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TEMPERATURE INFLUENCE ON CAVITATIONAL MASS TRANSFER IN THE CHANNEL OF LAVAL NOZZLE TYPE

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ABSTRACT

Based on the results of experimental studies of cavitation treatment of oil in a cavitation device, hydrodynamic small bubble cavitation was observed. A stand was developed to test the operation of the device to determine its performance and to visualize the appearance of cavitation. A study of a hydrodynamic cavitation device showed a significant effect of temperature and as a result of a change in viscosity to cavitation processes.

INTRODUCTION

Generally, the process of cavitation is a very complex process, where, as a rule, mechanical effects border on chemical and electrical effects [1]. The appearance of cavitation nuclei is significantly affected by the amount of dissolved air, viscosity and purity of the medium (1-20 micron particles easily become embryos of cavitation) [2, 3]. During cavitation, energy dissipation occurs, which leads to a change in the temperature and viscosity of the working fluid, and this can directly affect the characteristics of the working elements of the hydraulic system. The physical cause of cavitation is the ability of the liquid to resist rupture, otherwise - the breaking strength [4,5]. In accordance with the type of impact, hydrodynamic, acoustic and thermal cavitation are distinguished.

The phenomenon of cavitation is accompanied by a number of effects, among which one of the least studied is the hydro-luminescence [1].

Thermal cavitation occurs during the heating of liquid when the pressure of saturated vapors (or gases) increases to the ambient pressure.

Cavitation can cause various effects:
-thermal;
-shock point pressure increase;
-electrification of liquid;
-sonoluminescence;
-tribolyuminscence;
-hydroluminescence;
-flowrate stabilization.

The thermal effect consists in increasing the temperature of the liquid in the flow due to the shock increase in pressure during the collapse of the cavitation bubble (Fig. 1) [6].

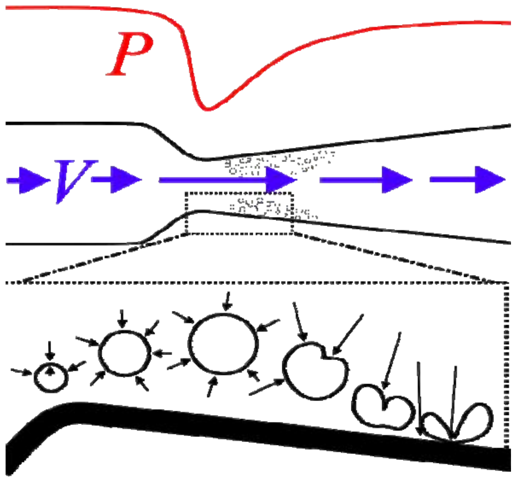

Fig. 1. Occurrence of cavitation at the point of narrowing of the stream

If the bubble is near a wall or an adjacent bubble, the collapse of the bubble occurs with the formation of energetically powerful cumulative jets capable of destroying solid surfaces. The pressure value for a bubble collapse is calculated assuming that a local hydraulic shock occurs. The formula for finding the shock increase of pressure [7]:

$$P_{max} = \sqrt{\frac{3}{2}\frac{\rho\, c^2}{\chi a^5}}\,, \tag{1}$$

where: χ - bulk modulus, c - the speed of sound, a - the bubble radius at the moment of collapse, ρ is the density of the liquid.

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In [8], the calculation of the heating temperature of a liquid when a single cavitation bubble collapses by the method of partitioning into spheres is presented. The results of the calculation showed that the liquid around the bubble can be heated pointwise to 1300 ° C. To use the received heat energy, various devices are created, for example, vortex heat generators [8].

EXPOSITION

To study the effect of hydrodynamic cavitation, a nozzle was made of transparent polished organic glass with a channel in the form of a Laval nozzle (Fig. 2) [9-14].

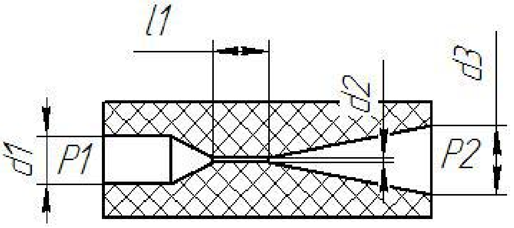

Fig. 2. Nozzle

To measure the flow characteristics, a digital flow meter and a digital temperature sensor, immersed directly in the working fluid at the outlet of the cavitation apparatus, were installed on the stand. Both digital sensors are connected to the ArduinoUno microcontroller, which was programmed to receive and process data from the sensors and record at 10 seconds intervals to a computer with Microsoft Excel [14].

The effect of temperature on the flow coefficient through the calibrated throttle was determined for the hydraulic oil of the HL-P category. At experiments on the nozzle, a pressure drop of 5 MPa was set. Flow characteristics were determined for a temperature range of 20 ... 50 ° C.

The resulting flow characteristics allow determine the dependence of the Reynolds number on the coefficient of discharge [15]:

$$Re = \frac{v \cdot d_h}{\nu}, \tag{2}$$

where v - the flow velocity in the section, dh is the hydraulic diameter, and ν - the kinematic viscosity.

The coefficient of discharge of working fluid through the nozzle was determined by the formula [15]:

$$\mu = \frac{Q_a}{Q_t}, \tag{3}$$

where Q_a - the actual flow rate, Q_t - the theoretical flow rate.

In the general case, the viscosity of the temperature depends nonlinearly and is described by the Frenkel-Andrade equation.

The Newtonian coefficient of viscosity depends only on temperature and pressure:

μ = f (T, p).

The analytical dependence of μ on T according to the studies of GM. Panchenkov is:

$$\mu = 3\sqrt{6R} \cdot \sqrt{\frac{\omega_w^2}{N_0}} \cdot \rho^{\frac{4}{3}} \cdot M^{-\frac{5}{4}} \cdot T^{\frac{1}{2}} \times \times e^{-\frac{\varepsilon}{R \cdot T}} \cdot \left(1 - e^{-\frac{\varepsilon}{R \cdot T}}\right)^2 \tag{4}$$

where R - the gas constant; ω_w - the intrinsic volume of molecules in calculations per 1 -mole; N_0 - number of molecules in the volume of 1g-mol; M - molecular mass; ρ -density; ε - the binding energy of the liquid molecules, determined by the work that needs to be spent, to move to infinitely large distances from its original position (this work is equal to the latent heat of evaporation divided by half the coordinate number of the liquid).

For in-depth study of light emission, a schematic diagram of the experimental stand has been developed (Fig. 3). The stand is built on the basis of a hydraulic station and contains measuring equipment for fixing the pressure drop on the model and the costs. Visualization of the flow occurs with the help of a high-speed camera with a fixing frequency of up to 1000 fps.

To determine the critical values of flow parameters (pressures and velocities) at which cavitation starts, a dimensionless cavitation number (Euler number) was used [3]:

$$\chi = \frac{2 \cdot (p_1 - p_2)}{\rho \cdot V_1^2}, \tag{5}$$

where p_1, V_1 - pressure and velocity at the input, p_2 - the pressure of the saturated vapor of the liquid at ambient temperature.

From the flow equation in the Laval nozzle, the diameter of the throttle (d_2) can be calculated from the formula [15]:

$$d_2 = \sqrt{\frac{4Q}{\pi V_2}} \tag{6}$$

where V2 - the velocity of the liquid in the nozzle.

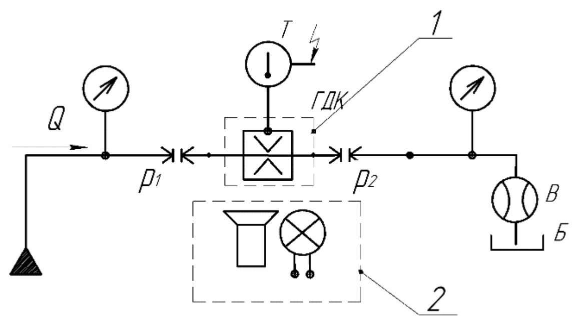

Fig. 3. The basic hydraulic circuit diagram of the stand for the study of the hydrodynamic cavitator (1-cavitation nozzle, 2-high-speed camera)

As a result of the experiment, the dependence of the flow coefficient on the temperature of the working fluid was obtained (Fig. 4).

The dependence has a character close to linear and in the first approximation it can be expressed by linear equation. And with a temperature change from 20 ° C to 50 ° C, the flow coefficient has changed almost to 2,5 times.

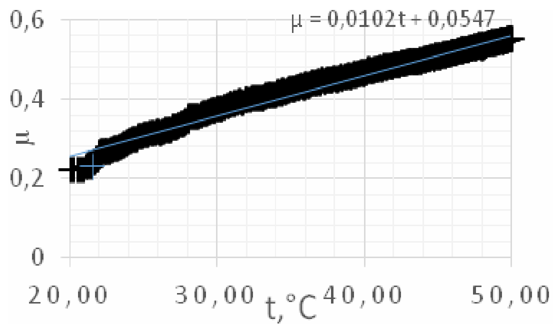

Fig. 4. Discharge coefficient (μ) as a function of the temperature (t°C) (Δp = 50 bar, nozzle diameter d2 = 0,8 mm)

The pressure drop across the cavitator was kept constant at 50 bar.

The experiment began at a temperature of 20 °C. At this temperature, the flow velocity in the section of channel d_2 was 24 m / s. The experiment was completed at a temperature of 50 °C, at which the flow velocity in the section of channel d_2 was 60 m / s.

As a result of the experiment, the dependence of the flow coefficient on the temperature of the working fluid was obtained (Fig. 5).

A significant (up to 5 times) change in viscosity with increasing fluid temperature was observed.

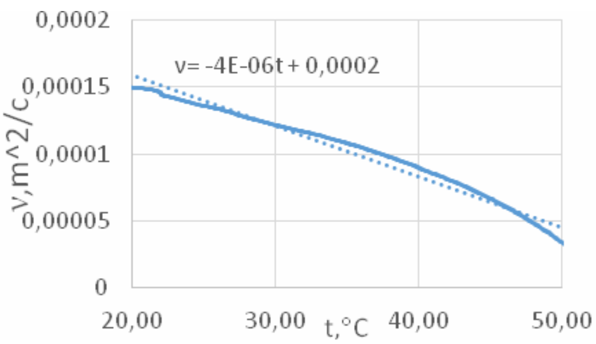

Fig.5. Dependence of the kinematic viscosity of the working fluid on the temperature °C (Δp = 50 bar nozzle diameter d2 = 0.8mm)

At a velocity of more than 30 m/s, a pronounced cavitation flare was observed (Fig. 6).

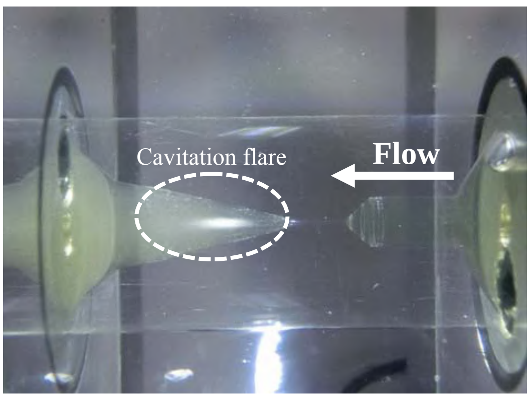

Fig. 6. The process of cavitation in the nozzle (t = 20 °C)

As the temperature increased, the cavitation processes intensified in the cross section d_2 (Fig. 6 and Fig. 7). At a temperature of flow more than 50 °C, the effect becomes maximum (Fig. 8).

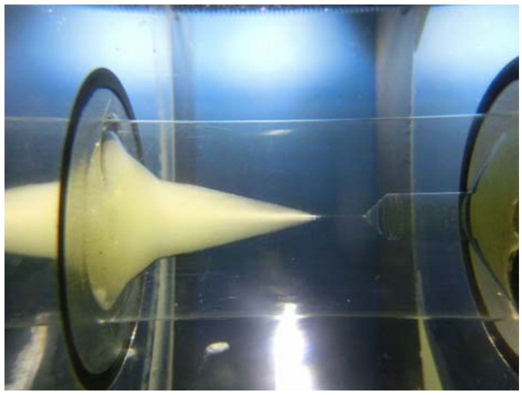

Fig. 7. The process of cavitation in the nozzle (t=40 °C)

During the experiment, pressure pulsations were periodically observed visually observed in the flowmeter flask as a short-term change in the intensity of the flow. The presumed cause of the effect is that gas bubbles formed in the liquid hit the cavitation zone.

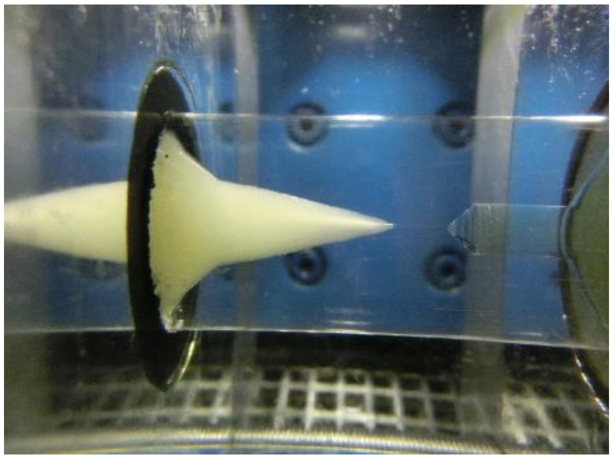

Fig. 8. The process of cavitation in the nozzle (t=50 °C)

In the course of operation, when the flow velocity approaches the maximum values, the effect of merging small diameter bubbles (visually << 1mm) into bubbles of a much larger diameter (visually 2 ... 5mm) in the deadlock chamber (Fig. 7) was observed [14].

Estimating the intensity of cavitation is approximately done with the help of a graphic editor, by determining the weighted average brightness level of the image pixels, which is obtained by multiplying each luminance level by the number of pixels of a given level, and then divided by the total number of brightness levels (Fig.9). The higher the weighted average value, the higher the brightness of the image.

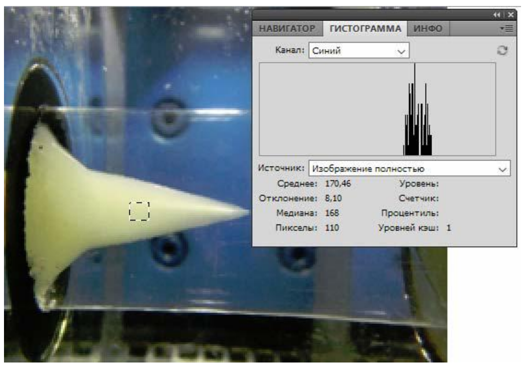

Fig. 9. Estimation of the intensity of cavitation with a change in the temperature of the liquid

The image region on the axis of the cavitator was chosen and the weighted average brightness level of the image section was estimated. In this case, the low value of the average brightness corresponds to the absence of cavitation or its low intensity.

The comparison carried out in this way showed that the intensity of cavitation increases with increasing liquid temperature.

With the increasing of the oil temperature and, correspondingly, a decreasing of viscosity, the flow rate through the throttle cross section d_2 increased (during the experiment to 2,5 times). Due to the increase in the velocity of fluid movement, the effect of cavitation was enhanced. During the experiment, we can also note a characteristic sound, similar to passing through a narrow section of a liquid with a large content of dissolved gas in it. In the course of the experiment, the phenomenon of coagulation was also observed.

Cavitation processes in the flow of mineral oil (SAE 20W-40 of Leol M20 brand) were studied. No light emission of "hydro-luminescence" occurred. Therefore, it can be assumed that the dependence of light emission on the rheological properties of mineral oil, the pressure of its saturated vapors and the composition of additives.

In the study of cavitation processes and their study, it is necessary to choose rational directions of analysis that can be considered from the point of view of the phenomenon of momentum transfer, mass, heat transfer in the hydrodynamic cavitator:

Change in viscosity of a liquid from temperature. Transfer of momentum, Newton's law of viscosity [11]:

$$\tau = \mu \, grad \; u \, , \tag{7}$$

μ - the coefficient of internal friction (dynamic viscosity),
u - the velocity of the medium in space.

The change in the density of the liquid from temperature.

Mass transfer, Fick's diffusion law [11]:

$$q_t = D \, grad \; C \, , \tag{8}$$

where D - the diffusion coefficient, C – the concentration of molecules in the substance.

Change in temperature, heat transfer.

Heat transfer (thermal conductivity Fourier law) [11]:

$$q_e = Q_\lambda \, grad T \, , \tag{9}$$

where Q_λ - the coefficient of thermal conductivity, T - the temperature of the medium.

CONCLUSION

Thus, the developed stand allows visualization and research of the features of the emergence of hydrodynamic cavitation. By the results of the analysis of the experiment, it can be concluded that when the temperature rises, the number of cavitation nuclei increases.

In the future, it is planned to upgrade the stand for the possibility of determining the critical distance at which cavitation processes can be neglected or controlled by changing the rheological properties of the liquid by operating characteristics of the apparatus (control the flow or stabilize the flow).

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