The Effect of water Temperature and Flow Rate on Cavitation Growth in Conduits

Taiseer Abu-Rahmeh, Omar Badran, Aiman Al-Alawin, Najdat Nashat, Ahmed Awwad Mechanical Engineering Department, Faculty of Engineering Technology, Al-Balqa' Applied University, Amman, Jordan

Abstract

Cavitation is a major concern in many hydraulic systems because it can result in reduced pump performance and conduits and fixtures damage. During the cavitation process, vapor forms in a flowing liquid when the local static pressure falls below the vapor pressure of the local fluid. Cavitation can be dependent upon the fluid flow rate and its fluid temperature. The effect of flowing water temperature and flow rate on cavitations inception in conduits has been studied using flow visualization technique and pressure prediction.

A test rig with a variable flowmeter and, pressure reducing valve and heater are used to vary the flow rates, pressure and temperature of water flowing in conduits. They flow can be varied independently. The temperature and flow rate varied from 30°C to 40°C and from 255 to 750 L/h respectively. From the experimental results of all cases it is obvious that cavitation's diffusion increases with increasing fluid temperature and flow rate. Therefore, cavitation can be avoided by careful design of hydraulic system such as avoiding high fluid velocities, low pressures and high temperatures that could lead to cavitation formation and diffusion. The obtained results were found to be in agreement with different studies. Also the results showed that an increase in water temperature and flow rate speeds up cavitation and widen the downstream diffusion.

Keyword: cavitation, temperature effects, bubble collapse, conduits

1. INTRODUCTION

Cavitation is the phenomenon where small and largely empty cavities are generated in a fluid, which expand to large size and then rapidly collapse, producing a sharp sound. The cavitation usually appears when a liquid is subjected to rapid changes of pressure that cause the formation of cavities in the liquid where the pressure is relatively low. When subjected to higher pressure, the voids implode and can generate an intense shock wave and choke. Cavitationsoccurs normally in pumps, propellers, impellers and piping systems..

Perhaps the most ubiquitous engineering problem caused by cavitation is the material damage that cavitation bubbles can cause when they collapse near a solid surface. Consequently, this subject has been studied quite intensively for many years by different researchers [1-6].

Cavitation is a significant cause of wear in some engineering contexts. Collapsing voids that implode near to a metal surface cause cyclic stress through repeated implosion. These results in surface fatigue of the metal which in its role causes a type of wear also called "erosion". The most common examples of this kind of wear can occur in pump impellers and piping bends where a sudden change in the direction of liquid occurs.

Cavitation is, in many cases, an undesirable occurrence. In devices such as propellers and pumps, cavitation causes a great deal of noise, damage to components, vibrations, and a loss of efficiency. Cavitation has also become a concern in the renewable energy sector as

it may occur on the blade surface of tidal stream turbines. However, it is sometimes does not cause damage when the bubbles collapse away from machinery.

In industry, cavitation is often used to homogenize, or mix and break down, suspended particles in a colloidal liquid compound such as paint mixtures or milk. Many industrial mixing machines are based upon this design principle. It is usually achieved through impeller design or by forcing the mixture through an annular opening that has a narrow entrance orifice with a much larger exit orifice.

Cavitation plays an important role for the destruction of kidney stones in shock wave lithotripsy. Currently, tests are being conducted as to whether cavitation can be used to transfer large molecules into biological cells (sonoporation). Nitrogen cavitation is a method used in research to lyses cell membranes while leaving organelles intact.

In industrial cleaning applications, cavitation has sufficient power to overcome the particle-to-substrate adhesion forces, loosening contaminants. The threshold pressure required to initiate cavitation is a strong function of the pulse width and the power input. This method works by generating controlled acoustic cavitation in the cleaning fluid, picking up and carrying contaminant particles away so that they do not reattach to the material being cleaned.

Cavitation plays a key role in non-thermal, non-invasive fractionation of tissue for treatment of a variety of diseases. Cavitation also probably plays a role in HIFU, a thermal non-invasive treatment methodology for cancer.

When the cavitation bubbles collapse, they force energetic liquid into very small volumes, thereby creating spots of high temperature and emitting shock waves, the latter of which are a source of noise and stress. The noise created by cavitation is a particular problem for military submarines, as it increases the chances of being detected by passive sonar. There are many researchers studied the cavitation phenomena and used different techniques to detect the cavitation phenomena, such as;

Kimand Song(2015) studied temperature effects on the critical cavitation number and rotating cavitation in a turbopump inducer experimentally in water. Unsteady pressure sensors and a high-speed camera were used to measure static pressures upstream and nondimensional thermal parameter has been adopted downstream of the inducer to figure out the cavitation performance, and its instabilities. In addition, nondimensional thermal parameter was adopted to quantify temperature effects. The results showed that an increase in nondimensional thermal parameter shifted the onset of rotating cavitation to a lower cavitation number and reduced the intensity of rotating cavitation. However, for values larger than 0.540 (340 K, 5000 rpm), the critical cavitation number and the rotating cavitation onset became independent of the nondimensional thermal parameter.

Matevzand Olivier(2013) used an experimental approach to study the thermodynamic effects associated with the growth and collapse of a single cavitation bubble. Their study focused on the temperature variations in the liquid surrounding the bubble. Experiments were performed in a cylinder partially filled with water at ambient temperature and atmospheric pressure. The results showed that, bubble growth resulted from the expansion of an initial air bubble, due to the pressure wave generated by a so-called "tube-arrest" method. Several locations of the bubbles, at different distances from the bottom wall of the cylinder, were considered. Experimental results were compared to

the predictions of the "thermal delay" model. In this approach, the temperature variations were related to the latent heat exchanges during the vaporization and condensation processes. Moreover, the effects of phase change and air dilatation / compression in the bubble dynamics were discussed.

Webb et al (2011) used a Keller-Miksis equation to find the variation in inertial cavitation threshold with temperature in water and when coupled with a Kelvin-Voigt viscoelastic model, in biological tissue. Simulated thermal ablation treatments in liver and muscle were used to explore the changes in cavitation dynamics, and the resultant frequency spectra of secondary acoustic emissions, due to tissue denaturation. Results indicated that viscosity was the key parameter controlling cavitation dynamics in biological tissues. Also, the results illustrated that the cavitation dynamics was affected by heating and by the changes in mechanical properties of tissue resultant from thermal denaturation; however, the nature of the change was not known and forms the focus of the current study. Experimental validation of these observations offered an improved method to monitor therapeutic ultrasound treatments.

Saleh et al (2011) analyzed the effect of viscosity on the wear particles produced by vibratory cavitation erosion tests on Al-99.92 in distilled water and glycerol-water solutions. The scanning electron microscope images of wear particles during incubation period were illustrated. The surface topography examination revealed that the erosion particles were formed by fatigue. The stress produced by cavitation bubbles decreases with increase of viscosity.

Liuet al., (2011) focused on thermodynamic cavitation based on the Rayleigh-Plesset equation and modified the mass transfer equation with fully consideration of the thermodynamic effects and physical properties. The external and internal flow fields, such as hydrofoil NACA0015 and nozzle were found to validate the modified model. They calculated the hydro-foil NACA0015's cavitation characteristic by using the modified model at different temperatures. The pressure coefficient was found based on the experimental data. The results of the nozzle cavitation under the thermodynamic condition was calculated and compared with the experiment.

Tanaka(2011) used liquid nitrogen to investigate the thermodynamic effect which affects the cavitation performance of a cavitating centrifugal pump experimentally. An experimental rig was constructed to measure the pump cavitation performance using both liquid nitrogen and cold water. Cavitation performance through measurement of pump suction and delivery pressure, temperature, and the discharge flow rate. The experimental results showed that cavitation performance using liquid nitrogen was better than that using cold water. And the estimated temperature depression due to the thermodynamic effect decreased with a decreasing flow coefficient. Moreover, it was shown that the estimated temperature depression due to the low cavitation performance impeller was larger than that on the high cavitation performance impeller at the same flow coefficient.

Plesset (2010) investigated the temperature effects on cavitation damage for different materials within the range of distilled water temperatures 0 C to 90 °C. The results showed that the maximum in the damage rate occurs at temperatures in the range 40 C to 50 °C. The rise in damage at the lower temperatures has a less obvious interpretation and may be due to an increase in chemical activity with temperature. Al-Arabi (2008) studied experimentally the effect of water temperature on performance and cavitation inception of a centrifugal pump. A special test rig with a testing centrifugal pump was constructed for this purpose. The rig was designed so that the flow rate ratio, suction pressure, rotational speed and water temperature could be varied independently. The temperature and speed were varied from 15° C to 60° C, and from 1800 rpm to 2800 rpm respectively, while the ratio of flow rate to optimum flow rate was varied from 0.245 lit/sec to 0.767 lit/sec. The results showed that increasing water temperature

speeds up cavitation. Also, the net positive suction head was found to increase with the increase of temperature up to a maximum value and then decreased again.

Tokumasu,et. al,(2003) investigated the thermodynamic effects of cavitation numerically. A cavitation model was introduced to predicate these effects. A sheet cavity around a 2-D hydrofoil was simulated using this model and the dependence of the thermodynamic properties of fluids on the thermodynamic effects of cavitation were analyzed. The numerical results explained the thermodynamic effects very well.

The aim of the present work is to study and investigate the appearance, growth and diffusion of cavitation in a conduit. Through the the effect of fluid temperature and flow rate on the cavitation intiation and spreading. detected by visualization technique..

2.THEORY

Based on continuity and Bernoulli equation for a fluid flowing through constricted conduits with diameters of d_1 and d_2 , diameters ratio can be expressed by flowing equation:

$$\frac{d_1}{d_2} = \sqrt[2]{1 - \frac{2(P_2 - P_1)}{\rho V_1^2}}$$

From the equation it is clear that the diameters ratio can be obtained by using the pressure drop and fluid properties.

4. EXPERIMENTAL SETUP

Based on continuity and Bernoulli equation for a fluid flowing through constricted conduits with diameters of d_1 and d_2 , diameters ratio can be expressed by flowing equation 1:

From the equation 1 it is clear that the diameters ratio can be obtained by using the pressure drop and fluid properties.

4.1 Measuring equipment and tools

Several types of measuring instruments were used in the experimental part of this work. These instruments were used to measure temperature, flow rate, and images. Adjustable reducing pressure valve is used; the flow rate is controlled by ball valves and measured by using rotameter. Thermometer for measuring water inlet temperature and three pressure gauges are used.

Figure (1) shows the schmetic diagram with detailed description of experimental test rig used in the investigation of flowing fluid temperature and flow rate effects on cavitation formation and spreading through the conduit.



Figure (1):Schmetic diagram of experimental test rig.1. Water feed connection; 2. Pressure reducing valve; 3. Spherical valve; 4. Variable area flowmeter; 5. Thermometer; 6. Pressure gauges; 7. Venturi pipe; 8. Water drain connection.

4.2 Experiment rig photos

Figure (2) shows the complete set up of experimental work in the research lab.



Figure (2): Experiment setup.

5. RESULTS AND DISCUSSIONS

To investigate the effect of temperature and flow rates on the cavitation formation, spreading and diffusion, several cases (case 1,2,3,4,5,6) are considered as shown in Table (1).

Volume Flow rate	Temperature	Pressure at throat
L/h	°C	bar
255	30	0.55
	35	0.67
	40	0.80
400	30	0.31
	35	0.30
	40	0.40
540	30	0.10
	35	0.15
	40	0.20
700	30	0.11
	35	0.15
	40	0.21
750	30	0.14
	35	0.15
	40	0.24

Table 1: The experimental data at different temperatures and flow rates.

Figure (3) shows the effects of the temperature on cavitation formation for cases 1 and 2 for flow rates of 750 and 700 L\h respectively. It is evidence from the results of experiment that the cavitation within investigated area increases as temperature and flow rate increase which is consistent with the general definition of cavitation formation.



Figure (3): Case 1 for flow rate 750 L/h, and Case 2 forflow rate 700 L/h at different inlet temperatures.

Figure 4 shows the effects of the temperature on cavitation for cases 3 and 4 for flow rates 540 and 400 L/h respectively. Again, it is evidence from the results of experiments that the cavitation within the investigated area increased as temperature and flow rate increases which is consistent with the general definition of cavitation formation. The diffusion of the cavitation is moderate in these cases due to the moderate rate of flow, as compared to the cases 1 and 2 in figure 3.



Figure (4): Case 3, the flow rate of 540 L/h; and Case 4 the flow rate of 400 L/h at different temperature.



Figure (5): Case 5 the flow rate of 255 L/h at different temperatures.

Furthermore, figure (5) shows the effects of the temperature on cavitation for case 5 for at flow rate of 255 L/h, which considered to be the best case in the point of view of reducing the cavitations in conduits. From the results of the experiments, the cavitation within investigated area has been minimized at lower temperatures, while a cavitation formed in small region downstream the throat at higher temperatures.

Finally, figure 6 demonstrates the effect of temperature on static pressure for different flow rates. It is clear that the pressure at the throat falls as the flow rate of the water is increased which indicate the beginning of the formation of cavitation. The experimental results showed that the cavitation can be decreased by decreasing the static pressure and the rate of flowing fluid. However, this technique can only be applied to delay the effect of cavitation in conduits. Also figure 6 shows that the temperature can increase the pressure in conduits due to formation of the cavitation bubbles that will pressurize the fluid flow that will increase the fluid stress on conduits inner walls.



Figure (6): Effect of temperature on fluid pressure for different flow rates.

6. CONCLUSION

From the results of the experimental work of different cases, it is obvious that the cavitation increases with the increase of fluid temperature and flow rate. Therefore, cavitation can be avoided through careful design of hydraulic systems, by avoiding high fluid velocities, sudden pressure reduction at critical sections of fixtures or conduits such as sudden enlargements or orcontractions and by reducing high temperatures that can lead to the formation and spreadings of cavitation.

REFERENCES

- Kim,J and Song, J., (2015), Measurement of Temperature Effects on Cavitation in a Turbopump Inducer, J. Fluids Eng 138(1), 011304, Paper No: FE-14-1462.
- Matevz,D and Oliver, C. (2013), *Thermodynamic Effects during the Growth and Collapseof a Single Cavitation Bubble*, J. Fluid Mech., Volume 736 / December 2013, pp 44 – 66.

- Webb,L.R.,Payne,S.J. and Coussios,C.,(2011),*The Effect of Temperature and Viscoelasticity on Cavitation Dynamics During Ultrasonic Ablation*, The Journal of the Acoustical Society of America 130, 3458.
- Saleh, B.A. El-Deen, E. and S. M. Ahmed, S.M., (2011), *Effect of Liquid Viscosity* on Cavitation Damage Based on Analysis of Erosion Particles, Journal of Engineering Sciences, Assiut University, Vol. 39, No 2, pp. 327-336.
- Liu, D.-M., et al.(2011), *A Thermodynamic Cavitation Model Applicable To High Temperature FlowThermal Science*, Vol. 15, Suppl. 1, pp. S95-S101 S95.
- **Tanaka, T., (2011)**, *Thermodynamic Effect and Cavitation Performance of a Cavitating Centrifugal Pump*, Kumamoto National College of Technology, Yatsushiro, Kumamoto, Japan Paper No. AJK2011-06025, pp. 135-143..
- Plesset, M.S.,(2010), *Temperature Effects in Cavitation Damage*, J. Basic Eng. 94(3), pp 559-563.
- Al-Arabi, A.S.(2008), *Effect of Water Temperature on Centrifugal Pumps Performance under Cavitating and non-cavitatingConditions*, 8th Internal Conference on Sustainable Energy Technologies; Seoul, Korea.
- Tokumasu,T.,Sekino, Y.,andKamijo, K., (2003), *A New Modeling of Sheet Cavitation Considering the Thermodynamic Effects*, Fifth International Symposium on Cavitation (CAV2003)Osaka, Japan, November 1-4.