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CAVITATION DAMAGE AT ELEVATED TEMPERATURE AND PRESSURE

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by

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Most past studies of cavitation damage have been performed at room temperature, in water. and at about atmospheric pressure. However, very often cavitation damage in the field occurs in regions where the pressure is many atmospheres, where the temperature is elevated, and in a growing number of cases, with fluids other than water. The present study considers cavitation damage produced in a vibratory device over a broad range of temperature and pressure and including fluids other than water, although the new data herein discussed is primarily with water at high temperature and pressure. In the field, cavitation damage is encountered at high pressure but room temperature in water in high-head pumps used in pumped-storage plants as boiler feed pumps, etc.; it is encountered at high pressure and high temperature in other boiler feed pumps, boiler circulating pumps both in nuclear and conventional plants, etc. For fluids other than water at various temperatures and pressures, it is encountered with liquid metals in nuclear reactor pumps, in liquid propellant rocket pumps, aircraft fuel pumps, etc.

From the viewpoint of theoretical expectations, increased pressure or temperature involve conflicting mechanisms which might be expected to either increase or decrease damage. For example, an increase in suppression pressure would surely diminish the number of bubbles, size of cavity, etc., thus reducing damage, but on the other hand the collapse violence for those bubbles which do exist would be increased, so that damage might increase. An increase in temperature, from a temperature near the freezing point to a moderate range appears experimentally to increase damage for various not-completely understood reasons; a further increase in temperature for constant suppression pressure should reduce damage through the increased action of thermal restraints, but on the other hand damage might increase in some cases through the weakened resistance of materials at high temperature.

The present paper reports primarily new results obtained in a vibratory cavitation damage faciltiy (20 kHz, 2 mil) upon a single steel alloy in water for temperatures ranging from room temperature to about $300^{\circ}F$ and for pressures up to about 100 psig, giving a suppression pressure (NPSH x ρ)[*] at the maximum temperature of about 3 atm. To our knowledge, this is by a wide margin the highest temperature water damage data yet reported from a vibratory facility, and also the highest pressure data, though we reported previously (1, e. g.) similar data at a similar suppression pressure but lower temperature. In the present paper, this older data has been combined with previous data earlier obtained in our laboratory to allow a mapping of the probable effects of temperature and pressure variation up to about 350°F and 170 psig, upon cavitation damage in this type of test. The comparison is made by normalizing the steel data to the brass data at a common test point. The possible application of this type of data to field devices, where a broad range of pressures and temperatures may be encountered, is obvious. The present results are summarized in Fig. 1, 2, and 3.

Fig. 1 shows the effects upon maximum volume loss rate (MDPR)[**] in our vibratory damage facility (20 kHz, 2 mil) in water, primarily upon bearing brass (SAE-660), of increasing temperature up to 250°F at various constant suppression pressures up to 3 atm., as previously presented (1). An abscissa in terms of vapor pressure, more directly involved mechanistically, is included. New higher temperature data, obtained subsequent to ref. 1, has now also been included, which allows an extrapolation of the curves to about 350°F and 130 psig vapor pressure, for suppression pressures to about 4 atm. In addition, curves of constant subcooling are included, and the locus of the maximum damage temperature is shown, This temperature increases from about 120°F for a 1 atm. test to about 200°F for 4 atm. suppression pressure.

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[*] Fig. 1 is based on full surface area, so MDPR and volume loss rate are in direct proportion at all times.

[**] NPSH = Net Positive Suction Head = $(p - p_v)/\rho$ in vibratory facility for these tests.

Fig. 2 shows the same results in a somewhat different format, more convenient perhaps for heat transfer engineers, i.e., in terms of curves of constant sub-cooling. Here maximum MDPR is plotted against NPSH. In these terms, it is shown that damage maximizes at an intermediate NPSH for any given sub-cooling. Fig. 2 also shows the detailed difference in results created by basing MDPR (mean depth of penetration rate) upon whether full surface area, or an estimate of the area noticably damaged (which depends upon suppression pressure, i.e., NPSH). This effect is shown in Fig. 3, where it is noted that the percent area damaged decreases from about 90% (at 1/3 atm. NPSH) to about 40% at 3 atm. NPSH. This effect was also noted and explained in ref. 1 by the fact that the vibration-induced pressure oscillation reduces from a maximum at the center of the specimen to near zero at the outer edge. While only a relatively small "undamaged rim" exists in the usual open beaker test, this "rim" becomes much larger for the high pressure test.

The above effect of varying NPSH upon increase of "undamaged rim" area has also been observed here in 1 atm. tests with fluids of widely differing density (2,3), wherein fluids with density ranging between 13.5 (mercury) and 0.5 (molten lithium) were tested. It can also be discerned, in results by Young and Johnston at NASA (4), for tests on sodium at differing temperatures and pressures.

Conclusions

1) Appreciable cavitation damage rates exist in water up to at least 350^{o}F and 4 atm. NPSH, in a 20 kHz, 2 mil vibratory facility. However, damage decreases strongly with decreasing NPSH, as also reported ref. 4 and 5.

2) The general effects of temperature upon damage rate experienced in the open beaker test extends to considerably higher temperatures and pressures, with the maximum damage temperature increasing somewhat with the increased NPSH.

3) Increased NPSH causes a strong increase of damage in this type of facility up to at least 4 atm. NPSH. Obviously, damage must maximize at some higher NPSH and then decrease to near zero, since the number and size of bubbles decreases with increasing NPSH (though their collapse violence increases), reaching zero at sufficiently high NPSH, depending upon facility frequency and amplitude.

References

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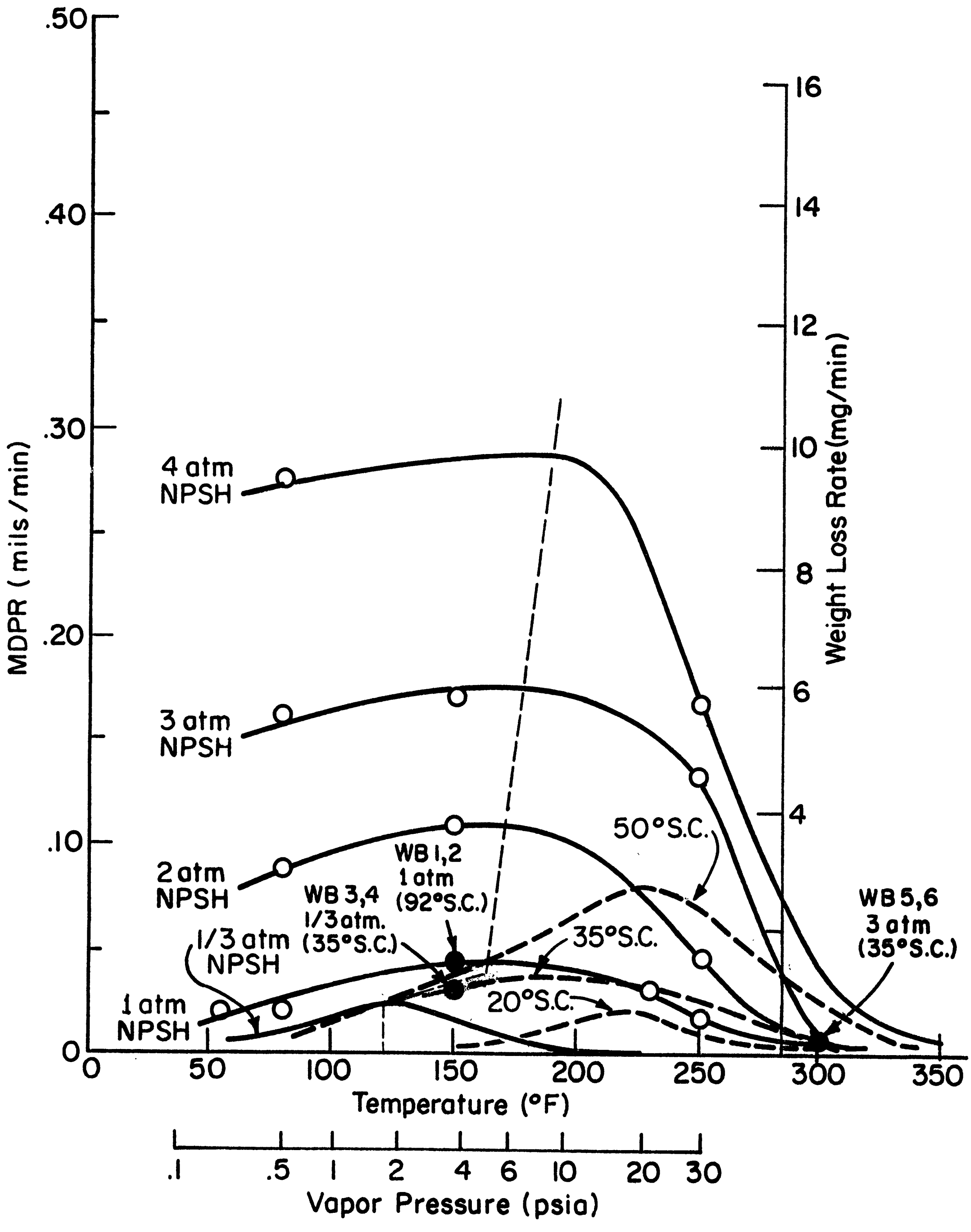
List of Figures

Fig. 1 Max. MDPR vs Temperature and Vapor Pressure for Bearing Brass (SAE - 660)

Fig. 2 Max. MDPR vs. Net Positive Suction Head (ft), Bearing Brass (SAE - 660)

Fig. 3 % Area Damage vs. NPSH (atm)



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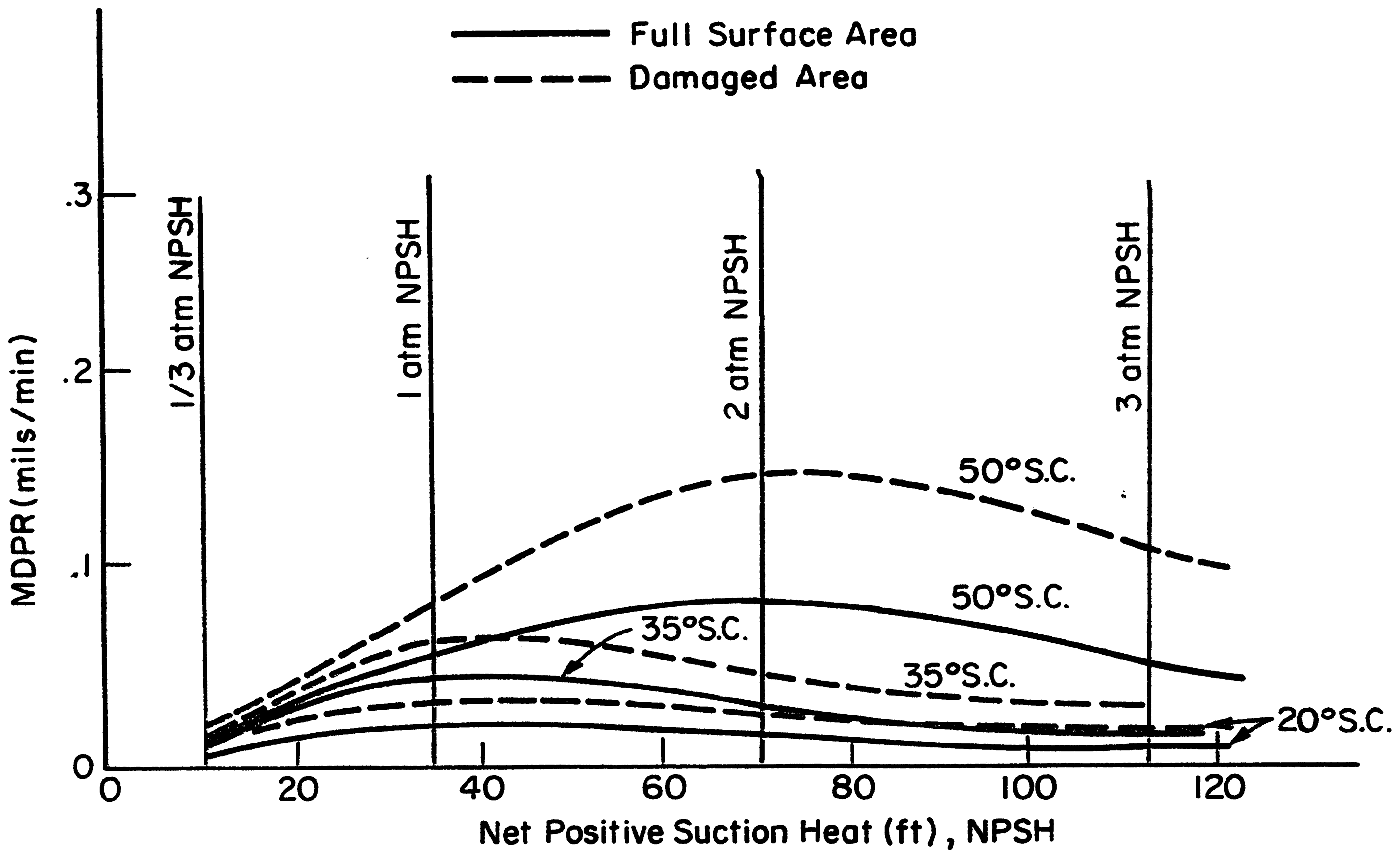

Fig. 2 Mac. MDPR vs. Net Positive Suction Head (ft), Bearing Brass (SAE - 660)

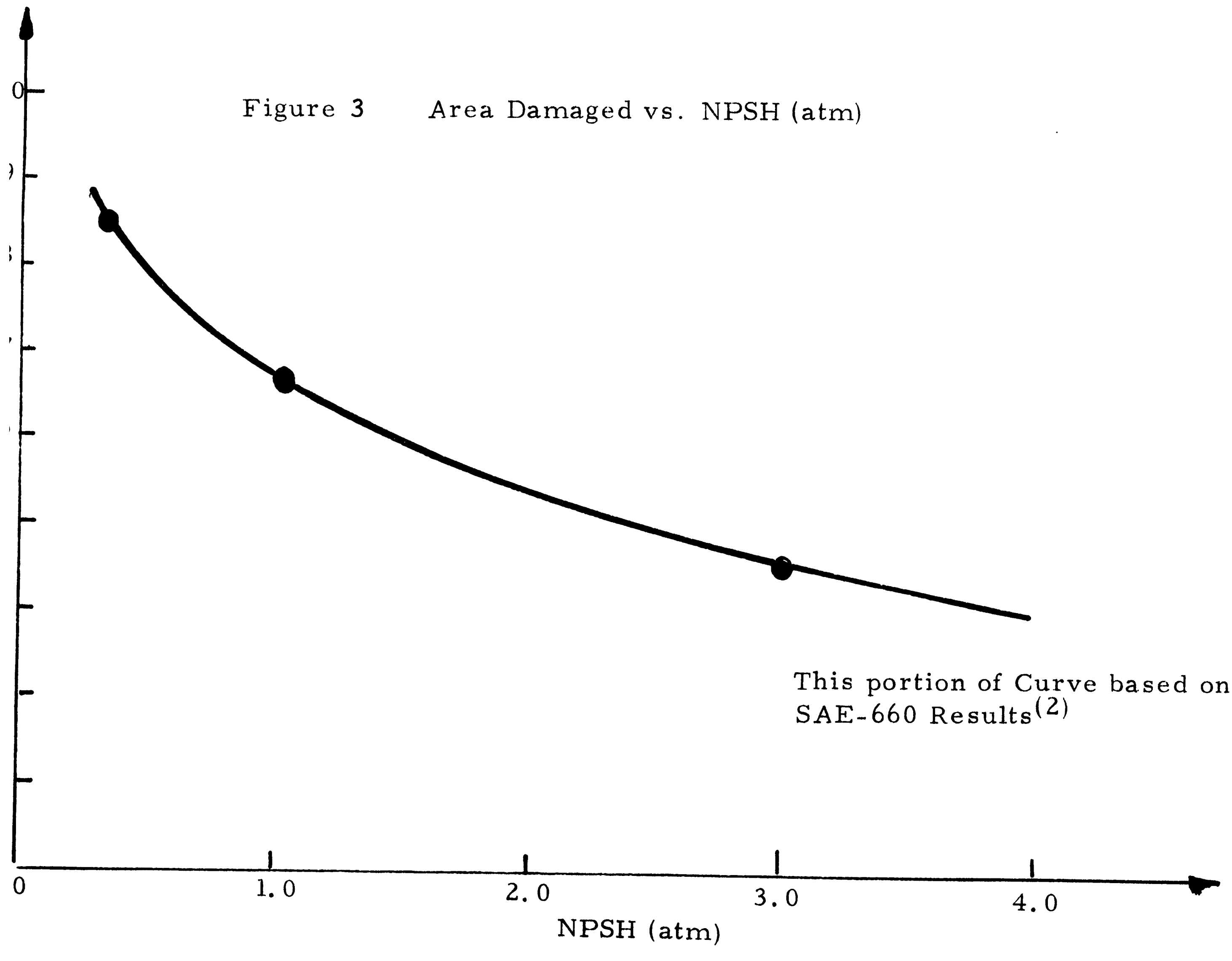

Figure 3 Area Damaged vs. NPSH (atm)