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EROSION STUDIES & SCALE EFFECTS DUE TO THE IMPINGEMENT OF CAVITATION INDUCED WATER JETS

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SUMMARY Experimental results pertaining to erosion studies on a liquid jet impingement test rig are reported. The importance of the peak volume loss rate is discussed with regard to erosion obtained using liquid jets varying from 4 to 12 mm diameters. The growth of erosion and the intensity of erosion is also presented. Several peaks in rate of erosion as observed in cavitation and plain jet impingement erosion by non-cavitating jets were not significantly observed for cavitating jets. The scale effects for the cavitation inducer and the velocity are discussed in comparison to erosion in a venturi and rotating disc.

1 INTRODUCTION

Impingement erosion occurs in a variety of Engineering equipments such as water turbines under high pressure heads and high speed turbines working under severe moisture conditions. These situations, along with the droplet impingement on air crafts flying through rain storms (1), may be due to the impact alone or to a combined action of impact and cavitation. There is a need to understand the characteristics of erosion due to the variation of the parameters such as velocity of impact, size of jet, angle of impingement volume of liquid impinging and roughness of materials by laboratory test devices. Out of the several devices developed, jet impingement test-rigs simulate considerably the field situations. Erosion characteristics due to impingement have been studied by a number of investigators (2-7) contributing to an understanding of the erosion phenomena related to material correlations, cavity characteristics and prediction of erosion. Several investigators have reported that the characteristics erosion rate curves of damage resulting from cavitation or impingement could be discussed in terms of four zones. The time scale effects and prediction of erosion - time curves were considered by Heymann (8), Thiruvengadam (10, 11) and Tichler et al (12). Hackworth and Arndt (13), Wood et al (14) and Ramamurthy and Bhaskaran (15) have investigated the scale effects with reference to erosion due to cavitation. Thiruvengadam (16) has discussed about the formulations of erosion modelling as well as corrosion - erosion modelling.

This paper presents the effects of test time and piercing of a hole through the specimen on erosion rate time curves for aluminum material, tested in a liquid jet impingement device. The erosion characteristics with respect to cumulative erosion are highlighted. The scale effects corresponding to the cavitation inducer as well as velocity are discussed.

2 EXPERIMENTAL SET-UP

Fig.1 presents the details of the experimental set up used for the investigations. The test rig consists of two liquid jets issuing from a pair of identical nozzles impinging onto four test specimens continuously at the centre of their faces. The rotating disc is housed in a chamber provided with glass windows for visual observation. The disc is connected to the shaft of a variable speed D.C. Motor. A 305m head pump supplies water for the jets.

For cavitating jets, the cavitation inducer is introduced into the nozzle as shown in Fig.2. The inducer is a sphere suitably located on the axis of the jet. The test specimens are cut out of a 3mm thick commercially pure aluminum sheet to a size of 50 mm x 38 mm. The range of jet velocity investigated was from 5 to 45 m/sec and over a frequency of 33 to 100 Hz. The damage data were obtained for jets with cavitation inducers (diameter ratios D/d of 1.53, 1.81, 2.22 and 2.6). All the experiments were conducted at a constant stand-off distance where the erosion was observed to be a maximum.

3 EFFECT OF TEST DURATION ON EROSION

Erosion studies were made for several jets (4 to 12 mm) at several frequencies of impingement. It was observed that the erosion pattern was similar to the erosion pattern observed in cavitation studies: with four zones - incubation zone, accumulation zone, attenuation zone and a zone of constant erosion rate (17). However, it was felt that in understanding the intensity of erosion, the peak erosion plays a significant role. In view of this tests were done and the peak values noted. Fig.3 presents a plot of peak rate of erosion with the time to attain the same. It is seen that over the several frequencies of impingement and jet diameters the peak rate increases almost linearly with the time attain it. This is contrary to the trend observed in the case of cavitation tests made with a rotating disc (19). The inferences obtained at peak conditions assist in the evaluation of materials for turbines and in understanding the characteristics of erosion.

Fig.4 presents the growth of area of erosion caused by the cavitation induced jets at a jet velocity of 25 m/s. The figure indicates that for the jet of diameter ratio 10/4.5, the erosion progresses rapidly in the direction opposite to that of rotation while for the diameter ratio 12/4.5 the erosion spreads in the lateral direction perpendicular to the direction of rotation.

Fig.5 presents the variation of normalized area of erosion with test time for two impingement frequencies. The increase in area of erosion is faster initially upto a test time of about 140 minutes and later the increase in area is negligible. As the target is exposed to erosion, the eroded area acts as a cushion and thereby the increase in area is reduced. In comparison with the rate of erosion with plain jets (jets without cavitation inducers) the difference in area of erosion observed between any two cavitating jets is not much (17). The jet diffuses in the beginning and after the closure of the cavity behind the inducer the jet does not diffuse for a short distance. In view of this the area over which the jet impinges is less and the total impact takes place over a smaller area. This is reflected by an increase in erosion. Similar erosion situations occur in case of the nozzles with spear regulator arrangement for the pelton turbine installations. A proper design of the spear nozzle assembly would tend to reduce erosion considerably.

4 CHARACTERISTICS OF IMPINGEMENT EROSION

Erosion investigations were made by varying the test time upto a maximum of five hours. Observations of the eroded test specimens at several test durations indicated that initially the material was removed uniformly from the surface. A detailed analysis of the data at different jet velocities and frequencies of impingement have indicated that the erosion rate attains a peak initially and later the erosion rate decreases. With cavitating jets the incubation and accumulation zones are not significantly shown and the erosion rate is higher than in comparison with non-cavitating jets. For tests made with venturi and rotating disc, the piercing of the specimens was observed at several peaks in rate of erosion. This phenomena was not observed in case of jet impingement erosion this phenomena was not observed and the piercing of the hole occurred, in the viscinity of constant erosion rate. In case of aluminum the spreading of erosion over a larger area takes place initially. In case of cavitation studies, with a venturi (11), a hole pierced through aluminum specimens in 12 to 16 hours. However, with cavitating jets this occurs around 200 minutes.

Fig.6 indicates a typical set of average erosion rate versus cumulative erosion curves on aluminum specimens for three jet diameter ratios. The variations could be attributed to several mechanisms viz., area growth change, erosion dynamics of the rotating component and the resistance of the material. In comparison with tests made with a rotating disc (18) on different materials, similar trends are observed. Further, the cumulative erosion corresponding to a peak in average erosion rate increases as the strength of material decreases. This is also substantiated by the fact that increase in area and mean depth of penetration aré observed for low strength materials.

5 CAVITATION INDUCER EFFECTS

The variation of erosion with the size of cavitation inducer were investigated to study the scale effects in case of erosion due to liquid jet impingement. Several scaling laws have been proposed for cavitation studies (10, 14). Three cavitation inducers of size 4.5, 5.5 and 6.5mm are used. The experimental conditions are - jet velocities ranging from 15 to 45 m/s and frequency of impingement 100 Hz. The equation used is

$$\frac{(\text{Erosion rate})_{\text{dia ratio(1)}}}{(\text{Erosion rate})_{\text{dia ratio(2)}}} = \left[\frac{\text{Dia ratio(1)}}{\text{Dia ratio(2)}}\right]^n \quad ..(1)$$

The values of the exponent for aluminum are presented in Fig.7. The erosion rates are calculated as an average over the constant cumulative erosion. For the range of diameter ratios investigated, the exponent varies from 0.12 to 6. In case of studies made with rotating disc, the exponents were found to be 15 for aluminum and 7 for copper. It is observed that aluminum erodes fast but during impingement the erosion spreads to a larger area and the general trend indicates that the exponent decreases gradually with cumulative erosion. It is also inferred from the results that exponents of 4 to 6 are obtained once the erosion develops fully. Earlier results of Rao et al (9) with a venturi, and rotating disc indicated a critical maximum erosion zone as the inducer size increases. This aspect was not clearly observed in case of jet impingement erosion. It is desired that for a further understanding of this aspect a detailed study with a proportionate variation of the inducer size with the nozzle diameter is necessary.

6 VELOCITY EFFECTS BETWEEN JETS

There have been many attempts to relate impact velocity of jets and droplets with erosion (3, 6, 19). Though a common unified relationship has not been given between erosion rate and velocity of impact, a large increase in erosion occurred with increase in velocity. A detailed study of erosion rate pertaining to velocity effects in a jet impingement rig is conducted. The equation used is,

$$\frac{(\text{Erosion rate})_{V_1}}{(\text{Erosion rate})_{V_2}} = \left(\frac{V_1}{V_2}\right)^m \quad ..(2)$$

The variation of exponent m as cumulative erosion progresses is studied to explore the dependence of m on total volume of erosion. The test velocities were 15, 25, 35 and 45 m/s. For the present investigations the exponents varied from 0.06 to 0.42 considering frequencies of impingement from 33 to 100 Hz and cumulative erosion from 30 to 500 m^3. The value of the exponent decreases as the cumulative erosion increases. The velocity exponent (between 3 to 6) reported by earlier investigators for venturi and water tunnel was obtained after 1000 mm^3 cumulative erosion. From the results, it is necessary to identify new scaling parameters which are not influenced by the intensity of erosion.

7 CONCLUSIONS

In case of erosion tests with jets, erosion starts with a peak, in comparison with venturi and rotating disc where several peaks are observed. The peak rate of erosion and a hole piercing through the specimen do not occur at the same cumulative erosion. The effects involved with cavitation inducers of 4.5, 5.5 and 6.5 mm diameters indicate a variation of exponent from 0.12 to 6 and the exponent value decreases as the cumulative erosion increases. The values indicate that the scaling laws are very sensitive in view of the unsteady nature of erosion in rotating components and more extensive experimental data are necessary.

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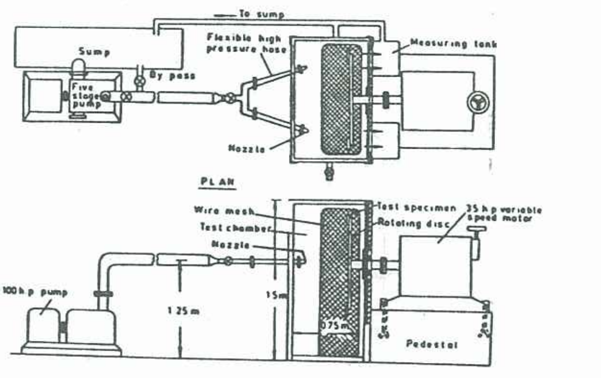

FIG. 1 - LIQUID JET IMPINGEMENT TEST RIG

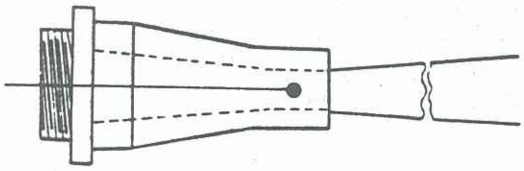

FIG. 2 . NOZZLE WITH CAVITATION INDUCER

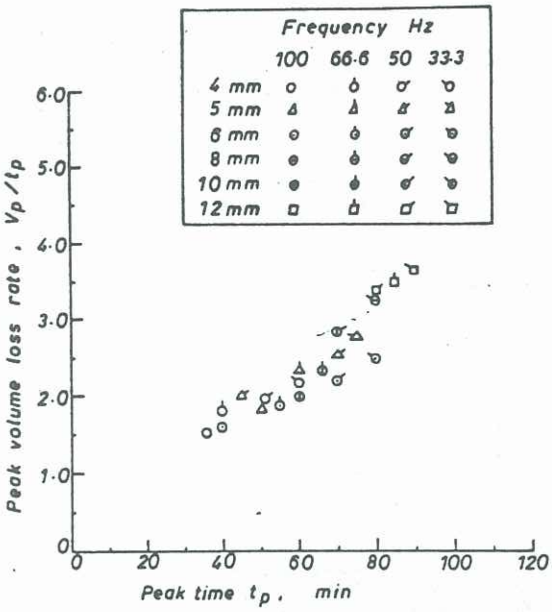

FIG. 3 - VARIATION OF PEAK VOLUME LOSS RATE WITH PEAK TIME

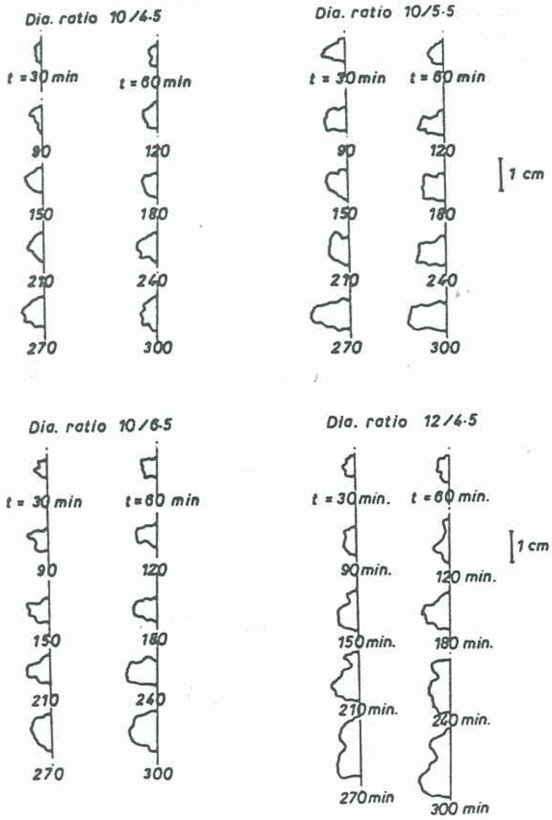

FIG. 4 - GROWTH OF AREA OF EROSION WITH TEST TIME U_o = 25 m/sec

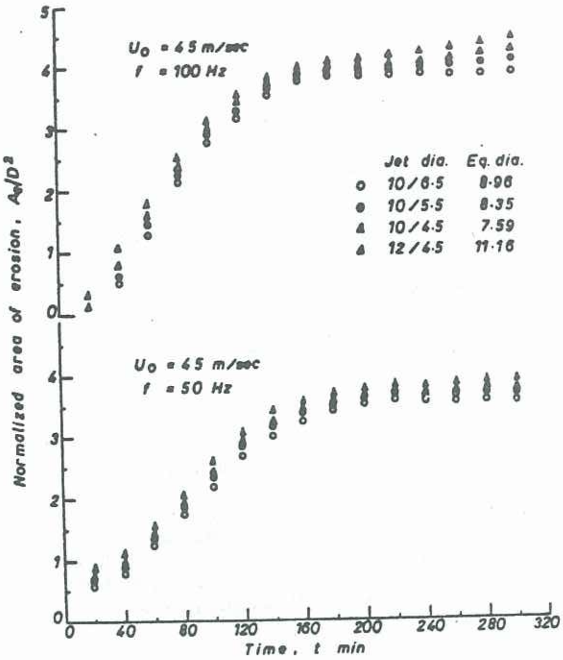

FIG. 5 - VARIATION OF AREA OF EROSION WITH TEST TIME

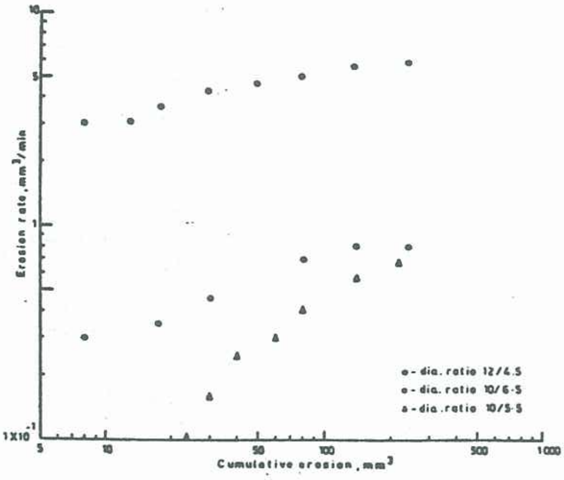

FIG. 6 - VARIATION OF EROSION RATE WITH CUMULATIVE EROSION

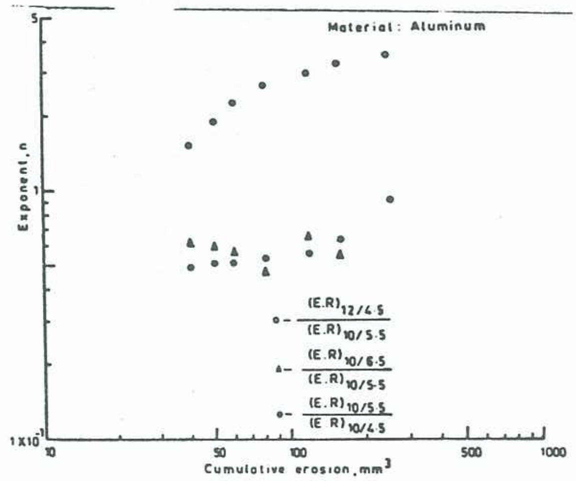

FIG 7 SIZE SCALE EFFECT IN JET IMPINGEMENT DEVICE