HEFAT2012
9th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics
16 – 18 July 2012
Malta

OBSERVATION AND STUDY OF CAVITATION IN CLOSED FLOW SYSTEM

Ahmed A. B. Alarabi
Department of Mechanical Engineering,
College of Engineering Technology,
Hoon,
Libya,
E-mail: bohmaid2000@yahoo.com

ABSTRACT

Cavitation phenomenon is one of the most problems affecting the performance and efficiency of hydraulic machines and causes erosion damage to the machine. In the last decades many of researches have been focused to eliminate and minimize the cavitation occurrence in hydraulic machines. A special water tunnel was designed and constructed in order to obtain adequate information about incipient, developed and breakdown cavitation in a closed flow system, and hence use it as criteria to evaluate the point of cavitation inception in centrifugal pumps. The cavitation has been obtained using different bodies of circle, triangle and rectangular shapes fixed at up-steam of the tunnel test section. The effects of flow velocity, discharge and cavitation source shape against the cavitation degree were obtained. The relationship between the flow velocity at throat of test section and cavitation inception number was obtained.

INTRODUCTION

It is well known that the principal effects of cavitation in hydrodynamic systems are erosion to all materials, loss of performance, change in flow pattern, vibration and noise. Due to impossibility to find the incipient of cavitation in hydrodynamic systems theoretically several experimental studies have been carried in order to provide adequate information about incipient and breakdown cavitation in a closed flow system. Moreover, the designer often lacks specific information on how design changes will affect cavitation behaviour of the machine or the system **[1]**. Changing flow velocity, power loading and size of machines may cause an unexpected cavitation problems. Therefore, the constructed model test becomes very important to predict the cavitation behaviour in prototype and then supplied the designers with useful information which led to a better design.

D. P. Hart et al. (1990), have designed and constructed a test apparatus to observe the effect of sinusoidal pitching oscillations on the cavitation of three-dimensional hydrofoils. The apparatus is capable of oscillating hydrofoils at a rate up to 50 Hz and provides for adjustments in oscillation amplitude and mean angle of attack. Several photographs have been taken at frequency degrees in order to observe the leading edge cavitation, and cavitation was observed from inception degree at the suction side of the hydrofoil, till developed cavitation degree at the trailing edge. The variation of the cavitation number with hydrofoil phase angle and geometric angle of attack were obtained at different excitation frequencies. paths predict the cavitation behaviour in prototype and then supplied the designers with useful information which led to a better design.

D. P. Hart et al. (1990), have designed and constructed a test apparatus to observe the effect of sinusoidal pitching oscillations on the cavitation of three-dimensional hydrofoils. The apparatus is capable of oscillating hydrofoils at a rate up to 50 Hz and provides for adjustments in oscillation amplitude and mean angle of attack. Several photographs have been taken at frequency degrees in order to observe the leading edge cavitation, and cavitation was observed from inception degree at the suction side of the hydrofoil, till developed cavitation degree at the trailing edge. The variation of the cavitation number with hydrofoil phase angle and geometric angle of attack were obtained at different excitation frequencies.

A. Konno, et. Al.,(1999), have observed the collapse of cavitation bubble clusters on a two-dimensional foil. The high-speed video was taken at a speed of 40,500 fps. Duration of collapse was the order of 10 to 100 microseconds, which was by far slower than that of an impulsive force that was around 5 microseconds. They reported that by calculations the impulsive pressure is generated when the cloud cavity collapses completely. But they found experimentally, that the peaks of impulsive force did not meet the instant of final collapsing, but were often some 10 to some 100 microseconds earlier than the final collapsing. Their results suggest that an impulsive force may not be caused by the global behaviour of a bubble cluster but by the behaviour of a part of cloud cavity. The collapse of a large single bubble in the cloud cavity and generation of micro-jet may cause such phenomenon. They agreed that this new finding should be verified more experimentally as well as theoretically. **Kotaro Sato et al.(2001),** studied experimental the characteristics of oscillating cavitation on a flat plate hydrofoil in a water tunnel. The used cavitation source was hydrofoil blade fixed in the test section of the tunnel. The studied parameters were carried at types of cavitation phenomena that i.e. the transitional cavity oscillation and the partial cavity oscillation. The studied parameters were the fluctuating inlet pressure, the attack angel and Strouhal number, Several photographs have been recorder but with low accuracy. They concluded that at small attack angle only sheet cavitation appeared, where the, Strouhal number does not largely depend on the inlet conduit length. On the other hand, cloud cavitation was observed under the condition with larger angle of attack. In the case of cloud cavitation, where the Strouhal number depends on the inlet conduit length. **Sheng-Hsueh Yang et al.(2009),** have carried an experimental investigation to study the bubble collapse visually They used a device of U-shape platform to generate a single cavitation bubble for a detailed analysis of the flow field characteristics. The bubble was collapsed by sending a pressure wave. They used a high speed camera to record the flow field of the bubble collapse at different distances from the solid boundary. The strength of the pressure wave was adopted to induce the bubble collapse flow is kept as low as possible so that the bubble collapses in a longer period of time. They found that a Kelvin–Helmholtz vortex is formed when a liquid jet penetrates the bubble surface after the bubble is compressed and deformed. **Alarabi and Selim (2009)**, investigated an experimental work for studying the cavitation inception in centrifugal pumps. The study based on the visual observation where a special Perspex face was manufactured for visual process. Several photographs at different operating conditions have been taken. According to the experimental results an empirical relationship between the visual NPSH and NPSH corresponding to 3% drop in head, taken into account three different parameters flow rate ratio, pump rotational speed and water temperature.

Tzanakis, I. and Hadfield, M., 2010, carried an experimental study using an ultrasonic transducer, submerged into the fluids (water-lubricant-refrigerant), to produce cavitation bubbles. Different images were focused on two critical areas: the lower surface of the horn and across the boundary of the sample. The sample consists of a chromium ball mounted on a Bakelite base and implemented on the bottom of the experimental tank. The results revealed that the lubricant bubbles have a similar behaviour to those produced in water, and the damage produced by the refrigerant bubbles is smaller than that observed within water and oil lubricant., and also the lubrication thickness layer developed across the boundary was observed to provide a cushion, absorbing the jet impact during the implosion of a bubble

EXPERIMENTAL FACILITIES AND PROCEDURE

EXPERIMENTAL FACILITIES AND PROCEDURE

A two dimensional closed circuit water tunnel with a rectangular test section of 40×20 mm cross section and length of 100 mm was constructed at the College of Engineering Technology – Hoon, Libya. The experimental test rig was designed and constructed according to the pump specifications in such a way that the pump must overcome the head losses in the system . Figure 1 shows a line diagram of the tunnel and a list of its major components. The most important part is the test section. The upper face of the test section was built with a transparent prespex

with dimension 260×40mm to permit visual study. The tunnel has the capability of operating at various flow velocities over a wide pressure range. The flow velocity can be regulated till a maximum value of 40 m/s and 8 bar respectively by means of a by pass line control. A U-tube manometer was used to measure the volume flow rate. The upstream static pressure was measured using Bourdon pressure gauge (0-7 bar) connected at three points of the test section in order to obtain the average value. A centrifugal pump of electric power 22 kW was used to satisfy the requirements of operating system. The suction line, delivery line and by pass line were of diameters 3", 2" and 2" respectively. The main tank has a volume of 0.191 m^3 with and it is made of cylindrical shape in order to avoid the turbulence phenomenon. When the tunnel operated at the first time, the water temperature increased rapidly due to the friction between the water and the inside walls of the pipes. To maintain a constant water temperature a special cooling was connected with main tank to keep the water temperature at a range (28 ^oC – 30 ^oC). Equation (1) shows the variation of water temperature with the time

$$T = 0.672\, t - 0.007276\, t^{0.8} \qquad \textbf{(}\textit{1}\textbf{)}$$

Where: T- The water temperature

t – The time

2.2 Cavitation Sources

The cavitation sources utilized in the present investigation were circular cylinders, 60^o symmetric wedges and square. All the cavitation sources were fabricated from copper and their surfaces were polished to prevent any possibility of roughness effects. The cavitation sources were fitted centrally into the working section spanning the 20 mm direction of the test section.

Two 60^o symmetric wedges with 20 mm and 25 mm side lengths and 20 mm height were used as cavitation sources. This configuration is similar to the types of cavitation occurring in the shears layers of the liquid flowing past a bluff body. The triangles were placed in the test section with apex upstream position.

Two circular cylinders with 15 mm and 25 mm diameters were used as cavitation inducers. The reason of the choice of circular cylinders is that the flow around it in the absence of cavitation is known from investigations of numerous authors.

1. The main tank
2. The suction line
3. The centrifugal pump
4. The electric motor
5. The pump base
6. The discharge line
7 & 13. The control valve
8. The test section
9. The orifice
10. The U- manometer
11. By pass line
12. The control unit
14. Refrigeration unit
15. The refrigeration unit pump

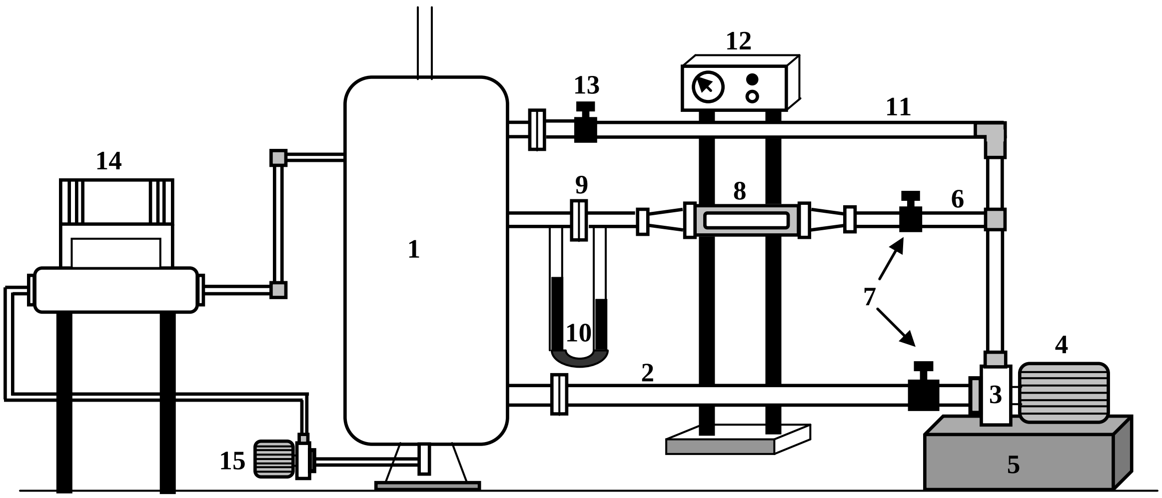


Figure 1 Water tunnel system

,

2.3 Test Procedure

During testing the cavitation sources for cavitation, some preliminaries are essential to ensure reliability of the data. The cavitation source should be carefully placed in the working section to maintain a perfect contact between source faces and test section surfaces. The flow system should be hydrostatically pressurized to avoid any leakage in the system. To avoid any formation of air bubbles in the system a preliminary circulation of tunnel water should be made for ten minutes, and then each test run could be started. Incipit, developed and breakdown cavitation were observed visually though the prespex window of the test section using stroboscopic lighting. During the experimental tests the pressure in the test section was varied from 0.7 bar at inception condition to 2.3 bar at breakdown condition passing the developed condition. For each test the pump was run and the bypass valve was closed gradually so that the flow velocity in the test section could be increased step by step till incept cavitation observed and then developed and breakdown cavitation appeared. The measurements of the pressure flow rate and temperature corresponding to each degree of cavitation were recorded. Based on these readings, the cavitation number at the inlet of the test section can be obtained from the following equation

$$\sigma = \frac{P - p_v}{0.5 \rho U^2} \qquad \textbf{\textit{(2)}}$$

Where, P and U are respectively the static pressure and flow velocity at the inlet of the test section, P_v is the vapor pressure at the corresponding water temperature, and ρ is the density of water

EXPERIMENTAL RESULTS AND DISCUSSION

Recording the results hundred percent depends on visualization of the flow through the prespex face. The stroboscope lighting was projected to illuminate the test section, where the photographs were taken and the measurements recorded. The photographs of different cavities degrees are shown in figures 2 to 5. In figure 2 a 60^o symmetric wedges with 25 mm has been used to generate cavitation at different flow rate ratios. It can be seen that in the cavitation inception starts at flow rate 2.91 lit/sec, while developed cavitation appears clearly at 4 lit/sec, with continues increase in flow rate breakdown cavitation established at 4.86 lit/sec. It can be noticed that breakdown point is very closed to developed cavitation compared with point of inception.

Figure 3 show different cavitation degrees using 60^o symmetric wedges with 20 mm. Concentrating on this figure a small difference can be noticed compared with 60^o symmetric wedges with 25 mm. In figure 4 a cavitation was generated at different degrees using a circular cylinder with 15 mm diameter. The degree of breakdown cavitation was established at flow rate of Q = 10.76 lit/sec. This means that the circular cylinder has a wide range to operate at many different degrees of cavitation.

Figure 5 shows the cavitation generation at varied degrees of cavitation. It can be seen from figures 5.a to 5.d that the cavitation degrees is varying from cavitation inception at 2 lit/sec to breakdown cavitation at 4.7 lit/sec, which is a small range if it is compared with circular cylinder source in figure 4. Figure 6 shows the relationship between the cavity length and the flow rate through the test section using 60^o symmetric wedges with 25 mm. It can be seen that the cavity length increases with the increase of flow till reaching the breakdown point at 0.0525 lit/sec. When using 60^o symmetric wedges with 20 mm as shown in figure 7 it can be seen that the breakdown point was reached earlier than in the case when using 60^o symmetric wedges with 25 mm as shown in figure 6. Figure 8 shows the variation of cavity length with flow using a cylindrical source of diameter of 25 mm. It can be noticed here that the flow takes long time to reach breakdown point. Using cylinder source of diameter 20 mm as shown in figure 9 gives much longer time to reach breakdown point. The breakdown point was appeared at 0.011 lit/sec. This means that the cylindrical source of 15 mm has a wide chance to operate at higher flow velocities and flow rates. Figure 10 shows the variation of cavity length with flow rate using a cavitation source of square 24×24 mm. It can be seen that the cavity length increases with increasing of flow rate till a point of breakdown. The breakdown point was achieved at about 0.0046 m^3/s.

Figure 11 shows the relation between cavitation inception number and flow velocity at the throat, using 60^o symmetric wedges with 25 mm. It can be seen that the inception cavitation number decreases with the increase of upstream flow velocity. The same relation has been shown in figure 12 but using 60^o symmetric wedges with 20 mm. The figure has the same behaviour but with greater values of cavitation inception number. The relation between cavitation inception number and flow velocity at the throat using both cylinders of diameters 25 mm and 20 mm in figures 13 and 14 respectively. It can be seen from these figures that the inception cavitation number decreases with the increase of upstream flow velocity, but with greater values of cavitation inception number in condition of 25 mm cylinder.

CONCLUSION

1- The cavity length increases with the increase of flow rate till reaching the break down point.
2- Cylindrical source body can be used as a cavitation source for a wide range of flow rates for the current flow system.
3- The inception cavitation number decreases with increase of flow velocity.
4- The designed test section can be connected with a different centrifugal pumps to examine it against cavitation.

REFRENCES

[1] B. A. Khalifa, Sobeih M. A., and R. A. El-Danaf, “Experimental investigation of the inception of cavitation on 60^o symmetric wedges. Eng. Research Bull., Faculty of Eng. and Tech., Menoufia University, Vol. VII part 2, 1985.

[2] Hart, D. P. and Brennen, C. E. and Acosta, A. J. Observations of Cavitation on a Three-Dimensional Oscillating Hydrofoil, American Society of Mechanical Engineers , New York, 1990, pp. 49-52.

[3] Hart, D. P. and Brennen, C. E. and Acosta, A. J., “Observations of Cavitation on a Three-Dimensional Oscillating Hydrofoil”. American Society of Mechanical Engineers , New York, 1990, pp. 49-52.

[4] Konno, A., Kato, H., Yamaguchi, H. and Maeda, M., “Observation of Cavitation Bubble Collapse by High-speed Video”, Proceedings of The Fifth Asian Symposium on Visualization, 1999, pp. 134-139.

[5] Sato, K. and Tanada, M. and Monden, S. and Tsujimoto, Y., “Observations of Oscillating Cavitation on a Flat Plate Hydrofoil”, Fourth International Symposium on Cavitation, June 20-23, 2001, California Institute of Technology, Pasadena, CA USA.

[6] Sheng-Hsueh Yang Shenq-Yuh Jaw Keh-Chia Yeh, “Single cavitation bubble generation and observation of the bubble collapse flow induced by a pressure wave”, Experiments in Fluids, 2009, Vol. 47, pp. 343–355

[7] Ahmed A. B. Al-Arabi1 and Sobeih M. A. Selim2, Reality of cavitation inception in centrifugal pumps”, 8th Internal Conference on Sustainable Energy Technologies; Aachen, Germany. 31th August – 3rd September, 2009

[8] Tzanakis, I. and Hadfield, M., “Observations of acoustically generated cavitation bubbles within typical fluids applied to a scroll expander lubrication system”, Journal of Hydrodynamics, 2010.

(a) Starting of cavitation inception (Q = 2.91 lit/sec)

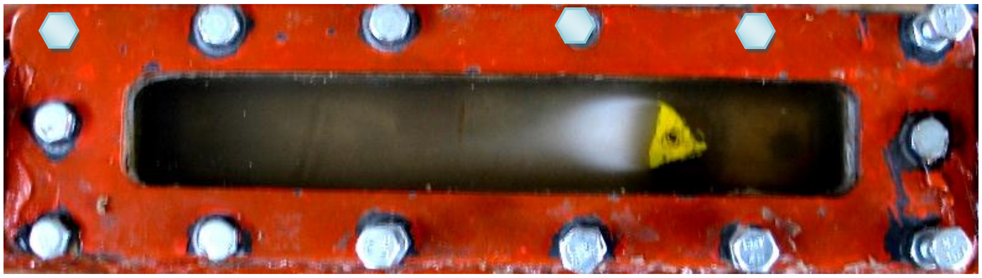
(b) Starting of developed cavitation (Q = 4 lit/sec)

(c) Increasing of developed cavitation at (p_o = 155 kPa Q = 4.77 lit/sec)

(d) Breakdown cavitation (Q = 4.86 lit/sec)

Fig. 2 Various degrees of cavitation at different flow rates using 60^o symmetric wedges with 25 mm

(a) Starting of cavitation inception (Q = 3.9 lit/sec)



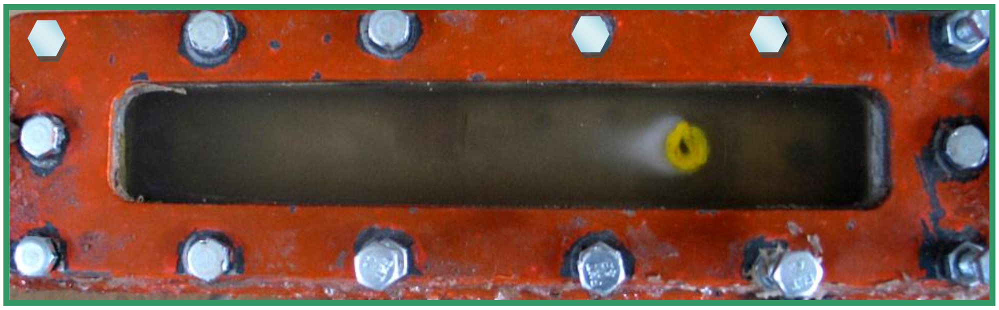
(b) Starting of developed cavitation (Q = 4.11 lit/sec)

(c) Increasing of developed cavitation (Q = 4.5 lit/sec)

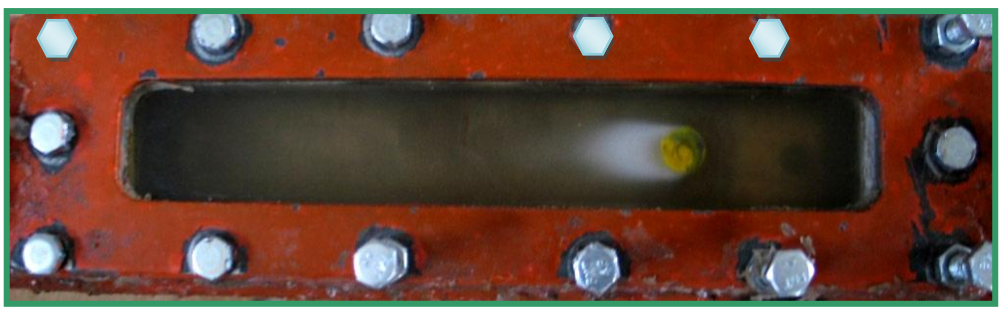
(d) Breakdown cavitation (Q = 4.86 lit/sec)

Fig. 3 Various degrees of cavitation at different flow rates using 60^o symmetric wedges with 20 mm

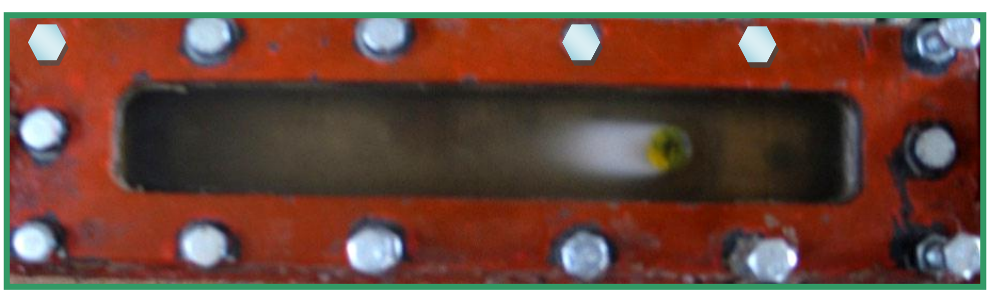
(a) Starting of cavitation inception (Q = 4.95 lit/sec)



(b) Starting of developed cavitation (Q = 7.35 lit/sec)

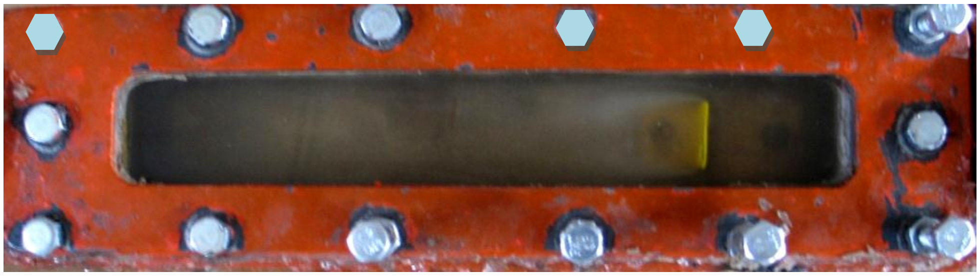


(c) Increasing of developed cavitation (Q = 9.59 lit/sec)

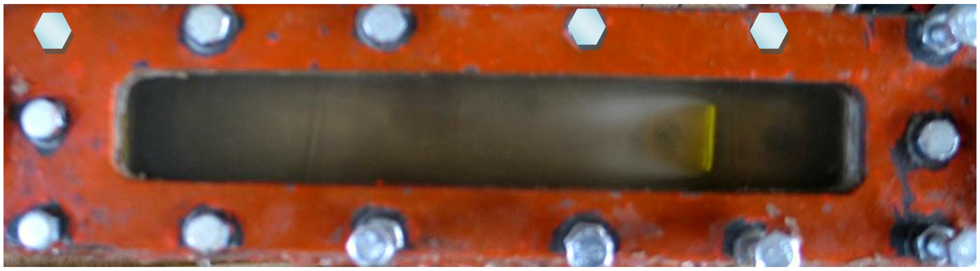


(d) Breakdown cavitation (Q = 10.76 lit/sec)

Fig. 4 Various degrees of cavitation at different flow rates using circular cylinder with 15 mm diameter

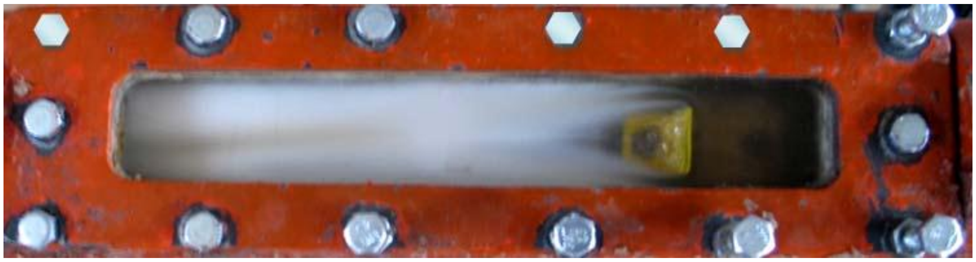


(a) Starting of cavitation inception (V= 2.5 m/sec Q = 2 lit/sec)



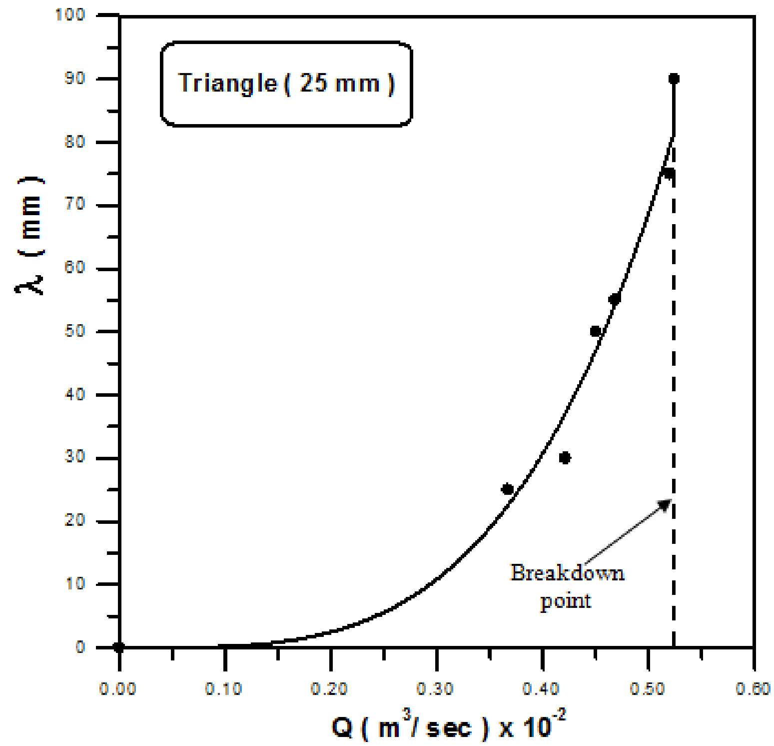
(b) Starting of developed cavitation (V= 4.3 m/sec Q = 3.44 lit/sec)

(c) Increasing of developed cavitation (V= 5.375 m/sec Q = 4.3 lit/sec)



(d) Breakdown cavitation (V= 8.75 m/sec Q = 4.7 lit/sec)

Fig. 5 Various degrees of cavitation at different flow rates using square with (24×24mm)



. Figure 6 Variation of cavity length with flow rate using 60^o symmetric wedges with 25 mm

.

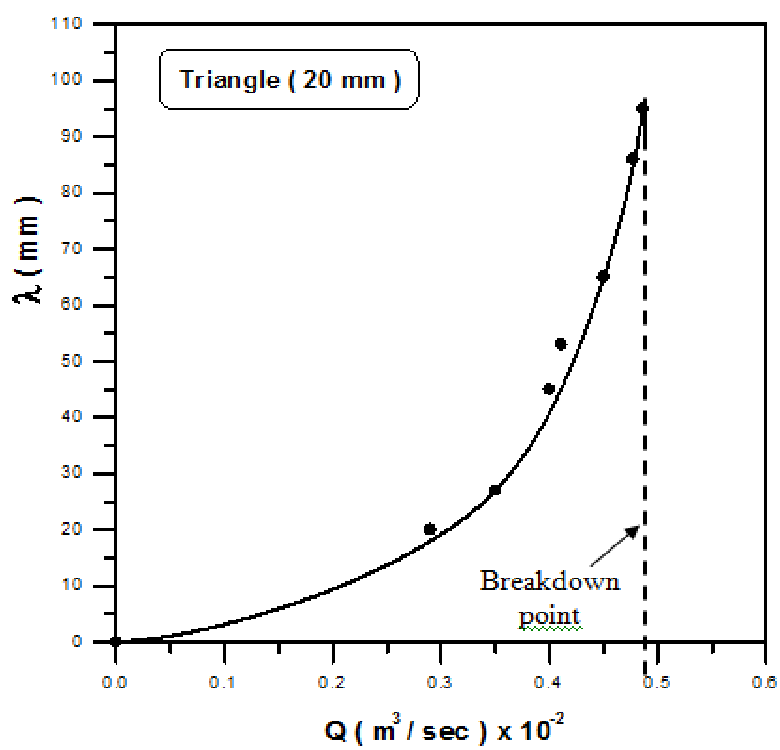


Figure 7 Variation of cavity length with flow rate using 60^o symmetric wedges with 20 mm

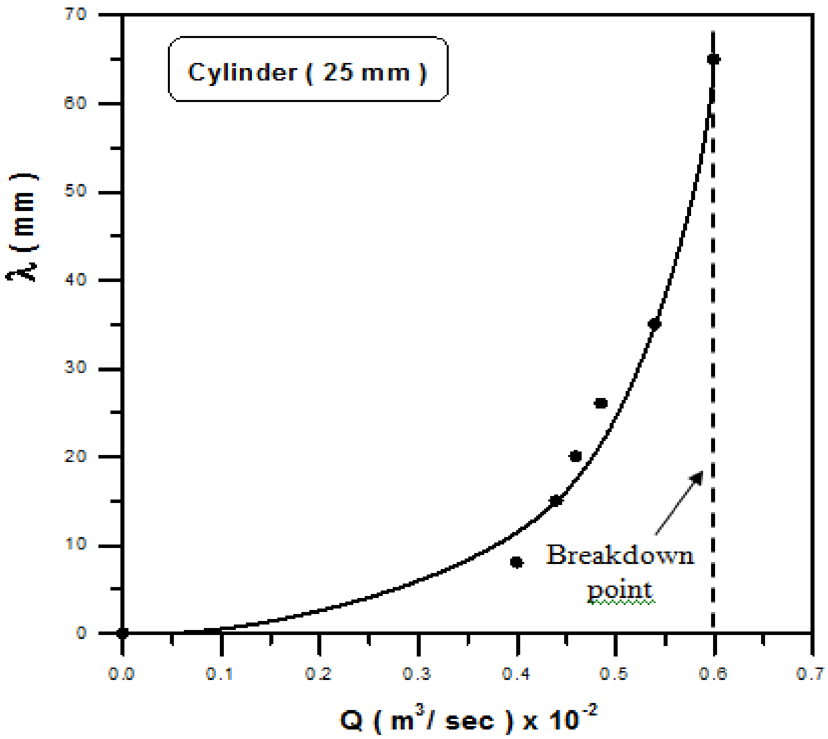


Figure 8 Variation of cavity length with flow rate using a cylindrical source of diameter of 25 mm

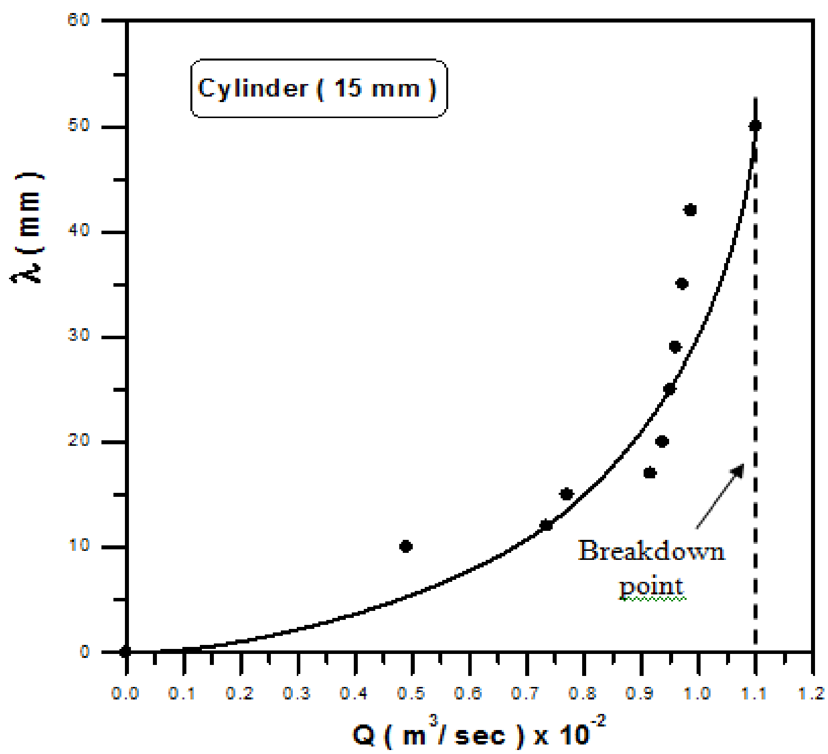


Figure 9 Variation of cavity length with flow rate using a cylindrical source of diameter of 15 mm

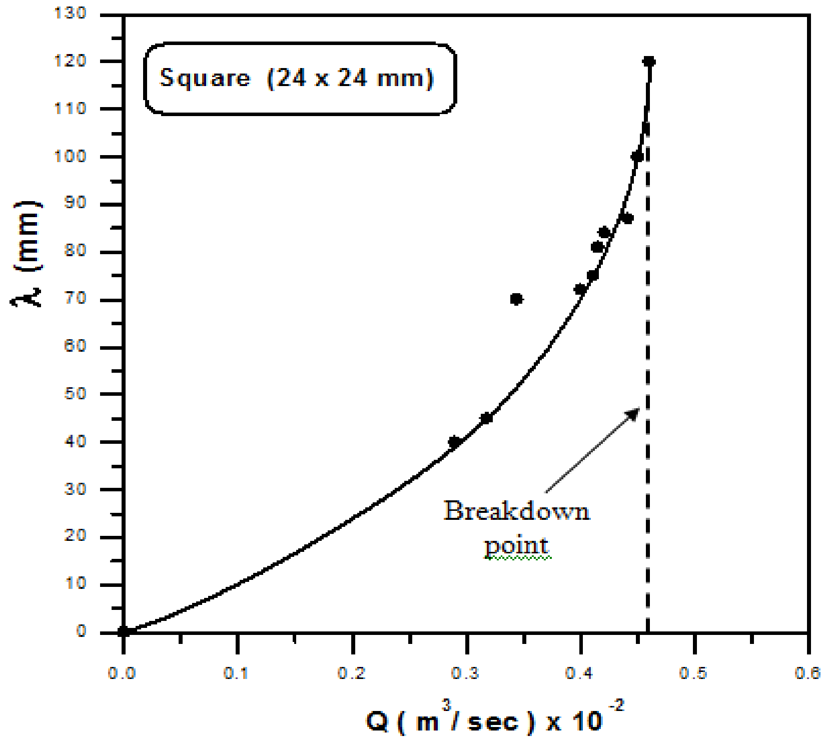


Figure 10 Variation of cavity length with flow rate using square source of 24 × 24 mm

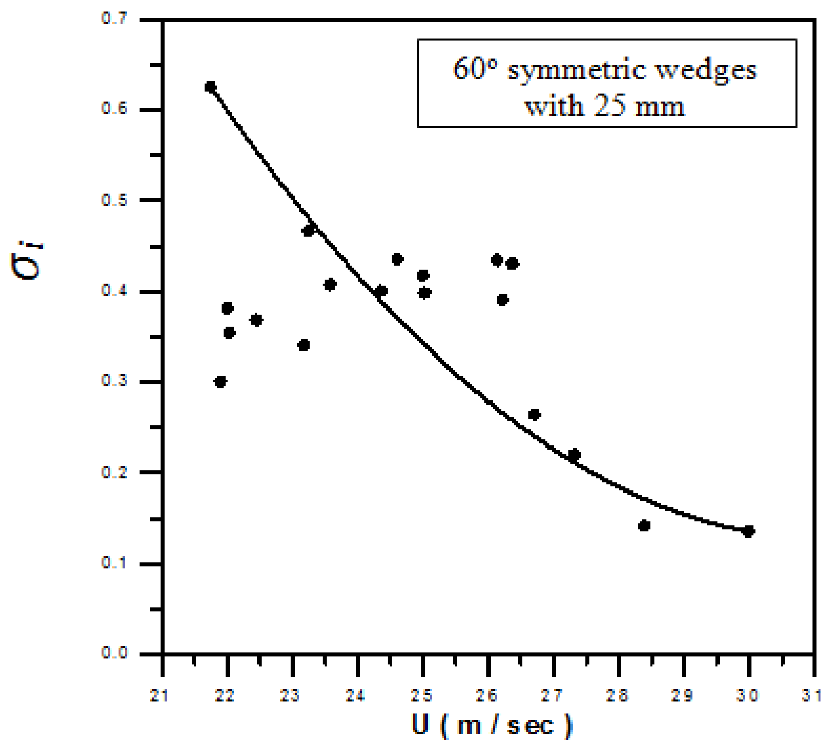


Figure 11 The relation between the cavitation inception number and flow velocity at the throat using 60° symmetric wedges with 25 mm

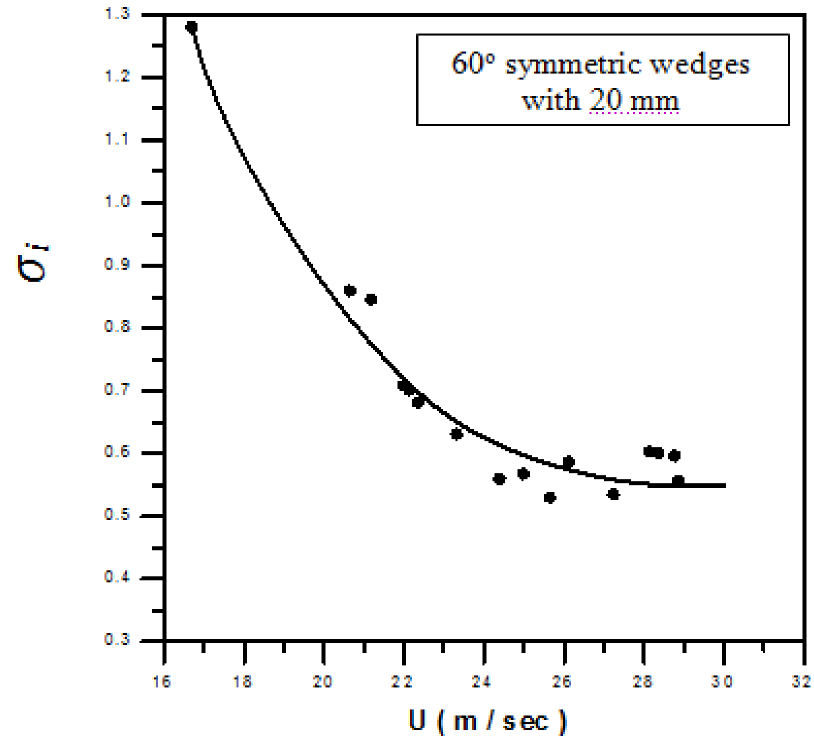


Figure 12 Effect of flow velocity against cavitation inception number using 60^o symmetric wedges with 20 mm

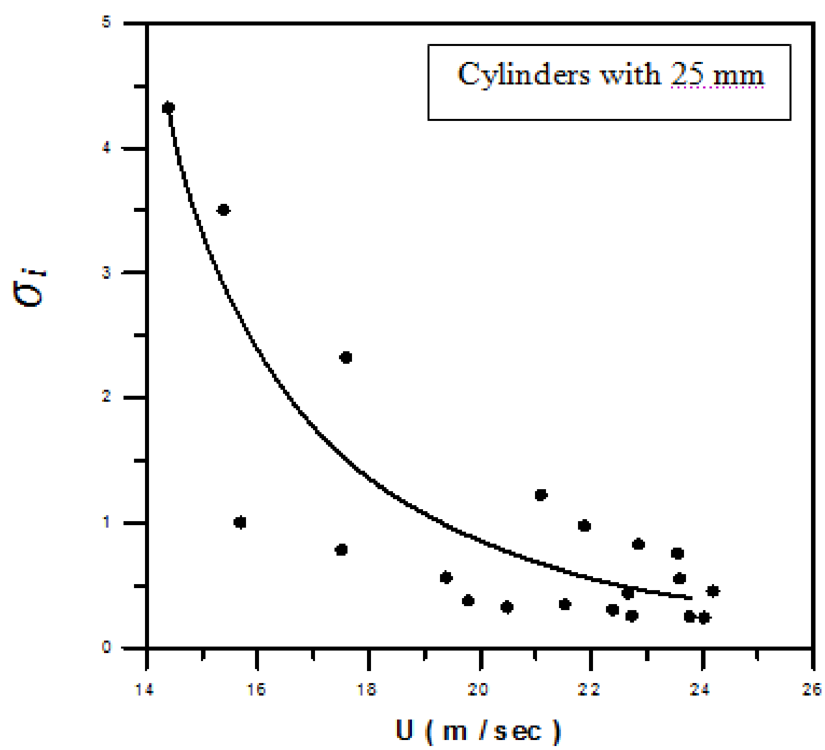


Figure 13 Effect of flow velocity against cavitation inception number using Cylinder of 25 mm diameter