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CAVITATION EROSION OF A STATIONARY SPECIMEN OSE PROXIMITY TO AN OSCILLATING SURFACE

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ABSTRACT

As a part of a broad program to investigate the resistance of materials to damage by rain erosion, a study has been made of the feasibility of using a vibratory cavitation facility to rank materials for erosion resistance. A cavitation facility has been modified to accept a stationary specimen so that brittle materials, such as ceramics, can be tested. The results of initial tests on this facility are presented. These results demonstrate the dependence of the erosion damage on the vibrator-specimen separation as well as the fluid temperature and purity.

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Introduction

It has been suggested on a number of occasions that the basic mechanisms of cavitation erosion and impact erosion are very similar (1,e.g.). In the past, jet impact tests have been used to rank materials for cavitation resistance (2). However, the development of ultrasonic facilities has led to a rapid and convenient method for the determination of cavitation damage with a result that it is now desirable to investigate the feasibility of using this type of facility to rank materials for impact erosion resistance. This desirability is indicated by the relatively expensive nature of conventional rain erosion tests (whirling arm or rocket sledge) as compared with the ultrasonic cavitation test.

Owing to the brittle nature of many materials which are of interest in the field of rain erosion, it would be difficult to mount material specimens on an ultrasonic horn as is done in the conventional cavitation test. This has led to consideration of the feasibility of a test facility having a stationary specimen mounted in close proximity to the oscillating tip of an ultrasonic horn.

Such a feasibility investigation comprised the first part of the present investigation and was followed by tests to determine the influence of some of the important test parameters. In this latter context, the effect of the separation distance between the specimen and the horn on the damage was of primary importance.

Test Equipment

The major part of the test equipment used for this study consisted of the ultrasonic cavitation facility available in this laboratory (3,4), modified to permit testing of stationary specimens. The ultrasonic horn was operated at a resonant frequency of 20.5 kc/s with a double amplitude of 0.002 inch. The existing equipment was modified by the addition of a plexiglass specimen holder suspended by three stainless steel supports (Figures 1,2), so as to accommodate the stationary specimens. The distance between the specimen and the tip of the horn was was varied by the use of shims, ranging in thickness from 0.001 inch to 0.010 inch, placed between the specimen holder and the shoulders of the supports.

Test Specimens

1100-0 aluminum was chosen as the specimen material for this study so that rapid results could be achieved. Plate stock, 0.25 inch thick, was polished with jewellers rough and a buffing wheel, before being cut up into individual specimens, 0.6 inch square. Figure 3 shows a dimensional drawing of a test specimen.

Test Procedure

Figure 3 shows a schematic of the test set up. The horn tip used in this study was a standard 304 stainless steel, 0.562 inch diameter, test button. The specimen to be tested was clamped into the specimen holder. The distance between specimen and horn tip was measured with a thickness gauge to an accuracy ± 0.001 inch. This distance was varied by the addition or removal of shims between the specimen holder and the supports as previously mentioned. After the apparatus had been completely assembled, the horn tip and specimen holder were immersed in the test fluid as shown in the schematic, Figure 2. For this series of tests, ordinary tap water, at room temperature, was used as the test fluid. No device for temperature control was employed.

The major objective of this study was to determine (a) the overall feasibility of the test procedure, and (b) the effect of the separation distance between specimen and horn tip on the damage rate. Tests were carried out at a number of separation distances ranging from 0.100 inch to 0.005 inch. Test durations varied from a few seconds to one hour. It was noted that the cumulative damage was not significantly affected by the periodic interruption of testing in order to make measurements.

The damage is reported both as mass of material removed and accumulated mean depth of penetration (M.D.P.), for one hour duration.

$$M.D.P. = \frac{M}{\rho A}$$

M = mass of material removed
ρ = density of material
A = area of damaged surface

Test Results

1) Damage vs. Distance

Since 1100-0 aluminum is a relatively soft and weak material, observable damage is produced in a relatively short test. Thus, exposure for 60 min was sufficient to secure the necessary data for the mass of material removed as a function of separation distance. This data is plotted in Figure 4, and also presented in Table 1. Figure 5 shows M.D.P. vs. distance of separation for 1 hour test duration. It should be noted that the damage rate is a strong function of separation distance with maximum damage occuring at 0.018 inch. The maximum damage for 1100-0 aluminum was found to be 62.78 mg in one hour. This is approximately twice the average damage for 1100-0 aluminum as reported by Garcia (3) for specimens tested by the conventional vibratory cavitation method, i.e., as a vibrating specimen in an open geometry at the same frequency and amplitude of vibration..

Consideration of the feasibility of a test operated at the maximum damage condition shows that an uncertainty of $\pm$0.001 inch in the separation distance would result in an uncertainty of less than $\pm$ 2% in the damage.

These results may be compared with those of Endo (5) who used a similar apparatus but with a resonant frequency of 22 kc/s* whereas the frequency used in this study was 20.5 kc/s. Endo reported a similar damage vs. distance curve, but found maximum damage occurring at a distance of 0.008 inch as opposed to 0.018 inch as in these tests. Endo also conducted an investigation of the variation of temperature near the surface of the specimen, with separation distance. He reported a curve of temperature vs. separation distance which is similar to that of damage vs. separation distance.

The variation of cavitation damage with temperature in a conventional, oscillating specimen, ultrasonic cavitation test has been measured on a number of occasions (4,e.g.). The similarity between the temperature at which maximum damage occurs in such tests, and the maximum temperature reported by Endo, is notable. These considerations suggest that some part of the variation of damage with separation distance is due to the associated thermal effect. However, the fact that the maxima of temperature and damage occur at different separation distances (0.005 inch and 0.008 inch respectively) indicates that this is not the only effect. It is

*This relatively similar test reported in the A.S.M.E. Journal of Basic Engineering, was not discovered until our own program was largely complete.

presumed that the reduced damage at small separation distances may be partly due to the fact that at these conditions the proportion of the volume enclosed between the specimen and the horn, which is occupied by vapor bubbles is large, thus introducing significant compressibility effect. The close clearance may also prevent the growth of bubbles to a size which is most damaging.

2) Damage Pattern vs. Distance

The damage pattern was found to be dependent on separation distance as illustrated by Figure 6. At relatively large distances such as 0.100 inch, the damage is contained in a circle of radius 0.25 inch with greatest damage occurring at the center. As distance from the horn is decreased, the damaged area becomes larger until its diameter reaches that of the horn tip (0.562 inch dia.). At distances in the vicinity of 0.025 inch, the initial damage (10 min test duration) occurred around the perimeter of the damage circle instead of at the center as with the greater distances. The increase in the diameter of the damaged zone as the separation distance is reduced is to be expected since theoretical consideration (6) show that in the absence of compressibility effects, the magnitude of the pressure fluctuations varies inversely as the cube of the separation distance and directly as $(r^2 - R^2)$ where r is the coordinate in the radial direction and R is the radius of the horn tip. Thus, as the separation distance is reduced, the pressure fluctuation increases sufficiently to cause cavitation out to greater radii. The concentration of the damage towards the outer edge of the damaged zone at small separation distances may be due to the effect of small clearances on the cavitation bubble dynamics, as discussed previously with regard to total damage. Such effects would be expected to be most important near the center of the damaged zone.

An interesting damage pattern was observed at a separation distance of 0.054 inch (Figure 7). In this case, the damage was circular with radial flutes. These flutes are also observed on specimens cavitated by the conventional vibratory method. Photomicrographs were taken of a sample exposed for 10 s at 0.018 inch. Figure 8 shows center, mid-radius and perimeter damage at a magnification of 100X.

3) Fluid Temperature Effects

As mentioned previously, no device for controlling the temperature of the fluid was employed in these tests. It was found that the fluid with an initial temperature $75^{o}F$ experienced a temperature rise of approximately 6 Deg F during a 15 min test period. Figure 9 shows a graph of temperature against time, but it must be noted that this time does not include those periods during which the specimen was removed for the measurement of damage (after 15 min and 30 min).

A test was also made to determine the effect on the damage of using a temperature control device. The temperature of the fluid was held at $75^{o}F$ throughout a 60 min test. It was found that the damage at 0.018 inch separation decreased by about 25% when the temperature of the fluid was held constant. Figure 10 shows the variation of damage with time both for the controlled temperature case and for the uncontrolled case. Curves of damage vs. temperature obtained in conventional cavitation tests (7) show about a 25% change in damage between a temperature of $75^{o}F$ and one of $95^{o}F$. The temperature effect in the present tests thus appears to be rather stronger than in the conventional tests because the mean temperature difference between the two tests shown in Figure 10 is only about 12 Deg F.

4) Tap Water vs. Distilled Water

A test was made to determine the effect on the damage of using distilled water as the cavitating fluid. The damage was found to be about 15% greater with distilled water than with tap water. In order to check that this was not due to uncertainties in individual tests, this comparison was made twice. The results of the two comparisons agreed with one another within 5%, thus, discounting the possibility that the apparent difference between tap water and distilled water was due to experimental inaccuracy. The data are shown in Figure 11.

In a further test, a bottle of tap water was allowed to stand for several days to allow the entrained air to escape. A comparison of the damage sustained in this fluid with that sustained in distilled water still showed a difference in the same direction of about 15%. Care must, however, be taken in concluding from this that entrained air is not responsible for the difference, because the air contents of the fluids were not measured. It is possible that the entrained air does not escape from the stagnant tap water because it is adhering to the solid impurities present in that water.

Plans for Future Work

This study has demonstrated the feasibility of the stationary specimen concept in ultrasonic cavitation testing with soft specimens. It is proposed to continue the work with the examination of the erosion characteristics of harder materials such as ceramics which are of interest in the rain erosion program. The present study has, however, also shown up a number of aspects of the test procedure on which further data are required.

It is proposed to continue the study of the differences between tap water and distilled water with particular reference being paid to the measurement of the air content of the water (using a Van Slyke apparatus). It is also proposed to continue the investigation of thermal effects, particularly the surveying of the temperature field between the specimen and the tip of the horn.

All the damage data obtained in the present tests are in the form of total damage, without reference to its distribution over the damaged area. Studies are in hand to determine also the distribution of the damage so that data on the local damage per area may be obtained.

Conclusions

A facility to enable ultrasonic cavitation tests to be carried out using a stationary specimen has been develope. The main characteristics of this facility have been measured and the feasibility of using it for the determination of the cavitation erosion resistance of materials of interest in rain erosion studies has been established. The separation distance between the specimen and the ultrasonic horn required to produce maximum damage has been found to be 0.018 inch and the feasibility of operating at this condition has been established. The rate of damage at this optimum condition is approximately twice that in a conventional ultrasonic cavitation test. Significant changes in the damage rate attributable to changes in the purity of the test fluid and/or changes in the thermal condition of the test, have been found, but the detailed mechanism of these effects is not yet understood.

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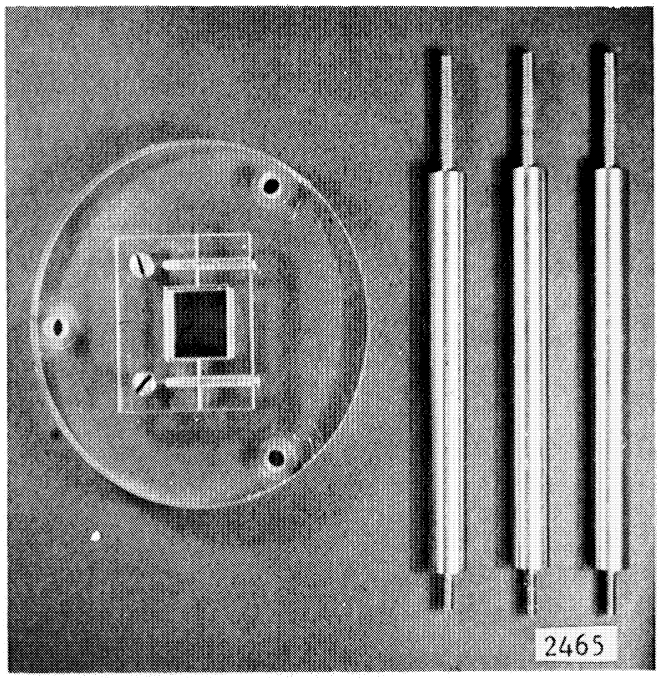


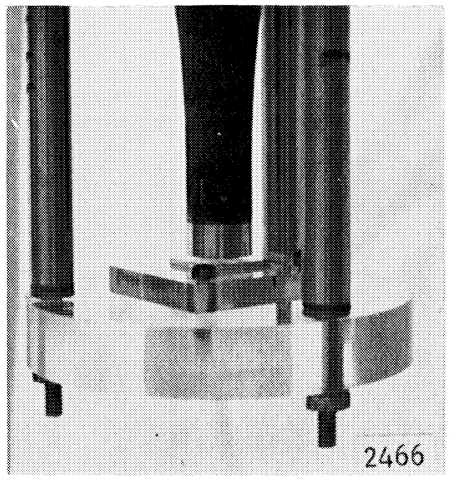


Fig. 1.--Photographs of specimen holders and supports.

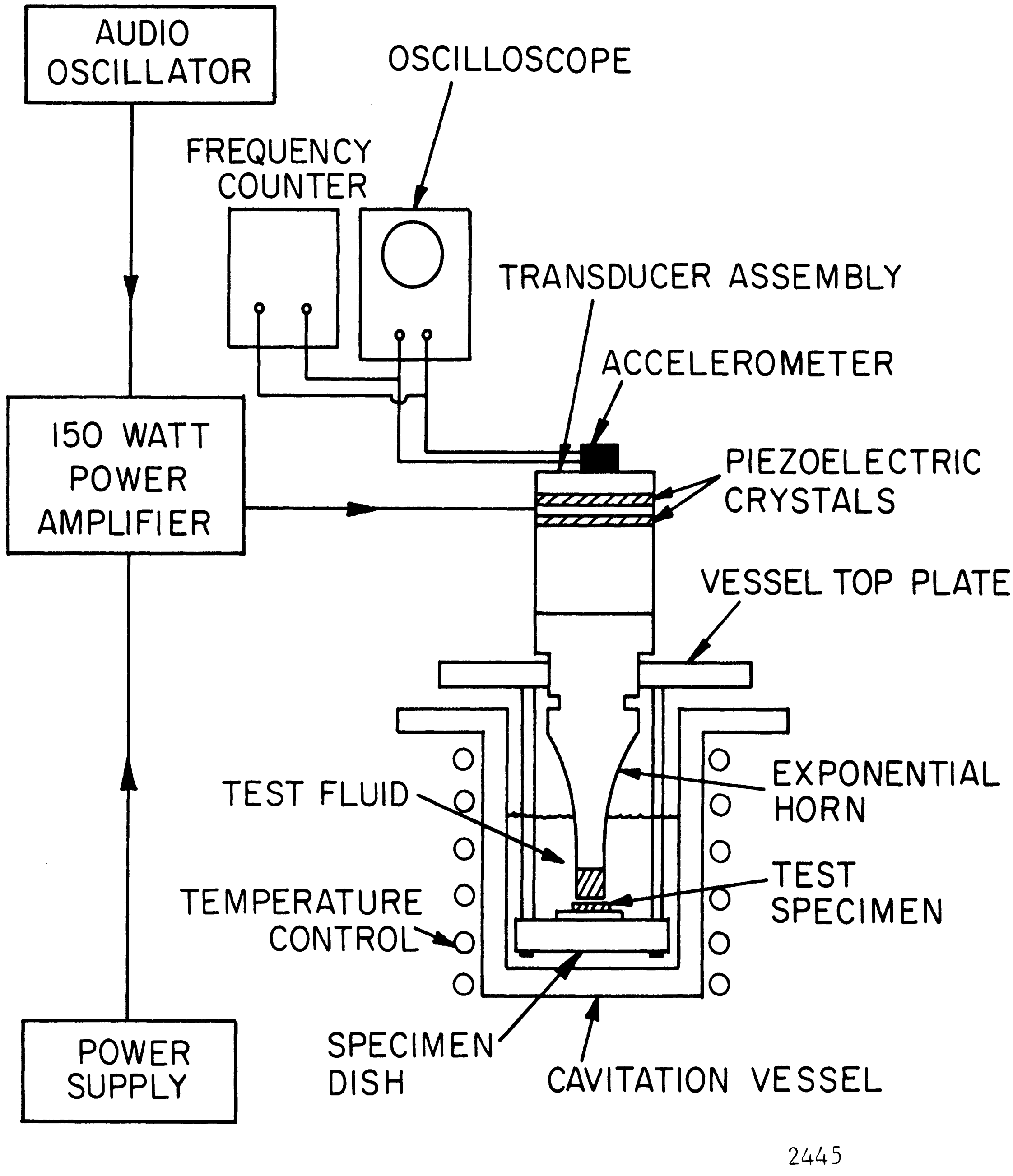


Fig. 2.--Schematic view of test facility.

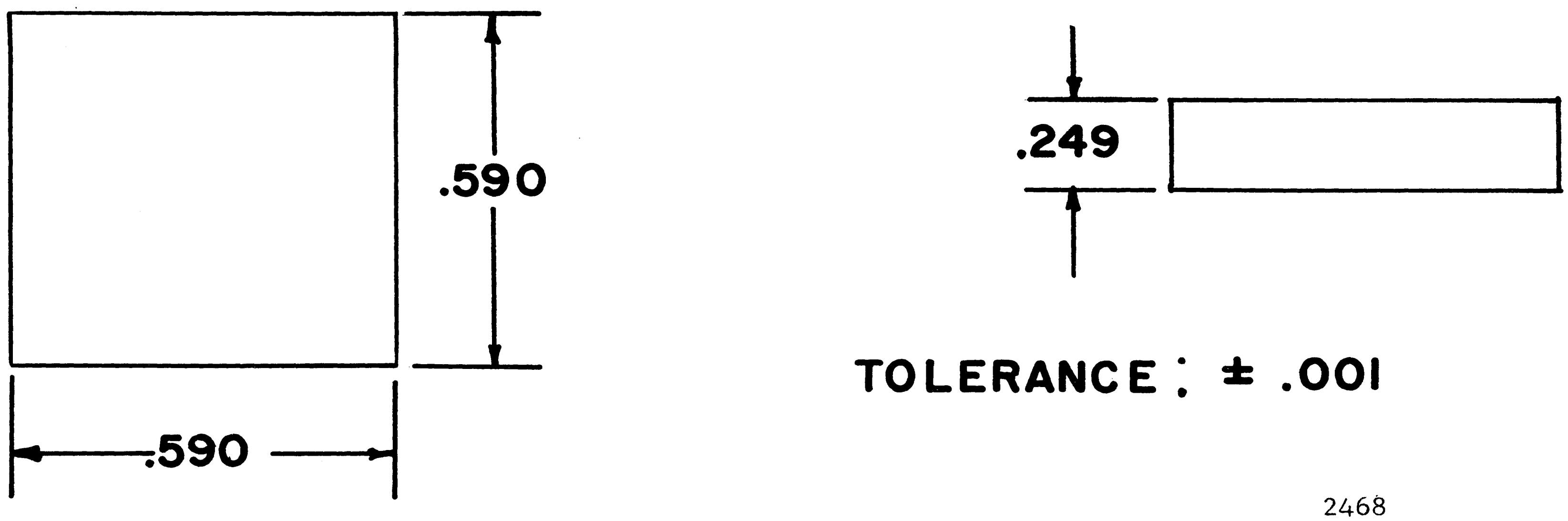


Fig. 3.--Drawing of test specimen.

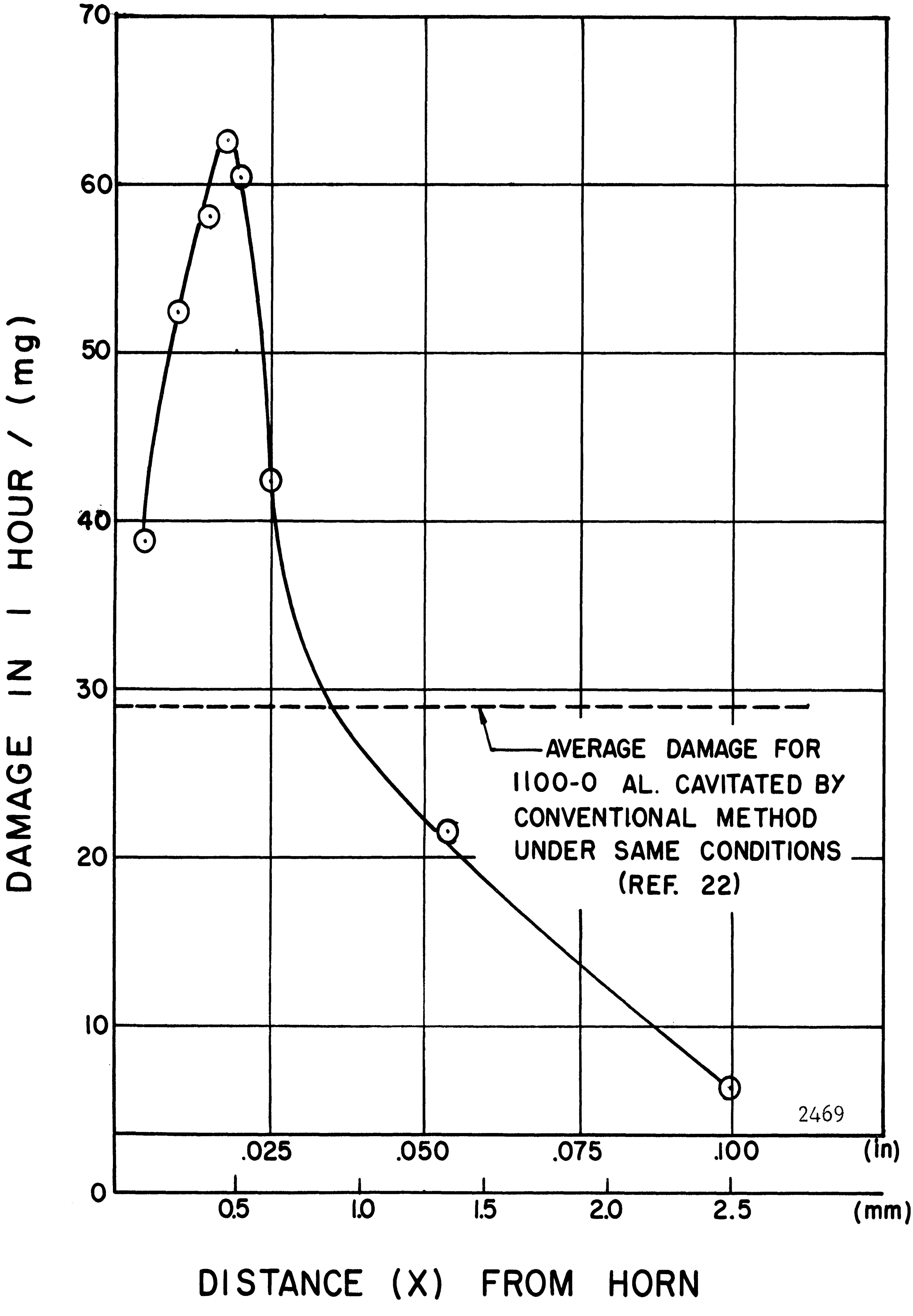


Fig. 4.--Damage vs. separation distance.

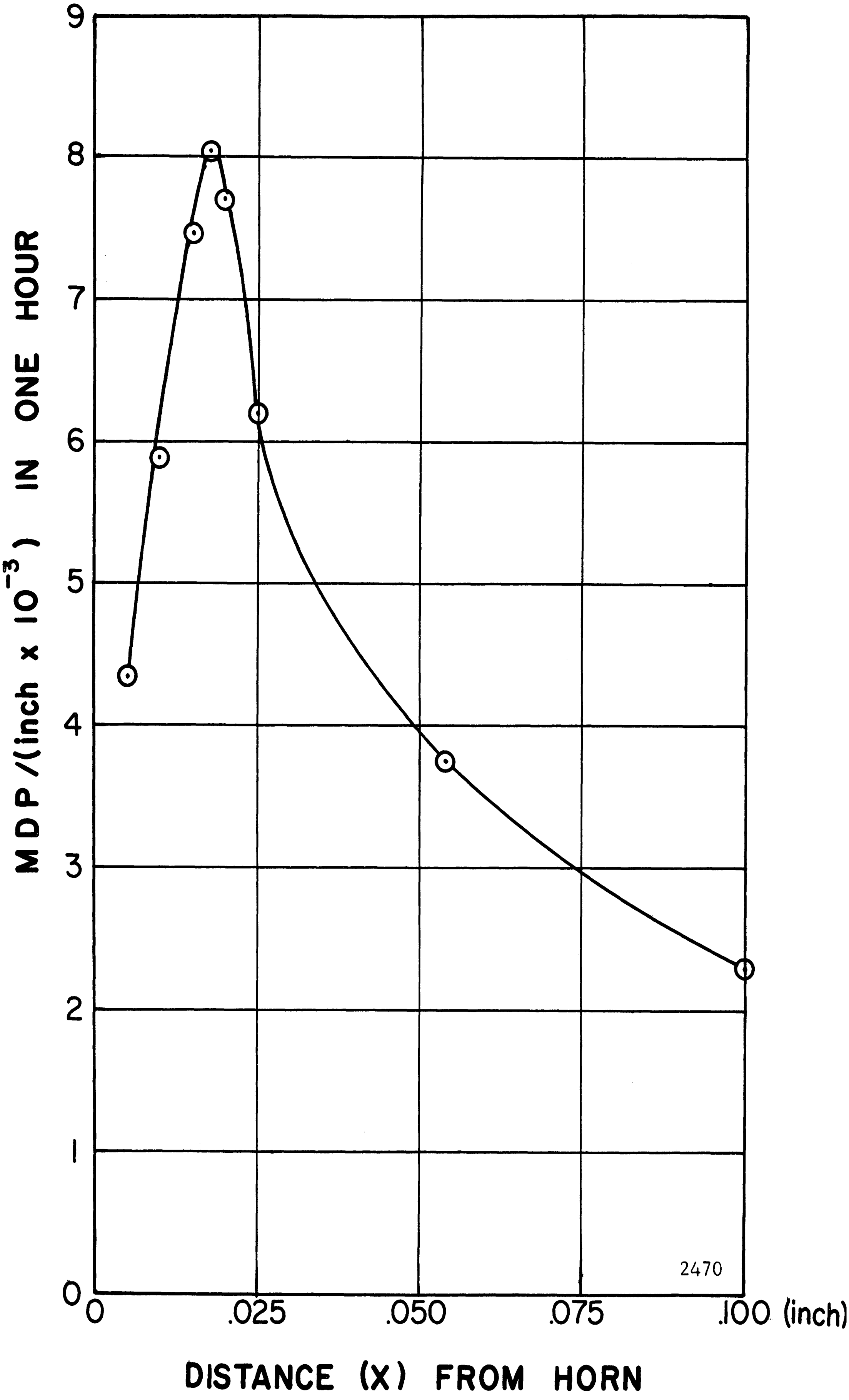
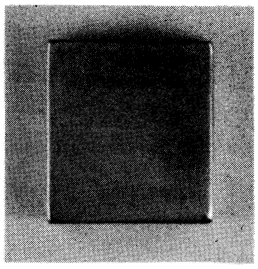
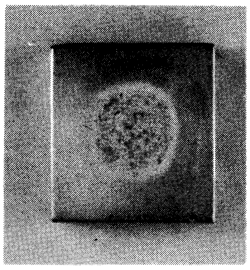


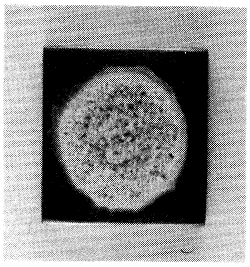
Fig. 5.--MDP in one hour vs. separation distance.



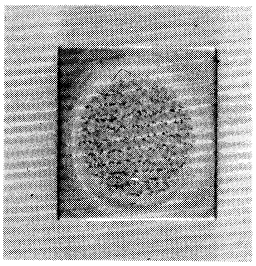
X=0.240 inches
(6.09 mm)



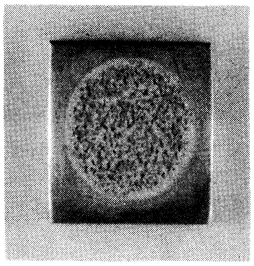
X=0.100 inches
(2.54 mm)



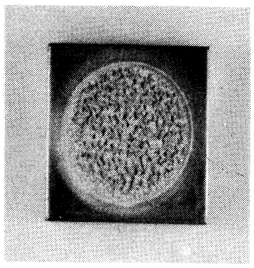
X=0.054 inches
(1.37 mm)



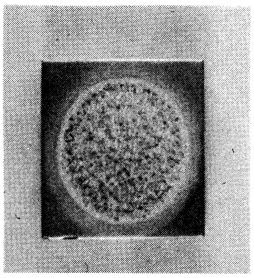
X=0.025 inches
(0.635 mm)



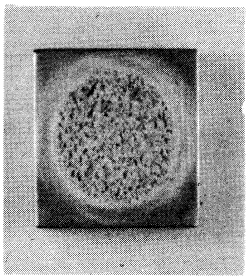
X=0.020 inches
(0.508 mm)



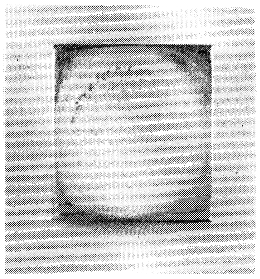
X=0.018 inches
(0.457 mm)



X=0.015 inches
(0.381 mm)



X=0.010 inches
(0.254 mm)



X=0.005 inches
(0.127 mm)

2447

Fig. 6.--Photographs of damaged specimens at various separation distances.

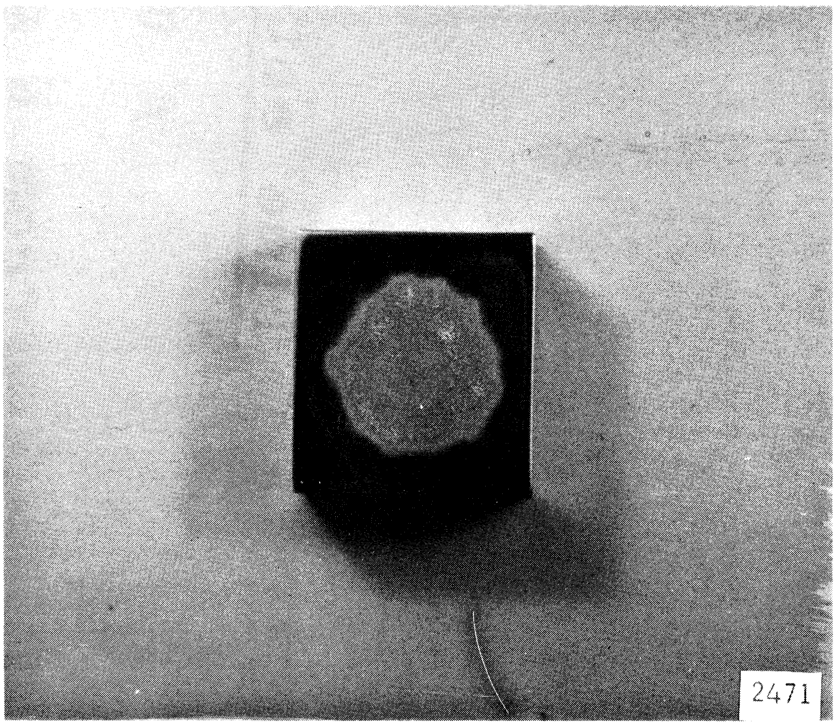
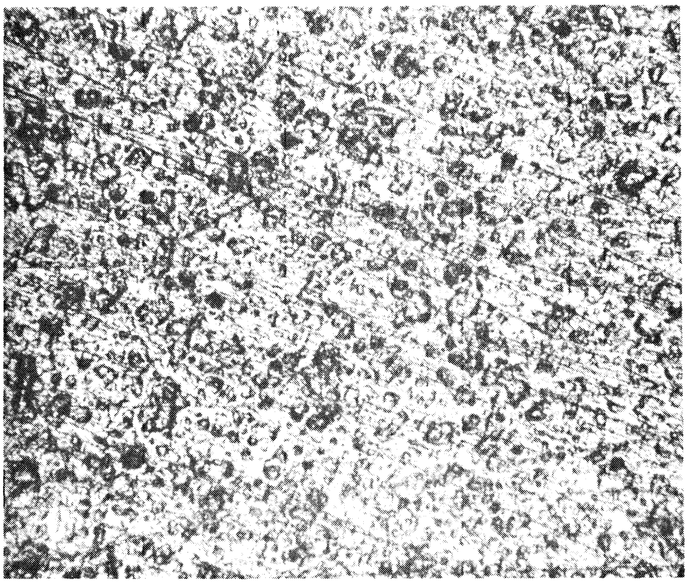
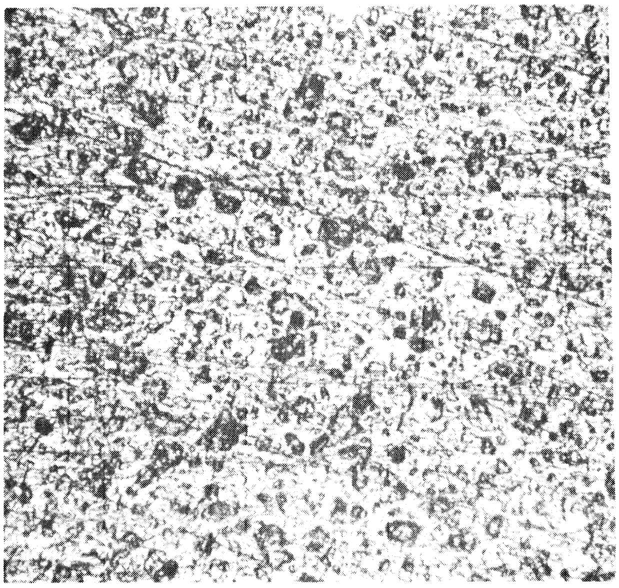


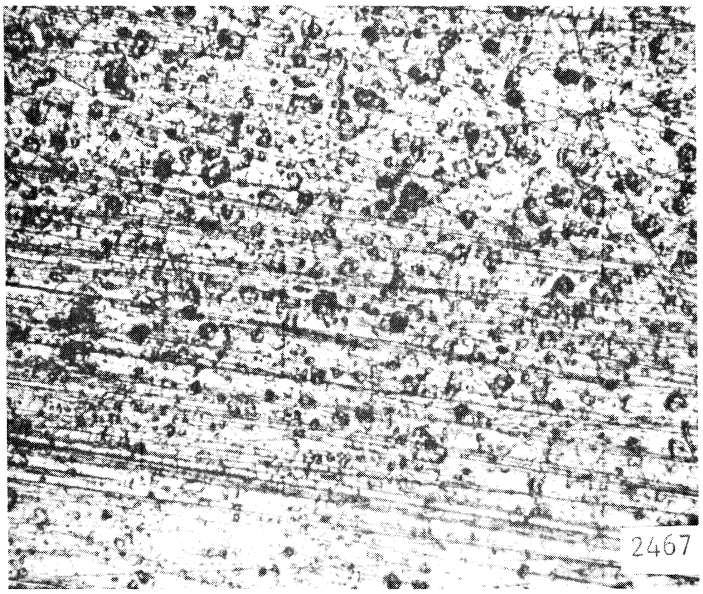
Fig. 7.--Photograph showing details of damage at 0.054 inch separation after 10 min exposure.



center



mid-radius



perimeter

Fig. 8.--Photomicrographs of specimen damage at different positions on the damaged surface after 10 s exposure at a separation distance of 0.018 inch(magnification 100X).

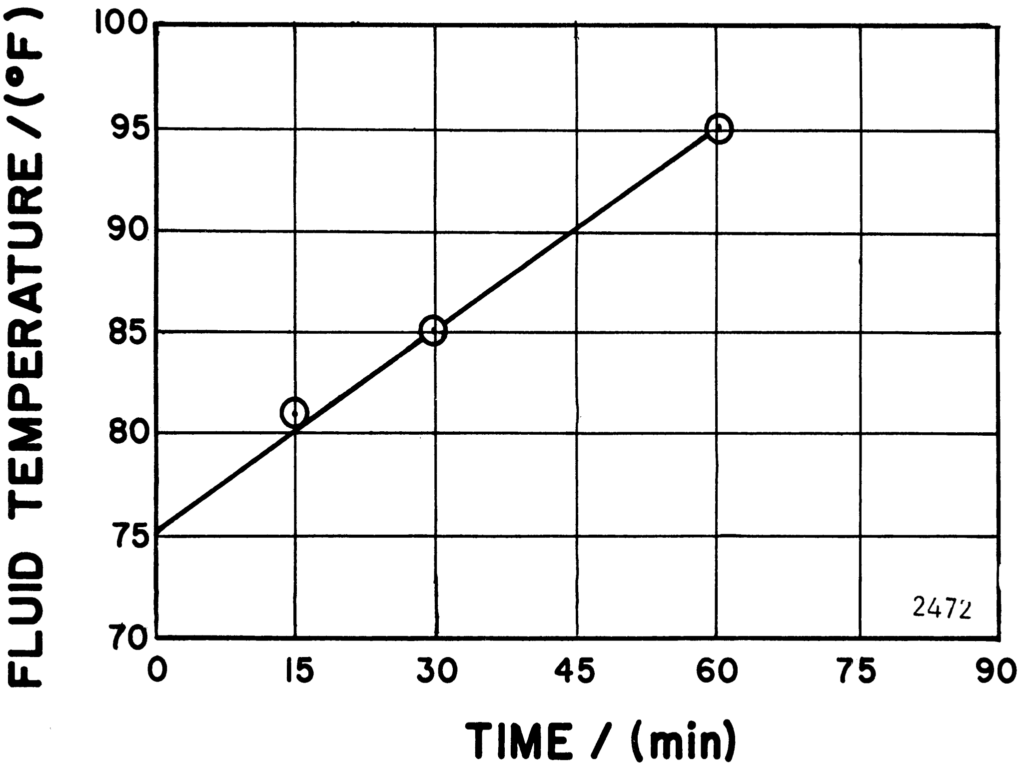


Fig. 9.--Temperature of test fluid vs. time; no cooling.

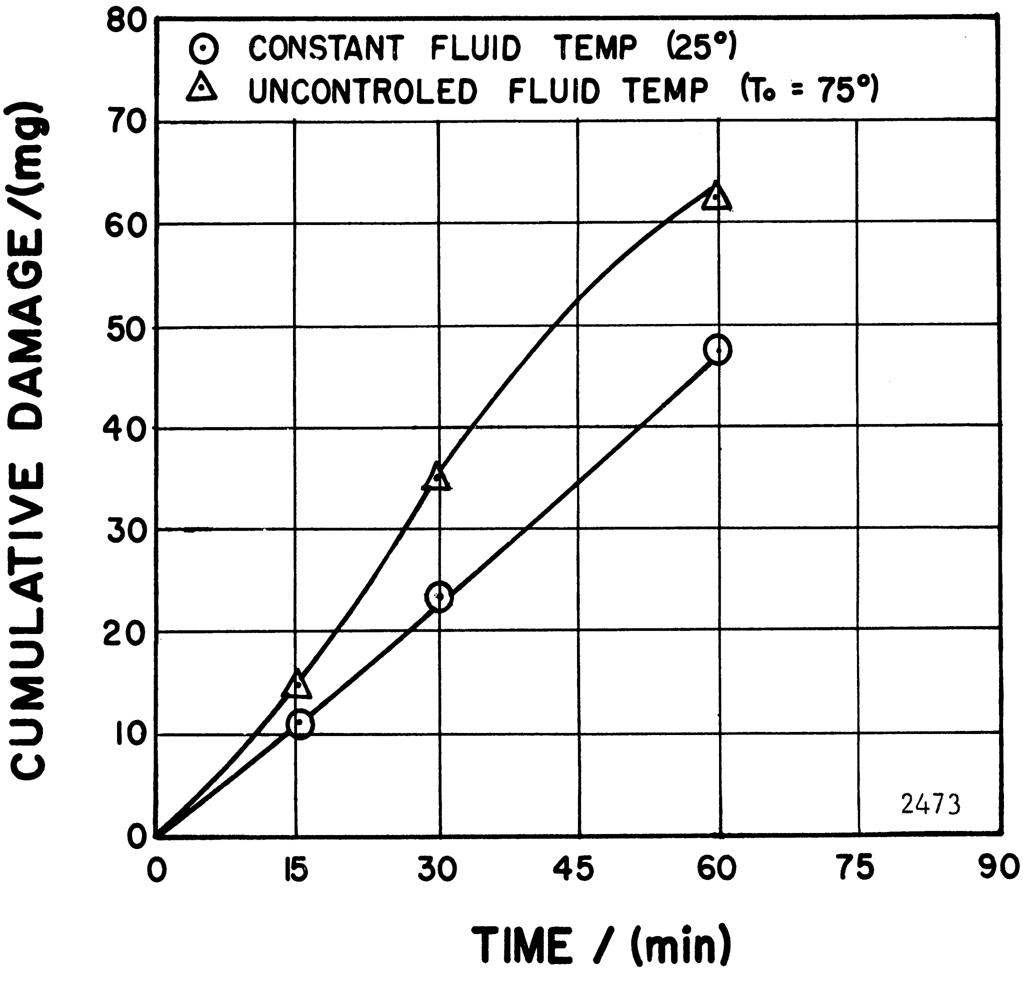


Fig. 10.--Damage vs. time for constant test fluid temperature and uncontrolled test fluid temperature.

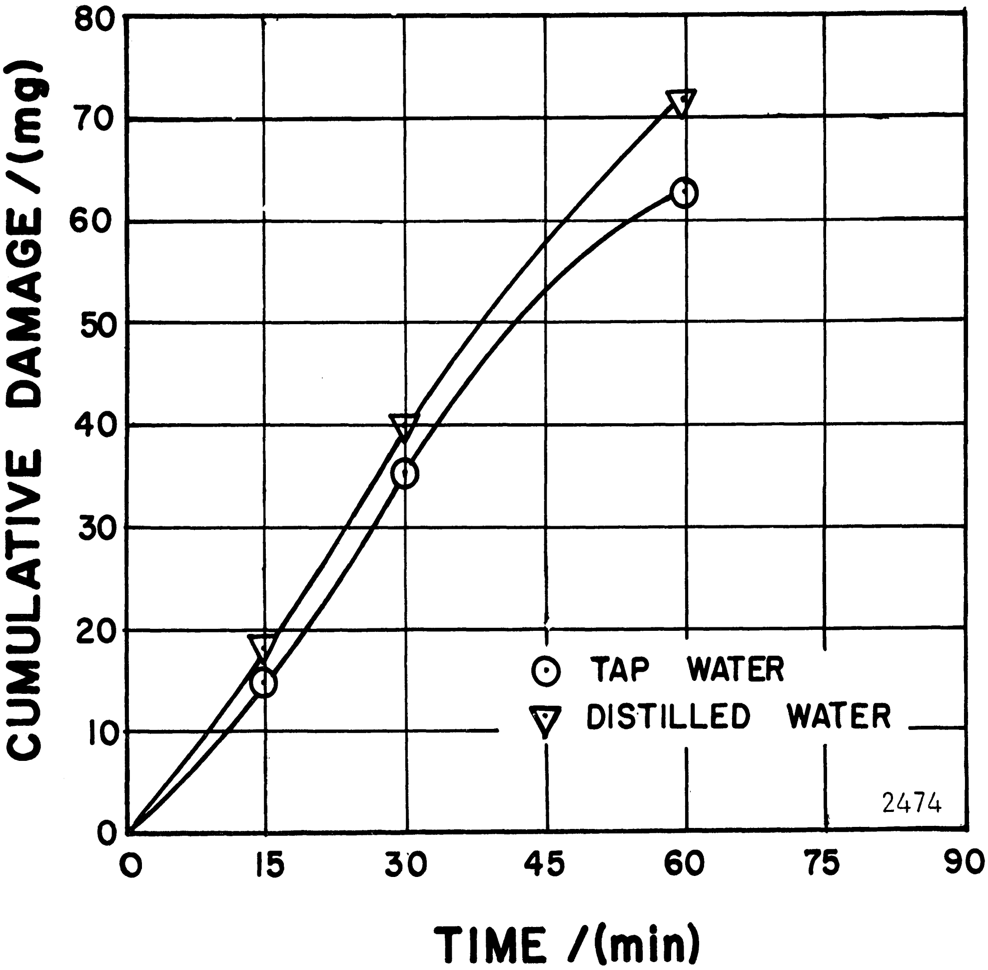


Fig. 11.--Damage vs. time for tap water and distilled water, 0.018 inch separation.

TABLE I

Damage vs. Separation Distance

Separation Distance/(inch)	Damage in One Hour: Material Removed/(mg)	Damage in One Hour: M.D.P./(inch x 10^{-3})
.100	6.46	2.30
.054	21.97	3.75
.025	42.25	6.22
.020	60.36	7.74
.018	62.78	8.06
.015	58.24	7.49
.010	52.44	5.90
.005	38.75	4.36