Experimental and simulation studies on critical cavitation pressure of oily medium

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Abstract. In order to control the cavitation generated by oily medium, the advantage of mechanical production brought by cavitation is better utilized, and the mechanical damage of parts caused by cavitation is avoided, it is concluded that the cavitation pressure of lubricating oil of oily medium. The pressure field, streamline diagram and cavitation phase diagram were obtained by Ansys Fluent numerical calculation of the oily medium in the flow field of expanding region, the analysis of the mechanism of cavitation. The test bench of cavitation jet is designed, and verified with the simulation results, the specific value of critical pressure of lubricating oil cavitation under different apertures is obtained, and collected cavitation images. The pressure field decreases from the pressure inlet to the outlet, the cavitation occurs in the vicinity of the low pressure zone and the high pressure zone. When the diameter of the jet hole becomes larger, the cavitation occurs more difficult. The lower the viscosity of the lubricating oil, the higher the temperature, the occurrence of cavitation requires higher pressure to stimulate.

1. Introduction
The study of cavitation originated from the study of propeller in the late 19th Century[1], the simulation and experimental research of cavitation have made considerable progress. The cavitation jet has been used in all aspects such as weapons [2] and bionics [3] and so on. Although the cavitation phenomenon has advantages, it can not be underestimated for the cavitation damage of the workpiece. At present, there are a lot of researches on the jets of water cavitation [4-6], but the research on the oily medium is very few. It is necessary to study the conditions of the cavitation in the oily medium.

V. Aeschlimann [7] et al. used a high-speed visualization technique to detect a bubble eddy current in two-dimensional vacuolar hybrid layer.(Using high-speed visualizations, cavitating vortices were examined in the two-dimensional cavitating mixing layer.),Observed a clear bubble diagram.Yi-Chun Wang[8], made sensors that measure the intensity of shock waves generated by a cavitation bubble to monitor the reliability and operation of a marine propeller. Nobuyuki Fujisawa[9], observed the process of the water cavitation by experimental means, the bubble grows from the process of growth to collapse, and the generation of the shock wave is related to the collapse behavior of the bubble. Akira Sou[10], Cavitation in two-dimensional (2D) nozzles and liquid jet in the vicinity of the nozzle exit were visualized using high-speed cameras to investigate the effects of cavitation on liquid jet
under various conditions of cavitation. Feng Hu[11], based on the CFD analysis, a converging and expanding cavitation jet nozzle was designed. Numerical simulation results show that the nozzle can make the submerged jet cavitation under the pressure drop of 1.5 MPa. The cavitation occurred mainly in the expanding section. But the boundary conditions of the cavitation pressure take empirical values and are not fully applicable to all types of lubricants.

2. Numerical simulation model
The present study still uses formula (1)[12] to calculate the occurrence of cavitation and the dimensionless parameters of cavitation state. The expression of the cavitation number $\sigma$ is:

$$\sigma = \frac{P_v - P_r}{\frac{1}{2} \rho V^2_{\infty}}$$

The formula of $P_v$ and $V_{\infty}$ are the inflow pressure and flow rate of the liquid; $\rho$ is the liquid density; $PV$ is the saturated vapor pressure of liquid at ambient temperature.

The simulation uses the Fluent software in the Ansys component and uses the Reynolds cavitation boundary. During the pressure field iteration, the pressure value less than the cavitation pressure is assigned to the cavitation pressure value, and the Reynolds boundary condition is approximated by iteration. Its calculation accuracy is high and it is widely used. The Reynolds cavitation boundary gives the conditions for the location of the oil film rupture[13]:

$$P = 0, \quad \frac{\partial P}{\partial \phi} = 0$$

The multiphase flow model uses Mixture, the main phase is incompressible oily medium, the secondary phase is oil vapor, the turbulence model is $k-\varepsilon$ model, the coupling of pressure and velocity is selected by SIMPLEC algorithm, and the second-order upwind turbulent transport equation and momentum equation are adopted. The nozzle and the flow field are axisymmetric structures, so the model of the axial section can be taken. The model is shown in Figure 1. The inlet of the flow field is set to the pressure inlet, and the pressure value of Inlet is 0.4MPa, the pressure value of the Outlet of the flow field is 101325 Pa (atmospheric pressure), and the other boundary of the model is solid wall. The fluid on the wall has no slip and no penetration, The wall function method is applied to deal with the near wall region. The simulation calculation was performed according to the physical parameters in Table 1.

The area of the flow field model is meshed, and the mesh of the throat and expansion section is encrypted. Flow field meshing is shown in Figure 2.

![Figure 1. Diagram of simulation domain.](image1)

![Figure 2. Flow field meshing.](image2)
### Table 1. Physical parameters.

| Physical Parameter                  | Value |
|------------------------------------|-------|
| Viscosity of lubricating oil(Pa.s) | 0.028 |
| Density of lubricating oil(kg/m³)  | 920   |
| Temperature(°C)                    | 20    |
| Inlet pressure(MPa)                | 1.2   |
| Outlet pressure(Pa)                | 101325|
| The diameter of jet(mm)            | 0.51  |

#### 3. Experimental verification

In order to verify the simulation results, the experimental device is designed as shown in Figure 3. Figure 3.1a is the flow chart of the experimental device, and the experimental object map is designed according to the flow chart in Figure 3 b. The main part is divided into the oil inlet pipeline, the unloading return oil pipeline and the oil outlet pipeline. The experimental medium is selected as several oils with different viscosity. The temperature of the experiment is changed by a silica gel heating plate, and the gear pump is used to connect with the motor to provide power for the entire closed cycle. The pressure gauge is used to monitor the pressure of the generating device in real time. The power input device of this experiment adopts the TUTHILL model JCB gear pump, which can pump water, oil and corrosive liquid. The advantage is that it not only has good adaptability to the working environment, the highest suction fluid temperature can reach 176°C, the motor is a motor with AC8040FC of CROSCHOPP, which can be connected with 220V power and the speed is 1400r/min. 1700r/min, the pressure gauge is installed in the front and rear sections of the generating device to measure, all of which use the pointer pressure gauge, the range of the pressure gauge is 1.6MPa and the dividing value is 0.05MPa, the adjustable temperature of the digital display silica gel plate is from room temperature to 150°C, fully satisfying the temperature requirement of the experimental adjustment; the cavitation generation in the cavitation generating device is observed by a microscope.

By adjusting the valve of the circuit to reduce the flow of the circuit, observe the pressure gauge at the front end of the cavitation device to control the pressure of the entire oil circuit, so as to better combine with the experiment. After the operation of the whole experimental device is stable, the experimental data are recorded again. The main recorded data is the pre-device pressure gauge reading and the video of the flow cavitation recorded in the micrograph.

![Figure 3. Experimental installation diagram.](image-url)
The part of the cavitation device is shown in Figure 4. In order to facilitate the real-time change of the medium in the observation tube and the cavitation phenomenon in the cavitation device, a transparent acrylic material is used, and the interface is matched with the front copper tube as an inch four-pipe. The size of the needle tube is matched to ensure the leakage prevention of the experiment. The inner diameter of the needle tube has multiple data from 0.06mm to 1.25mm, and the inner diameter of the red needle tube is 0.26mm, for example, Figure 4a, and the needle tube and the transparent acrylic tube, such as Figure 4b, make up the cavitation device after the anti-leakage treatment.

4. Results and analysis

4.1 Analysis of simulation results

Figure 5 shows the simulated pressure cloud of the cavitation device, which is iteratively calculated with a convergence factor of $10^{-5}$ until convergence. At the front end of the device is a high pressure zone, the throat pressure is gradually reduced, and the rear expansion zone is a low pressure zone. Due to the small diameter of the jet port, the high velocity fluid brought from the throat can only sustain the impact of a short distance. As shown in Figure 6, the cavitation zone is generated between the high pressure zone and the low pressure zone of the expansion zone. The critical pressure of the cavitation in the simulated calculation is derived from the experiment, as shown in Figure 11.

Figure 7 shows the flow diagram of the cavitation flow field, showing the flow of oily medium in the pipe. The flow line in the divergent region connected to the throat is maintained horizontally, and in the portion where the throat is in contact with the diverging region, two upper and lower vortex regions are generated, and the fluid in this region is deflected.
4.2 Analysis of experimental results

When there is a continuous and stable cavitation bubble at the nozzle of the jet, it is regarded as the initial pressure of cavitation phenomenon, and the pressure value of the inlet is recorded at this time. The effect of reducing the internal air content of the oil on the experiment is closer to the actual working condition. The oil used was placed in a vacuum box before the start of the experiment and evacuated for half an hour.

Set the control group as shown in Figure 8a is the case where no jet port is added, and the self-contained bubble in the oil is excluded; The simulation result diagram 6 shows that the cavitation bubble position produced by cavitation is as shown in figure 8c, which is usually small in volume and the bubbles are precipitated from the needle tube, while the larger volume of bubbles in figure 8b is from the device itself.

As shown in Figure 9, since the initial cavitation pressure is small under these inner diameter conditions, the overall flow rate in the experimental device is small, and when the residual bubbles in the device are not discharged well, and the cavitation phenomenon has occurred in the needle tube, which leads to the larger residual non cavitation bubbles in the image. At the same time, cavitation is also started in the needle tube. The volume of the generated bubble is small, and the formation process is short due to flow rate and velocity, the reason for the bubble movement is slower. When the inner diameter rises above 0.2mm, as shown in Figure 9c-d, it can be clearly found that the generated cavitation does not immediately discharge, but swirls at the outlet of the needle tube. This situation is a vortex phenomenon, under the current experimental conditions, when the inner diameter of the needle tube is small and the flow rate is not increased greatly, the generated bubble flows along the flow line as shown in Figure 7, and begins to swirl around the nozzle.

When the nozzle diameter continues to increase, the image as shown in Figure 10 will be generated. As the inner diameter of the needle tube is further increased, the longitudinal distance from the inner wall of the venturi tube is reduced, and the circulation phenomenon disappears. The residual bubbles in the device were discharged directly with the streamline, and the remaining vacuoles in the image could be seen. In this case, the bubble generation efficiency is further improved, and the
diameter of the bubble is also increased as the pipe diameter is increased. But due to the gas content of the oil, the vacuole inside is broken and continued. There are not too many other factors affecting the experimental Figure 10a-c, which is the best case of cavitation effects. As the inner diameter of the needle tube increases, the influence of the inlet pressure on the flow rate gradually becomes smaller. As shown in Figure 10d, the pressure is gradually increased until no cavitation occurs in the range of the pressure gauge. As the pressure increases, the bubbles in the experimental device are discharged in a large volume; in order to prevent the pressure gauge from being damaged, after the pressure gauge is unloaded, the pressure will continue to increase. The phenomenon of eddy current is produced in the device, and the large bubbles begin to shake off in the Venturi tube, and make a sound, causing the phenomenon as shown in the diagram.

As shown in Figure 11, the cavitation pressure of the oil medium is obtained for the different nozzle inner diameters. The initial pressure of cavitation gradually increases with the increase of nozzle inner diameter.
5. Conclusions
In this paper, the specific value of cavitation initial pressure of oil medium is studied by combining simulation and experiment, the nozzle with variable inner diameter is different from the venturi tube with fixed inner diameter in previous studies.

The simulation part of this model reflects the change of pressure field in the jet flow area. The pressure value decreases from the pressure inlet to the pressure outlet. Low pressure zone (eddy current zone) occurs at the upper and lower parts of the throat connected with the expanding area, and two pressure fields appear at the front, one high and one low. Cavitation occurs at the position where high pressure meets low pressure area in the expanding area. The area of cavitation in the experiment is consistent with the simulation and verified with each other. The phenomenon of different nozzle diameters is different in the test. When the diameter is between 0.06 to 0.16mm, because the pressure is too small, the number of cavitation bubbles is very small and the quantity is also small. When the diameter is between 0.2mm to 0.31mm, there is a phenomenon that cavitation obviously flows around the flow line, and the volume and quantity of cavitation increase significantly. When the diameter is between 0.41mm to 0.70mm, the cavitation area is the horizontal line connected with the throat area. At this time, it is most consistent with the simulation. When the diameter is more than 1.0mm, the experimental device cannot provide enough pressure to generate cavitation, but the gas inside the device will also move around the flow line.

Solving cavitation pressure of oil medium can better avoid cavitation damage caused by cavitation, such as cavitation corrosion inside workpiece, or the impact caused by cavitation can be used to provide accurate experimental data for simulating boundary conditions. However, due to the limitation of the device, the cavitation pressure of the bigger nozzle cannot be measured.

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