Performance analysis on solid-liquid mixed flow in a centrifugal pump

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Abstract. In order to study the solid-liquid mixed flow hydraulic characteristics of centrifugal pump, the Pro/E software was used for three-dimensional modeling of centrifugal pump chamber. By using the computational fluid dynamics software CFX, the numerical simulation calculation of solid-liquid two-phase flow within whole flow passage of centrifugal pump was conducted. Aim at different particle diameters, the Reynolds-averaged N-S equations with the RNG k-ε turbulence model and SIMPLEC algorithm were used to simulate the two-phase flow respectively on the condition of different volume fraction. The influence of internal flow characteristic on pump performance was analyzed. On the conditions of different particle diameter and different volume fraction, the turbulence kinetic energy and particle concentration are analyzed. It can be found that the erosion velocity ratio on the flow channel wall increases along with the increasing of the volume fraction.

1. Introduction
Solid-liquid two-phase transmission centrifugal pump has a very wide range of applications in the national economy departments, but the key technical problems exist in this kind of pump. One is due to the existence of solid material lead to low efficiency. The second is due to the erosion problem of poor reliability. Always restricts the solid-liquid two-phase transportation development and application of centrifugal pump. [1-2] Due to the different parameters of size, density and the concentration of the solid, combined with complex geometry and impeller pump flow channel in high-speed rotating factors, lead to the solid-liquid two-phase flow inside of the pump is very complex. [3-4] This article mainly research to solid-liquid mixed transportation flow inside the channel-type pump.

Commonly used methods for solid-liquid two-phase flow simulation are the Euler-Euler method and Euler-Lagrange method. [5-6]

For accurate and effective calculation analysis, the establishment of the model in the setup of each phase and solve, this paper puts forward the following hypothesis: [7-9]
- The continuous phase and discrete phase is incompressible fluid;
- Continuous phase for the same fluid medium, the discrete phase for spherical particles with the same diameter and the same density;
- The coupling between the continuous phase and discrete phase method for two-way coupling;
• Ignore the collision between particles and broken, there is no phase transition phenomenon;
• Don't consider the effect of temperature change flow field.

2. Calculation parameters and meshing

| Parameters | Value | Unit |
|------------|-------|------|
| Q          | 8     | m3/h |
| H          | 25    | m    |
| n          | 2989  | r/min |
| D1         | 35    | mm   |
| D2         | 150   | mm   |
| Q          | 8     | m3/h |
| H          | 25    | m    |

The basic parameters are shown below: flow rate of 8m3/h, head of 25m, speed of 2898r/min, the impeller diameter of 150mm, outlet width of 15mm and the discharge diameter of 50mm. The computational domain uses tetrahedral unstructured grids, totally 572,879 elements.

Figure 1. The geometric and the whole flow passage grid

3. Boundary conditions

Mass conservation equation, momentum conservation equation, three-dimensional incompressible pressure Reynolds N-S equations and RNG turbulence model equations have been chosen. Considering the commonly used two-phase flow model, Euler-Euler model is used to study the flow field. Each phase must satisfy the law of momentum and mass conservation. Conservation equation can be obtained by local instantaneous conserved overall average or mixed law of each phase. The velocity inlet, outflow and no slip boundary conditions are used. The given speed of initial value is v=2.3m/s.

4. Results and analysis

4.1 Numerical Simulation of Water Single-Phase Flow
Figure 2. The pressure distributions on the middle section

The pressure distributions in different moment when the impeller around volute tongue a cycle on the middle section are shown in the figure 2. It shows that: the moment of $t_1$-$t_2$, the blade passage just pass the volute tongue, the pressure around the volute tongue decline sharply, the pressure decline fastest at the moment of $t_3$.

Figure 3. The velocity distribution on the middle section

Figure 3 shows the velocity distribution in different moment when the impeller around volute tongue a cycle on the middle section. It shows that the velocity distribution is almost uniformity in the impeller and volute. The velocity in impeller is lower than volute, but the velocity at volute tongue fluctuate all the time.

### 4.2 Numerical Simulation Solid-Liquid Two-Phase Flow

**Table 2.** The program of numerical simulation

| Number | d (mm) | Solid phase volume fraction Cv(%) |
|--------|--------|----------------------------------|
| 1      | 0.05   | 5,10,30                          |
| 2      | 0.10   | 5,10,30                          |
| 3      | 0.30   | 5,10,30                          |

### 4.2.1 Influence of Solid Size

Figure 4. The particle volume fraction distribution on the middle section

Figure 4 shows the particle volume fraction distribution on the middle section under the influence of different particle sizes when the concentration of solid is 5%. With the increase of particle diameter, the volume distribution of solid phase obvious changes. Under different particle size, particle concentration on the working surface is greater than the back surface of the impeller, thus the erosion on working face of blade is relatively higher than the back face.
4.2.2 Influence of the concentration of Solid

Figure 5. The particle volume fraction distribution on the middle section

Figure 5 shows the particle volume fraction distribution on the middle section under the influence of different particle concentration when the particle size is set as 0.30mm. With the increase of particle concentration, the particle concentration of the inlet of the impeller is higher, due to centrifugal force, particles in the flow field deflect towards the working face of the impeller.

4.2.3. Turbulence Kinetic Energy of Flow

Figure 6. The turbulence kinetic energy on the middle section

Figure 6 shows the turbulence kinetic energy on the middle section under the influence of different particle sizes when the particle concentration is 5%. With the increase of particle diameter, the value of turbulence kinetic energy decline.

Figure 7. The turbulence kinetic energy on the middle section

Figure 7 shows the turbulence kinetic energy on the middle section under the influence of different particle concentration when the particle size is 0.30mm. With the increase of particle concentration, the value of turbulence kinetic energy increase.

4.3 Unsteady Numerical Simulation of Solid-Liquid Two-Phase Flow

The particle size is set as 0.05mm and the concentration of solid is 5%.
Figure 8. The pressure distribution on the middle section

Figure 8 shows the pressure distributions in different moment when the impeller around volute tongue a cycle on the middle section. We can see that the distribution of static pressure in the impeller and volute flow is relatively uniform at the moment of t1, and compared with the single phase unsteady calculation, the value of the pressure at the outlet is higher; At the moment of t1-t2, the impeller outlet is on the volute tongue, an increased pressure gradient near the volute tongue, but static pressure values near the volute tongue of this moment is lower than the static pressure value of unsteady single-phase calculate at the same time. At the moment of t2-t3, the pressure near the volute tongue began to recover, but the uniformity of pressure distribution inside the volute flow obvious deterioration.

Figure 9. The velocity distribution on the middle section

Figure 9 shows the velocity distribution in different moment when the impeller around volute tongue a cycle on the middle section. At the moment of t1-t2, the impeller outlet is on the volute tongue. Due to the hinder of the volute tongue, the flow where the impeller outlet meets the volute is very complicated, the velocity gradient is larger. At the moment of t2, the velocity near the volute tongue is low. At the moment of t2-t3, the area of low velocity increase fast until the moment of t4.

Figure 10. The particle volume fraction distribution

Figure 10 shows the particle volume fraction distribution in different moment on the middle section when the particle sizes is 0.05mm and the concentration of solid is 5%. At the moment of t1, the solids in the flow passage are relatively few. At the moment of t1-t2, Particles in outward movement at the same time under the influence of centrifugal force and inertia to favor the impeller of the working face and impeller hub side which cause they are serious damaged. At the moment of t2-t3, due to the mutual influence of gravity and centrifugal force, solid more concentrated on the wall of the volute which is in the larger impeller radius. At the moment of t3-t4, a large number of solid particles are still on the wall out of the volute.
4.4 Comparison of Predicted Results

![Figure 11](image)

Figure 11. The total head of unsteady two-phase flow and steady two-phase flow

Figure 11 shows the total head of unsteady two-phase flow and steady two-phase flow. The predicted value of unsteady two-phase flow is higher than it of steady two-phase flow. Under the two-phase medium, the total head of steady flow is 25.40 m and the total head of unsteady flow is 26.89 m.

5. Conclusions

(1) Under different particle size, particle concentration on the working surface is greater than the back surface of the impeller, thus the erosion on working face of blade is relatively higher than the back face.

(2) With the increase of particle concentration, the particle concentration of the inlet of the impeller is higher. Due to centrifugal force, particles in the flow field deflect towards the working face of the impeller.

(3) With the increase of particle diameter, the value of turbulence kinetic energy decline. But with the increase of particle concentration, the value of turbulence kinetic energy increase.

(4) Solid phase mixed have a certain influence on the static pressure fluctuation, velocity distribution and volume fraction distribution near the volute tongue.

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