The effect of gas fraction on centrifugal pump

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Abstract: In order to study the multiphase flow field in M 125 centrifugal pump, three-dimensional modeling was used for internal flow through three-dimensional software Pro/E. Then based on SST turbulence model combining with Rayleigh-Plesset cavitation model, and structured grid to simulate the hydraulic characteristics of volute and impeller within different gas conditions. The velocity, pressure and gas volume fraction distributions of the interior flow field of volute and impeller were obtained and analyzed, which revealed the effect of gas fractions on the flow characteristic of the centrifugal pump.

1. Introduction
When centrifugal pumps occur the phenomena of gas-liquid multiphase, due to the small centrifugal force caused by the small gas density, it will cause the performance degradation of centrifugal pumps, and, seriously, that the suction from impeller center cannot suck in the liquid into the pump so that zero flow occurs, and even that centrifugal pumps and its system occur serious accident.

With the rapid development of computational methods and numerical theory, calculation simulation has been widely used in the field of multiphase flow simulation. Many scholars have carried out a large number of technical and experimental researches on centrifugal multiphase flow simulation. Yang Minguan etc, Yuan Shouqi etc, Li bin etc carried out numerical simulation analysis of three-dimensional solid-liquid two-phase in special purpose centrifugal and obtained internal flow law; Pan Zhongyong etc, respectively, studied the pulp suspension flow in stirred pot. Xie Peng etc simulated two-phase flow field inside the pump, which initially revealed the characteristics of the pump gas-liquid two-phase flow.

This paper, basing on summarizing the results of previous studies and using centrifugal pumps with M125 models for the study and applying CFD Technology, describes the evolution of the internal flow structure of centrifugal pumps and analyses the changes of the internal gas rate of centrifugal pumps, and it is important for further studying the mixing and separation of the internal gas-liquid of centrifugal pumps and improving the performance of centrifugal pumps.

2. Numerical Simulation

2.1 Model and mesh
M125-100 centrifugal pump is selected to be the model pump. Using Pro/E software to establish a three-dimensional solid model of self-priming, the model includes four parts: impeller, volute, inlet and outlet pipelines.

The mesh was generated by software ICEM for numerical simulations. Inlet of pump and outlet of
volute were appropriately extended to increase the accuracy of calculations. Structural mesh was used in the hydraulic model. The boundary layers near stay vanes, guide vanes, and runner blades were refined. After examination, the quality of the grid meets the requirements, and the calculation model about has eight hundred thousand grid cells.

2.2 Numerical simulation settings

Numerical calculation based CFX software is conducted. Both equations of N-S and RNG k-\( \varepsilon \) are used to determine turbulent viscosity. Mixture model is used as the multiphase flow model. Using SIMPLC algorithm to solve the pressure-velocity coupling equations; Turbulence intensity is set to 5%; The total pressure and flow direction are imposed at the inlet, and the mass flow rate is given at the outlet. A no-slip wall condition is specified for all wall boundaries. Walls are modeled using the standard wall functions.\(^{[7-8]}\)

The flow in centrifugal pump contains the phase of water, the phase of air bubbles and the phase of cavitation bubbles. Several simulations were conducted, and gas fractions of inlet were set to 0%, 5%, 10%, 15%, 20%, while all the air bubbles fraction were set as 0.

3. Results and analysis

3.1 Velocity and static pressure distribution of internal flow field

As shown in the Figure 1, the velocity distribution of internal flow field in impeller and volute are normal. There are no phenomenon of flow separation and the impact overall, except in the field nearby tongue. The velocity increases from the inlet to outlet of the impeller. Then the velocity decreases from impeller field to volute field while increases along the direction of volute diversion, and declines in the outlet of the pump. This is consistent with the volute design methods. Besides, the phenomenon of reflux occurs near the outer wall of the volute, which is consistent with the actual situation.

Figure 2 reveals the static pressure contours under gas fraction of 0% and water fraction of 100%. It is apparent from the static pressure contours provided that static pressure increases from the inlet to outlet of the impeller. Most of the kinetic energy has been converted into pressure energy, so the variation of static pressure is large. A small area of the blade inlet has negative pressure. At the regions of same radius, the pressures of working sides are higher than that of suction sides. In the volute, because of the different curvature radius of the volute, static pressure along the flow direction becomes larger and larger\(^{[8-9]}\).

![Figure 1. Contours of velocity](image1)

![Figure 2. Contours of static pressure](image2)
3.2 Centrifugal gas-liquid two-phase simulation

3.2.1 Static pressure distribution of gas-liquid two-phase flow field
Figure 3 reveals the static pressure contours under gas conditions of 0%, 5%, 10%, 15% and 20%. It is evident from the static pressure contours provided that static pressure increases in radial direction; Under different gas conditions, the pressure gradients along the flow path direction are different; The higher gas content, the lower the static pressure.

![Static pressure contours](image.png)

**Figure 3.** Static pressure contours under the influence of different gas conditions

3.2.2 Velocity distribution of gas-liquid two-phase flow field. Figure 4 shows the velocity distribution contours under gas conditions of 0%, 5%, 10%, 15% and 20%. It is apparent from the velocity distribution contours supplied that gas-liquid two-phase flow in centrifugal pumps under the gas conditions is very similar overall. This is because the intercoupling and mutual influence between the gas-liquid two-phase. However, with the increase of gas fraction, the velocity in outlet decreased.

3.2.3 Gas distribution of gas-liquid two-phase flow field. Figure 5 reveals the gas-phase distribution contours under gas conditions of 0%, 5%, 10%, 15% and 20%. As shown in the figure, gas fraction on pressure side of impeller is higher than on suction side; Gas fraction on pressure side of impeller in the direction of the flow path reduced gradually; With the increase of gas fraction, gas fraction of flow channel area is increasing and high gas fraction area continues to expand. Especially when α≥15%, concentration of bubbles within the flow channel leads to the two-phase flow transition from bubbly flow to slug flow. The above phenomenon is the cause that liquid flow rate decreases as the increase in gas fraction, and then. Under the action of inertial force and centrifugal force, liquid-phase deviates from the normal flow lines track and moves to the back of the blade. At the same time, by reason of repelling effect of the liquid phase, gas-phase is forced to deviate from the normal flow lines track and moves to working surface of vane.

Gas fraction declines in radial direction in volute, and it is very low near the wall of volute. This is because the static pressure in volute radially increases. At same time, under the action of the inertia force, the liquid-phase closes to the wall of volute and repels the gas-phase. A glance at the figures of α=10%, α=15% and α=20% provided reveals large concentration of gas-phase at the outlet of the impeller.
3.2.4 Vapour distribution of gas-liquid two-phase flow field. Figure 6 shows the vapour distribution contours under gas conditions of 0%, 5%, 10%, 15% and 20%. From the figure provided, it is clear that the most intensive areas of cavitation releases in the second half of the blade suction surface and decreases along the direction which opposite to the direction of rotation of the impeller. This distribution is consistent with the static pressure distribution of the flow channel. With the growth of gas fraction, the area of the cavitation region decreases and then increases. A small area of cavitation occurs on the pressure side of blades because the static pressure value is too low.
3.2.5 Changes of head in two-phase flow centrifugal pump. As shown in Figure 7, when the gas enters the pump, the head falls rapidly. Compared with single-phase conveying, two-phase flow becomes more unstable and greater flow loss, so the head declines markedly.

With the increase of gas fraction, the head still sharply drops. As shown in Figure 5, when the gas fraction is low, the small bubbles begin to gather on the region of the blade from middle of pressure surface to outlet of suction surface, and the bubbles stagnant zone is formed on the pressure side region, so the head begins to decline sharply.

With the continuing increase of gas fraction (namely as $\alpha \geq 16\%$), the head further drastically slips. Because when $\alpha \geq 16\%$, the bubble stagnant zone extends to the rear of pressure surface of the blade which further reduce the channel section area, so that both of the flow relative velocity and the flow loss increase, so the head further drastically slips. This phenomenon is probably consistent with the gas-phase distribution of centrifugal pump.

![Figure 6. Vapour distribution contours under the influence of different gas conditions](image)

**Figure 6.** Vapour distribution contours under the influence of different gas conditions

![Figure 7. Head curves of model pump](image)

**Figure 7.** Head curves of model pump

4. Conclusions

1) Static pressure in impeller is increased in radial direction; With the increase of gas fraction, the pressure gradients along the flow path direction are different.

2) The distributions of gas-liquid two-phase flow under different gas conditions are very similar overall. With the increase of gas fraction, the velocity in outlet decreased.

3) With the increase of gas fraction, gas fraction of flow channel area is increasing and high gas fraction area continues to expand. Especially when $\alpha \geq 15\%$, concentration of bubbles within the flow channel.
4) The most intensive areas of cavitation releases in the second half of the blade suction surface and decreases along the direction which opposite to the direction of rotation of the impeller. A small area of cavitation occurs on the pressure side of blades.

5) The higher gas content, the lower the head. Especially, when $\alpha \geq 16\%$, the head further drastically declines.

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