Journal of Marine Science and Technology

Volume 25 | Issue 5 Article 1

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Recommended Citation

Salari, Mahmoud; Javadpour, Seyed Morteza; Farahat, Said; and Dept. Mech. Eng., University of Sistan and Baluchestan, Zahedan, Iran. (2017) "EXPERIMENTAL STUDY OF FLUID FLOW CHARACTERISTICS AROUND CONICAL CAVITATORS WITH NATURAL AND VENTILATED CAVITATIONS," *Journal of Marine Science and Technology*: Vol. 25: Iss. 5, Article 1.
DOI: 10.6119/JMST-017-0222-1
Available at: https://jmstt.ntou.edu.tw/journal/vol25/iss5/1

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Acknowledgements

This study was funded by Marine Research Center of Imam Hossein University in Iran.

Journal of Marine Science and Technology, Vol. 25, No. 5, pp. 489-498 (2017)
DOI: 10.6119/JMST-017-0222-1

EXPERIMENTAL STUDY OF FLUID FLOW CHARACTERISTICS AROUND CONICAL CAVITATORS WITH NATURAL AND VENTILATED CAVITATIONS

Mahmoud Salari[1], Seyed Morteza Javadpour[2], and Said Farahat[3]

Key words: natural cavitation, supercavitation, water tunnel, drag coefficient, ventilated cavitation.

ABSTRACT

Experiences have shown that creating a super-cavitating flows over underwater projectiles can significantly reduce their drag forces and change their dynamical behaviors. So the extended issues of this problem have been studied by researchers in the recent decades. In this paper, the geometrical characteristics of super-cavities, developed downstream of three conical cavitator with cone angles of 30°, 45° and 60°, are studied. A semi open-loop water tunnel with maximum flow velocity of 38 m/s is utilized. The measurements are done for both cases of ventilated or air-injected and natural cavitation in a range of $0.34 \leq \sigma_v \leq 0.36$. Validating of setup and measurements is done by comparison of present results with experimental data of a circular disk cavitator reported in the literature. Both the maximum diameter and the length of the cavities are determined from the relevant photos captured by a high speed camera. Also, to trace the pressure variations, the sensors which are located behind the cavitator, are used for determining the transient length of the cavity. Effects of important parameters such as the cavitation number, upstream flow velocity and cone angle of cavitators on the drag coefficients as well as cavity shapes and relevant dimensions are studied. The results also show that the most effective parameter on the drag coefficient is the cone angle of cavitators. In ventilated cases, reduction in drag coefficient is more sensitive to the amount of air-injection than the increasing of velocity. Also the measurements show that the cavity length increases dramatically as the supercavitation transforms from the natural to ventilated regime.

Paper submitted 11/18/15; revised 12/16/16; accepted 02/22/17. Author for correspondence: Said Farahat (e-mail: Farahat@hamoon.usb.ac.ir).
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I. INTRODUCTION

In practical issues, achieving to higher speeds for underwater vehicles is limited due to the considerable drag force generated by the water-surface friction. Cavitation, vaporizing of water due to decreasing of pressure to saturated vapor pressure, is observed in many hydrodynamic mechanical devices such as pumps, turbines, nozzles and marine propellers, and it can significantly change the performance of such devices. Cavitation may have either negative effects including mechanical damages, noise and power loss or positive effects such as drag reduction in underwater moving bodies. It may be beneficial to create a partial cavitation or a super-cavitation to reduce viscous drag intentionally. When an underwater body travels at high speed, the water pressure around the body decreases, and it may fall to below the saturated vapor pressure which causes the creation of a cavity on the surface and behind the body. This phenomenon is called super-cavitation, which can significantly reduce the drag of the body surrounded by the cavity. This is because the skin friction drag, which depends on the viscosity of the fluid near the surface, is reduced due to the vaporous pocket surrounding the body. Super-cavitation can be classified as natural super-cavitation and ventilated super-cavitation. The former is achieved by increasing the speed of vehicles and the latter is obtained by injection of a gas into the cavity.

In the last decade, several researchers have experimentally investigated supercavitating bodies. The studies on super-cavitating flows started in the late 1940s with the pioneering work of Reichardt (1946). Besides of general cavitating flows, there are many experimental studies on natural cavitating flows. Liu et al. (2004) performed an experimental study on a cavitation tunnel with four axisymmetric bodies at different attack angles. They analyzed the time series of the hydrodynamic coefficients using the wavelet method. The characteristics of a cavitation water tunnel test setup and cavitation experiments around a circular cylinder with free stream turbulence were studied by Gavzan and Rad (2009). They also measured the drag force, back pressure and location of cavitation inception. The drag force decreased smoothly from $\sigma = 2.20$ to $\sigma = 1.94$

and the drag force coefficient dropped with a small rate, ending up with a limited value of 0.68. Ahn et al. (2010) investigated the supercavity flow in 15° cavitator in a water tunnel (v = 15 m/s). They investigated only the effects of cavitation number change on the cavity length, demonstrating that with a decrease in the cavitation number, the cavity length will increase by 0.5 to 2.5 times of the body length. An experimental study of supercavitating flows around 15° cone cavitator (v = 15 m/s) was conducted in a cavitation tunnel by Ahn et al. (2012). Their results revealed a consistent variation in cavitation number, where a decline in the flow speed was associated with the increased length and width of cavity, with the cavity generated by the blunt cavitator being longer and wider than the slender one at the same cavitation number. Saranjam (2013) performed an experimental and numerical study of the cavitation on an underwater moving object based on the unsteady effects and dynamic behavior of the body. At the maximum velocity of body (about 80 m/s), the cavitation number was about 0.03, and when the velocity dropped to 60 m/s, the interface of supercavitation profile begins to disappear and change into the partial cavitation. Wei et al. (2014) studied the cavitating flows around different axisymmetric bodies based on experiments and numerical simulations. The curvature in front of the conical body was larger, resulting in flow separation at the shoulder of the axisymmetric body. The cavity continues to stretch downstream until it reaches a fixed cavity length and shape.

In the past decade, several researchers have experimentally investigated the ventilated supercavitating flows. Most of these studies focused on cavity shape, velocity and pressure distributions of flow field as well as the control and stability of supercavitating vehicles. Wosnik et al. (2003) examined some aspects of the flow physics related to such a supercavitating vehicle. In addition, they measured the amount of ventilation gas required to sustain an artificial cavity at different velocities. It was found that the strut shape had a significant effects on air demand through cavity-strut wake interaction. A series of experiments were conducted to investigate ventilated cavity physics of slender axisymmetric bodies in a high-speed water tunnel by Deng et al. (2004). They showed that for the same cavitation number, the relative length and slenderness ratio of supercavity will increase as the conic angle or cone diameter enlarges. Jia et al. (2006) performed their experiments on a slender body that covered a disk cavitator under ventilated conditions and worked out an empirical relationship between ventilated cavity shape and ventilation rate. The results revealed the dependence of cavity thickness and length on ventilated rate, as well as the existence of an empirical relationship between ventilated cavity shape and ventilation rate. An experimental study of ventilated supercavities on axisymmetric bodies in a water tunnel was undertaken by Vlasenko and Savchenko (2012). They also explored the effect of body geometry on gas entrainment and unsteady cavity size variation, finding that the gas injection rate necessary to sustain a ventilated cavity closed to a circular cylinder varied monotonically with the cavity length within the cylindrical part of the model. A numerical and experimental study of ventilated supercavities was carried out by Rashidi et al. (2014). They reported that at low air ventilation (CQ < 0.102) and for small dimensionless cavity length (less than 10), the gravity effect will not be significant, but with an increase in the air ventilation, the cavity length will grow and render more well-ordered.

Javadpour et al. (2016) compared the numerical and experimental results of supercavitating flows over two conical cavitators with cone angles of 30 and 60 degrees. They showed that a combination of RANS equations, the k-ε turbulence model and Rayleigh-Plesset mixture model presents good numerical results for the cavity dimensions in comparison the measurements.

There have been few comparative experimental studies on the shape characteristics of natural and ventilated supercavitation. Feng et al. (2002) examined the behavior of cavitating flow around a 45° cone with and without ventilation at several angles of attack (v = 12 m/s). They demonstrated that the presence of supercavity under the ventilation condition will reduce the drag of the model. Natural and ventilated cavitations generated on a smooth-nosed axisymmetric body were studied experimentally by Feng et al. (2005). They studied the fluctuation characteristics of natural and ventilated cavities over an axisymmetric body for cavitation numbers larger than 0.1. Zhang et al. (2007) performed a series of experiments in a closed-loop water-tunnel with a maximum velocity of 25 m/s to study the shape properties of natural and ventilated supercavitation. They found that both natural and ventilated supercavitation were similar when the cavitation number was small and identical in both cases.

The focus of the above works have been mainly on comparing shape characteristics or hydrodynamic forces of natural and ventilated cavitation at a constant velocity, but no comparison of these two have been made at varying velocities. Also, the paucity of experiments on multiphase cavitating flows at v > 25 m/s should be noted. Most of the experimental investigations on supercavitation phenomenon have been performed in a closed loop water-tunnel with a few researchers experimentally studying the supercavitating in an open-loop water tunnel.

In this study, both the natural and ventilated cavitation flows around a series of conic cavitators (v > 24 m/s) are carried out at an open-loop water tunnel firstly. Then, the both shape cavity and drag coefficient of natural and ventilated cavitation are compared experimentally at varying velocities.

II. EXPERIMENTAL SETUP

The experiments were conducted in a water tunnel at the Marine Research Center of the Imam Hossein University in Iran. The tunnel was a semi-open loop water tunnel which could generate velocities up to 38 m/s. The water tunnel was equipped with a computer system, control mechanism, high-speed data collection analyzer and high-speed photograph camera. A model with a nose and cylindrical body was selected. A schematic view of the components of the water tunnel is shown in Fig. 1. This water tunnel consisted of a cylindrical tank filled with water, which had been injected by the pressurized air. Depending on the speed which is necessary for the measurement, the air pres-

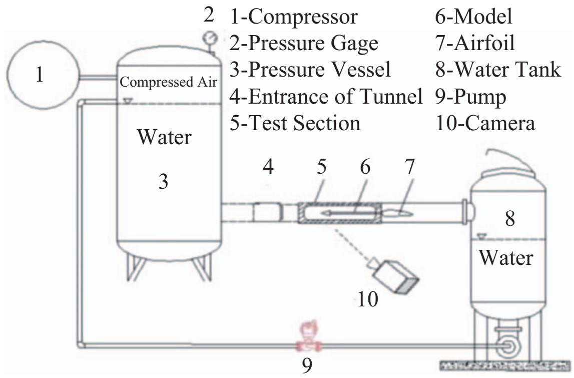

Fig. 1. The schematic view of the water tunnel.

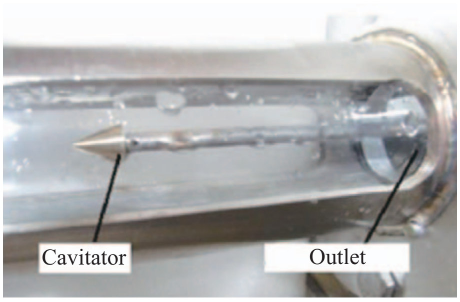

Fig. 2. Test section of water tunnel.

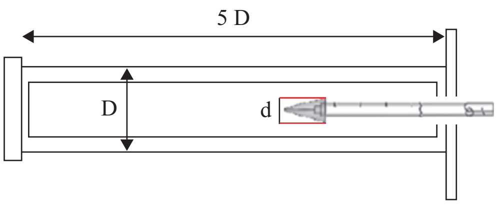

Fig. 3. Dimension of test section.

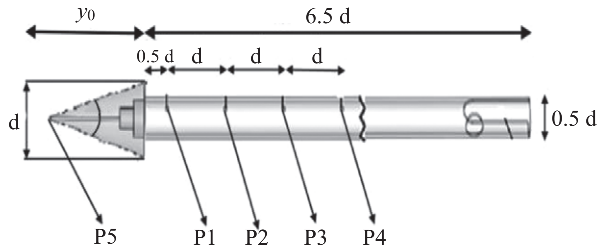

Fig. 4. A schematic view of the model and the position of pressure measurement cavities.

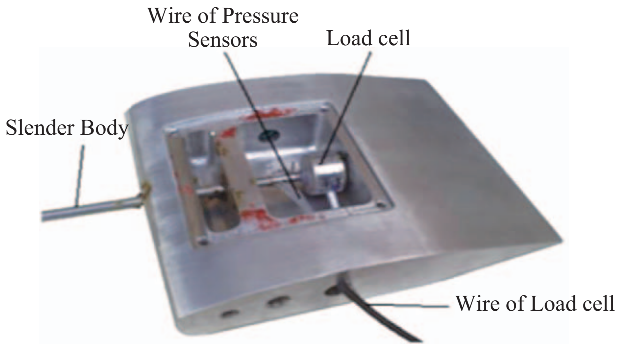

Fig. 5. Positioning of load cell in the airfoil.

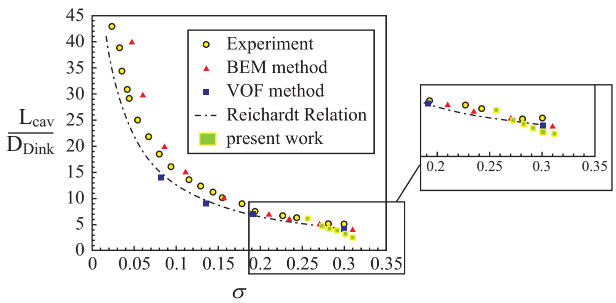

Fig. 6. Comparison of the present experimental results with that of Franc and Michel (2004).

sure injected into each test also varied. For v = 37 m/s, the pressure gauge was 10 bar with 5% uncertainty of the measured value. Since magnitude of the flow velocity, upstream the test section, is calculated based on the pressure difference of two pressure gauges, one measures total and the other measures static, the uncertainty of the velocity was less than 3%.

At the bottom of the tank, a horizontal cylindrical test section was designed. The end part of the test section reached the atmospheric pressure and the water was discharged into an open tank. For each test, measurements were conducted under similar room temperature (20°C).

Fig. 2 shows the test section where a conical cavitator is placed on. The test section is cylindrical with an internal diameter of D = 5 cm and a length of 5D (Fig. 3). The model with the conical cavitator is shown in Fig. 4. The base diameter of the conical cavitator is 10mm and the cone angles for the noses are 30°, 45° and 60°. The cone length of y_0 is calculated based on the cone angle with the velocity flow varying from 24 m/s to 37 m/s.

All sensors are electrical and their output is converted into digital codes via an A/D card to be recorded. It should be noted that the data frequency of ultimate vector in experiments was 1000 Hz for all sensors. Also, to measure the diameter and length of cavity in the back of cavitator, a high speed video with a shooting speed of 600 fps was used. The uncertainty for diameter and length of the cavities measured from the video frames was about 5%. Two parameters, unsteady characteristics and the measuring method, were considered to reach this amount. Pressure gauges had a 5% uncertainty in their values. The flow velocity, upstream the test section, is calculated from the pressure difference of two pressure gauges, one measures stagnation pressure and the other measures static pressure. The uncertainty of the velocity was less than 3%. To measure the drag coefficient, a 5 kg.f load cell of 20 mm diameter was used (Fig. 5). The average uncertainty of the force measurement was 1% of the measured value.

In Fig. 6, the results of the study about the dimensionless

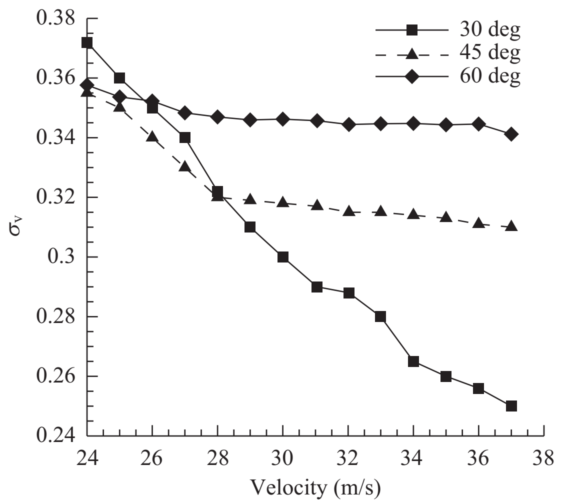

Fig. 7. Cavitation number variation with velocity.

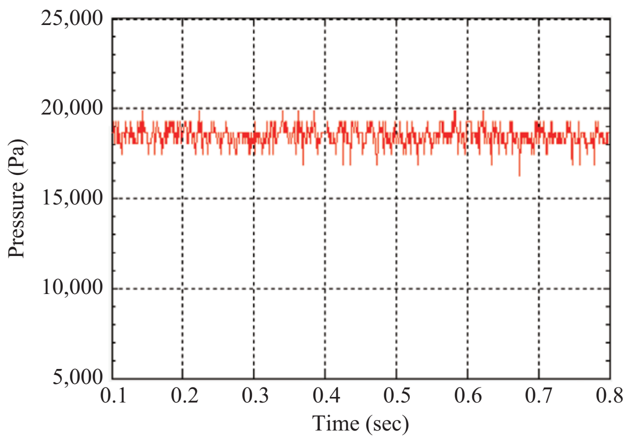

Fig. 8. Variation of pressure measured inside the cavity with respect to time at v = 36 m/s for the 30° conical cavitator.

cavity length (L_c/d) against the cavitation number of flow were compared with the experimental data reported by Franc and Michel result (2004). As can be seen, the results are consistent with the experimental data.

The critical value of cavitation number corresponding to the blockage can be estimated by Franc and Michel (2004):

$$\sigma_{blockage} = \frac{S_u^2}{S_d^2} - 1.0 \tag{1}$$

where S_u and S_d stand respectively for the cross-sectional areas of the upstream and downstream regions of the liquid flow.

According to Eq. (1), the theoretical value of the blockage cavitation number for present setup is 0.211, whereas the minimum value of cavitation number at the maximum velocity of tests is about 0.25. Since the relation of $\sigma_{blockage} < 0.25$ is satisfied, the effect of blockage on the measured drag coefficient and cavity shape will be negligible in this experiment.

III. RESULT AND DISCUSSION

Based on the vapor pressure and cavity pressure, the natural and ventilated cavitation numbers are defined as:

$$\sigma_v = \frac{P_\infty - P_v}{\frac{1}{2}\rho_l U_\infty^2} \tag{2}$$

$$\sigma_c = \frac{P_\infty - P_c}{\frac{1}{2}\rho_l U_\infty^2} \tag{3}$$

where P_∞ and U_∞ are the pressure and velocity of the inlet flow respectively, P_c is the cavity pressure and P_v is the vapor pressure at the bulk temperature.

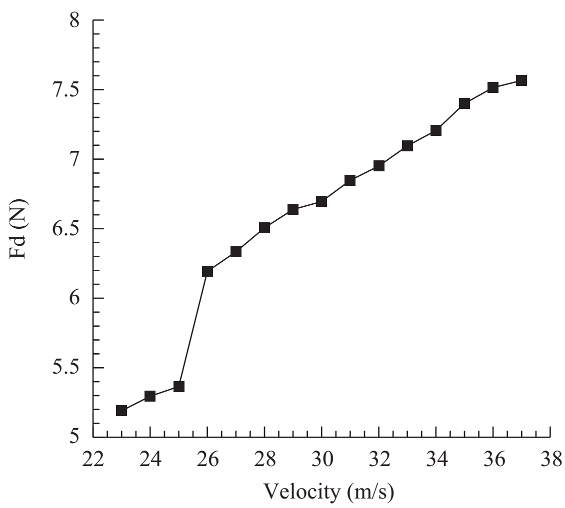

Fig. 9. Drag force variation with time for a 30° conical cavitator.

The cavitation number increases gradually as the flow velocity drops (Fig. 7). Eq. (2) shows the relation between flow velocity and natural cavitation number. The cavitation number variation is reduced with an increase in the cavitator angle. In other words, in cavitators with wider angles, the variation rate of ($P_\infty - P_v$) and square velocity will be low. Thus, at 24 m/s ≤ v ≤ 37 m/s, with an increase in the velocity, the cavitation number variation in the 30° conical cavitator will grow six times greater than that of 60° conical cavitator. For v ≥ 28 m/s, the variation of cavitation number will be low in 45° and 60° conical cavitators, which explains the identical variation rate of ($P_\infty - P_v$) and square of velocity (Fig. 7). Also, at v < 26 m/s, the values of cavitation number for three cavitators will be relatively identical, which is due to partial cavitation at v < 26 m/s.

The transient cavitation number depends on the inside pressure of the cavity, ambient pressure and flow velocity. As a sample, demonstration of the transient behavior of pressures measured inside the cavity is presented for the 30° conical cavitator in Fig. 8.

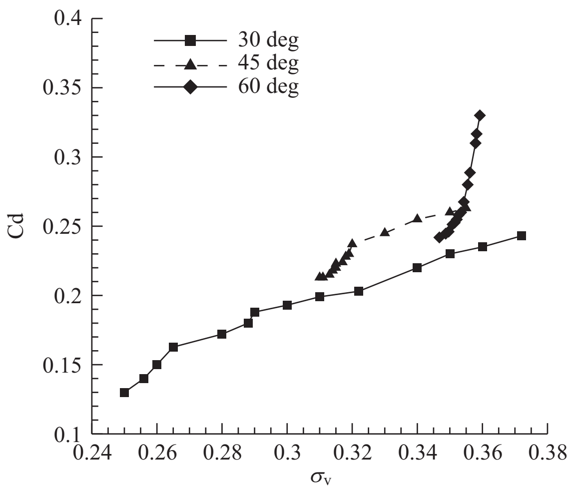

Fig. 10. Variation of drag coefficient with cavitation number.

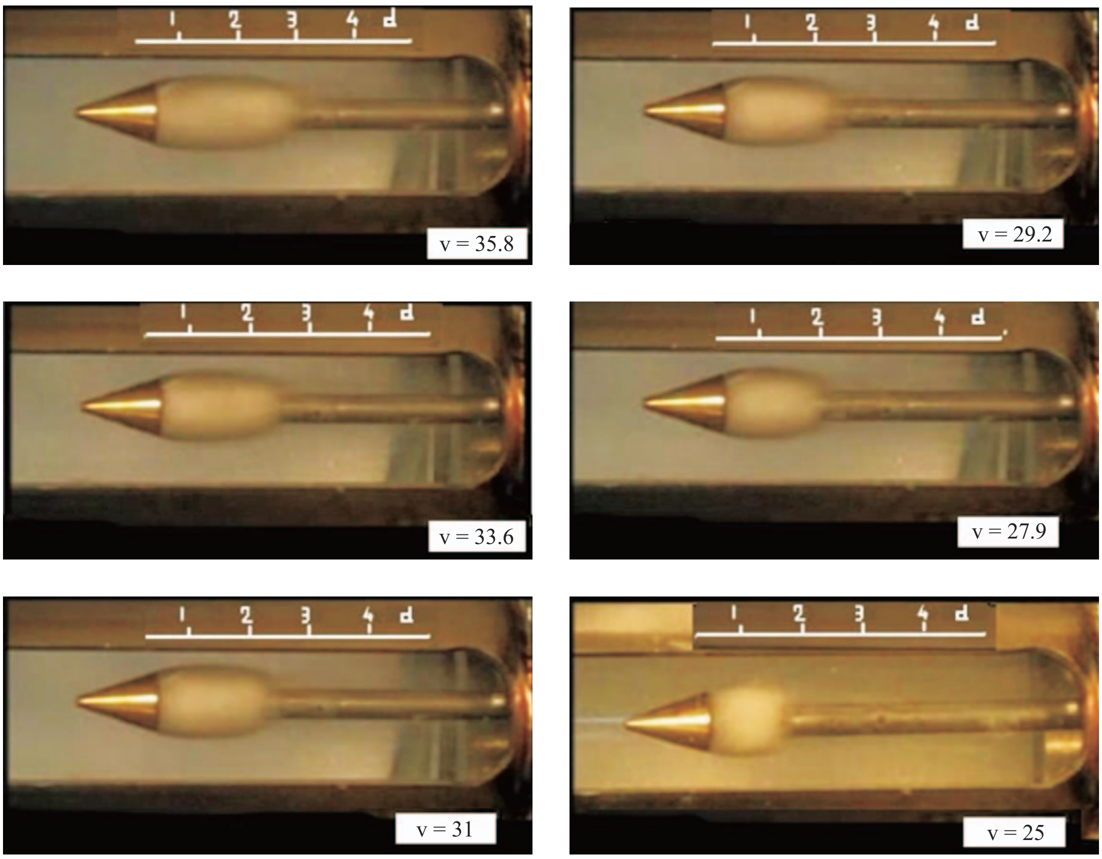

Fig. 11. The experimental results related to the formation, evaporation, and condensation of supercavitation at 30°conical cavitator in water tunnel at different velocities.

1. Drag Force

With a reduction in the flow velocity, the drag force declines at a constant slope (Fig. 9). Also, at $v \cong 26$ m/s when the supercavitation transits to the partial cavitation, a sharp drop in the drag force is observed. It is caused due to the increased pressure in cavity and re-entrant jet. Then, the drag force is dropped again at a constant slope.

The results show that the drag coefficient drops by increasing velocity against drag force. On the other hand, although the ca-

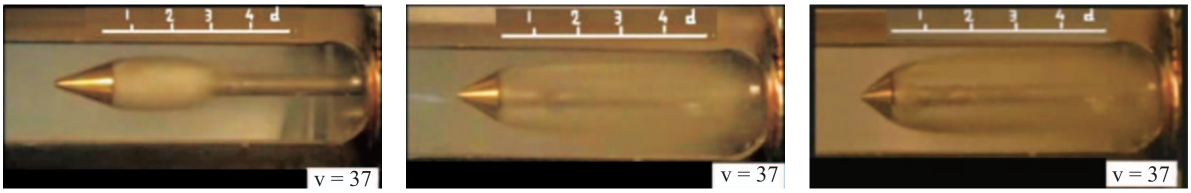

Fig. 12. Experimental results related to the formation, evaporation and condensation cavity of different cavitators in water tunnel at a velocity of 37 m/s.

vity pressure remains constant, a decrease in the flow velocity raises the pressure in the tip of cavitator. Thus, as the flow velocity declines, the friction drag drops and the pressure drag rises as a result of reduced total drag. Finally, the drag coefficient goes up since variation in the square of velocity is greater than that of total drag reduction (Eq. (4)).

$$C_d = \frac{F_d}{\frac{1}{2}\rho_l U_\infty^2 A} \tag{4}$$

Fig. 10 shows the effect of cavitation number on drag coefficient. The results show that at constant velocity, the drag coefficient increases by raising the cavitator angle (Fig. 7 and Fig. 10). According to Eq. (5), since the gravity and diameter of the test section is constant, the velocity and Froude number will be identical in terms of variation.

$$Fr = U_\infty /(gD)^{0.5} \tag{5}$$

As it can be seen, drag coefficient declines with either an increase in the velocity or a reduction in the cavitation number. For 45° and 60° cavitators and at $28 \le v \le 37$ m/s, the variation of natural cavitation number will be constant as a result of reduced drag coefficient at a constant rate. Also, at wide cavitator angle by increasing the angle of cavitator, the gradient of drag coefficient versus velocity decreases. Thus, according to Eq. (4), with increased cavitator angle, square velocity changes so that the drag force grows identical.

According to Reichardt's theory (Reichardt, 1946) the semi-empirical relation between drag coefficient and cavitation number is as follows.

$$C_D = C_{Do}(1+\sigma_v) \tag{6}$$

Similar to Reichardt's formula, drag coefficient variation with cavitation number will be approximately linear (Fig. 10). Also, with increased angle of cavitator, the gradient of drag coefficient variation versus cavitation number rises. It is occurred at 60° cone cavitator where an increase in the cavitation number will dramatically increase cavity length. At $0.34 \le \sigma_v \le 0.36$ and in 30° and 60° conical cavitators, by increasing the cavitation number, the drag coefficient is raised by about 7 and 36% respectively.

2. Cavity Shape

Fig. 11 shows the effect of velocity change on cavity shape in a 30° conical cavitator. As it can be seen, the effect of velocity on the length of cavity is not significant. In Fig. 12, the cavity shape of different cavitators at the velocity of 37 m/s is displayed. At low velocities, the change of cavity length for three cavitators are negligible due to existence of partial cavitation in these three cavitators. At v = 34 m/s and in a 60° cavitator, the length of cavity is 3.5 times greater than that of a 30° conical cavitator and. Also, at v = 28 m/s and for a 60° conical cavitator, the length of cavity is 1.5 times greater than that of a 30° conical cavitator. The results suggest that with increased velocity, the effect of cavitator angle grows stronger, as does the length of cavity. Thus, the effect of cavitator angle on cavity length is greater than that of the velocity flow.

A fundamental dimensionless parameters of natural supercavities is Froude number (Eq. (5)). The variation range of Froude number is between 33 and 53 with the cavitation number varying between 0.25 and 0.37. Semenenko (2001), drawing on Logvinovitch (1973), stated that the effect of gravity can be significant if $\sigma Fr < 2$. Thus, at the present study, the effect of gravity is negligible without the need to include gravity effects.

At low velocity or high cavitation number, the maximum diameter of cavity remains approximately unchanged. Result shows that the variations of the maximum diameter of cavity are low when angle of cavitator is decreased. The reason is that changes of drag coefficient and diameter cavity is similar. Also, the results reveal that in small angles, the maximal diameter of cavity remains constant when the cavitation number decreases (Fig. 13). Comparison of the results, shown in Figs. 10 and 13, indicate that for all cavitators, the drag coefficient is increased as the cavitation number increases while there is an inverse relation between the cavity diameter and the cavitation number. By decreasing the cavitation number in a 60° conical cavitator, the cavity diameter increases to 12.5%, but in a 30° conical cavitator, the cavity diameter remains relatively constant.

It is observed that the cavity pressure remains constant and where the cavity is closed, the pressure reaches its maximum level, which is followed by a gradual decline. Thus, the length of cavity can be estimated based on this phenomenon. For instance, when the flow velocity is 30 m/s, the cavity length will be 41 mm (Fig. 14). The cavity length L_c is usually defined as the double distance of the leading edge of cavity from the point with the maximum cavity diameter of *d*, which is used for $L_c > 6.5$ cm.

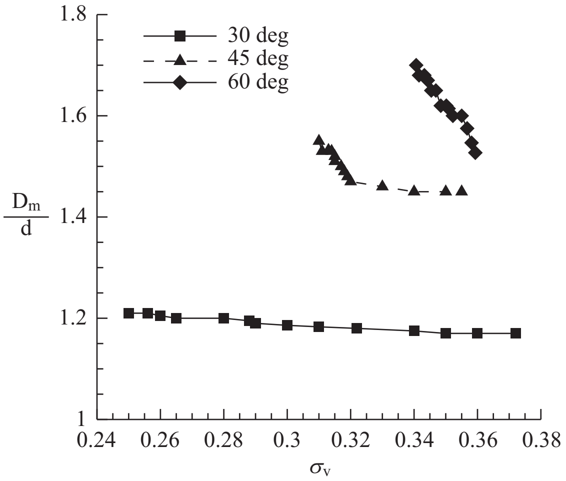

Fig. 13. Variation in the maximum cavity diameter with the cavitation number for various types of cavitator.

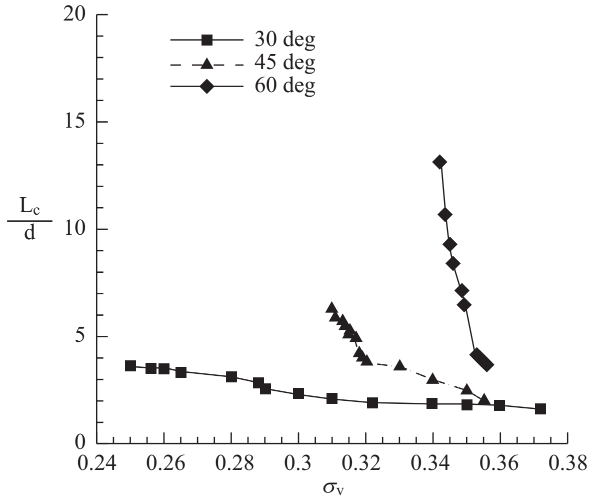

Fig. 15. Cavity length variation with the cavitation number for various cavitators.

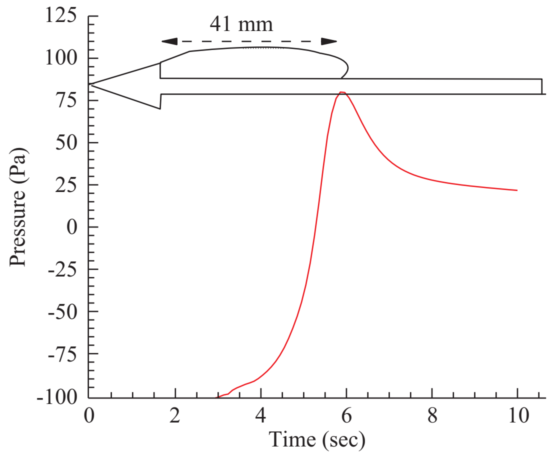

Fig. 14. Distribution pressure behind cavitator at v = 24 m/s for a 60° cavitator.

Fig. 15 shows L_c/d of 30°, 45° and 60° conical cavitators. According to Fig. 15, in any cavitator, the cavity length varies with a constant slope and increased angle of cavitator causes more variations.

Fig. 15 shows that the cavity length decreases as the cavitation number rises. Also, by increasing the angle of cavitator, the effect of cavitation number variation on the cavity length will be magnified. In a 60° conical cavitator, small variation of cavitation will increase the length of cavity by 4 times. However, in a 30° conical cavitator, with an increase in the cavitation number, the cavity length difference will be insignificant. Also, by increasing the angle of cavitator, the rate of cavity length variation will increase dramatically.

The results show that the cavity length is correlated with the cavitation number, flow velocity, and other parameters like geometry of cavitator. For example, in a 30° conical cavitator, when the cavitation number is high (with a variability range of 0.12), the dimensionless cavity length variation will be negligible (less than 2). However, in a 60° cavitator, when the cavitation number is high (with the variability range of 0.02), the variation in the dimensionless cavity length will be significant (less than 9).

3. Ventilated Cavitation

For air ventilation, we used four ports around the slender body at a distance of 0.5 d from the leading edge of cavitator. In this study, the rate of ventilation flow was 0.0851 lit/s and the temperature of the injected air was approximately equal to the water temperature in the tunnel. The results indicated the significant effect of air injection on the cavity length at different velocities (Fig. 16).

Fig. 17 displays the dimensionless supercavity length in which a comparison has been drawn between the results of the ventilated cavitation and natural cavitation for 30° conical cavitator. According to the results, ventilation has a significant effect on the length of cavity. The experimental results show that with an increase in the flow velocity, the cavity length remains relatively constant for a while until it rises. That's way that at low velocity and ventilated cavitation, increasing velocity flow pressure inside cavity in not increased mostly. In the ventilated cavitation, the cavity length is increased by 120% compared to the natural cavitation. As it can be seen, the cavity length can be increased by 110% at lower velocities, while this figure can reach as high as 75% for higher velocities (Fig. 17). In other words, the sensitivity of the cavity length to the air injection is reduced while the flow velocity is increased. This can be caused by suppressing the effects of air-pressure on the cavity shape at higher flow velocities.

For the same cavitation number, the ventilated cavity and natural cavity are relatively equal in terms of length, with less than 10% difference (Fig. 17). The rate of cavity length rises is similar for both natural and ventilated cavitation as the cavitation number drops. In all velocity ranges, the ventilation rate leads

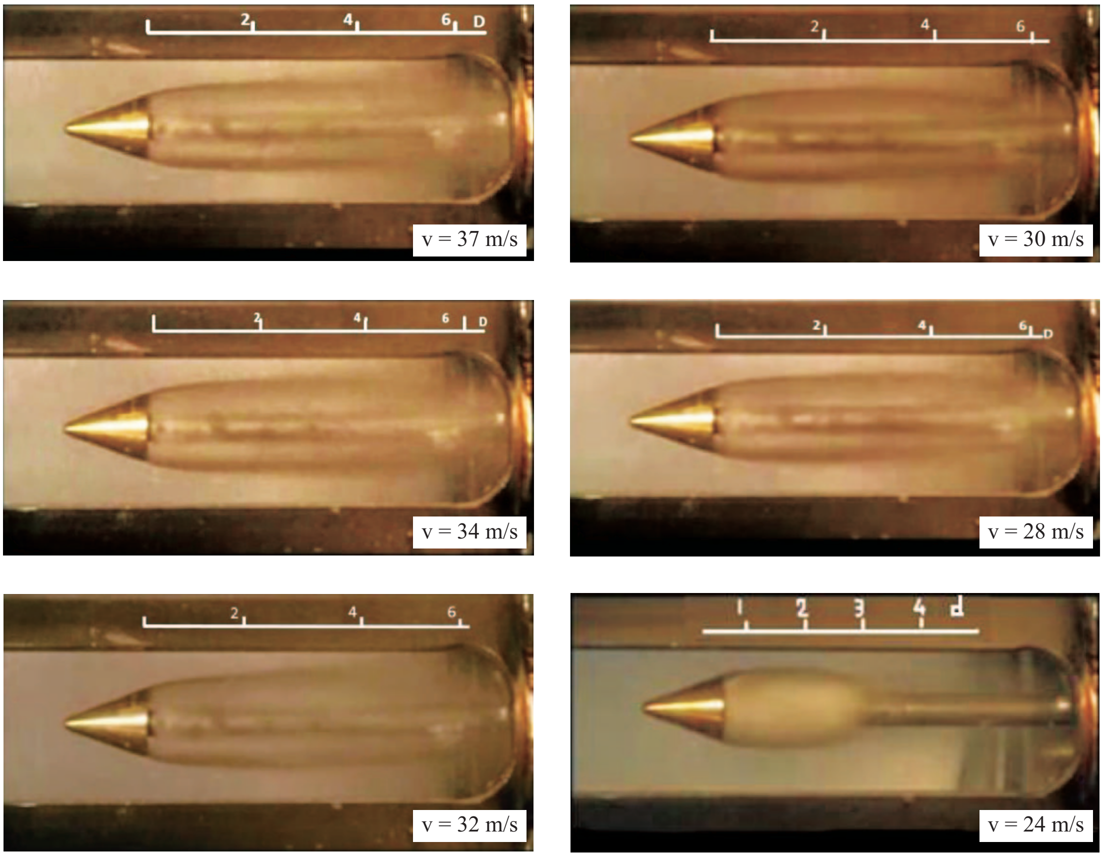

Fig. 16. Ventilated cavity results on a 30°conical cavitator in a water tunnel at different velocities.

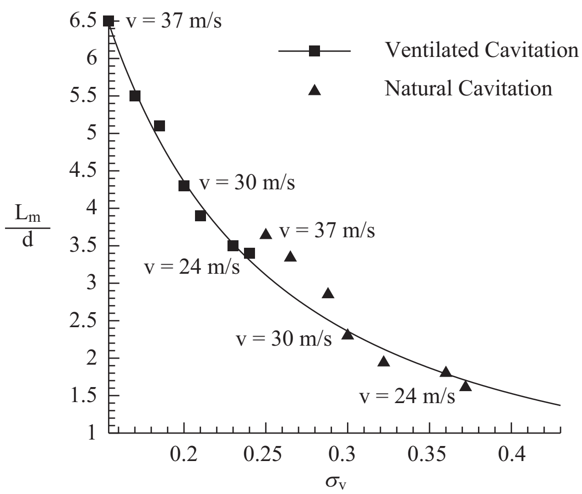

Fig. 17. Comparison of cavity length versus cavitation number for ventilated cavitation and natural cavitation.

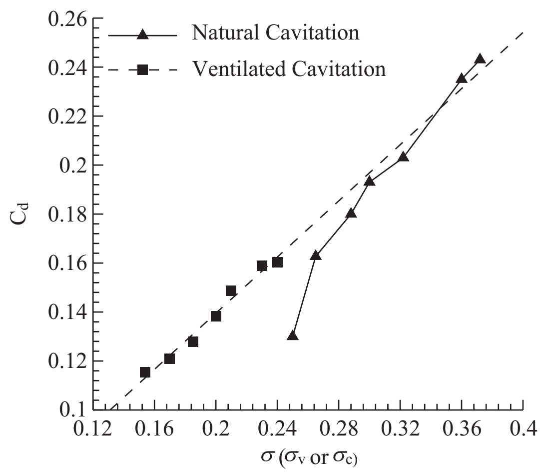

Fig. 18. Comparison of drag coefficient versus cavitation number for ventilated cavitation and natural cavitation.

to a decrease of averagely 45% in the cavitation number.

According to Fig. 7 and Fig. 18, natural cavitation and ventilated cavitation are identical in terms of drag coefficient reduction at v < 30 m/s, which is mainly due to the specified velocity, open end of cavity and the direct ejection of ventilated air. For this reason, at v > 30 m/s, the rate of drag coefficient variation will be different for natural cavitation and ventilated cavitation.

At low velocities, the ventilated cavitation triggers 30% drag coefficient reduction. However, at high velocities, the drag coefficient difference between natural cavitation and ventilated cavitation would be insignificant. It is due to the constancy of the pressure inside cavity because at high velocity, cavity length and pressure inside cavity remain almost unchanged for both natural and ventilated cavitation.

Generally, at high velocities, the effect of ventilated cavitation on drag coefficient reduction will be negligible.

In natural and ventilated cavitation cases, the increasing of flow velocity from 24 m/s to 37 m/s causes the drag coefficient reduction up to 30% and 48% respectively. This means that the effect of increased velocity on drag coefficient reduction at $24 \leq v \leq 32$ m/s will be less than the effect of air injection.

Thus, for the ventilated cavitation, the drag coefficient varies linearly with the cavitation number. At $0.15 \leq \sigma_c \leq 0.24$, with an increase in the cavitation number, the drag coefficient rises to 50%.

In natural cavitation, the slope of drag coefficient versus cavitation number will be greater than that of ventilated cavitation. As such, in natural and ventilated cavitation, the slope of drag coefficient variation will be 0.66 and 0.45 respectively.

IV. CONCLUSION

In this paper, the cavity flow on various cavitators was studied experimentally at $v \geq 24$ m/s. The experimental observations were carried out in a high-speed water tunnel. The effect of a number of factors such as cavitator angle, flow velocity and the cavitation number on cavity shape and drag coefficient were investigated for natural and ventilated cavitation.

The following conclusions can be drawn from this study:

1. Cavity length is proportional to the angle of cavitator. In fact, the best way to increase cavity length is to increase the angle of cavitator. In small cavitator angles, increased velocity does not affect the length and diameter of the cavity.
2. At $24 \leq v \leq 37$ m/s, with increased velocity, the cavitation number variation in a 30° cavitator is increased by 6 times compared to a 60° conical cavitator, which is due to the negligible pressure variation in the 60° conical cavitator.
3. Drag coefficient decreases as the cavitation number drops. By increasing the cavitator angle, the rate of drag coefficient reduction is increased. At $v \leq 26$ m/s, the rate of drag coefficient reduction remains almost constant, but at $v > 27$ m/s, it is reduced by an increase in the angle of cavitator, which is due to low variation of cavitation number at $v \leq 26$ m/s.
4. The maximum diameter of the cavity and its length decrease contrary to the cavitation number. The length and diameter variation of cavity is directly related to the cavitation number variation. By increasing the cavitation number in a 60° conical cavitator, the cavity diameter increases to 12.5%, but it remains approximately constant in a 30° cavitator. Also, with a 5% reduction in the cavitation number, the cavity length grows by 3, 25 and 75% for 30°, 45° and 60° conical cavitators respectively
5. The most effective parameter on the drag coefficient is the angle of cavitator. Thus, at $0.34 \leq \sigma_v \leq 0.36$ in a 30° and 60° conical cavitator, by increasing the cavitation number, the drag coefficient will go up by 7 and 36% respectively.
6. The effect of increased velocity on drag coefficient reduction at $v \leq 32$ m/s will be less significant than the effect of air injection. At low velocities, the ventilated cavitation triggers 30% drag coefficient reduction. However, at high velocities, the drag coefficient difference between natural cavitation and ventilated cavitation would be insignificant.
7. At low velocities, the effect of ventilated cavitation on cavity length is significant. Thus, the cavity length can be increased by 110% at low velocities, while this figure can reach as high as 75% at high velocities. For the same cavitation number, the ventilated cavity and natural cavity remain relatively equal in terms of length.

ACKNOWLEDGEMENTS

This study was funded by Marine Research Center of Imam Hossein University in Iran.

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