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EFFECTS OF MAGNETIC AND ELECTRIC FIELDS UPON CAVITATION IN CONDUCTING AND NON-CONDUCTING LIQUIDS - RUSSIAN RESEARCH RESULTS

by

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ABSTRACT

Results, primarily of Russian research over last 5 year period, indicating various effects of magnetic and electric fields upon cavitation in both conducting and non-conducting liquids, are reviewed. Measurable effects, particularly upon cavitation damage, appear to exist for all the above cases. However, tests at University of Michigan upon cavitation threshold in salted and tap water and also in mercury indicate no effect of 6kG magnetic field.

I INTRODUCTION

Over the past several years various articles have appeared, by Russian authors, concerning the effects of magnetic and also electric fields on cavitation in non-conducting (1-5) and conducting liquids (6). For both types of fluids, relatively substantial effects are reported, even though they seem unlikely at first glance for non-conducting fluids, as no obvious mechanism seems to exist. On the other hand, for conducting fluids such as liquid metals, important magneto-fluid dynamic effects are certainly possible.

Conceivably, strong magnetic or electric fields could affect cavitation or boiling, either in terms of inception (nucleation) or behavior once fully developed. In terms of cavitation, the imposed fields could affect the growth and distribution of bubbles and bubbly regions, thus affecting such parameters as efficiency, developed head, etc., and also damage phenomena. The Russian research has found effects in all of these areas, as will be discussed in the present document. However, in recent research in our laboratory (7, 8) we have found no measurable effect upon bubble nucleation threshold pressure in a vibratory system for a magnetic field of 6kG in tap water.

Magnetic and electric field effects can be of considerable importance in some fusion reactor concepts, where it is necessary to pump conducting fluids (lithium and/or sodium) through very strong magnetic fields (~50-100 kG). It is of course, also of considerable basic interest if substantial effects of magnetic or electric fields are found upon cavitation or boiling, particularly for non-conducting fluids. The only apparent explanation suggested for such observations (as the Russians have made) is the existance of a strongly ionized layer between vapor and liquid in these fluids. The motion of such an electric charge in a magnetic field would of course, create magneto-fluid-dynamic effects.

The Russian work so far is concentrated in only two groups, both in Moscow. All the work in non-conducting liquids is by K.K. Shal'nev and his colleagues, (1-5), and that on conducting liquids (presumably a liquid metal such as sodium) by Perel'man and Govorskii (6). As far as I know, no similar work has been done elsewhere in the world, except for our own measurement of the effect of a magnetic field on cavitation inception in tap water (7, 8).

II RESULTS ACHIEVED

A. Non-Conducting Liquids

1. Shal'nev and Shalobasov, 1970 (1) The first of these papers, (1), chronologically speaking, is by Shal'nev and Shalobasov, is in English, and was presented at the IAHR Stockholm meeting in 1970. It describes tests in a small water tunnel using tap water, where cavitation is excited by a transverse circular cylinder in a plane-parallel flow in a constant flow area working chamber. The maximum velocity is ~20 m/s . The axis of the magnetic field (7 kG maximum strength, i.e., 0.7 tesla) is parallel to that of the transverse cylinder. This geometry has been used by Shal'nev and his colleagues in numerous previous studies, but without magnetic field. Damage is observed upon plates inserted flush with the working chamber wall behind the exciting transverse cylinder. In the present, as well as various previous studies, soft lead is used as the damageable material, since results are thus obtained with maximum rapidity. In the present study (1) the effects of the magnetic field upon the length and breadth, as well as area, of the eroded region were measured, as well as the damage itself, i.e., mass of material removed.

It was found that both length and breadth of the eroded area, and hence the area itself, were increased with magnetic field, depending upon its strength and the time of exposure. Increase in each of these parameters is ~20 - 30%. The weight loss rate is also increased by the magnetic field (for all values above ~4 kG), especially at the end of the incubation period. Effects on length of incubation period are of ~30 - 50%. There is less effect on the maximum damage rates once established, but still the magnetic field appears to increase damage rates somewhat. In general, the existence of ions on vapor-liquid interfaces are assumed to provide the most probable explanation for these observed effects.

2. Shalobasov and Shal'nev, 1971 (2)

This paper published in a Russian journal, describes essentially the same data as that covered in ref. (1). However, more discussion is presented of possible mechanisms. Beyond the general presumed effect of ionized layers, previously mentioned, some discussion is presented upon the possible effect of magnetic fields upon individual bubble collapse. It is postulated that bubble break-up will be promoted by the magnetic field both in growth and collapse. In their opinion, with which I tentatively disagree, additional microjet formation during collapse and increasing damage will be thus caused.

3. Shal'nev, Shalobasov, Zyiagencef, 1973 (3)

This paper, also in a Russian journal, is essentially a continuation of the water tunnel work (1, 2), discussed above. The facility is the same as previously described, except that a somewhat stronger magnetic field is used (10 kG max.), and the effect of variation of its vector direction between parallel to the exciting cylinder axis (1, 2), and perpendicular to both the cylinder axis and flow velocity direction. Flow velocity is here 23 m/s. As before, damage effects upon lead samples inserted in the cavitating region downstream of the cylinder are observed as a function of magnetic field strength and direction. Again, damage area is reduced in size, its shape is altered, and damage rates are now reduced. In fact, the magnetic field perpendicular to the cylinder appears to reduce observed damage rates by almost 50%, without having much effect on incubation period. This is opposite the effects observed (1, 2), and previously discussed here, for the magnetic field parallel to the cylinder. A further interesting result is that an optimum magnetic field strength (~5 kG)from the viewpoint of damage reduction is observed.

4. Shalobasov, Shal'nev, Zyiagencef, Kozyrev, Haldeev, 1974 (4)

This paper, also from a Russian journal, involves an entirely different experimental set-up from those previously discussed (1-3), but again the test fluid is tap water, and the maximum magnetic field strength is 7 kG. In this case the growth of individual bubbles, generated by the discharge of an electric spark, is studied with and without a magnetic field. High-speed cinematography is used to record their shapes as a function of time. It is reported that the shape, growth and collapse rates are significantly affected by the magnetic field. The bubble surface area is plotted with and without magnetic field as a function of time throughout the life of the bubbles as recorded photographically. It is found that both growth and collapse rate, and maximum diameter are increased by the magnetic field. The effect upon collapse rate is the largest, reaching 60 - 80%, toward the end of collapse. The increase in maximum bubble diameter is the order of 10% (area increase of ~20%). If this result is general, as seems unlikely, since MHD effects normally tend to restrain fluid motion, then cavitation damage should increased by a magnetic field. This was the case for ref. 1, 2, and 6 but not for 3.

5. Shal'nev, Shalobasov, Kozyrev, Bologa, Paukov, 1974 (5)

This paper summarizes again for the most part the work already discussed (1-3). It does bring to light two pertinent earlier references in the Russian literature (9, 10), also by Shal'nev and his colleagues.

New information in this Edinburgh Conference paper (5) concerns also the effects of an electric field. This is described in terms of current density (order of ± 10 mA/cm^2, and up to - 50), and no indication of voltage is given. Thus the effects, particularly upon erosion, are at least closely related to those previously considered as due to cathodic or anodic "protection". It is reported (5) that the incubation period was prolonged considerably by both negative polarity (85%) and positive (35%). Also the negative polarity increased* the maximum damage rate by a factor of 1.8.

Another observed effect of the electric field was upon the spacing of vortices behind the transverse cylinder. It was found that this spacing was not changed by current density up to 50 mA/cm^2. It is further remarked that a major effect of external magnetic and electric fields is alteration of the boundaries of the damage zone in this particular experimental arrangement.

B. Conducting Fluids

1. Perel'man and Govorskii, 1971 (6)

This Russian journal article reports upon cavitation damage tests using a magnetostriction vibrator (22 kHz and 7 μm) in a "conducting liquid". Tests were at 450°C for 90 minutes on an 18-8 type stainless steel with argon pressurization. While the liquid is not further identified, the other test parameters listed above lead to the presumption that it is a "liquid metal" such as sodium or potassium (or perhaps lithium). The tests involved investigation of the effect of varying cover gas pressures, from about 0.25 to 4.5 bar. An increase of damage is found, with or without magnetic field, as is common for this type of test (11, eg.). However, the increase of damage rate with pressure is less than usual, particularly over the lower portion of the pressure range. This is probably because the vibration amplitude with this facility (7 μm) is less than usual, 51 μm in our own facility being typical. Then the pressure oscillation is also less, and the effect of increasing cover gas pressure on reducing cavitation activity is greater so that the increase of damage is reduced. The Russian results (6) show no

*This apparent failure of "cathodic protection" may not be surprising since corrosion effects between lead and water are negligible.

effect of increasing cover gas pressure from 2 to 4.5 bar, which is not readily explicable in terms of other previous results (11, eg.).

The magnetic field, applied to the cavitation zone, was $\sim$ 2.4 kG. This succeeded in reducing damage rate at all cover gas pressures, but by only about 20% for pressures below 2 bar. However, for higher cover gas pressures, there is a strong decrease in damage rate with magnetic field applied,to a value about 50% the no-magnetic field rate at 2.5 bar. With the magnetic field applied,the damage rate then climbs with increased pressure, becoming almost equal to the no-magnetic field rate at 4.5 bar. This "fine structure" of the magnetic field damage curve above 2 bar is not theoretically explicable at this point, so far as I know. However, the general trend that a magnetic field reduces cavitation damage in a conducting liquid is explained by the authors on the basis that MHD effects will generally tend to reduce velocities, and thus, the intensity of the cavitation attack. As previously mentioned. this would be consistent with ref. 3, but counter to ref. 1, 2, all for non-conducting liquids.

It is further reported (6) that the temperature of the stainless steel test specimen rose from 450 (liquid temperature) to 900°C when the magnetic field was applied. If adjacent liquid temperature also increases, it may be partly responsible for a change in damage rate, rather than any direct action of the magnetic field, since damage rate in this type of test is in general strongly temperature dependent (11, eg.). Such an increase in specimen temperature would also cause severe mechanical weakening of the specimen so that, damage would increase as reported. The specimen temperature increase may be primarily due to eddy current generation in the specimen as it vibrates in the magnetic field, as partially suggested by the authors.

III CONCLUSIONS

The following conclusions seem warranted from these Russign investigations.

1. There are measurable effects of magnetic fields in the range 1 - 10 kG upon cavitation damage rates and distributions in flowing systems using ordinary tap water, as well as upon the overall flow pattern. According to present evidence, damage rates may be either increased or decreased, depending upon details of the experiment, including relative direction and strength of the magnetic field. The existence of these effects seems to indicate the existence of a strongly ionized layer between vapor and liquid.

2. There are also measurable effects upon cavitation damage of electric current intensities in flowing tap water systems of order of 10 mA/cm^2. Such an electric field may either reduce or increase damage, depending on polarity, etc.

3. There are also measurable effects upon cavitation damage in conducting liquids such as liquid metals (sodium, etc.) of imposed magnetic fields. In the one test reported (6) the magnetic field reduces damage. This is surprising, since such MHD effects normally reduce fluid velocities.

4. Individual bubble growth and collapse rates in water are affected measurably by imposed magnetic fields of 1-10 kG intensity. However, in tests in our own laboratory, no effect within $\pm$ 1% upon cavitation threshold pressure was found in tap water or in water with 0.3% by mass salt addition or in mercury for a magnetic field intensity of 6 kG. Acoustically-inducted, rather than flowing system cavitation, was involved.

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