \( j \) is coordinates of a tensor.

3. Performance Analysis of Separation Device

3.1. Structure design
In order to make water and sand separated, the sand must have large enough inertia force and speed, a contracted surface is designed in the inlet passage of the device to accelerate the liquid in it. When the liquid reaches the contracted surface, the velocity reaches the maximum. Under the action of the gravity and the boundary, the medium is divided into two parts, a part of sands enter into the separation channels, will reach the goal of sand separation. According to this principle, a separation device is designed. The shape and section of the device are shown in Figure 1.
3.2. Analysis on motion trajectory
According to the diameter, the sand is divided into three kinds in the simulation: large, medium and small size, in which the large size is 3.0mm, the medium size is 0.5mm, the small size is 0.1mm. In the same calculation conditions, the trajectory of the three grains is simulated and compared. The results are shown as below.

From the qualitative analysis of the trajectories, we can see that under the influence of the self-inertia of the sand grains, the size of sand particles is an important factor affecting the distribution of water flow, the follow property of small grains is better. The larger the particle size, the larger influence of gravity, the more easily to gather nearby the outlet of the separator, resulting a larger concentration gradient in near wall region. Under the same conditions, with the increase of sand particle size, more and more sand particles are concentrated at the outlet of the separator, the sand and water are separated.

3.3. Analysis on separation efficiency
According to the operating conditions, the flow rate in the calculation is set at 20 m3/h, and the particle size of the sand particles is 0.03mm, 0.07mm, 0.1mm, 0.2mm, 0.3mm, 0.5mm, 0.7mm, 1.0mm, 1.5mm, 2.0mm, 2.5mm and 3.0mm. The separation efficiency of the sand particles with different particle sizes is calculated.
Figure 3. Separation Efficiency of Different Sands.

It shows the flow following of small size (below 0.1mm) is better, the separation efficiency of the sand grains is under 10%. With the increase of grain size, the separation efficiency is gradually increased. When the diameter of sand particles reaches 1mm, the separation efficiency can reach more than 99%. When the diameter of sand grains is up to 1mm, the separation device can separate all the sand particles.

From the above analysis, it can be seen when the particle size increases to 0.5mm, the inertia of sand grains increases obviously, the flow following property of sand grains becomes worse, and the separation effect is greatly improved. At this time, the motion trajectory of the large scale sand particles is determined by its own inertia force and the collision between the sand and the wall. The profile line of the separation part has a great influence on the separation efficiency.

3.4. Analysis on profile line

By changing the line coordinates of separation parts, changing the section area of the separation channel, changing the shrinkage of the channel and changing the flow velocity of the liquid, three separate structure schemes are designed. The contrast of the three schemes is as shown in Figure 4. And the separation effect of the three schemes is shown in Figure 5.

Figure 4. Comparison on Profile Line.
Figure 5. Comparison on Separation Efficiency.

It shows that the separation efficiency of small size sand (below 0.1mm) is near 10%. With the increase of sand particle size, the separation efficiency increases gradually. When the particle size is above 1mm, the separation efficiency can reach more than 99%. Theoretically, when the diameter of sand grains reaches 1mm, the three schemes can achieve the total separation of sand and water. From the perspective of separation effect, the larger the cross section area of the separator, the better the separation of sand water.

Figure 6. Comparison on Discharge Ratio.

The discharge ratio is an important index of the separation device, it reflects the loss of the flow. In principle, the smaller the loss, the better performance of the device. However, the discharge ratio can only be reduced as far as possible. From the above diagram, we can see that increasing the area of the separation section will greatly increase the discharge ratio of the device, which is not conducive to the overall power consumption control of the system. Therefore, the separation efficiency and discharge ratio should be taken into account in the design and operation of the separation device.

4. Experimental Analysis of the Test Device

4.1. Brief introduction of test system

A performance test system is set up, and the separation efficiency and discharge ratio of the device is tested. The test system consists of a power device, a sand adding device, a swirling device, a steady
flow section, a sand collecting device and an auxiliary testing instrument. According to the demand, sands of the specified size are selected and added to the test rig after weighing. The sands enter into the separation device after swirling and rectifying. After the separation, the sands entering the sand collector are weighed, and the separation efficiency is calculated. At the same time, the flow before and after the separation are compared and analyzed. The pressure gauge reading is used to calculate and analyze the pressure loss of the device. In order to reduce the wear of sand particles on the pump set, the solid sand used in the test is soft coral sand.

![Figure 7. Schematic Diagram of the Test System.](image)

4.2. Separation efficiency

Separation efficiency is the most important parameter to measure the performance of the separator. The quality percentage of sand before and after separation is used to illustrate the effect of separation.

\[ \eta = \frac{m}{M} \]  

(6)

Where \( M \) is the quality of sand particles added to the separation device, \( m \) is the quality of sand grain quality in the collection device.

![Figure 8. Experimental Comparison of Separation Efficiency.](image)

From the separation efficiency test of the separation device, it can be seen that:

1. The test results are the same as those of the simulation results, but there are some differences. This is due to the impact action of flow and the loss of some experimental samples in the collection process.
(2) The separation area has great influence on the separation efficiency of the separation device. Increasing the area of the separation section will significantly improve the separation efficiency of the device for small particle size sand.

4.3. Characteristic of discharge ratio

The discharge ratio is an important index to measure the power consumption of the device. The formula is as follows:

\[
\frac{\Delta Q}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}} \tag{7}
\]

Where \(Q_{in}\) is the import flow, \(Q_{out}\) is the outlet flow.

It can be seen from the above diagram that the test results are the same trend as the simulation results, but there are certain differences. The separation section area has a great influence on the separation efficiency of the separation device. Increasing the area of the separation section will significantly increase the discharge ratio of the device, which has a negative impact on the overall power consumption of the system.

5. Conclusions

In this paper, the movement of water flow and the separation efficiency are numerically and experimentally analyzed. The following conclusions can be made:

(1) The size of sand particles is an important factor affecting the distribution of water flow. The larger the particle size, the larger the gravity, the more easy to settle and gather near the outlet of the separator. Under the same conditions, with the increase of sand particle size, more and more sand particles are concentrated at the outlet of the separator.

(2) Simulation analysis shows that the separation efficiency small size sand is near 10%. With the increase of sand size, the separation efficiency increases gradually. When the size is above 1mm, the efficiency is much better.

(3) The test results are the same trend as the simulation results. The experiential and simulative results are different in numerical value under the restriction of test conditions.

(4) The separation section area has a great influence on the separation efficiency. Increasing the separation section area will significantly increase the separation efficiency of the small size sands, but
it will also greatly increase the discharge ratio of the device, which is not conducive to the overall power control of the system. The separation efficiency and discharge ratio should be taken into account in the design and operation of the separation device.

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