"A study on Cavitation erosion and its effect on metals”

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Abstract

This paper devoted to the mass and volume losses of metals subjected to cavitation. It studies the Relation between the Cavitation index, operating condition, time elapsed and the mass loss. Three venturies with different throttling area were used to generate cavitation**.** Aluminum sheet (0.9 mm) and stainless steel sheet were subjected to the cavitation and they were weighted before and after the experiment using 0.001 accuracy Balance. Using the curves in this paper, the life time of the alloy can be predicted. During the experiment the mass loss increased by 25 % when the Cavitation decreased by 30%. And the effect of material hardness and Reynolds number was studied.

Introduction

Cavitation is a process of the formation and rapid collapse of bubbles where there is a considerable local reduction in the pressure [1].

It has been studied in the past for several times. Lord Rayleigh’s work in 1917 approved that a vapor bubble can actually generate very high loads capable of damaging solid walls when collapsing [2]. One of the most difficult problem facing the researchers is how to predict the mass loss due to cavitation erosion. Pereira et al [3] found a relation between the volume of transient cavities and its rate of production. S. Wu et al [4] conducted a study about the effect of cavitation on several materials to check the effect of material properties on the mass loss rate. Dular *et al.* [5] showed that specific visual information of cavitation can be used to predict cavitation erosion.

Abdulaziz, et al. [6-8] confirmed that the cavitating venturi is a precise tool for controlling mass flow rate. Hammitt et al. [9,10 and 11] used cavitating venturi to obtain erosion data on 1100-0 aluminum specimens. Recently there were many attempts to predict the magnitude of the cavitation erosion for example Pereira et al. [12], Matevˇz Dular et al, [13] and Keiichi Sato. [14] Proposed a relation between the volume of transient cavities and its rate of production to the material deformation energy. Finally Hua et al. [15] studied the effect of the bubble size on the cavitation erosion. All the previous studies aimed to predict the life time of the alloy and how to reduce the bad effect of the cavitation.

Theoretical background

This section presents the necessary equations for the proposed mathematical model of vapor formation inside the divergent part of a venturi.

Applying Bernoulli’s equation between the inlet and throat of the venturi along the center streamline gives:

$$\frac{P_u}{ƒ_l} + \frac{v_u^2}{2} = \frac{P_{th}}{ƒ_l} + \frac{v_{th}^2}{2} \qquad (1)$$

According to Bernoulli's eq. as the throat area decreases the velocity increases and consequently the throat pressure decreases.

If the throat pressure is decreased below the vapor pressure, the cavitation occurs.

It can be expected, that the level of damage is dependent on the combination of hydraulic, geometric and material parameters of the experiment, so is reasonable to use non-dimensional parameters for description of selected relationships. Well known and widely used criterion in the cavitation research is the cavitation index σ.

$$\sigma = \frac{P_{u-}\ P_v}{ƒ\frac{{v_{th}}^2}{2}} \qquad (2)$$

Where Pu is the reference pressure, Pv is the liquid vapor pressure at corresponding temperature, ƒ the liquid density, and v_{th} the reference velocity at the throat. From Eq. (2), the effect of decreasing reference pressure on the cavitation number is equivalent to increasing the reference velocity for the same fluid maintaining constant temperature. The cavitation index σ is commonly used as an indicator of the development or extent of cavitation in a liquid flow.

To define the erosion progress, we use the mass loss in order to avoid the effect of density difference between the different materials tested. The erosion time history is presented here in terms of the volume loss, V, versus time, defined as:

$$V(t) = \frac{m\,(t)}{f_m} \qquad (3)$$

where m(t) is the mass loss at time t and $\square_m$ is the eroded material density.

Experimental setup

A specially designed test rig was constructed to test the effect of cavitation on different types of metals at the Faculty of Engineering, Ain Shams University. The test rig of the experiment, shown in figure (1), consists of a horizontal inline centrifugal pump, venturi, Polypropylene piping system, pre-calibrated flow meter, pressure gauges and pressure transmitter. Water is recirculated to a tank 90 liter volume. Three different venturies were used to generate cavitation. The venturi upstream and downstream pressures are measured by dial gauges pre calibrated against deadweight tester. The pressure at the venturi throat is measured by a glycerin vacuum pressure gauge to suppress pressure fluctuations. The angles of the convergent and divergent parts are the same and equal to 7 degrees. The upstream and downstream diameters are 21.2 mm whereas the throat diameter are different for the three venturies (2, 4, and 5) mm. Figure (2) shows the schematic drawing of the venturies.

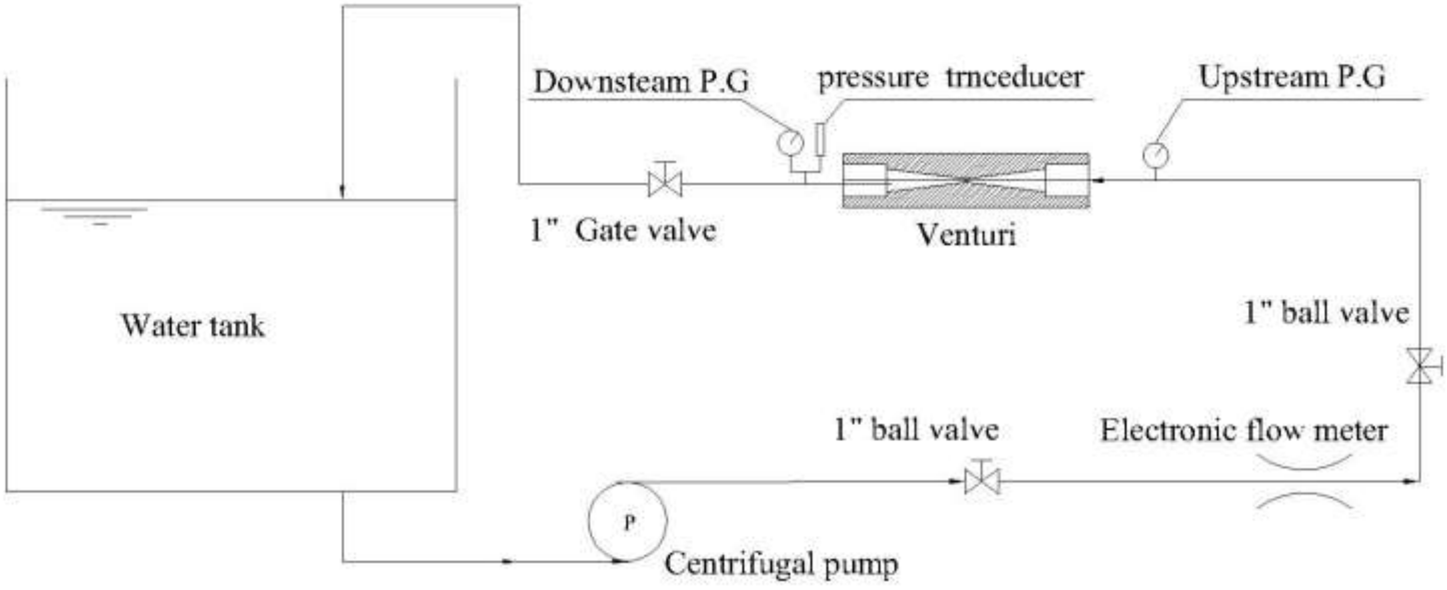


Fig. 1. Venturi test rig.

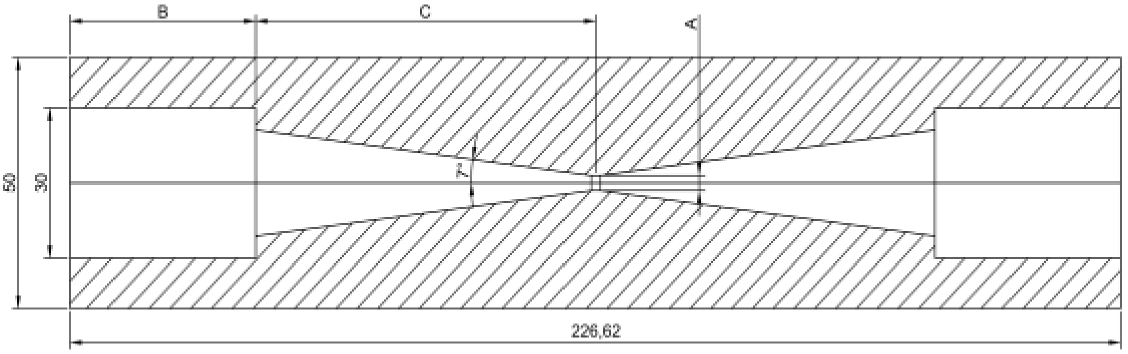


Fig. 2. Venturi schematic drawing.

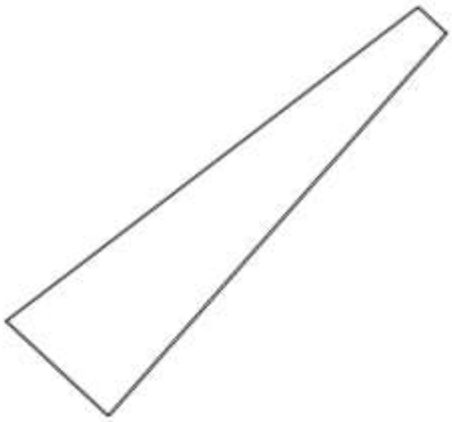


Fig. 3. A metal plate of 0.1 mm thickness

Experimental Procedure

A metal plate of 0.1 mm thickness with the same angle of the venturi divergent part as shown in fig.3 is inserted and squeezed inside the divergent part of the venture. Two materials, Stainless steel … and Aluminum … are tested. Each plate is weighed before and after each run with an electronic balance of accuracy ± 0.001 g.

For each venturi, at a constant upstream pressure, the downstream pressure is regulated in steps and the corresponding mass flow rate is measured. The range of upstream pressure is 1-5 bar. The range of downstream pressure is 1-3 bar. Experiments objective is to study, within the cavitation region (demonstrated by constant mass flow rate, see Fig. (3), the effect of cavitation number, σ, throat Reynolds number and metal type on the metal mass loss. Cavitation number as declared by Eq. (2) is varied by varying the venturi throat diameter. Variation of Reynolds number is consequence of varying the throat diameter which affect the throat velocity. Total time of experiments is more than 240 h.

Results and discussion

Figure (4) indicates that the mass flow rate, through the tested venturi, is well correlated to the pressure ratio. The solid lines indicate the measurements while the dotted lines are merely expectation since the mass flow rates at pressure ratio one are equal to zero. The mass flow rates increase as the pressure ratio is decreased up to the critical pressure ratio 0.6 – 0.7 for all upstream pressure values. As the pressure ratio is decreased beyond this critical value, the flow is choked and suffers from cavitation where the its index increases, for constant downstream pressure, as the upstream pressure increases, as can be seen from Eq. 2.

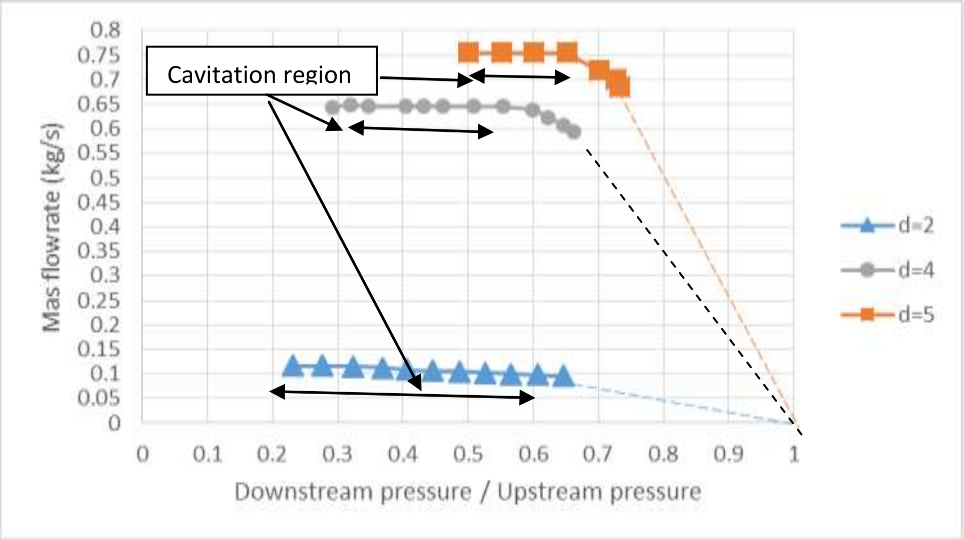


Fig.4. Mass flow rate versus pressure ratio

Figure (5) shows the cumulative mass loss for an aluminum sheet versus time for different cavitation index. Tests were carried out up to total duration of 40 hours for each specimen and were weighed every 10 hours. The figures show that there is no effect for the cavitation index for the first twenty hours.

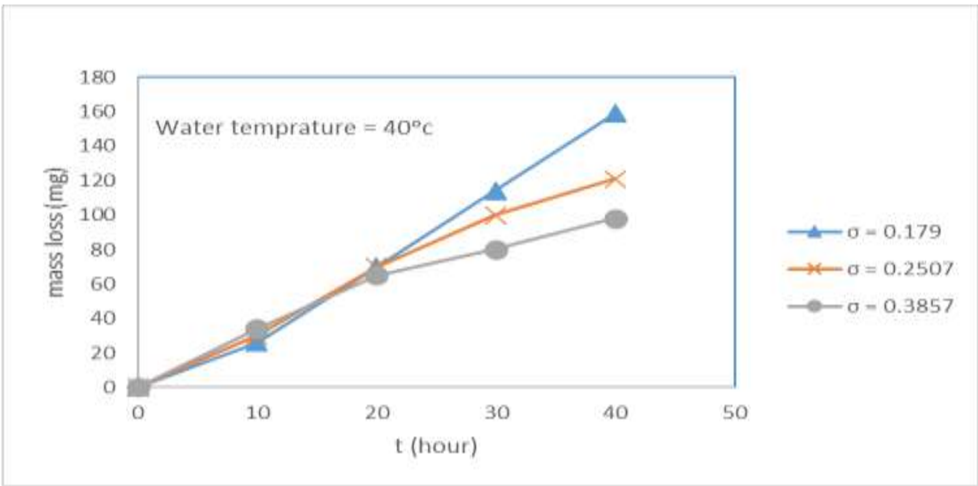
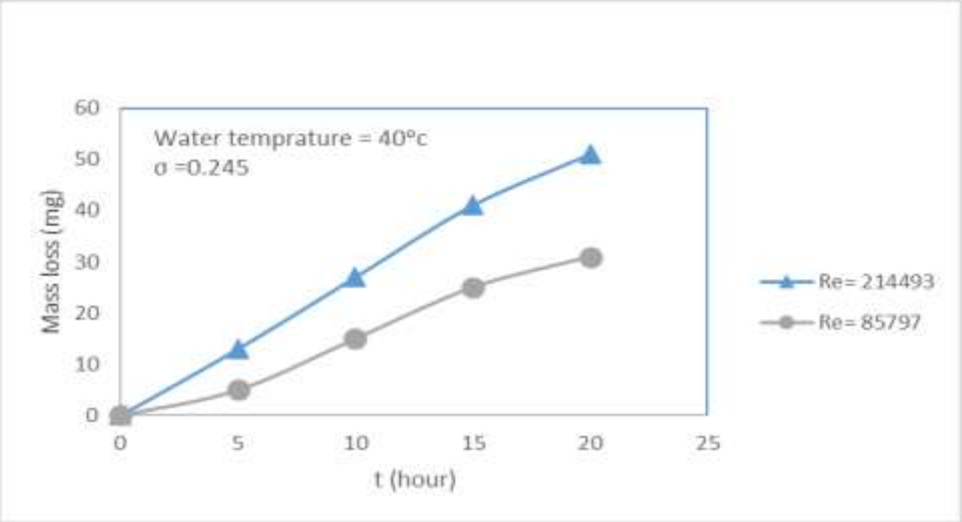


Fig.5. Aluminum sheet mass loss vs time for different cavitation index

Figure 6 shows the effect of Reynolds number on the mass loss rate. Tests were carried to total duration of 20 hours for each specimen were weighed every 5 hours. The figure shows that the mass loss rate increase with Re for the same σ. There are two reasons for this strongly non-linear effect of the flow velocity. One reason is that the amplitude of the impulsive loads increases with flow velocity. This is because when the velocity is increased at constant σ, the ambient pressure has also to be increased in order to conserve the cavitation number. The bubbles then experience a larger pressure during their dynamic process and this results in a stronger bubble collapse and an



impulsive load of higher amplitude [16].

Fig.6. mass loss vs time for the same cavitation index

Comparison of the erosion resistance of different materials should be done carefully. The resistance to cavitation of a material could depend on the cavitation intensity level to which the material is exposed. It is well known that the cavitation erosion progress is classified into: an incubation stage, an acceleration stage, and a maximum rate stage. In the incubation stage, plastic deformation takes place on the material surface without mass loss. After an initiation time, the mass loss commences and proceeds at an increasing rate with time of erosion. This is termed the acceleration stage. The mass loss rate accelerates to a terminal value, referred to as the maximum rate stage. In the maximum rate stage, the erosion rate remains constant for a period of time, thus the maximum rate stage is also known as the steady-state stage.

Figure (7) shows two materials specimens subjected to cavitation to characterize their cavitation erosion resistance the first material is aluminum and the second one is stainless steel. The mass loss for various materials increases at a low rate in the incubation stage, before increasing at a rapid rate. Moreover, one can see that the slope of the maximum rate stage becomes smaller for materials with longer incubation periods as stainless steel.

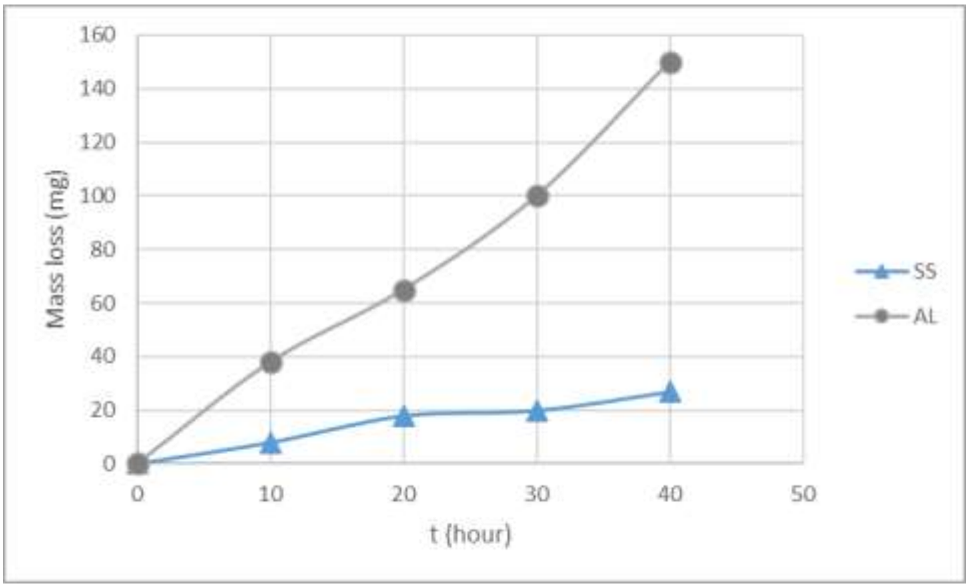


Fig 7. Mass loss vs time for two different material

Conclusions

1. Mass flow rate through a specific venturi is choked at a certain pressure ratio (0.6 - 0.7) depending on the operating temperature.
2. The mass loss rate decrease with increasing the cavitation index at a constant velocity for different materials. For this experiment the mass loss decreased by 25 % when σ increased by 30%
3. The mass loss rate increases with increasing Re for the same σ. During this experiment for constant σ the mass loss increases by 67% when the Reynolds No. increases by 150%.
1. The response of the solid material to the cavitation varies and the response is specific for each material. The response is depending on the material properties, chemical composition, structure and treatment of the material of the solid surface. For this experiment the aluminum mass loss is 500% more than Stainless steel for the same σ

Nomenclature		**Greek symbols**	
A	Throating diameter	σ	Caviation index
B	Straight part length	ρ	Water density
C	Convergent part length	**Subscripts**	
$\dot{m}$	Mass flowrate	v	Vapor
P	Pressure (bar)	th	Throating
Re	Reynolds number	u	Upstream
V	Velocity (m/s)		

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