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Study on the distribution regularity of gas volume in multiphase pump

G T Shi[1,2], K Luo[1], Z W Wang[1], Y Liu[1] and X P Jiang[3]
[1]Department of Power Machinery, University of Xihua, Chengdu, China
[2]State Key Laboratory of Hydroscience and Engineering & Department of Thermal Engineering, Tsinghua University, Beijing,100084, China
[3]School of Mechanical Electronic & Information Engineering, China University of Mining &Technology(Beijing), Beijing 100083, China

657598226@qq.com

Abstract.In order to reduce the phase separation, air plug and turbulence vortex in the multiphase pump. The two-fluid model and the standard k- ε turbulence model are selected, the distribution regularity of gas phase volume within the multiphase pump is researched using the CFD software about air-liquid two-phase under the different working conditions. The results of the study showed that the gas phase gathers at the rim when the gas-liquid two-phase enter into the impeller inlet, and the gas phase is gradually increased at the rim with the increase of the flow rate, the gas is concentrated in the hub at the second half of the impeller, and the most serious aggregation is the small flow rate condition. When the flow is constant, the gas obviously increases in the guide vane hub with the increase of the gas volume fraction. With the increase of the gas volume fraction, the uniformity of the gas phase in the circumferential direction is deteriorated in the inlet and the middle of impeller, and the lower gas volume fraction region is decreased in the impeller. The results of the study reveal the distribution regularity of gas volume within the multiphase pump, provide the reference basis for the design of the multiphase pump under the higher gas volume fraction.

1. Introduction

The rotodynamic multiphase pump is a supercharging equipment to transport the multiphase mixture medium in the oilfield. The pump is used to transport multiphase medium with high gas phase volume, at present, the study on multiphase pump is mainly concentrated in internal flow law, external characteristics, optimized design of structure and so on. The literature[1-3] reveal the internal flow law of oil-gas multiphase pump. The literature[4] reveals a 3D design method of impeller blade for multiphase Pump. The literature[5] is carried out the numerical calculation of the multiphase pump with different number of guide vanes, the results show that increasing of the vane leave numbers can slow down the decrease of the pump head. The external characteristics of the pump are studied in the literature[6], it is found that the increasing of the suction pressure can increase the flow rate, but it will decrease the efficiency of the pump. The hydraulic model of the pump is optimized in the literature[7-10], so make the hydraulic performance of the pump improved. The influence of the axial clearance of the pump on the hydraulic performance of the pump is analyzed in the literature[11], the numerical calculation shows that the axial distance of the pump is increasing ,and it will obviously make the efficiency and head higher than others. From the above literatures, it is found that there are few reports on distribution of gas phase volume in the multiphase pump.

This paper selected the two-fluid model, numerical simulation of three-dimensional flow field for the multiphase pump is carried out under different flow rate and different the gas volume fraction conditions, finally, the distribution regularity of gas volume for the multiphase pump in the axial and the circumferential are obtained under different working conditions, which can provide reference for hydraulic performance optimization of the multiphase pump.

2. Research object

This paper is mainly to study the multiphase pump, the pump is consisted by several compression units, each compression unit has the effect of step-by-step supercharging and consisted by a guide vane and impeller. The high-speed rotation of the impeller makes the multiphase fluid obtain the mechanical energy, and then through the diffusion of guide vane turn the mechanical energy into the pressure energy to achieve the effect of supercharging. The main parameters are: the design flow Q_d=110m^3/h, the head H=85m, the design speed n=2950r/min, the power of motor P=55kW, the gas volume fraction GLR=0—73%, the efficiency $\eta = 33\%$. The UG software is used to model the calculation area of three dimensions for the multiphase pump, the hub of impeller and guide vane are designed to be tapered, the diameter of rim d_2=230mm, the number of impeller blades Z_1=4, the number of guide vane blades Z_2=9.

3. Numerical method

3.1. Governing equation

In this paper, the standard k-ε turbulence model is selected as the turbulence model, k-ε turbulence model include two equations: the turbulent kinetic energy k and the turbulent dissipation rate ε.

K equation: $$\frac{\partial}{\partial t}(\alpha_l \rho_l k)+\frac{\partial}{\partial x_j}(\alpha_l \rho_l u_{lj} k)=\frac{\partial}{\partial x_j}\left(\alpha_l \frac{\mu_l}{\sigma_k}\frac{\partial k}{\partial x_j}\right)+\alpha_l (G-\rho_l \varepsilon)$$

In which: $$G=\mu_l \frac{\partial u_i}{\partial x_j}\left(\frac{\partial u_j}{\partial x_i}+\frac{\partial u_i}{\partial x_j}\right)$$

ε equation: $$\frac{\partial}{\partial t}(\alpha_l \rho_l \varepsilon)+\frac{\partial}{\partial x_j}(\alpha_l \rho_l u_{lj} \varepsilon)=\frac{\partial}{\partial x_j}\left(\alpha_l \frac{\mu_l}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_j}\right)+\alpha_l \frac{c_l \varepsilon}{k} G - c_2 \alpha_l \rho_l \frac{\varepsilon^2}{k}$$

Where the turbulence kinetic energy dissipation rate is the Prandtst number σ_ε ,and σ_k , σ_ε , C_μ are constant, the value flow is used in the single-phase: σ_k =1.0、 σ_ε =1.314、 C_μ =0.09.

3.2. Meshing and boundary condition

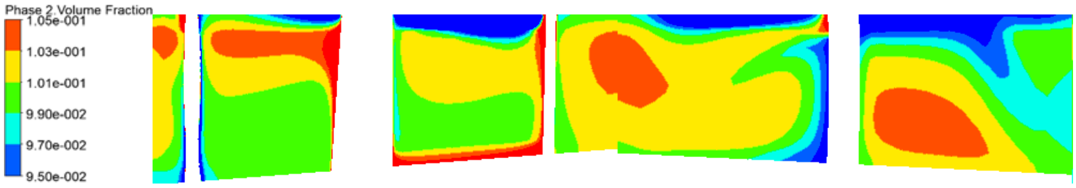
The impeller and the guide vanes are subjected to a hexahedral structured grid for the computational fluid domain, the leaf wall is encrypted with an O-grid, a highly adaptable tetrahedral mesh is used for the suction chamber and the extrusion chamber, as shown in figure 1. Eventually, the number of suction chamber cells was 855534, the number of extrusion cells was 692624, the number of impeller cells was 528219, the number of guide vanes cells was 461768, and the mesh independence has been verified. The mass flow inlet and the pressure export were selected as the boundary condition with the calculation domain, the non-slip was selected as wall boundary condition.

Figure 1. multiphase pump calculation domain grid division

4. Calculation results and analysis

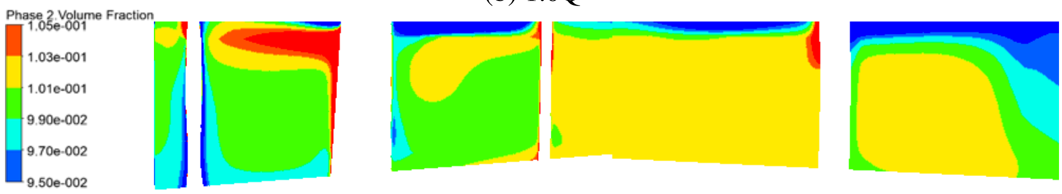
4.1. Axial gas volume distribution

Figure 2 was the axial of the gas phase volume distribution for the gas volume fraction of 10% within the multiphase pump first compression unit under the different flows. As can be seen from the figure, the gas gathered at the rim when the gas-liquid two-phase entered into the impeller inlet, this may be due to the fact that the gas-liquid two-phase in the impeller inlet was not affected by the apparent centrifugal force of the impeller rotation and the gas-liquid mixing uneven, therefore the gas phase was mainly distributed near the side of the impeller rim, and with the increase of the flow rate, the gas was gradually increased at the rim in the impeller inlet. And the gas was mainly concentrated in the second half of the impeller hub, this may be due to the fact that the gas-liquid two-phase was affected by the obvious role of the centrifugal force in the impeller, the centrifugal force of the liquid was greater than the gas, so the liquid flow to the rim, the gas is forced to flow to the hub by the squeezing action of the liquid, at the same time it can be seen that the aggregation of the gas was not obviously with the increase of the flow rate. It can also be seen that the gas volume distribution is relatively uniform after entering into the guide vane, this may be due to the gas-liquid two-phase was not affected by the centrifugal force and affected by the sheer force of the guide vane blades after from the impeller entered into the guide vanes, so made the bubble began to break, gas-liquid two-phase gradually became relatively uniform, the gas began to gather at the hub in the guide vane outlet.



(a) 0.8Q

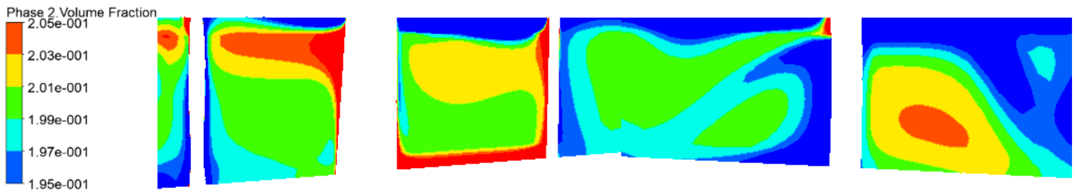
(b) 1.0Q



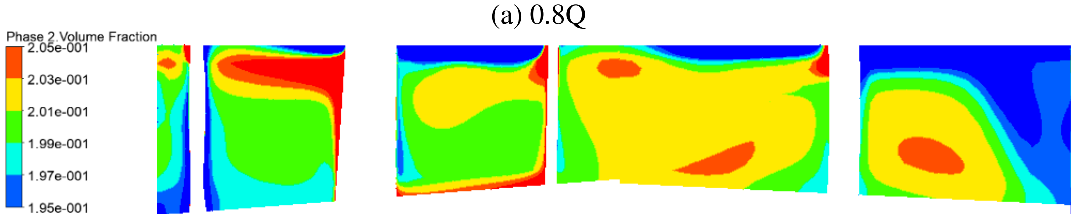
(c) 1.2Q

Figure 2. IGVF=0.1 the axial of the gas volume distribution within the multiphase pump first compression unit under the different flows

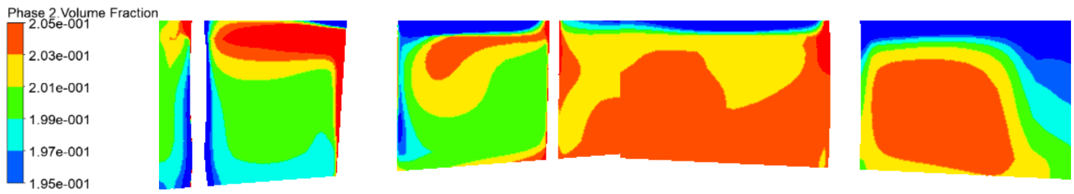
Figure 3 was the axial of the gas volume distribution for the gas volume fraction of 20% within the multiphase pump first compression unit under the different flows. Figure 4 was the axial of the gas volume distribution for the gas volume fraction of 30% within the multiphase pump first compression unit under the different flows.



(a) 0.8Q

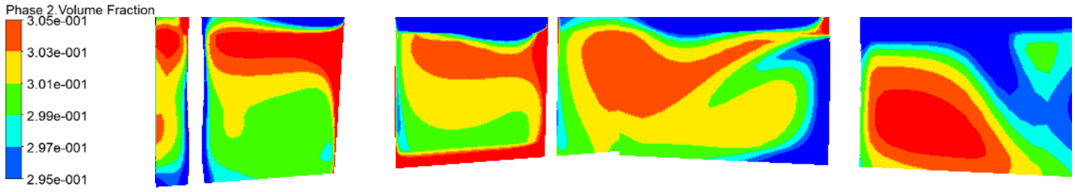


(b) 1.0Q

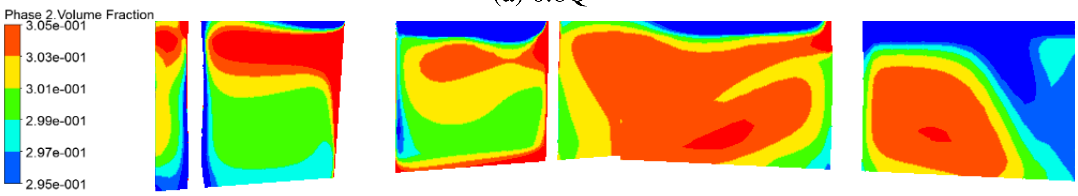


(c) 1.2Q

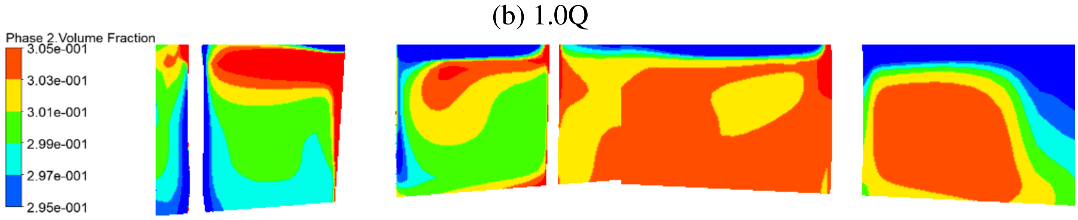
Figure 3. IGVF=0.2 the axial of the gas volume distribution within the multiphase pump first compression unit under the different flows



(a) 0.8Q



(b) 1.0Q



(c) 1.2Q

Figure 4. IGVF=0.3 the axial of the gas phase volume distribution within the multiphase pump first compression unit under the different flows

Compared figure 2, figure 3, and figure 4, when the flow was constant, the aggregation of the gas phase was obviously at the impeller rim with the increase of the gas volume fraction, this may be due to the effect of supercharging dropped sharply for the multiphase pump when the gas volume fraction from 10% added to 30%[12], the increase of the gas volume fraction leaded the decrease of the pressure in the first half of the impeller, and the same time was not affected by the obviously centrifugal force of air-liquid two-phase, therefore the phase separation increased with the increase of gas volume fraction in the first half of the impeller, and at the same time the aggregation of the gas was gradually increased at the rim with the increase of gas volume fraction , and the gas phase fraction changed little in the second half of the impeller hub, this showed that the changes of the gas volume fraction have a few effect on the distribution of gas with the same flow rate in the second half of the impeller. The aggregation degree of the gas is the most obvious in the second half of the impeller hub under the small flow rate condition, with the increase of the flow rate, the aggregation of the gas is not the most obvious under the large flow rate condition; the gas volume distribution is more and more uniform in the first half of the guide vane with the increase of the flow rate, but when the flow is constant, the aggregation degree of the gas is obviously in the guide vane hub with the increase of the gas volume fraction.

4.2. Circumferential gas volume distribution

Figure 5 was the circumferential of the gas volume distribution for the gas volume fraction of 10% within the multiphase pump first impeller under the different flows. Figure 6 was the circumferential of the gas volume distribution for the gas volume fraction of 20% within the multiphase pump first impeller under the different flows. Figure 7 was the circumferential of the gas volume distribution for the gas volume fraction of 30% within the multiphase pump first impeller under the different flows.

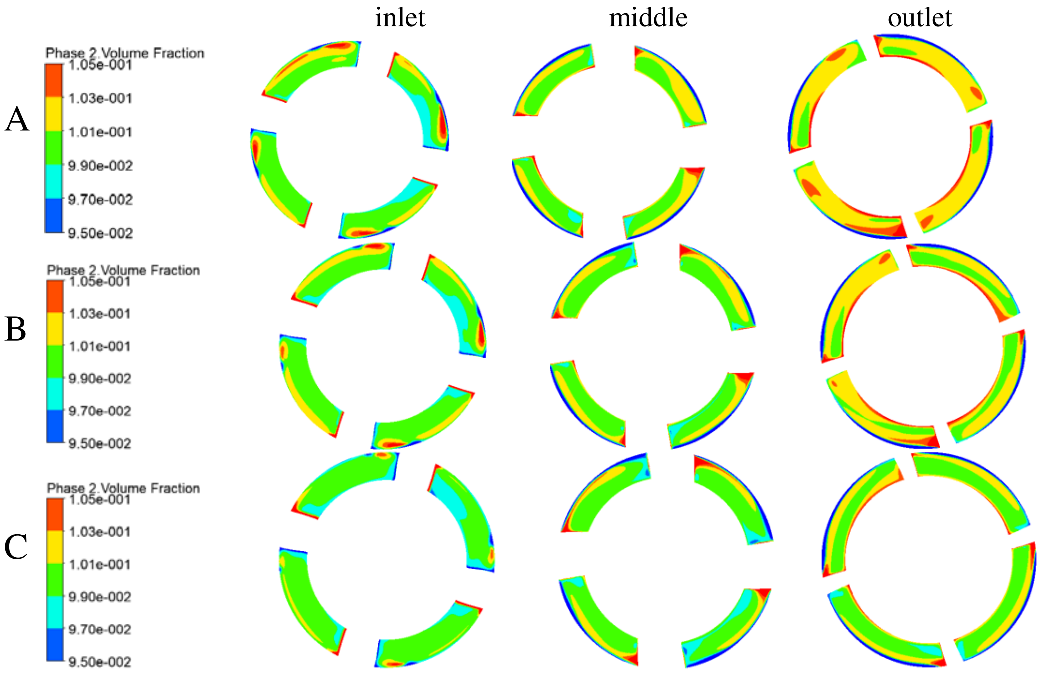
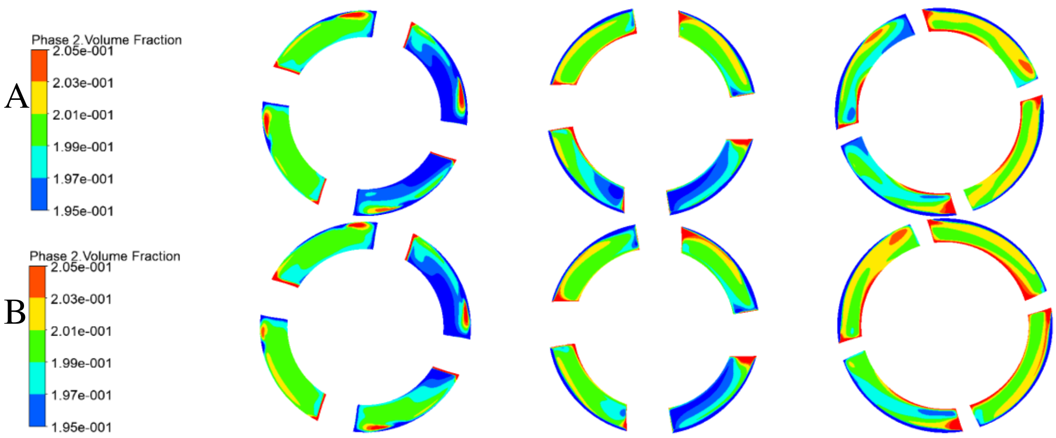


Figure 5. IGVF=0.1 the circumferential of the gas volume distribution within the multiphase pump first impeller under the different flows.



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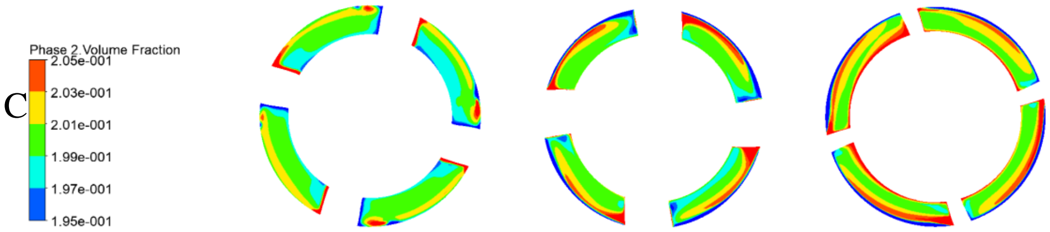

Figure 6. IGVF=0.2 the circumferential of the gas volume distribution within the multiphase pump first impeller under the different flows.

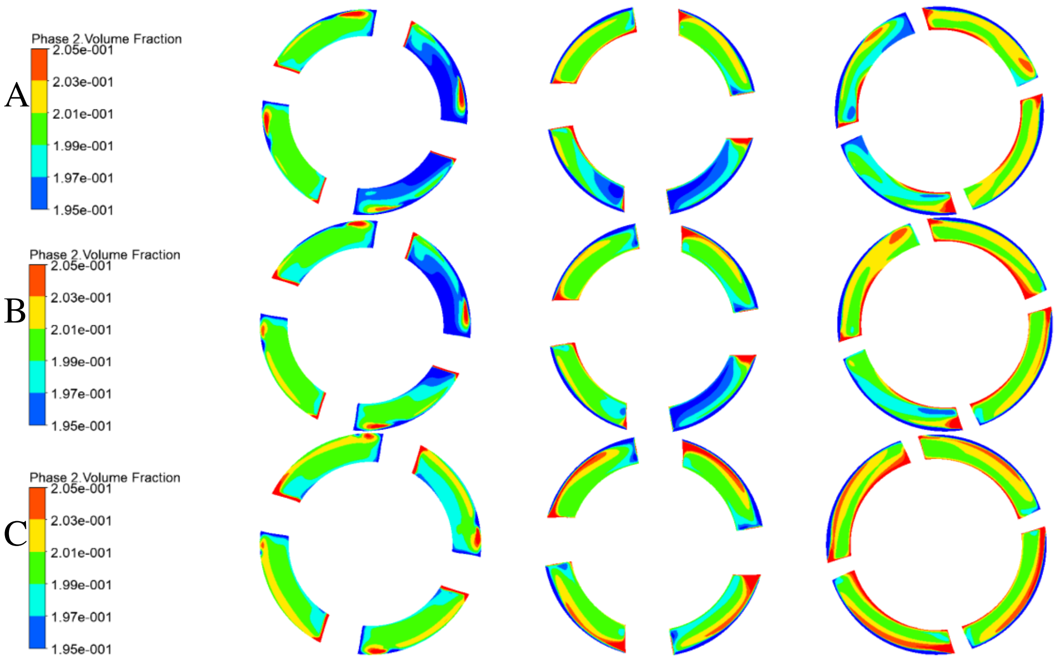

Figure 7. IGVF=0.3 the circumferential of the gas volume distribution within the multiphase pump first impeller under different flows.

（A represents the flow rate of 0.8Q, B represents the flow rate of 1.0Q, C represents the flow rate of 1.2Q）

From the figure 5, it can be seen that the circumferential of the gas volume distribution at the impeller inlet and outlet was more uniform, and the impeller outlet gas volume fraction was the highest with the increase of the flow rate under the lower gas volume fraction. From the figure 6, it can be seen that the circumferential of the gas volume distribution at the impeller inlet and middle was becoming worse, and the lower gas volume fraction of impeller increased with the increase of the flow. From the figure 7, when the gas volume fraction reached 30%, the uniformity of the gas volume distribution was improved in the impeller circumferential, and compared the lower gas volume fraction condition, the higher gas phase volume fraction area was significantly increased at the impeller outlet. Compared figure 5 and figure 6, the lower gas volume fraction area increased at the rim in the figure 6, and the lower gas phase fraction area was increased at the rim from the impeller inlet to outlet; compared with figure 6, it can see from figure 7, the lower gas volume fraction area was reduced in the impeller inlet area, but the higher gas volume fraction was increased significantly in the impeller outlet area, and the aggregation degree of the higher gas volume fraction increased. Compared figure 5, figure 6 and figure 7 can be seen that the lower gas volume fraction area was mainly concentrated in the impeller rim under the different flow rate and the different gas volume fraction.

5. Conclusion

From the axial gas volume distribution, it can be seen that the gas phase gathered at the rim when the gas-liquid two-phase enter into the impeller inlet, the gas is gradually increased at the rim with the increase of the flow rate, the gas phase mainly concentrated in the hub at the second half of the impeller. The distribution of gas volume is relatively uniform at the guide vane.

When the flow is constant, the gas obviously increases in the guide vane hub with the increase of the gas volume fraction, but the gas volume fraction changes little in the second half of the impeller hub; the aggregation degree of the gas is the most obvious in the second half of the impeller hub under the small flow condition, with the increase of the flow rate, the aggregation of the gas phase is not the most obvious under the large flow condition. The distribution of gas volume is more and more uniform with the increase of the flow rate in the first half of the guide vane, but when the flow is constant, the aggregation degree of the gas is obviously increased in the guide vane hub with the increase of the gas volume fraction.

From the circumferential gas volume distribution, it can be seen that the circumferential of the gas volume distribution at the impeller inlet and outlet is more uniform, and gas volume fraction is the highest the impeller outlet at with the increase of the flow rate; the circumferential of the gas volume distribution is becoming worse at the impeller inlet and middle and the low gas volume fraction of impeller increased with the increase of the flow.

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