

Numerical Study of Internal Flow and Leakage Characteristics in an Ω -Type Twin-Screw Pump

Jing Zhou*, Yong Cao

School of Mechanical Engineering, Tianjin University of Science & Technology, Tianjin, 300457, China

**Corresponding author*

Keywords: Twin-screw pump; Numerical simulation; Leakage characteristic; Radial clearance; Circumferential clearance

Abstract: To investigate the internal flow and leakage characteristics of an Ω -type twin-screw pump, a three-dimensional transient numerical model was established to analyze the pressure field, velocity field, and operational performance under reference conditions. The study also examined the effects of rotational speed, radial clearance, and circumferential clearance on flow rate, leakage, volumetric efficiency, and shaft power under different viscosity conditions. The results indicate that the pressure inside the pump increases in a stepwise manner along the axial direction, rising from 98.328 kPa to 557.143 kPa; the velocity field exhibits a distribution characterized by “high in the middle and low at both ends,” with the maximum velocity in the central meshing zone reaching 9.31 m/s, making it the primary region for leakage and energy loss. As the rotational speed increases, the flow rate and volumetric efficiency increase, while the shaft power rises; as the radial and circumferential clearances increase, the flow rate and volumetric efficiency decrease, and the leakage volume increases. Low-viscosity media are more sensitive to changes in clearances, and the effect of circumferential clearance is more significant than that of radial clearance. The research results can provide a reference for the structural optimization and operating condition matching of twin-screw pumps.

1. Introduction

Due to their advantages of smooth flow, excellent self-priming capabilities, and strong adaptability to high-viscosity media, twin-screw pumps are widely used in the petrochemical, marine, energy, and hydraulic systems industries[1-3]. Their operation relies on the synchronous meshing of the drive and driven rotors to form a sealed working chamber, thereby enabling the continuous delivery and pressurization of the medium[4-6]. However, due to the complex three-dimensional unsteady flow within the pump and the inevitable clearance between components, fluid leakage, shear, and localized vortices are prone to occur in the meshing and clearance zones, thereby affecting the pump’s flow rate, volumetric efficiency, and energy consumption[7-9]. Therefore, conducting numerical simulation studies on the internal flow and operational performance of twin-screw pumps is of great significance for improving pump design and operational efficiency.

In the field of numerical simulation and performance analysis of screw pumps, Wang Zhaqiang [10] used Fluent to conduct an in-depth analysis of the influence of inlet-outlet pressure differences and clearances on the axial force of a three-screw pump. Jiang Xiaoping et al. [11] combined moving-mesh technology to perform multi-condition simulations of an A-line twin-screw pump turbine, focusing on the impact of outlet backpressure on its energy recovery characteristics. Yan D [12] used three-dimensional CFD simulations to predict the instantaneous flow rate and rotor torque of a twin-screw pump and introduced a model to calculate bearing mechanical losses. Ye Z [13] established a full three-dimensional transient flow model for an internally meshed twin-screw pump, simulating the entire medium delivery process and evaluating flow uniformity by analyzing the transient changes in flow rate and pressure. In studies of multiphase flow and hydraulic characteristics, Liu P [14] established and validated a numerical model for multiphase flow delivery, systematically analyzing pump performance under different gas content, rotational speeds, and pressure differentials. Zhang D [15] combined SCORG and Pumplinx software to conduct CFD simulations and experimental validation, dissecting the hydraulic characteristics of twin-screw pumps under various operating conditions. Regarding rotor tooth profile manufacturing and thermodynamic effects, Khalifa N B [16] proposed a new hot extrusion process for helical profiles, analyzed the impact of friction and other factors on contour accuracy, and optimized the die design; Patil A [17] investigated the effects of discharge temperature rise caused by compression heat during wet gas compression on the volumetric and mechanical efficiencies of the pump. Additionally, Yan D [18], incorporating a cavitation model, found that cavitation within the pump increases torque and power consumption; although gap cavitation can reduce leakage rates to improve volumetric efficiency, the expansion of the cavitation zone under high-speed conditions leads to a significant decrease in volumetric efficiency.

This paper focuses on Ω -type twin-screw pumps, establishing a three-dimensional numerical model to analyze their internal pressure and velocity fields, as well as their performance under standard operating conditions. It further investigates the effects of rotational speed, radial clearance, and circumferential clearance on flow rate, leakage, volumetric efficiency, and shaft power under various viscosity conditions. The findings of this study can serve as a reference for the structural optimization and operating condition matching of twin-screw pumps.

2. Geometric models and numerical methods for twin-screw pumps

2.1. Structural parameters of twin-screw pumps

Twin-screw pumps can be modeled in Creo software. First, select the curve derived from the equation; then, enter the parametric equations for each segment of the rotor end face profile to obtain the end face curve. Let the end face curve as a plane, add a centerline and enter the helix equation to form the helix; then scan the end-face curves around the helix according to the selected helix direction, pitch, and length. After scanning, a 3D model of a single screw rotor is obtained. A 3D cross-section of the twin-screw pump model created using Creo software is shown in Figure 1, and Table 1 lists the initial parameters of the pump's main components. Where: R_1 is the radius of the tooth tip circle; R_2 is the radius of the tooth root circle; A is the rotor center distance; l is the screw pitch; L is the screw length; C_r is the radial clearance; C_t is the circumferential clearance.

Table 1: Initial design parameters for twin-screw pumps

Parameters	R_1 /mm	R_2 /mm	A /mm	l /mm	L /mm	C_r /mm	C_t /mm
value	27.5	17	44.66	40	160	0.16	0.2

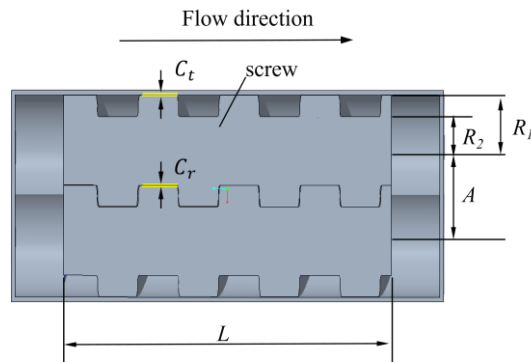


Figure 1: 3D cross-sectional view of a twin-screw pump

2.2. Boundary condition setting

Set one rotation of the rotor as 180 time steps, select the standard k- ϵ turbulence model, adopt a pressure inlet and a pressure outlet, and the wall surface is a no-slip wall surface. The specific parameters are that the inlet pressure is 0.10 MPa, the outlet pressure is 0.55 MPa, the main screw rotor rotates clockwise, the slave screw rotor rotates counterclockwise, the rotational speed is set to 1500 r/min, the oil viscosity is 40 cP, and the density $\rho = 830 \text{ kg/m}^3$.

2.3. Mesh generation and irrelevance verification

In view of the characteristics of the synchronous counter-rotating double-rotary motion of the working chamber of the twin-screw pump, and the problem that the ordinary grid division is difficult to achieve due to the narrow internal clearance and the complex structure of the fluid domain, SCORG is used to carry out the structured grid division of the fluid domain, and Simerics MP+ is used to divide the grids of the inlet and outlet fluid domains[19-20]. The specific form of the fluid domain grid of the twin-screw pump is shown in Figure 2.

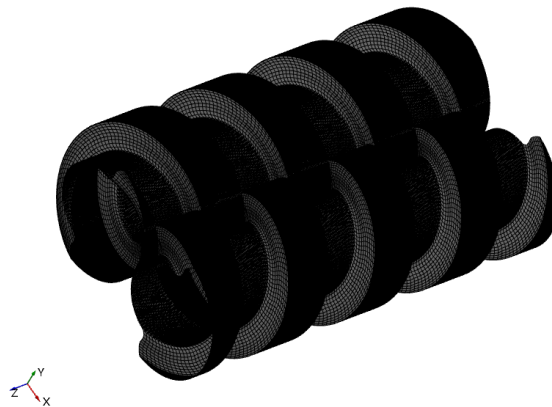


Figure 2: Fluid domain meshing

Grid division has a significant impact on the accuracy and time consumption of the calculation results of the fluid domain of the twin-screw pump. In order to reduce the calculation time on the premise of ensuring the calculation accuracy, taking the outlet volume flow Q of the twin-screw pump as the reference index, the grid independence verification is carried out. The results are shown in Figure 3. It can be seen from the figure that the difference between the calculation results of the fifth group (the number of grids is 733,384) and the sixth group is small. Therefore, the fifth group of grids is used for calculation.

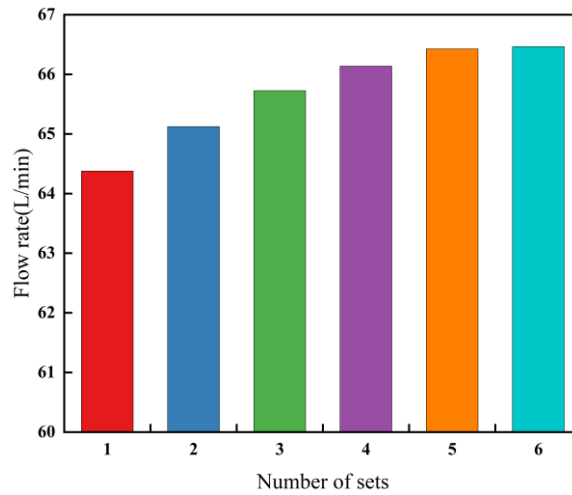


Figure 3: Verification of grid independence

3. Analysis of the internal flow field of the twin-screw pump

3.1. Distribution characteristics of the pressure field

As shown in Figure 4, it is the pressure distribution diagram in the fluid domain of the Ω -shaped twin-screw pump after stabilization. It can be seen from the figure that the pressure distribution in the pump chamber shows an obvious gradient distribution. The pressure of the fluid in the axial direction gradually increases. The pressure at the inlet end of the pump is only 98.328 kPa. As the fluid is transported axially to the outlet end under the meshing action of the screw, the pressure also increases. Until the pressure at the outlet is 557.143 kPa, which indicates that this Ω -shaped twin-screw pump has a good pressurization and transportation capacity. This pressure change in the axial direction is not a sudden increase, but shows a stepwise upward trend with the screw lead, indicating that the fluid is undergoing a stable energy transfer process in the continuous meshing chambers, effectively avoiding the hydraulic shock caused by local pressure mutation.

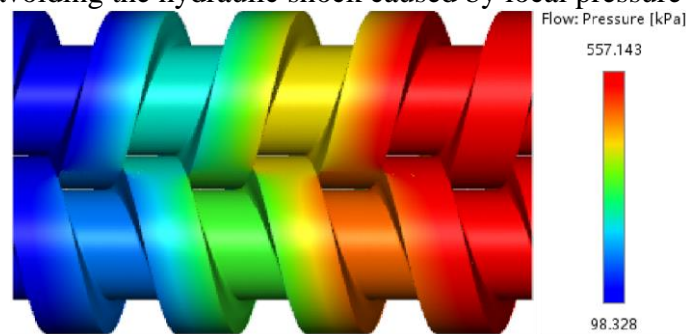


Figure 4: Pressure distribution in fluid domain of twin screw pump

3.2. Distribution characteristics of the velocity vector field

As shown in Figure 5, this figure illustrates the velocity vector distribution at six equally spaced points along the axial direction of the twin-screw pump. The figure reveals that the magnitude of the fluid velocity follows an axial distribution characterized by “highest in the middle and lowest at both ends.” At the inlet ($z = 0$ mm) and the outlet ($z = 160$ mm), the maximum velocities are approximately 4.20 m/s and 4.30 m/s, respectively. In the central section ($z = 32$ mm to $z = 128$ mm), the velocity increases significantly; within this region, the maximum velocity occurs at $z = 96$

mm, reaching 9.31 m/s. This indicates that the fluid is influenced by the interaction between the screws, undergoing a process where kinetic energy is gradually converted into potential energy. At the meshing gap between the two screw rotors, the direction of the velocity vectors changes abruptly, forming a localized region of high-speed flow concentration. The degree of velocity vector turbulence varies across different regions: turbulence is greatest at the meshing points in the middle sections ($z = 64$ mm and $z = 96$ mm), where the range of high flow velocities is also the widest. This indicates that shear forces are strongest in these areas, and eddy currents and secondary flow phenomena are most severe, constituting a major cause of energy loss within the pump. In contrast, the velocity distribution at the inlet and outlet meshing points is relatively smooth, with minimal disturbance.

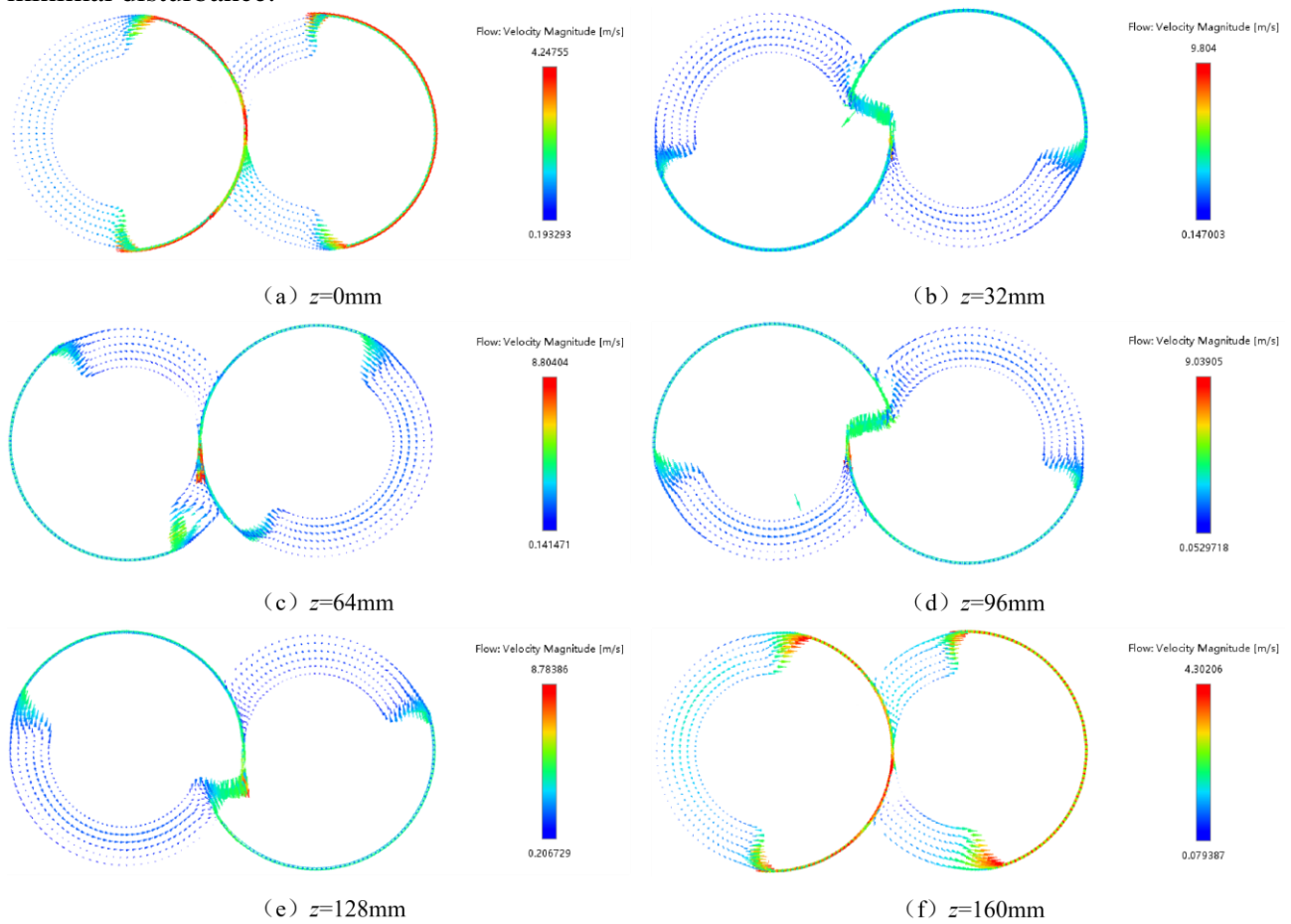


Figure 5: Velocity vector field at the cross-section

3.3. Analysis of operational performance under reference conditions

As a typical positive-displacement fluid machinery, the stability and uniformity of flow output in twin-screw pumps are the primary criteria for evaluating their performance and key factors affecting the efficiency of the entire system. Under actual operating conditions, the combined effects of the meshing clearance between rotors, fluid compressibility, and vibrations caused by turbulence in the flow passages result in a difference between the actual flow rate and the flow rate calculated under ideal conditions, with the actual flow rate varying in a regular pattern. Therefore, conducting flow characteristic studies of twin-screw pumps through numerical simulation not only provides a clear understanding of flow variations but also lays a solid foundation for further improvements in rotor profiles, reduction of clearance leakage, and enhancement of the pump's

volumetric efficiency and operational reliability. Figure 6 shows the flow rate of a twin-screw pump obtained from numerical simulation.

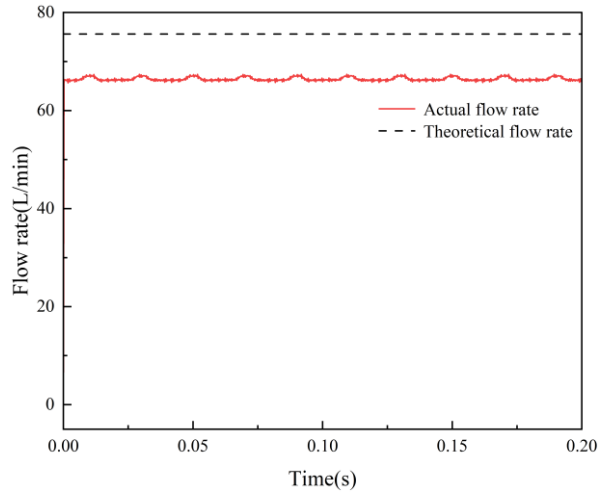


Figure 6: Flow characteristic curve

As can be seen from the figure, the simulated flow curve remains below the theoretical flow curve throughout, indicating that volumetric losses occur during the operation of the twin-screw pump. This is primarily caused by high-pressure fluid leaking into the low-pressure chamber due to the high pressure in the meshing gap area. In addition, the simulated flow curve exhibits certain periodic minor fluctuations. This is because the volume of the sealing chamber continuously changes as the rotors rotate, and when the fluid is squeezed into the meshing region, it is immediately released, resulting in variations in flow rate. Although this variation is small, it must be minimized in applications requiring high flow stability. This can be achieved by improving the rotor meshing configuration or by appropriately setting the clearance, thereby enhancing the performance of the twin-screw pump.

The shaft power of a twin-screw pump is a key indicator of its energy consumption and overall dynamic performance. Figure 7 shows the shaft power characteristic curve.

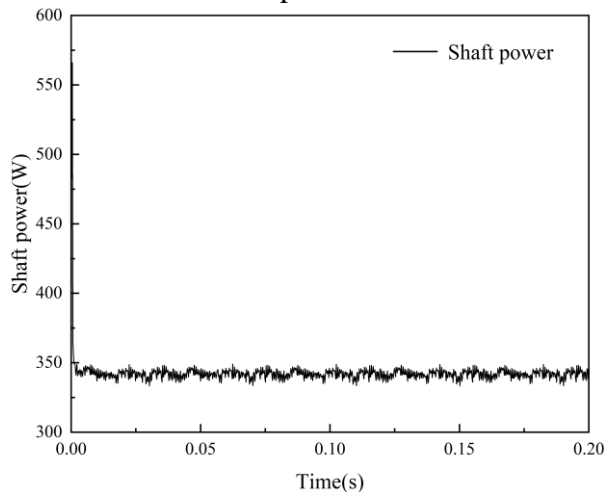


Figure 7: Shaft power characteristic curve

As can be seen from the figure, the shaft power remains stable at around 340 W, exhibiting overall smoothness without any abrupt changes, with only minor periodic fluctuations. This indicates that the hydrodynamic load within the pump varies minimally and that the rotors are meshing well. Furthermore, the shaft power does not exhibit a trend of gradual increase or decrease.

This indicates that during this operating period, there were no instances of abnormal load increases or accelerated energy loss within the pump, further validating the stability and reliability of the pump's operation.

4. Effect of parameters on the performance of twin-screw pumps

4.1. Effect of screw speed on the performance of twin-screw pumps

Set the inlet pressure of the twin-screw pump to 0.1 MPa and the outlet pressure to 0.55 MPa. The fluid medium is set to oil, with a density of 830 kg/m^3 and a dynamic viscosity of 40 cP. Numerical simulations were performed for the twin-screw pump at different rotational speeds. Figure 8 shows the variation of the twin-screw pump's flow rate and leakage volume with rotational speed. As can be seen from the figure, both the theoretical flow rate and the actual flow rate increase in a nearly linear relationship as the rotational speed increases. The theoretical flow rate is always greater than the actual flow rate; the difference between them represents the volumetric loss caused by internal leakage. Furthermore, as the rotational speed increases, the absolute difference between the theoretical and actual flow rates also grows larger. That is, while higher rotational speeds can increase the pumping capacity, they simultaneously widen the pressure differential between the high-pressure and low-pressure sides, making it easier for high-pressure fluid to flow into the low-pressure side and thus causing greater leakage.

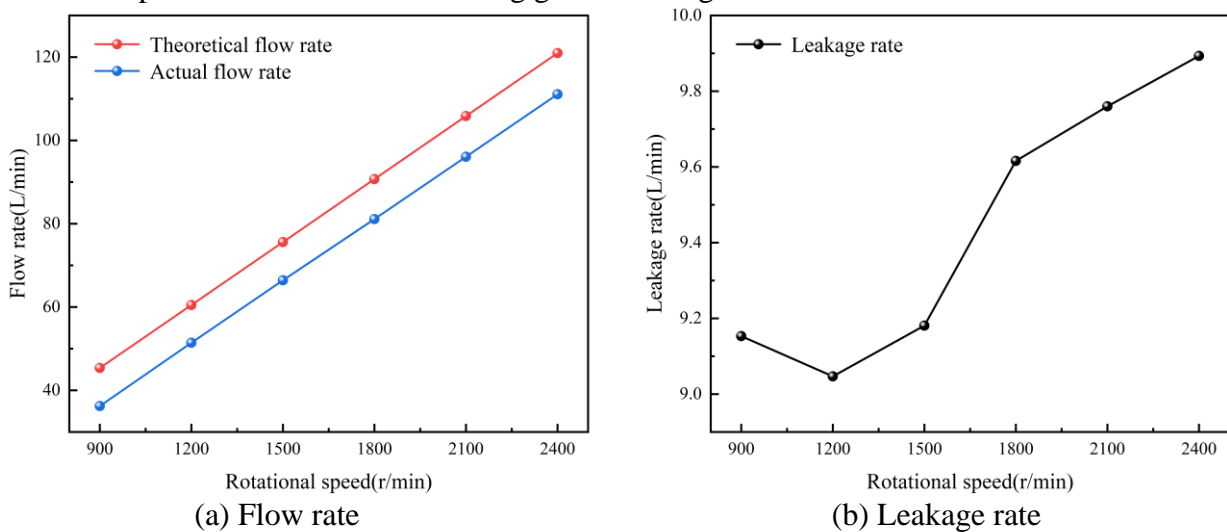


Figure 8: Variation trend of flow and leakage of twin screw pump with rotating speed

As shown in Figure 9, this graph illustrates the variation of volumetric efficiency in a twin-screw pump with respect to rotational speed. It can be observed that the volumetric efficiency of the twin-screw pump increases continuously as the rotational speed rises. At low speeds, the fluid has sufficient time to flow within the meshing gap, resulting in significant leakage and relatively low volumetric efficiency; however, as the rotational speed increases, the rate of change in the volume of the sealing chamber accelerates, and the proportion of leakage decreases, thereby improving the volumetric efficiency.

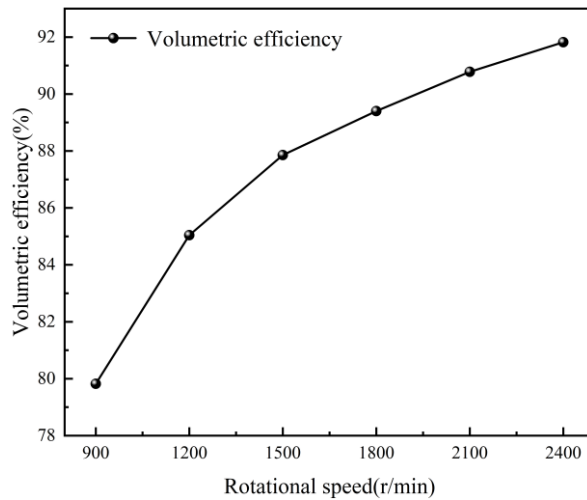


Figure 9: Variation trend of volumetric efficiency of twin screw pump with rotating speed

As shown in Figure 10, this graph illustrates the variation of shaft power in a twin-screw pump with respect to rotational speed. It can be observed that the shaft power of the twin-screw pump increases in an approximately linear manner as the rotational speed rises. This is because, as the rotational speed increases, the volume of fluid transported per unit time increases, leading to enhanced fluid compression and shear forces. At the same time, leakage flow and turbulence at the rotor meshing gaps also intensify, resulting in a significant increase in energy dissipation within the pump.

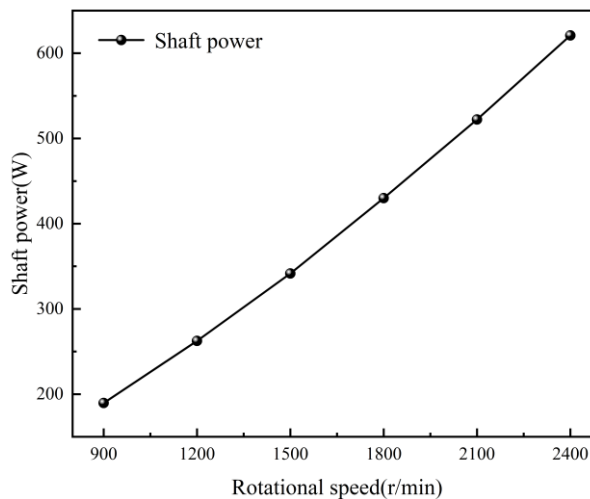


Figure 10: Variation trend of shaft power of twin screw pump with rotating speed

4.2. Effect of radial clearance on the performance of twin-screw pumps under different viscosity conditions

To investigate the effect of clearance parameters on the operational performance of twin-screw pumps and to reveal the modulating effect of fluid viscosity on clearance effects, numerical simulations were conducted under four viscosity conditions (10, 40, 100, and 200 cP) for various radial and circumferential clearance conditions. The twin-screw pump was set to operate at 1500 r/min, with an inlet pressure of 0.1 MPa and an outlet pressure of 0.55 MPa. The fluid medium selected was oil, with a density of 830 kg/m³. As shown in Figure 11, the figure illustrates the variation in flow rate and leakage of a twin-screw pump with different radial clearances under various viscosity conditions. It can be observed that, for the same radial clearance, the higher the

medium viscosity, the greater the actual flow rate of the pump; whereas under the same viscosity conditions, the flow rate decreases as the radial clearance increases. This is because high-viscosity fluids have greater viscous resistance, which suppresses leakage through the clearance, resulting in a larger discharge flow rate. In contrast, low-viscosity media are more sensitive to changes in clearance; leakage increases sharply as the clearance widens, causing the flow rate to decrease rapidly.

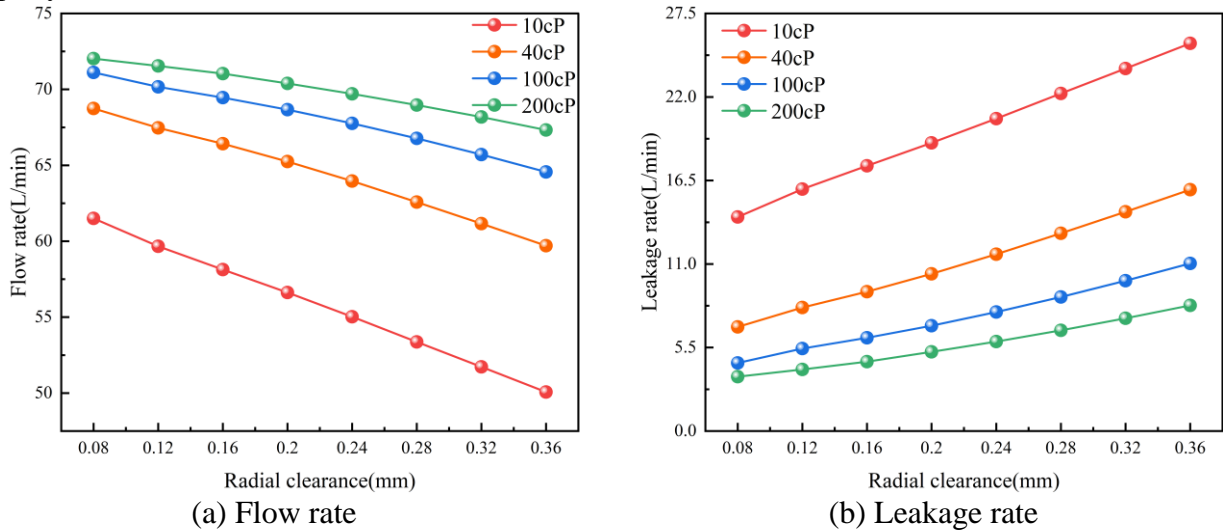


Figure 11: Trends in flow rate and leakage of a twin-screw pump as a function of radial clearance at different viscosities

As shown in Figure 12, this figure illustrates the variation in volumetric efficiency of a twin-screw pump with different radial clearances at various viscosities. It can be observed that, for a given radial clearance, volumetric efficiency increases as the medium viscosity increases. At a constant viscosity, volumetric efficiency decreases continuously as the radial clearance increases, and the rate of decrease is significantly greater for low-viscosity media than for high-viscosity media. This indicates that low-viscosity operating conditions are more sensitive to changes in clearance.

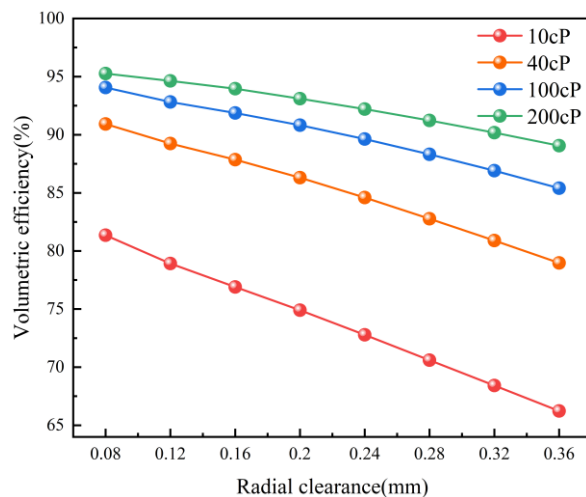


Figure 12: Trend of volumetric efficiency of a twin-screw pump as a function of radial clearance at different viscosities

As shown in Figure 13, this graph illustrates the variation in shaft power of a twin-screw pump with different radial clearances at various viscosities. It can be observed that the shaft power of the

twin-screw pump increases as the viscosity of the medium rises, while it shows a slight downward trend as the radial clearance increases. At the same clearance, the shaft power for a high-viscosity medium (200 cP) is significantly higher than that for a low-viscosity medium (10 cP). This is because high-viscosity fluids have greater shear resistance, resulting in higher energy losses. At the same viscosity, shaft power decreases slightly as the radial clearance increases from 0.08 mm to 0.36 mm. This is because, although a larger clearance increases leakage, it also reduces the frictional shear loss between the fluid and the rotor walls. Overall, medium viscosity is the primary factor affecting shaft power, while the influence of radial clearance is relatively limited.

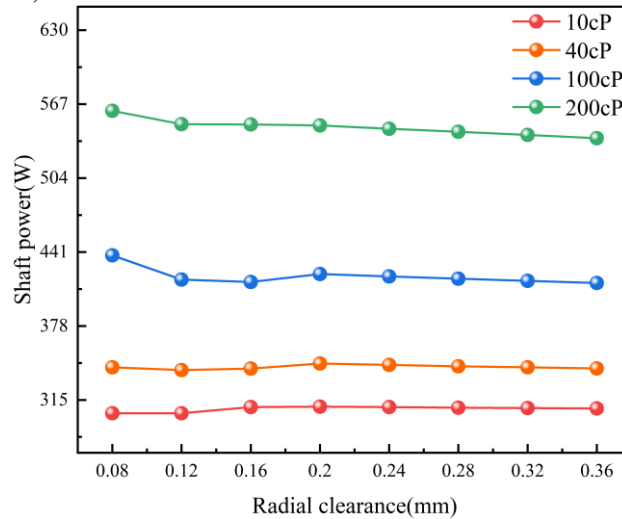


Figure 13: Trend of shaft power in a twin-screw pump as a function of radial clearance at different viscosities

4.3. Effect of circumferential clearance on the performance of twin-screw pumps under different viscosity conditions

The circumferential clearance also has a significant impact on the internal flow field of a twin-screw pump. The pump speed is set to 1500 r/min, the inlet pressure to 0.1 MPa, and the outlet pressure to 0.55 MPa. The fluid medium is oil, with a density of 830 kg/m³. Assuming all other structural parameters remain constant, numerical simulations were performed for twin-screw pumps with different circumferential clearances. As shown in Figure 14, the graph illustrates the variation in flow rate and leakage volume of the twin-screw pump under different circumferential clearances and at various viscosities. It can be observed that as the circumferential clearance increases, the actual flow rate of the pump decreases for all viscosity levels, while leakage volume continues to rise. Furthermore, the decrease in flow rate and the increase in leakage volume for 10 cP are significantly greater than those for 200 cP. For the same circumferential clearance, higher fluid viscosity results in greater flow rate and lower leakage. This is because the viscous resistance of high-viscosity fluids significantly suppresses leakage at the circumferential clearance, reducing the volumetric loss caused by an increased clearance; conversely, low-viscosity fluids have high fluidity, and an enlarged circumferential clearance directly increases the cross-sectional area of the leakage path, leading to a significant rise in leakage and, consequently, a substantial drop in flow rate.

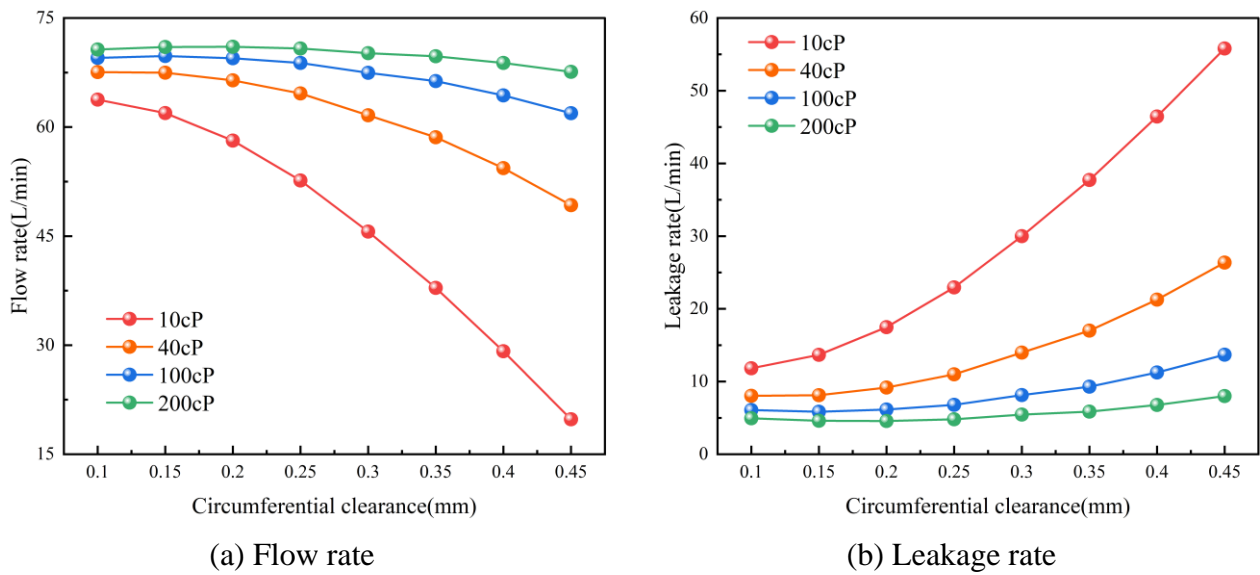


Figure 14: Trends in flow rate and leakage of twin-screw pumps as a function of circumferential clearance at different viscosities

As shown in Figure 15, this figure illustrates the variation in volumetric efficiency of a twin-screw pump with different circumferential clearances at various viscosities. It can be observed that, at the same viscosity, the volumetric efficiency of the twin-screw pump decreases as the circumferential clearance increases. At a given circumferential clearance, the variation in volumetric efficiency is minimal for high-viscosity media, whereas low-viscosity media are significantly affected by changes in clearance. This pattern is consistent with the trend observed for radial clearance, but the circumferential clearance exhibits a more pronounced dampening effect on efficiency.

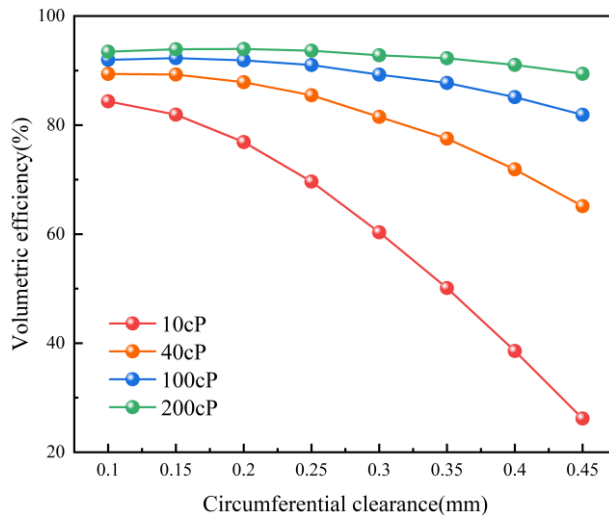


Figure 15: Trends in the volumetric efficiency of twin-screw pumps as a function of circumferential clearance at different viscosities

As shown in Figure 16, this figure illustrates the variation in shaft power of a twin-screw pump with different circumferential clearances at various viscosities. It can be observed that, for a given circumferential clearance, shaft power increases as the viscosity of the medium increases, because the shear resistance of high-viscosity fluids is significantly greater than that of low-viscosity fluids. At a given viscosity, as the circumferential clearance increases, the shaft power continues to

decrease. This is because, although an increased clearance exacerbates leakage, it significantly reduces the frictional shear loss between the fluid and the inner wall of the pump casing, and this effect is dominant. In comparison with radial clearance, it is evident that circumferential clearance—as the fitting clearance between the rotor and the pump casing—has a more pronounced effect on reducing fluid shear losses when increased; therefore, the reduction in shaft power is greater than that observed under radial clearance conditions.

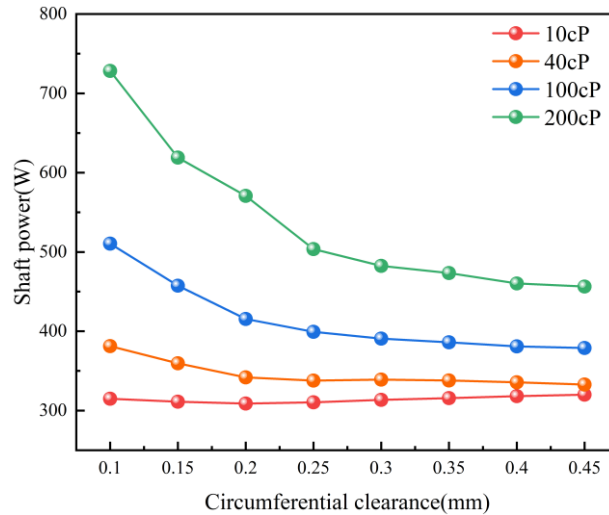


Figure 16: Trends in the shaft power of a twin-screw pump as a function of circumferential clearance at different viscosities

5. Conclusions

This study establishes a three-dimensional computational fluid dynamics model of an Ω -type twin-screw pump and conducts a systematic numerical simulation analysis of the unsteady flow characteristics and operational performance under various operating conditions. The main conclusions are as follows:

(1) By using a structured moving mesh for the rotor generated by SCORG, we addressed the challenge of large mesh deformation in the meshing zone and at the micro-gaps of the twin-screw pump. Pressure field analysis indicates that the fluid exhibits a distinct step-like pressure increase along the axial direction, with the Ω -shaped tooth profile forming an effective seal at all cross-sections. Velocity field analysis reveals the presence of significant high-speed jets and turbulence in the meshing gap, which are the primary causes of internal leakage and energy dissipation in the pump.

(2) Both the theoretical and actual flow rates of twin-screw pumps increase in an approximately linear fashion with rising rotational speed. Although high rotational speeds exacerbate leakage across the pressure differential, the impact of rotational speed on flow rate is greater; consequently, the pump's volumetric efficiency increases as rotational speed rises, while shaft power exhibits a linear increase with rotational speed.

(3) An increase in radial and circumferential clearances significantly reduces the pump's volumetric efficiency. Low-viscosity fluids are highly sensitive to changes in clearances; even a slight increase in clearance can lead to a substantial drop in volumetric efficiency. High-viscosity fluids, due to their high viscous resistance, can effectively suppress leakage through the clearances but result in a significant increase in shaft power. Therefore, in engineering design, it is necessary to balance the relationship between machining clearances and energy efficiency based on the characteristics of the fluid.

References

- [1] Li, F.T. (2010) *Screw Pump*. China Machine Press.
- [2] Pan, S.Y., Zhao, L.Z., Li, X.Q., et al. (2022) *Design of Multi-Point Meshing Rotor and Internal Flow Characteristics of Twin-Screw Pump*. *Journal of Drainage and Irrigation Machinery Engineering*, 40, 895-901.
- [3] Che, X.H. and Zhang, F. (2022) *Numerical Simulation of Hydraulic Characteristics of Twin-Screw Water Pump Based on Pumplinx*. *Journal of Yangzhou University (Natural Science Edition)*, 25, 54-60.
- [4] Muhammed, A.R.A. and Childs, D.W. (2013) *Rotordynamics of a Two-Phase Flow Twin Screw Pump*. ASME Turbo Expo: Turbine Technical Conference & Exposition.
- [5] Li, Z.L., Yu, R., Zhang, Q., et al. (2020) *Flow Field Simulation and Experimental Study of Omega-Shaped Twin-Screw Pump*. *Computer Simulation*, 37, 60-65.
- [6] Liu, P., Morrison, G. and Patil, A. (2019) *Experimental and Analytical Investigation of a Novel Multistage Twin-Screw Pump*. *Journal of Energy Resources Technology*, 141, 1-25.
- [7] Cao, L., Jiang, X.P., Pan, H.S., et al. (2021) *Numerical Simulation of the Effect of Tooth Clearance on Leakage in Twin-Screw Turbine*. *Journal of Drainage and Irrigation Machinery Engineering*, 39, 351-357.
- [8] Qi, Y.Q. and Yu, Y.F. (2016) *Numerical Simulation and Analysis of Leakage Process in Twin-Screw Expander*. *Journal of Shanghai Jiao Tong University*, 50, 496-501.
- [9] Zhang, W., Jiang, Q., Bois, G., et al. (2019) *Experimental and Numerical Analysis on Flow Characteristics in a Double Helix Screw Pump*. *Energies*, 12, 3420.
- [10] Wang, Z.Q., Zhu, H.B., He, G., et al. (2019) *Calculation of Axial Force on Screw of Triple-Screw Pump Based on CFD*. *Hydraulics Pneumatics & Seals*, 39, 4-7.
- [11] Jiang, X.P., Liu, S.H., Wang, Y., et al. (2017) *Effect of Outlet Back Pressure on Performance of Twin-Screw Pump as Turbine*. *Journal of Drainage and Irrigation Machinery Engineering*, 35, 1042-1047.
- [12] Yan, D., Kovacevic, A., Tang, Q., et al. (2017) *Numerical Modelling of Twin-Screw Pumps Based on Computational Fluid Dynamics*. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, 231, 4617-4634.
- [13] Ye, Z., Zeng, Z., Lei, C., et al. (2024) *Analysis of Operating Performance Parameters of the Internal Twin Screw Pump*. *Iranian Journal of Science and Technology, Transactions of Mechanical Engineering*, 48, 957-970.
- [14] Liu, P., Patil, A. and Morrison, G. (2018) *Multiphase Flow Performance Prediction Model for Twin-Screw Pump*. *Journal of Fluids Engineering*, 140, 031103.
- [15] Zhang, D., Cheng, L., Li, Y., et al. (2020) *The Hydraulic Performance of Twin-Screw Pump*. *Journal of Hydrodynamics*, 32, 605-615.
- [16] Khalifa, N.B. and Tekkaya, A.E. (2011) *Newest Developments on the Manufacture of Helical Profiles by Hot Extrusion*. *Journal of Manufacturing Science and Engineering*, 133, 061010.
- [17] Patil, A. and Morrison, G. (2018) *Performance of Multiphase Twin-Screw Pump During the Period of Wet-Gas Compression*. *SPE Production & Operations*, 33, 68-72.
- [18] Yan, D., Kovacevic, A., Tang, Q., et al. (2018) *Numerical Investigation of Cavitation in Twin-Screw Pumps*. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, 232, 3733-3750.
- [19] Su, X.X., Li, D.C., Gan, Z.Q., et al. (2020) *Dynamic Numerical Analysis of Water-Based Fluid Triple-Screw Pump*. *Machine Tool & Hydraulics*, 48, 164-170.
- [20] Rao, J. (2020) *Research on Clearance Leakage of Twin-Screw Compressor*. *Sichuan Metallurgy*, 42, 24-28.