

The influence of water air content on cavitation erosion in distilled water

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The influence of increased air content of the cavitating liquid (distilled water) was studied in a rotating disk test rig. A rise in the total air content (including dissolved and entrained air) of the water in the undersaturated range resulted in bubble collapse cushioning and reduction of cavitation damage. When the water was oversaturated with air, large air bubbles formed and cavitation damage was drastically reduced, probably due to both bubble collapse cushioning and shock wave attenuation.

Keywords: cavitation erosion, air (gas) content, distilled water

Introduction

The existence of cavitation at positive liquid pressures depends on the presence of small gas pockets or nuclei¹. Thus gas (usually air) content is an extremely important factor in various aspects of cavitation, including nucleation and cavitation inception, bubble dynamics, bubble collapse violence and chemical reactivity of the eroded surface.

The nucleation threshold of a liquid depends very strongly on the number and size distribution of the nuclei in the liquid². It was found³ that these microbubbles range in diameter between approximately 10^{-6} and 10^{-4} mm. In terms of volume the portion of so-called entrained gas is extremely small ($\sim 10^{-6}$ of the total gas content). The remaining dissolved gas constitutes the major portion of the total gas content and may play an important role in bubble growth, especially in situations where prolonged diffusion or rectified diffusion³ takes place. Thus bubble collapse will be retarded due to the presence of a finite volume of gas in the bubble and damage will decrease.

Chemically active gases like oxygen will influence corrosion reaction rates on the eroding surface. In the case of less noble metals and alloys, the rate of corrosion will increase. The influence of gases on more noble materials or protected by the formation of passive films is determined by the balance between the rates of corrosion and surface-layer formation⁴.

Numerous studies (see reference 3 for a summary) regarding the influence of air or gas content on cavitation inception sigma have been reported.

(Inception sigma is defined as $\sigma_1 = (P_i - P_v) / (\rho v_i^2 / 2)$, where P_i is the undisturbed liquid pressure at inception, P_v the liquid vapour pressure, ρ the liquid density and v_i the relative undisturbed liquid velocity at inception.) Most of these studies were carried out in flow cavitation systems, although some work was done in vibratory test rigs as well. In general, inception sigma was found to increase with increasing gas content, as illustrated in Fig 1. However, the dynamic processes are not yet fully understood, mainly for two reasons. First, it is extremely difficult to measure the nuclei population and size distribution, although the existence of a number of promising laboratory-scale measuring systems have been reported. These include optical and acoustic techniques and the measurement of electrical conductivity in the fluid³. Second, it is not possible to describe in sufficient detail the actual flow patterns and thus to derive the pressure and velocity history of a given nucleus.

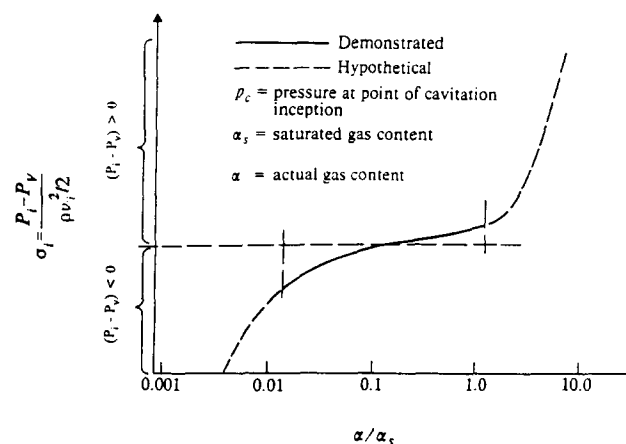


Fig 1 Inception sigma versus relative air content (hypothetical example)³

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Studies on the effects of gas content on cavitation damage are far more limited. Reported results include theoretical modelling^{5,6} and experimental studies in venturi⁷⁻⁹, rotating disk^{8,9} and vibratory¹⁰⁻¹² test rigs. The presence of gas in a liquid stimulates nucleation and thus at high cavitation sigma values may determine the existence or not of cavitation. Once cavitation has been established, further increase in gas content will, for the same reason, enlarge the number of cavitation bubbles, the collapse of which may contribute to cavitation damage. However, large quantities of entrained or dissolved air has been found to reduce damage¹³. This may be related to increased gas content in collapsing bubbles and thus cushioning of collapse, or to more rapid attenuation of shock waves in the surrounding liquid³. These opposing mechanisms result in the occurrence of a peak in the hypothetical erosion rate curve (Fig 2).

In the present study, the influence of air content on cavitation erosion in a flow cavitation system has been investigated by means of a rotating disk test facility. Different techniques for controlling air content have been considered, with respect to their applicability in practical hydraulic systems.

Erosion test procedure

Each test involved the erosion, using a rotating disk test rig, of specimens of AA type 1200 Al alloy for 1 hour in distilled water. (Details of the test rig and sample material are given elsewhere¹⁴.) The test procedure was as follows. The samples were machined to 65 × 25 × 4 mm, after which the surfaces exposed to cavitation erosion were ground and polished to a finish of $R_a \sim 0.1 \mu\text{m}$. They were then stored in a dry desiccator. Three samples were tested simultaneously under the following conditions: water temperature 40.1°C; water pressure 0.15 MPa; water flow rate 30 ℓ/min; and disk velocity 3620 rpm. Before and after each test the samples were cleaned in ethanol, dried, and weighed to the nearest 0.1 of a milligram. The average mass loss of the three samples, converted to volume loss, was used to determine the erosion or damage rate. Several tests were duplicated to verify reproducibility of results.

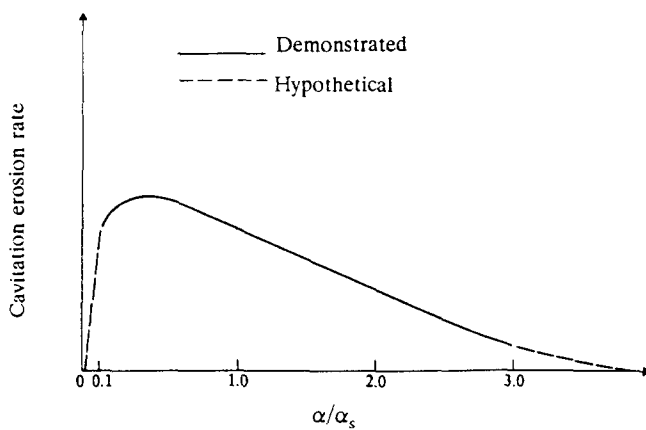


Fig 2 Erosion rate versus relative air content (hypothetical example)³

The dissolved oxygen content of the water was measured during testing, as an indication of the behaviour of the dissolved air content and thus also the total air content. The air content of the water was varied as follows.

An increase in the air content was achieved by blowing compressed air through a diffusing nozzle into the reservoir. To diminish the air content in the water, it was boiled before being passed into the flow system. Supersaturated conditions, corresponding to an increase of the entrained air portion, were also created by blowing compressed air directly into the test chamber. For these tests, the degree of supersaturation was assumed to be proportional to the rate at which air was released.

Results and discussion

In the case of the undersaturated tests a stable dissolved oxygen value was soon reached. Over the dissolved oxygen range tested the trend was for decreasing damage with increasing oxygen level, as shown in Fig 3. This decrease may be ascribed to the increased diffusion rate of air into cavitation bubbles during the growth cycle, leading to collapse cushioning. It may also be assumed that at very low dissolved oxygen levels a decrease in the damage rate will occur due to the diminishing of nuclei numbers and the resulting increase in water tensile strength^{1,15}. This would result in a peak erosion rate as proposed in Fig 2. However, such conditions are not achievable in practical hydraulic systems.

Gaseous cavitation¹³ developed with increasing feed rates in tests in which air was blown into the test

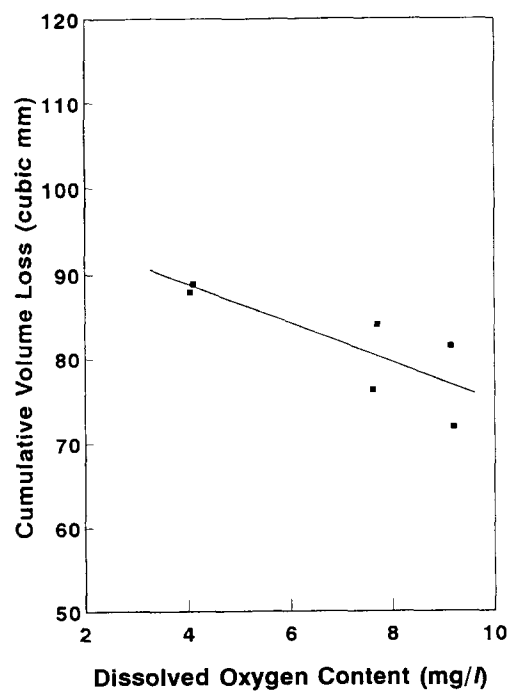


Fig 3 One-hour cumulative volume loss as a function of dissolved oxygen content for the tests under non-saturated conditions

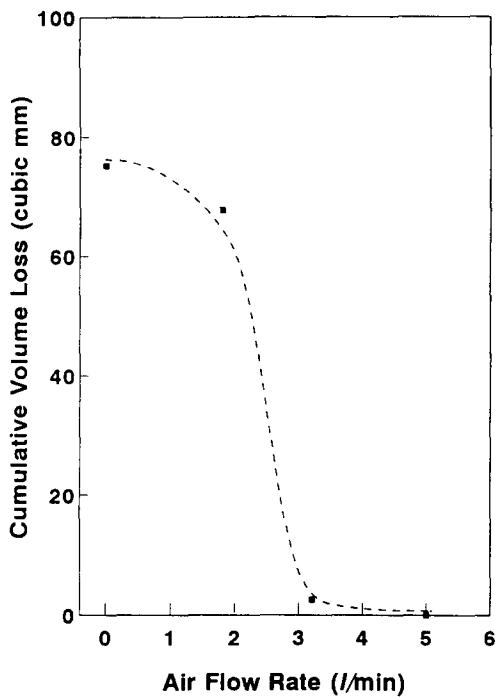


Fig 4 One-hour cumulative volume loss as a function of air flow rate for the supersaturated air content tests

chamber, thus creating oversaturated conditions. *In situ* observation showed the presence of large (1–2 mm) air-filled ‘nuclei’ in water entering the test chamber. This resulted in collapse cushioning and perhaps attenuation of shock waves from collapsing bubbles³ and thus reduction in volume loss (Fig 4). Almost complete termination of damage was achieved at relatively low air flow rates.

Conclusions

A study using distilled water in a rotating disk test rig showed that cavitation damage was reduced with increasing air content under both undersaturated and supersaturated conditions. In the former case, the reduction in damage was probably due to increased

air content in collapsing bubbles and thus bubble collapse cushioning. This mechanism, together with shock wave attenuation, could have been responsible for damage reduction under supersaturated conditions.

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