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Research on wear properties of centrifugal dredge pump based on liquid–solid two-phase fluid simulations

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Abstract. The impeller and casing of dredge pump are worn by sediment in the flow. However, there are few studies about abrasion of the impeller and casing for normal pump operating conditions. This paper investigated the relationship between the wear rates on the surfaces of the impeller as well as casing and the sediment concentration, with the distribution of the wear rates for normal pump operating condition analyzed. An Eulerian-Lagrangian Computational Fluid Dynamics (CFD) procedure was used to simulate steady liquid–solid two-phase flow for various operating conditions. The Finnie model was then used to predict the abrasion. The results show that, the wear rate relative value of impeller and casing surface increase as the sediment concentration increases. The wear rate relative value of impeller and casing surface is larger when the pump is in low flow rate condition, and the value of casing surface is larger than that of the impeller. The wear rate relative value of pump is low when pump is in high efficiency condition. This paper shows the abrasion characteristics on the impeller and casing with sediment flow and provides reference data for predicting the abrasion conditions in the flow passage components for a dredge pump.

1. Introduction

With the development of China's coastal port infrastructure, dredge manufacturing industry is developing at an alarming speed. China has become a veritable dredger built big country. The dredge pump is the key equipment dredger; the annual demand for dredge pumps and dredge pump accessories is huge. Severe wear makes dredge pump itself damaged and affects reliability and stability of operation, resulting in dredge pump efficiency and head lowered, shortening the life of the flow components. Research on wear properties of centrifugal dredge pump within different condition is meaningful.

With the development of computational fluid dynamics (CFD) and the improvement in performance of computer, it is possible to use numerical simulation to study two-phase flow in fluid machinery.

Patankar N A [1] [2] used LNS method to simulate the flow of particles, solving fluid phase continuity and momentum equations in the Euler-type grid, using Lagrangian method to simulate

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particle phase, using the fluid phase momentum equation to process momentum exchange between particles and fluid.

Wu [3] used k- ϵ -Ap two-phase turbulence model to calculate two-phase turbulent in turbine runner and according to the three-dimensional velocity field to estimate sediment abrasion within runner blade surface. Li [4] used k- ϵ two-equation model and SIMPLE algorithm to simulate the internal flow of slurry pump. Li [5] used k- ϵ -Ap model to simulate the solid-liquid two-phase flow in the desulfurization pump, and particle concentration distribution, velocity distribution and wear characteristics were studied. Liu [6] used Eulerian-Lagrangian turbulence model to study sediment abrasion in turbines. By calculating the wear rate of the guide vanes, the result is more consistent with the actual. Cao [7] thought that the factors that affect the wear included collision wall velocity, impact angle, particle concentration. Because solid particles flow laws in the fluid machinery are complex, the conclusions of many researchers are not exactly same.

In this paper, the solid-liquid two-phase flow in a centrifugal dredge pump was simulated, with the pump casing and impeller abrasion in the different concentrations and different flow conditions analyzed.

2. Numerical theory

Numerical simulations of the two-phase flow were based on the solution of single phase flow without sediment. The two methods used to analyze two-phase flows are Eulerian-Eulerian method and Eulerian-Lagrangian method. In this study the Eulerian-Lagrangian method was used.

2.1. Governing equations

2.1.1 Continuity equation.

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u_i}{\partial x_i} = 0 \quad (i = 1, 2, 3) \quad (1)$$

Variable i from 1 to 3 stands for the x , y , z axis, ρ is the density and u_i are the u , v and w velocity components in the x , y and z directions.

2.1.2 Fluid phase governing equations.

$$\frac{\partial(\rho u \Phi)}{\partial x} + \frac{\partial(\rho v \Phi)}{\partial y} + \frac{\partial(\rho w \Phi)}{\partial z} = \frac{\partial}{\partial x}(\Gamma_\Phi \frac{\partial \Phi}{\partial x}) + \frac{\partial}{\partial y}(\Gamma_\Phi \frac{\partial \Phi}{\partial y}) + \frac{\partial}{\partial z}(\Gamma_\Phi \frac{\partial \Phi}{\partial z}) + S_\Phi + S_{p\Phi} \quad (2)$$

where Φ is a governing variable that represents u , v , or w for the momentum equation, and S is the general dissipation source term. For details see the reference [8].

2.2. Abrasion prediction model

The abrasion on the wall surface caused by the solid particles is usually modeled as a function of the particle motion, particle characteristics and wall surface characteristics. For most metallic surfaces, the abrasion is a function of the impact angle and the velocity of the particle. The Finnie model [9] is:

$$Er = k V_p^n f(\alpha) \quad (3)$$

$$f(\alpha) = \begin{cases} \frac{1}{3} \cos^2 \alpha & \tan \alpha > \frac{1}{3} \\ \sin 2\alpha - 3 \sin^2 \alpha & \tan \alpha \leq \frac{1}{3} \end{cases} \quad (4)$$

Er is the abrasion rate defined as the ratio of the target material abrasion mass to the impact particles mass; k is an empirical coefficient; V_p is the particle velocity and α is the angle between the particle trajectory and the wall surface. For details see the reference [8].

3. Liquid–solid two-phase numerical simulations

3.1. Basic pump parameters

Flow rate $Q=9000\text{ m}^3/\text{h}$, head $H=34\text{ m}$, rotate speed $n=258\text{ r/min}$, the impeller diameter $D=1940\text{ mm}$, blade number $z=3$.

3.2. Three-dimensional numerical model

The dredge pump whole flow passage is composed of a casing, impeller and inlet, as shown in figure 1. An unstructured mesh was used in the simulation.

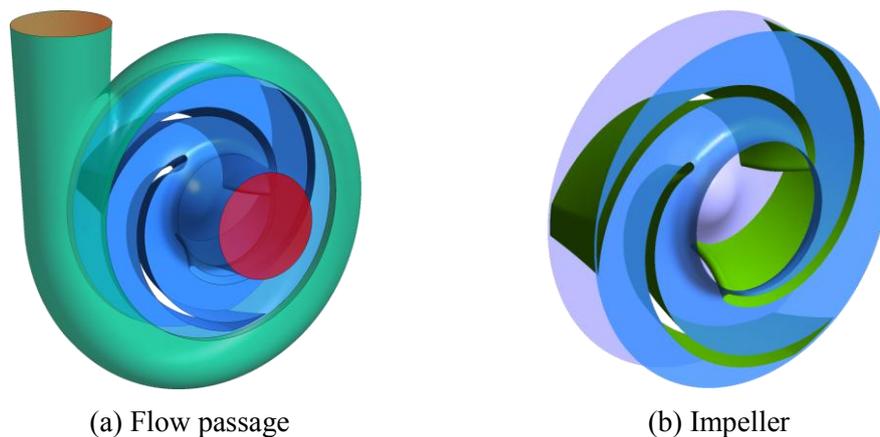


Figure 1. Dredge pump three-dimensional model.

3.3. Operating conditions and boundary conditions

Rotate Speed is 258 r/min, the flow rate are 3000, 5000, 7000, 9000, 11000, 13000, 15000 m^3/h , and the volume of sediment concentration is 5%, 10% for a total of 128 operating conditions.

The velocities were set at the inlet with fluid phase velocity set according to the inlet mass flow and the solid phase velocity set to the same velocity as the fluid phase. The pressure at the pump outlet was specified the value of 600000 Pa. The wall surface was a rough surface with a roughness of 0.2 mm. The discrete particles were solid with the shape assumed to be spherical. The side wall considered to have perfectly elastic collisions, and collisions between particles were neglected as well as the influence of particles on the flow field. The particles were assumed to have a minimum diameter of 0.005 mm, a maximum diameter of 0.25 mm, a median diameter of 0.20 mm, a standard deviation of 0.15 mm and a particle density of 1950 kg/m^3 .

4. Numerical results and analysis

4.1. Wear rate relative value

The liquid–solid two-phase flow simulations were used to model the wear rate distribution on the pump casing and impeller surfaces. The results gave the total and maximum wear rates on the casing and impeller surfaces. The relative wear rate was then calculated relative to the maximum. Figure 3 shows the pump casing, the impeller surface of the wear rate of the relative value with the flow rate variation. C05 represents sediment volume concentration of 5%, and C10 represents a volume concentration of 10% sediment. Figure 2 shows the dredge pump performance curve, effective range occurs between the flow rate of 11000 m^3/h and 15000 m^3/h .

4.2. Abrasion distribution characteristics for various operating conditions

Figure 3 and figure 4 show that C10 curves are higher than C05 curve, which indicates that the wear rate relative value increased with the sediment concentration to exacerbate abrasion of dredge pump flow parts.

Figure 3 shows that the wear rate relative value of pump casing surfaces relative value increases first then decreases with the increasing of flow rate. The maximum of wear rate relative value occurs between flow rate of 5000 m³/h and 7000 m³/h. The reason is that the backflow is severe during the flow district and the dredge pump efficiency is relatively low. With the increase of flow rate the backflow from pump tongue decreased, the efficiency of the pump improved and the wear reduced. Figure 4 shows the maximum of wear rate relative value of impeller occurs at flow rate of 5000 m³/h and keeps unchanged when the flow rate is from 9000 m³/h to 15000 m³/h. Generally, the wear rate value of the pump casing surface is higher than that of the impeller.

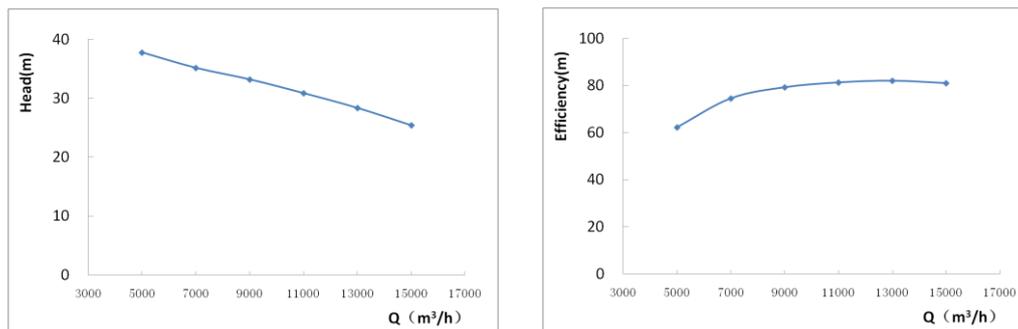


Figure 2. Dredge pump performance curve.

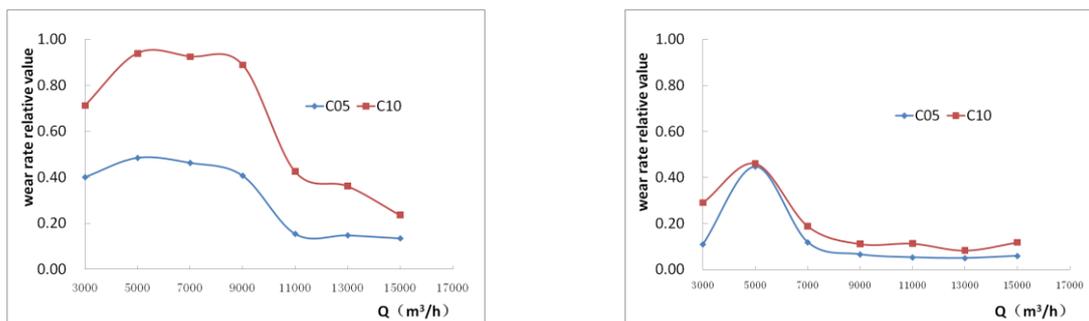


Figure 3. Wear rate relative value of pump casing.

Figure 4. Wear rate relative value of impeller.

Figure 5 shows that the wear area is at the back of the impeller, the blades of the head and the intersection between surface of the front cover and the work face of blade. Figure 6 shows that the wear area of pump casing is between 3 to 8 section, and it is relatively large at flow rate of 7000 m³/h.

5. Conclusions

The main conclusions are as follows:

- 1) With the increase of sediment concentration, the wear rate relative value increased accordingly.
- 2) The wear rate relative value of impeller and casing surface is larger when pump is in low flow rate condition and the value of casing surface is larger than that of the impeller.
- 3) The wear rate relative value of pump is low when pump is in high efficiency condition. So the dredge pump should be avoided to run in a small flow rate condition.
- 4) This paper shows the abrasion characteristics on the impeller and casing with sediment flow and provides reference data for predicting the abrasion conditions in the flow passage components of a dredge pump.

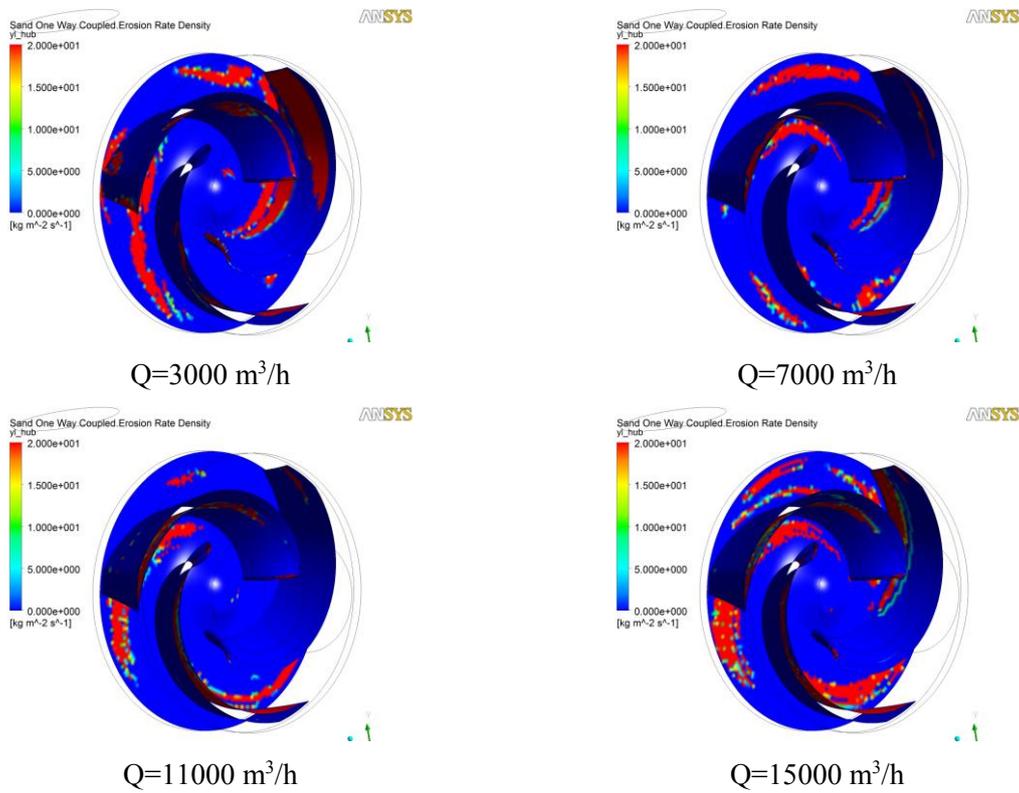


Figure 5. Wear rate distribution in pump impeller-C05

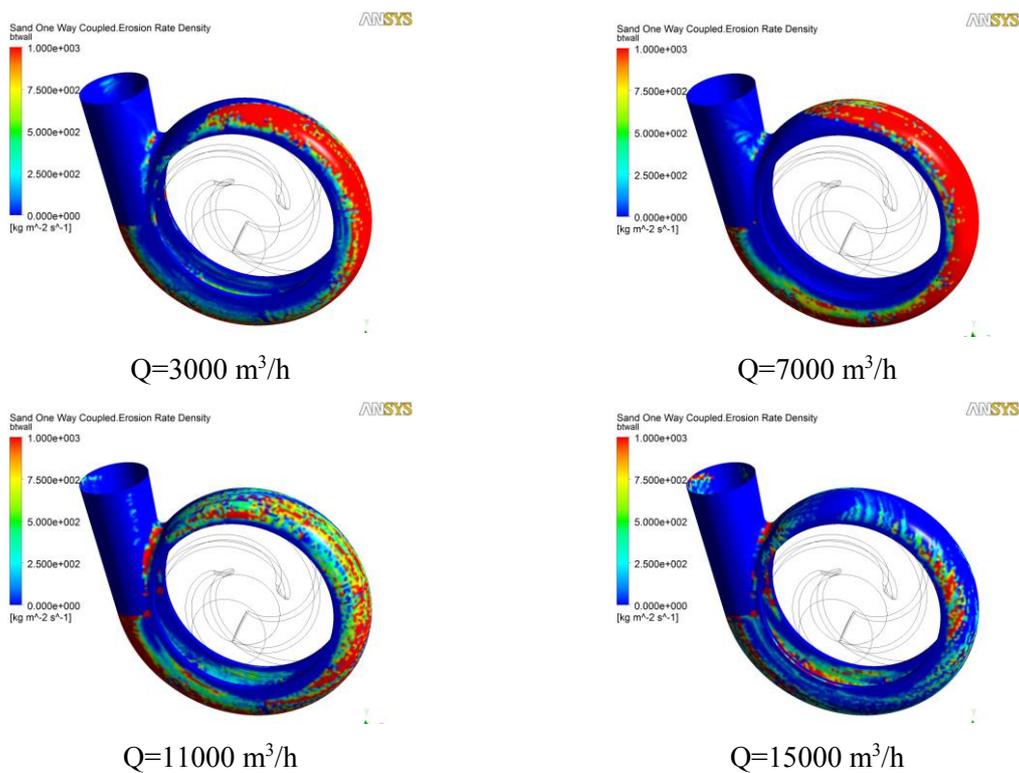


Figure 6. Wear rate distribution in pump casing-C05.

Acknowledgments

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