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Research on the influence of fluid viscosity on the inlet flow parameters of wiped film molecular distillation

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Abstract. Wiped film molecular distillation is a kind of evaporation device with rotating scraping film structure, which is used to separate and purify viscous materials at molecular level. The feed pump of a wiped film molecular distillation is a centrifugal pump driven by a brushless DC motor. The fluid flow at the outlet has an important effect on the evaporation process. Based on the geometric model of the test pump generated by Gambit, the unsteady flow and head in the pump under optimal, low flow and shut off conditions were calculated, and the influence of liquid viscosity on the flow parameter pulsation behind the impeller, that is, inside the volute was investigated. The head calculated by unsteady flow model and steady flow model is compared with the experimental values. In addition, the calculated liquid velocity distribution during water transport is compared with the measured results of LDV in detail. The results show that the increase of fluid viscosity weakens the flow parameter pulsation behind the impeller of the feed pump and the flow separation tendency near the blade face.

Keywords: Molecular distillation, Centrifugal pump, Fluid viscosity, Unsteady flow, Fluctuating flow, CFD.

1 Introduction

The separation purity and yield of the wiped film molecular distillation are closely related to the fluid flow state in the scraped film structure, and the fluid stability at the outlet of the feed pump is the key to the successful separation [1]. Most of the feeding methods of the wiped film molecular distillation use a standard low-speed centrifugal pump to transport the viscous material to the evaporation chamber, as shown in Figure 1. In recent years, most of the researches on the unsteady flow in centrifugal pumps have adopted the method of computational fluid dynamics (CFD) method, but most of these studies have ignored the influence of the change of liquid viscosity on the unsteady flow in centrifugal pumps. The number of impeller blades of a centrifugal pump is limited. At the exit of the impeller, the

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pressure and flow rate between the blades change, and the frequency of pressure and velocity pulsation is discrete. The fluid boundary layer shed from the blade surface forms a turbulent wake behind the blade, and the frequency of velocity and pressure pulsation in the wake is a continuous wide frequency [2]. There are Karman vortices in the wake caused by blade tail thickness. Pressure pulsation will cause the change of radial force. Total pressure and pressure pulsation will cause hydraulic turbulence and noise in the pump [3]. The total pressure and pressure pulsation are the source of hydraulic turbulence and noise for the feed pump of the wiped film molecular distillation. It is important to study the total pressure and pressure pulsation behind the impeller of the centrifugal pump for evaluating the dynamic radial force and hydraulic turbulence and noise.

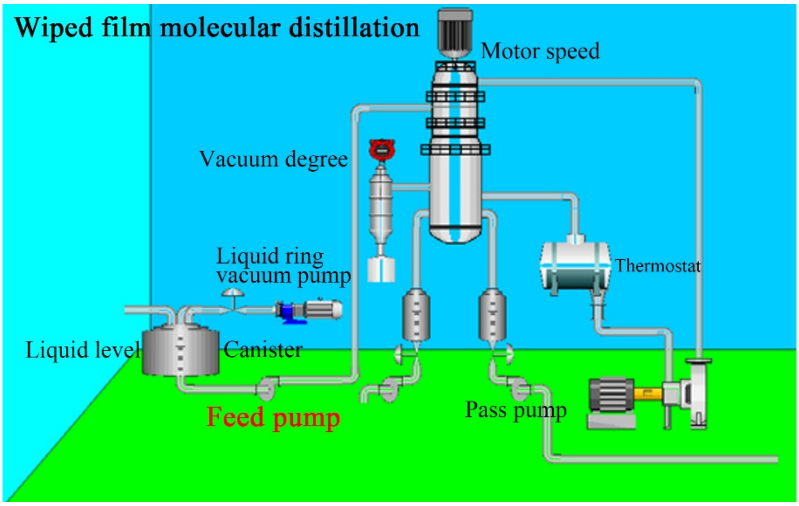


Fig. 1. Wiped film molecular distillation still structure diagram.

In recent years, domestic and foreign scholars have studied the unsteady flow, pressure pulsation and radial force pulsation of centrifugal pumps at different positions such as inside the shell wall and outlet of the impeller on the surface under different working conditions through calculation methods such as high-frequency pressure sensor, LDV laser measuring instrument and CFD program [4-6]. However, in these calculations, the fluid is all water. The effect of decreasing Reynolds number caused by increasing liquid viscosity on flow pulsation is ignored.

In this paper, using the centrifugal pump generated by Gambit as a model, the internal unsteady flow of the feed pump of the wiped film molecular distillation under optimal, low flow and shut down conditions was calculated, and the influence of liquid viscosity on the amplitude attenuation of pressure and total pressure pulsation was analysed. In order to verify the reliability of the calculated results, the calculated pump head curves for conveying water and viscous oil are compared with the experimental values. At the same time, the velocity behind the impeller calculated by CFD is compared with the measured results of LDV.

2 Model establishment of centrifugal pump

The flow characteristics of the inlet pump impeller of a wiped film molecular distillation under different fluid viscosity conditions were studied by numerical simulation. Firstly, a model of the inlet pump impeller of a wiped film molecular distillation is established, and the influence of fluid viscosity on the outlet flow parameters of the impeller is considered. Through numerical simulation, we simulated the flow field distribution on the surface of impeller blade under different fluid viscosity, and analysed the influence of fluid viscosity on the force of impeller blade. The feed pump model we use is a low-speed volute centrifugal pump with a specific speed of 80.

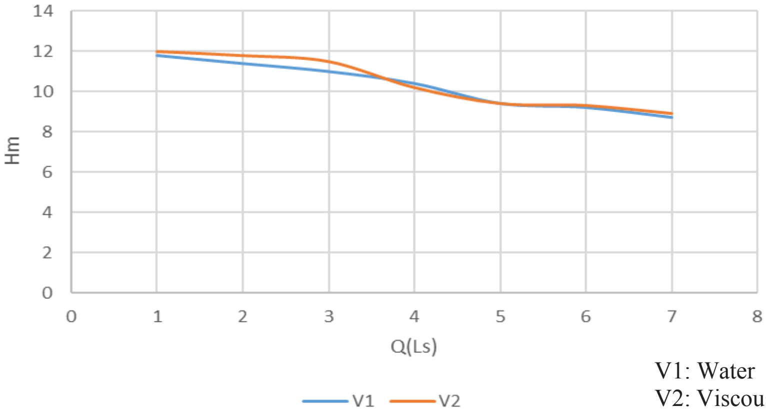
Through experiments, we will obtain impeller flow parameter data under different fluid viscosity conditions, including velocity, pressure distribution, blade surface pressure, etc. Combined with numerical simulation results, the actual influence of fluid viscosity on impeller flow parameters was verified. During the test, the pump performance curve for conveying water and viscous oil was measured [7]. We used LDV to measure the fluid unsteady velocity at 130 measuring points on different sections of the volute during water transport under optimal (Q_{BEP}=4.37 L/s) and low flow (0.37Q_{BEP}) conditions. The experiment shows that the efficiency error of the pump is in the range of 0.71% ~ 1.18%. The measurement error of LDV flow rate is 1.7%, the probe positioning error is 5.3%, and the total measurement error of LDV is 5.2%. Record the total pressure at each time surface, the total torque applied by the fluid to the blades and the front and rear cover plates. Record the total pressure and static pressure at the suction inlet point at all times. The unsteady flow parameters vary along the volute width, but the flow parameters pulsate the most on the symmetric surface of the volute [8]. Therefore, in the volute, the changes of pressure and velocity with time at the distance of different sections on the symmetric plane at the impeller outlet radial distance of 3mm, 6mm and 9mm were recorded.

The fluid flow calculation inside the pump is done by Fluent software. The standard $k-\varepsilon$ model is used to calculate the turbulence eddy viscosity caused by turbulence. The method of discrete flow continuity equation, time-mean N-S equation and k, ε equation is "SIMPLE" [9]. The rotation speed of the fluid domain of the impeller is assumed to be 1235/min. During the initial calculation, the movement type of the impeller fluid domain was selected as "movingreferenceframe", and after the calculation was completed, the movement type was changed to "movingmesh". Set the normal inflow velocity at the entrance and 1 atmosphere of pressure at the exit. In calculation, the time step is 1×10^{-4}s, the non-steady time difference is selected as the second-order implicit lattice, and the convergence error is 1×10^{-4}.

3 Experimental result

3.1 Head curve comparison

Figure 2 shows the comparison between the pump head calculated by CFD and the lift curve measured by the test. For the steady flow model, the slope of the calculated head curve is different from that of the test curve. Under low flow condition, the calculated viscous oil transport head is lower than the test value, but under high flow condition, it is higher than the test value. In the closed condition, the calculated values of the unsteady flow model are very close to the experimental values. In general, the calculated values of the unsteady flow model are in good agreement with the experimental values. When the viscosity ν=1mm^2/s, the calculated value is 5%~10% higher than the test value. When the viscosity ν=41mm^2/s, the difference between the calculated value and the test value is -1%~5%.

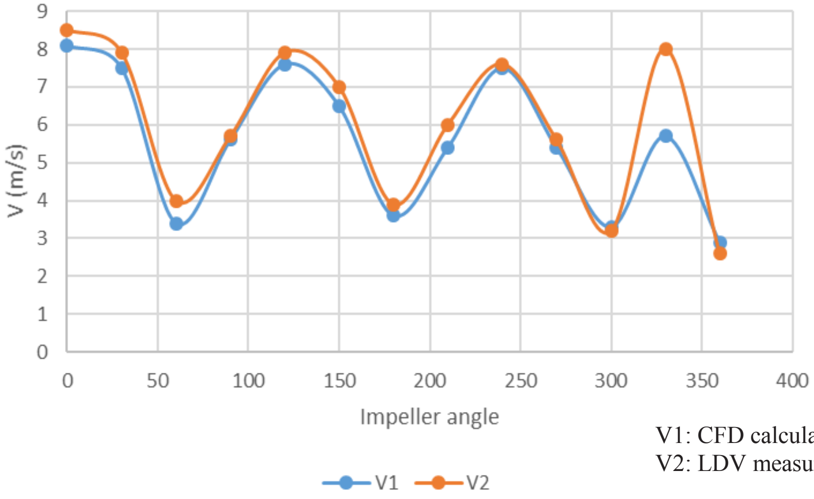


V1: Water
V2: Viscous oil

Fig. 2. Contrast of head curves.

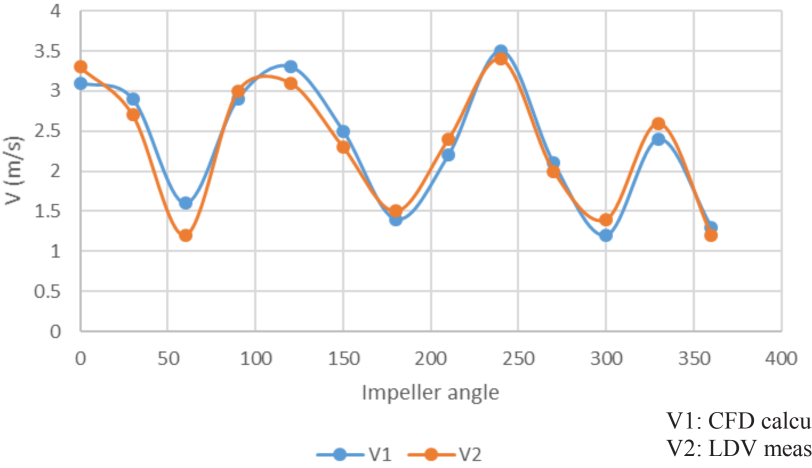
3.2 LDV measurement data comparison

Figure 3 and Figure 4 respectively show the variation curves of the fluid circumferential and radial velocity components calculated at 3mm away from the impeller outlet on different sections and the measured LDV values with the impeller angle Φ during water transportation. As can be seen from the figure, the circumferential velocity distribution calculated by CFD is in good agreement with the measured values of LDV, while the radial velocity distribution is quite different from the measured results. In low flow condition, the difference between the calculated value and the measured value is larger than that in the optimal condition, and the variation regularity of the calculated value with the impeller angle is not strong. In general, the calculated values are in good agreement with the measured results of LDV.



V1: CFD calculation
V2: LDV measurement

Fig. 3. Flow rate comparison under optimal conditions.

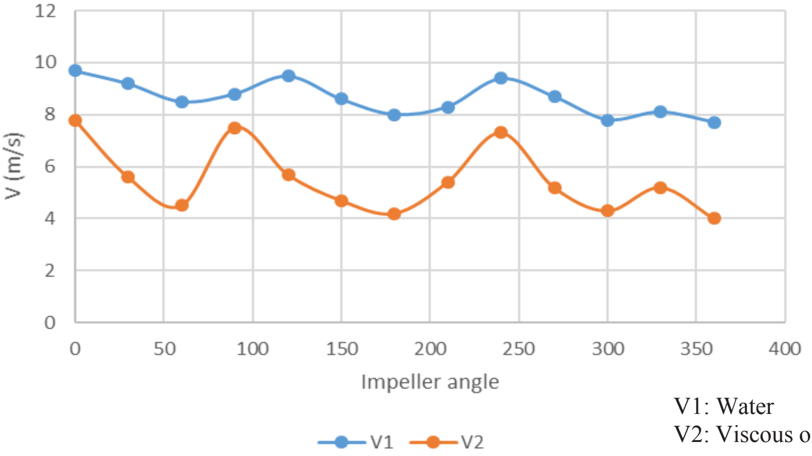


V1: CFD calculation
V2: LDV measurement

Fig. 4. Velocity comparison under low flow condition.

3.3 Changes in torque and total pressure

Figure 5 shows the variation curve of the calculated total torque on the front and rear cover plates and blades of the impeller with the rotation angle of the impeller under different working conditions when conveying water and viscous oil. The curve shows that the total torque pulsates periodically with the impeller angle, and the pulsation of viscous oil is smaller than that of water.



V1: Water
V2: Viscous oil

Fig. 5. Variation of impeller torque with blade angle.

4 Conclusion

In this paper, the unsteady turbulent flow of water and viscous oil in centrifugal pump is numerically calculated by using CFD program Fluent. The pump head calculated by using steady and unsteady flow models is compared with the experimental values. At the same time, the calculated unsteady velocity distribution at the impeller outlet is compared with the measured LDV values. The influence of viscosity on torque and head pulsation of impeller was investigated, and the relationship between fluid pressure and velocity head pulsation amplitude and working condition and fluid viscosity was analyzed. We found that the increase of the fluid viscosity of the feed pump will weaken the flow parameter pulsation behind the impeller and weaken the flow separation tendency near the blade face, which has a great impact on the separation result of the evaporator. These conclusions have important reference significance for the optimization and improvement of the feed pump of the wiped film molecular distillation.

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