

Numerical simulation on the performance of the vortex pump for transporting solid-liquid two-phase with light particles

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Abstract. With the purpose of studying performance of the vortex pump for transporting solid-liquid two-phase with light particles whose relative density smaller than 1, the numerical simulation of solid-liquid two phase flowing in the whole channel of a vortex pump with the particle diameter being 0.5 mm, 1 mm, 2 mm, 3 mm and the initial solid phase volume concentrations being 10%, 20% and 30% are respectively carried out by using the commercial software ANSYS Fluent by adopting RNG κ - ε turbulent flow model, Eulerian-Eulerian multi-phase flow model and SIMPLEC algorithm. The simulation results show that in the impeller region, the particles concentrate on the non-working surface of the blades, and the particles are rare on the working surface of the blades. As the initial solid phase volume concentration and particle diameter increase, the pump delivery head of vortex pump decrease. The pump delivery head of vortex pump with different initial solid phase concentrations and different particle diameters are predicted and compared with those obtained by an empirical formula, and they shows good agreement.

1. Introduction

With the advantage of strong passing ability of transporting solid-liquid two-phase particles, vortex pumps are widely used in the fields of transportation of slurry transportation, hydraulic transmission and waste water processing [1]. In the past, the solid particles with relative density larger than 1 was the main research object in vortex pumps, but the research on the solid particles with relative density smaller than 1 was rare. Due to the different relative density of solid particles, the particles in liquid is with different behaviors of settling, as solid particles with relative density larger than 1 or floating, as solid particles with relative density smaller than 1, which will have different influences on the performance of vortex pump. Therefore, it is of great significance to study the performance of solid particles in liquid phase and its influence on internal flowing field and external properties of the vortex pump. The numerical analysis on performance of a vortex pump for transporting solid-liquid two-phase with light particles whose relative density smaller than 1 is carried out based on the commercial software ANSYS Fluent.



2. Calculation model and method

2.1. Fundamental assumptions

In order to study solid-liquid two-phase flowing pattern inside vortex pump with plastic particles whose relative density smaller than 1, the following assumptions are taken [2]:

- (1) Liquid phase (water) is treated as in-compressible fluid, particle as disperse phase, the physical properties of each phase remain constant;
- (2) Particles are treated as round, even-diameter solid particle without phase transition;
- (3) Internal flow of the pump treated as steady flow with water as principle phase, solid particle as secondary phase;
- (4) Axial velocity of inlet is well-distributed, and solid particles and water are evenly mixed with same velocity.

2.2. Calculation model

Numerical simulation was carried out with the type 65-310 vortex pump made by a pump manufacturer where its main design parameter being water flow rate $Q=48.78\text{m}^3/\text{h}$, delivery head $H=38.48\text{ m}$, rotation speed $n=1470\text{ r/min}$, impeller diameter $D=310\text{ mm}$, density of particle phase $\rho=900\text{ kg/m}^3$. The 3-D modelling of flowing region of the vortex pump was built with a CAD software, and the entire calculation domain was divided into two parts, where one being impeller (rotational region), another one being volute (static region), which are shown in figure 1. With the purpose of making solid-fluid two phase of the inlet portion evenly mixed and fluid of outlet fully developed, both inlet pipe and outlet pipe were properly extended [3].

2.3. Mesh Division

For the volute region and impeller region, unstructured tetrahedral meshes were relatively generated with gambit, and the mesh of impeller region was properly refined, which is shown in figure 2. Independence analysis of mesh was conducted in consideration of limitation of computer memory and requirement of time to reach a convergence, as shown in table 1, which turns out that when difference of calculated external property is less than 2%, the requirement of mesh independence is met [4-5], where the total amount of meshes is 603,454, in which the total amount of meshes of volute region is 297,251, whereas the amount of meshes of impeller region is 306,203.



Figure 1. 3-D model of flowing region



Figure 2. Meshes of Calculation domain

Table 1 Independence analysis of mesh

Mesh amount, N	Pump head, H (m)
603454	42.38
743088	42.20
1131349	42.34
1608276	42.54

2.4. Boundary conditions

Inlet velocity was set as constant flow rate, since the pressure and velocity of the boundary of outlet is unknown, thus free outflow condition was adopted; Eulerian-Eulerian multi-phase model was adopted as multi-phase model, only the special inter-phase drag was retained as interaction between solid phase and liquid phase [6]; velocity and pressure coupling calculation was realized by using SIMPLEC algorithm, the closed RANS equation of RNG κ - ε two-equation turbulence model with curved wall which adapts to intense rotational flow was used; non-slip boundary condition was used at wall, moreover, standard wall function was used at the low Reynolds number zone near wall to deal with problems which caused by high Reynolds number turbulence model; multi-reference model (MRF) method was adopted to conduct data transfer between rotational region and static region in consideration of the rotor-stator interference between impeller region and volute region.

3. Results and Analyses

3.1. The external characteristic of vortex pump transporting clear water

Firstly, the numerical simulation of the external performance of the vortex pump transporting clean water is conducted, and the numerical simulation results are compared with the experiment results, the results are shown in figure 3. It can be seen that the flow curve trend between the simulation delivery head and the experiment delivery head is basically the same, the simulation value of the delivery head is higher than the experiment delivery head, and the reason for this is that the cumulative error caused by the factors such as casting, machining, and not considering the factors such as the roughness of the surface of the impeller and the roughness of volute interior, etc. The trend of simulation efficiency changing with flow rate is in accordance with that of the experiment efficiency that when flow rate is approaching the operating point, and the difference between the simulation efficiency and the experiment efficiency is minor.

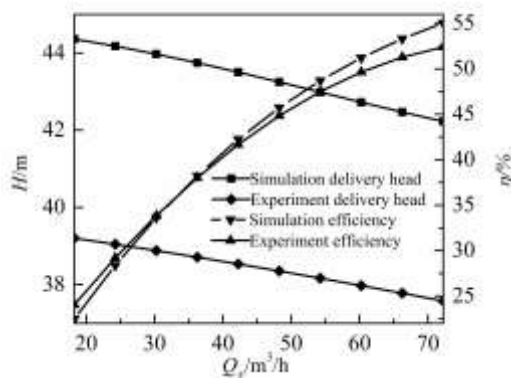


Figure 3. The comparison of vortex pump transporting clean water between simulation results and experiment results

3.2. The distribution of solid phase volume concentration under different particle diameter

Figure 4 shows the solid particle volume concentration distribution in the impeller region with different particle diameter where the initial volume concentration of solid phase being 10%, and the particle diameter respectively being 0.5 mm, 1 mm, 2 mm and 3 mm. It can be seen from the figure 4 that the particle volume concentration distribution trend is consistent with the different particle diameters. Due to the boundary condition in inlet of impeller is set that the velocity of two phases is same, so the volume concentration distribution of solid phase is well distributed under the same particle diameter. When the solid particles enter the impeller, the solids volume concentration changed as the impeller doing work, and there is obvious concentration gradient from non-working surface to working surface of the blade at the same radius. The concentration of solid particles on the blade of non-working surface is significantly higher than that of the working surface. As to the longer and shorter blades, solid particle accumulates more on the longer blades than that of the shorter blades.

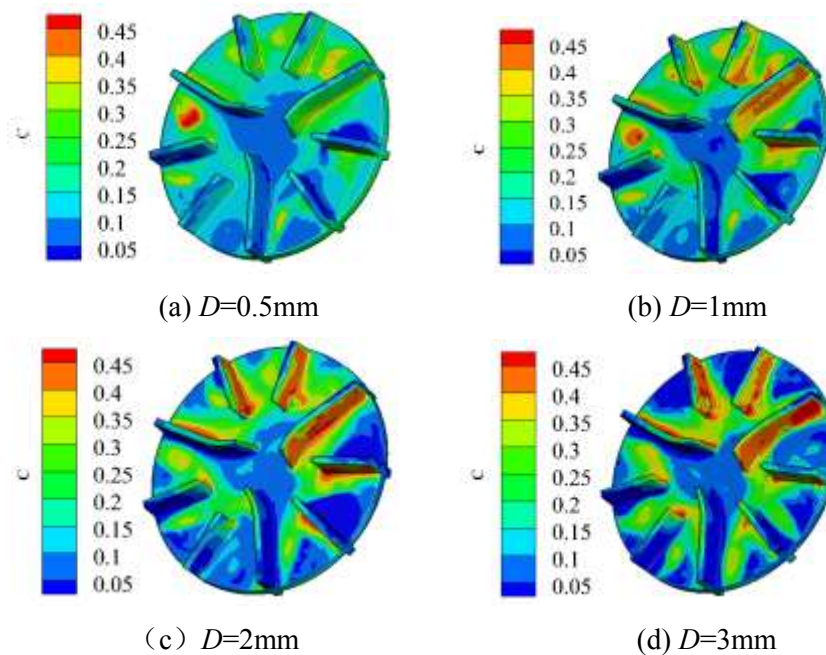


Figure 4. The solid phase volume concentration distribution with different particle diameter($C=10\%$)

3.3. The distribution of solid phase volume concentration under different initial volume concentration

Figure 5 shows the solid particle volume concentration distribution in the impeller region with different initial volume concentration where the particle diameter is 3 mm, and the initial volume concentration respectively being 10%, 20% and 30%. It can be seen from the figure 5, in the process of solid particles moving from inlet to outlet, the solid volume concentration on non-working surface of the blades is significantly higher than those on the working surface. As the solid phase initial volume concentration increases, the solid phase volume concentration in middle part of the impeller passage increases, and high solid volume concentration area expands, which means it will aggravate the abrasion on the surface of the impeller, and reduce the service life of the vortex pump under the high initial volume concentration.

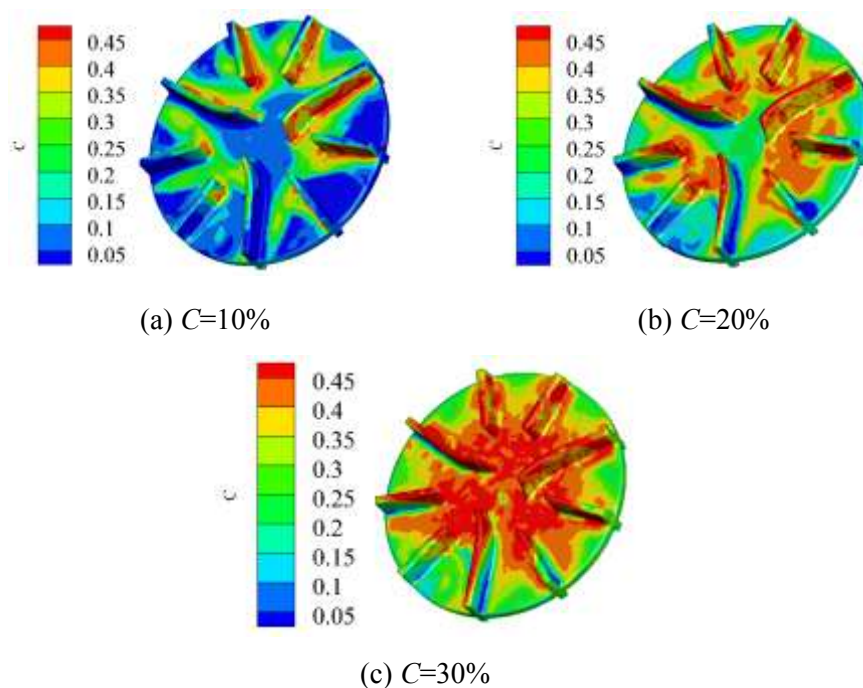


Figure 5. The solid phase volume concentration distribution with different initial volume concentration ($D=3\text{mm}$)

3.4. The comparison between the simulation delivery head and the prediction delivery head

In order to verify the simulation delivery head of the vortex pump with different initial volume concentration and different solid phase particle diameter, the experience equation presented by Pengcheng He etc. [7] used to predict the slurry pump delivery head is adopted to predicate the pump delivery head. The formula is shown as:

$$H_s = HR \cdot H_w$$

Where, H_s is the pump head with slurry, H_w is the pump head with clean water;

$HR = (1 - C_w)^n$; C_w is weight concentration of solid; $n = (0.21 + 0.066 \ln d_{50}) \cdot S$, where d_{50} is the

mass median diameter, $S = \rho_s / \rho_w$, the relative density, ρ_s is the density of the solid particle, ρ_w is the density of the water.

The numerical simulation pump delivery head and the prediction pump delivery head by the experience equation are shown in figure 6 and figure 7 with different initial volume concentration and different particle diameter respectively.

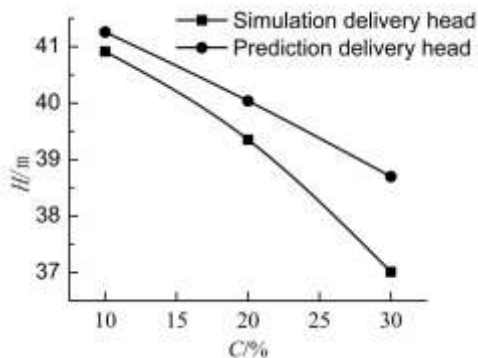


Figure 6. The pump delivery head by numerical simulation and experience equation with different volume concentration, where $D=3\text{mm}$

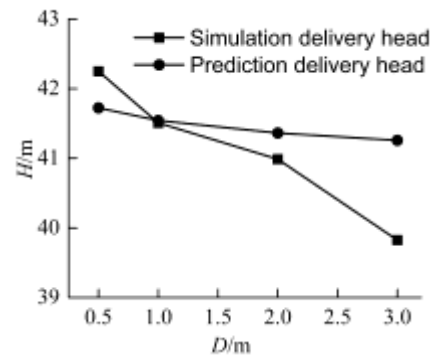


Figure 7. The pump delivery head by numerical simulation and experience equation with different particle diameter, where $C=10\%$

As figure 6 shows, both the pump head predicted by Fluent software and by the experience equation decrease with the initial volume concentration increase. The maximum error between the simulation head and equation prediction head is 4.36%.

As figure 7 shows, both the pump head predicted by Fluent software and by the experience equation decrease with the particle diameter increase. The maximum error between the simulation head and equation prediction head is 3.47%.

4. Conclusions

(1) As to clean water, both the pump head curve and the efficiency curve by numerical simulation are consistent with those by experiment. The simulation head is slightly higher than the experiment head.

(2) The particle volume concentration distribution trend is consistent with the different particle diameters. The volume concentration of light solid particles on the blade non-working surface is significantly higher than on the working surface.

(3) As to different initial volume concentration of light solid, most of the particles are concentrated in the middle and upper part of the impeller passage near the centre. As the solid phase initial volume concentration increases, the solid phase volume concentration in middle part of the impeller passage increases, and high solid volume concentration area expands.

(4) As the solid phase initial volume concentration and particle diameter increase, the pump head and pump efficiency decrease. The numerical simulation pump head are consistent with prediction results by empirical equation.

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