EFFECT OF A HIGH-FREQUENCY ELECTROMAGNETIC FIELD ON BOILING HEAT TRANSFER

V. G. D'yakonov and A. G. Usmanov

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The heat transfer of various liquids boiling on tubes made of different materials has been investigated for the case of direct heating with high-frequency currents.

Recently, there have been a number of studies of the effect of electromagnetic fields on heat transfer rates. In these studies, the frequency of the field did not exceed 60 Hz.

It was established that under these conditions considerable intensification of heat transfer is observed.

We have made an experimental study of boiling heat transfer in a high-frequency electromagnetic field.

Under conditions of direct high-frequency heating the heat is released in a thin surface layer of the tube. Therefore, the temperature inside the tube and at its surface are practically the same, which at small depths of current penetration completely excludes the necessity of introducing a correction for the temperature drop over the thickness of the wall, which in turn results in a corresponding increase in the accuracy of the measurements.

This makes it possible to establish more reliably the effect of such factors as the material of the surface, which is very difficult to take into account quantitatively in normal circumstances owing to the increased error of the measurements.

Boiling heat transfer was investigated under pool conditions at atmospheric pressure with direct heating of the surface by high-frequency currents ($650 \cdot 10^3$ Hz), which created a rapidly varying electromagnetic field around the tube.

The apparatus and method of measuring the heat fluxes are described in detail in [4, 5]. Here, we merely note that the maximum errors in determining the heat fluxes, by calorimetry, and the heat-transfer coefficients did not exceed 4–6% and 5–7%, respectively.

Four principal liquids were investigated: double-distilled water, benzene, acetone, and 96% rectified ethyl alcohol, which differ in dielectric constant and in the degree of polarization of the molecules.

To investigate the effect of the material of the heating surface, we conducted experiments on tubes made of brass, copper, chromium-plated copper, and 1Cr18NiTi stainless steel with an outside diameter of about 6 mm.

For these materials, the equivalent depths of penetration are 0.168, 0.089, 0.089, 0.54 mm, respectively, and the temperature drops Θ over the thickness of the wall at a heat flux $q = 200 \cdot 10^3$ W/m^2 0.125; 0.003; 0.003 and 3.580° C, respectively.

From these data it follows that the use of copper, chromium-plated copper, and brass tubes is most desirable, since in view of the smallness of Θ it is not necessary to introduce a correction in calculating the temperature of the outer surface of the heating tube.

Before the experiments were performed, all the heating tubes were identically treated and stabilized.

The results of our measurements make it possible to decide questions connected with the effect of the high-frequency electromagnetic field and the material of the heating tube on the intensity of heat transfer.

We compared our own experimental data, for a stainless steel tube heated with high-frequency and 50-Hz current (Fig. 1). The effect of the high-frequency field on α was not uniform. For benzene it led to a slight increase

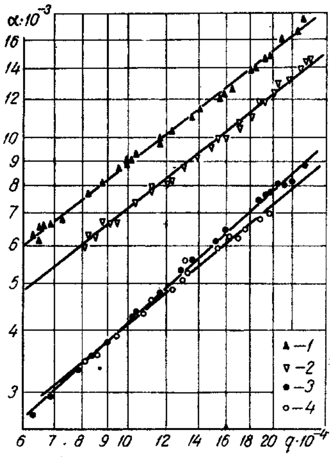

Fig. 1. Effect of electromagnetic field (W/m^2) on the rate of boiling heat transfer (W/m^2 · deg): 1, 2, 3, 4) the authors' data for water and benzene, respectively (1, 3—high-frequency heating; 2, 4—heating at a frequency of 50 Hz).

in α at $q = 100 \cdot 10^3$ W/m^2 as compared with ordinary heating, giving a steeper slope; water gave an increase in α by 23%. This means that the field has a greater effect on the boiling heat transfer of liquids with polarized molecules.

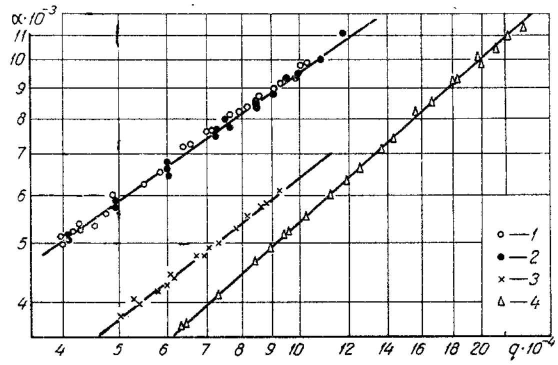

Fig. 2. Effect of heater material on the rate of boiling heat transfer for ethanol: 1, 2, 3, 4) the authors' data for copper, brass, chromium-plated copper, and stainless steel tubes, respectively.

The experimental data for high-frequency currents could not be generalized by either the Kruzhilin [6] or the Labuntsov [7] equations. This indicates a specific effect of the high-frequency field on the heat-transfer process.

In our experiments owing to the symmetry of the field relative to the heating tube there is no force causing electroconvection [1, 8]. The electromechanical force [1], by acting on the vapor bubbles during the period of their formation and growth, may intensify the heat-transfer process somewhat.

According to [9], the liquids we investigated do not undergo dielectric heating in a field with a frequency of $650 \cdot 10^3$ Hz. At the same time, this does not exclude the possible action of the field on the molecules at the phase interface: vapor-liquid, solid-liquid, which, in turn, may lead to a change in the surface forces and the contact angle. It may be assumed that the nature and intensity of this effect depend on the strength and frequency of the field and on the electrical properties of the molecules of the substance investigated. According to existing notions, the latter affects the nucleating properties of the active centers and, consequently, the rate of boiling heat transfer.

Thus, the high-frequency field modifies the local properties of the liquid and the vapor in the region of active centers and, hence, intensifies the process.

To a certain extent this interpretation is consistent with the experimental results of [10], where by special treatment of the heating surface it was found possible to modify the properties of the surface, the liquid, and the vapor in the region of an active center. This led to a considerable increase in boiling heat transfer.

Our results clearly reveal a relation between the heat-transfer rate and the material of the heater surface. The stratification of the data according to the tube material is illustrated in Fig. 2. Other things being equal, the heat-transfer coefficients increase from stainless steel through chromium-plated surfaces and copper to brass.

A similar picture is also observed in the case of boiling benzene, acetone, and water.

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Kirov Chemical Engineering Institute, Kazan