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BOILING OF SUPERHEATED n-PENTANE IN AN ELECTRIC FIELD

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Results are presented from an experimental study of the effect of a stationary electric field on the probability of boiling of superheated n-pentane.

The time that a system exists in the metastable state is determined by the probability of the nucleation of a new phase capable of subsequent growth in the system. The work expended in the formation of the new phase depends on the properties of the metastable system and external conditions [1]. In particular, according to theoretical estimates [2-4], the energy of formation of a critical vapor bubble in a superheated liquid increases, which leads to a decrease in the probability of boiling and an increase in the temperature of maximum superheating.

Relatively few studies [5-7] have experimentally investigated the effect of an electric field on a superheated liquid and each study has reported the effect opposite to that predicted by the theory, i.e., an electric field initiated the phase transition. The allowance made for compressibility of the liquid in later theoretical works [8, 9] showed that under certain conditions (restricted free movement of the liquid), an electric field can initiate boiling.

It should be noted that, according to the theoretical estimates, the effect of an electric field should appear at field-strengths close to the breakdown value — 10^8–10^9 W/m.

We studied the effect of a stationary electric field on the boiling of a superheated dielectric liquid. The mean strength of the field in the liquid was about 10^6 W/m. We used the method from [1] to measure the mean lifetime of the liquid in the prescribed metastable state. The method makes it possible to obtain comparable measurements with and without a field at relatively low field strengths (thus eliminating the possibility of breakdown of the liquid).

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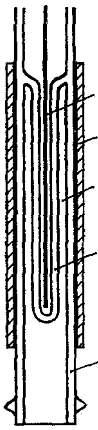

Fig. 1

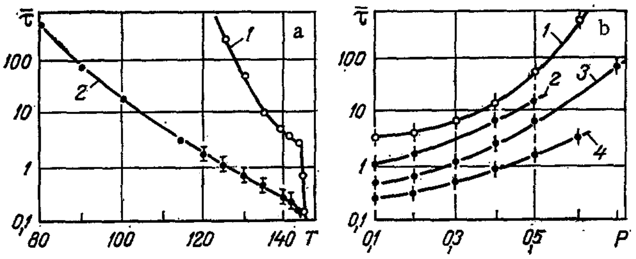

Fig. 2

Fig. 1. Diagram of working cell: 1) external tube; 2) internal capillary tube; 3) test liquid; 4) external electrode; 5) internal electrode.

Fig. 2. Dependence of the mean lifetime of the superheated liquid on temperature (a) and pressure (b): a) P = 0.1 MPa; 1) U = 0 V; 2) 900; b) U = 0 V; 1) T = 140°C; U = 900 V; 2) T = 125°C; 3) 135; 4) 140.

The experimental unit was an automated miniature bubble chamber. The test liquid was located in an apparatus consisting of a glass tube (∅5.5/3.1 mm) and a glass cylinder coaxially sealed in the tube (∅1.9/0.5 mm). The volume of superheated liquid was about 0.14 cm^3. The internal electrode was produced by tightly packing powdered graphite into an internal capillary tube, while the external electrode was produced by the vacuum deposition of Al. The outer part of the apparatus was placed in an oil thermostat. With allowance for the graduation of the thermocouple, the temperature measurement error was ±0.5°K, while the thermostatting error was 0.05°K.

The liquid was converted to the metastable state by a sharp pressure reduction. Voltage was supplied to the apparatus from a VS-27 source for a certain period of time prior to the pressure reduction and was cut off immediately after the liquid began boiling. The mean strength of the field in the liquid was about 7.7U, V/cm.

The tests were conducted with n-pentane, which was chosen due to its low electrical conductivity and the simplicity of removing various impurities (traces of water, etc.) from it. Throughout the investigated temperature range 80-144°C we observed a marked initiating effect by the electric field. Figure 2 shows the temperature and pressure dependence of $\bar{\tau}$ obtained in the tests in the presence of the electric field and under natural conditions. Each empirical point $\bar{\tau}$(P, T) was obtained by averaging the results of 40-200 tests. The vertical symbols denote the statistical error of $\bar{\tau}$ from the limited number of tests.

It was established in earlier tests [10] that the magnitude of the initiation effect depends on the moment the electric field is applied. Figure 3 shows results of calculation of the probability of boiling in relation to the time of action of the electric field. These results were obtained by analyzing histograms from tests in which the cell was supplied with voltage simultaneously with a pressure reduction. Since measurement of the current passing through the cell showed that the Joule heating of the liquid and electrolysis were negligibly small, then the initial nonsteady section was connected with the establishment of the field in the liquid. To eliminate this transience, the voltage was supplied to the cell for 60 sec prior to the pressure reduction. Analysis of the histograms obtained showed that in this case the liquid was in the metastable state under unchanged conditions.

The study [7] described a phenomenon which the authors termed "prenucleation relaxation." The character of change in the time of this relaxation and the period of transience established in our tests in relation to the temperature of the liquid and the voltage are qualitatively the same. The magnitude of the initiating effect decreases with an increase in temperature but remains significant up to a temperature close to the temperature of maximum superheating.

The period seen in our tests during which the probability of boiling of the liquid was nonsteady during connection of the electric field and the character of its change with tem-

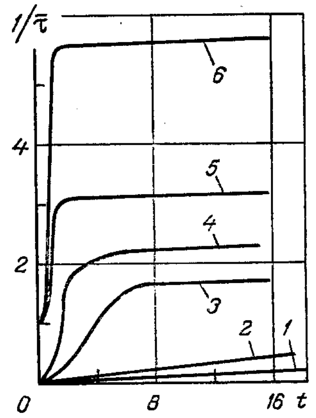

Fig. 3. Dependence of the probability of boiling of a superheated liquid on the time of action of an electric field: 1) T = 125°C, U = 400 V, 2) 135 and 400; 3) 130 and 800; 4) 135 and 800; 5) 144 and 400; 6) 144 and 800 V.

perature may be related to the time of formation of the double electric layer on the walls of the apparatus. In [11] an estimate was made of the initiating effect of a double electric layer on the boiling of a superheated liquid due to the electrocapillary effect on the liquid–metal boundary. A similar calculation for a liquid–glass boundary is made difficult by the lack of the necessary reference data in the literature. An attempt to explain the results of out tests through the electrocapillary effect alone leads to a situation whereby surface tension must be reduced by 60%.

Important information on the mechanism of the initiating effect of an electric field is given by the pressure dependence of the mean lifetime of the superheated liquid (see Fig. 2b). Analysis of test data obtained showed that the magnitude of the effect depends on the pressure in the liquid, while the magnitude of the electrocapillary effect is independent of pressure.

Thus, the observed initiating effect of an electric field cannot be explained merely by the electrocapillary effect. A more detailed analysis is needed of processes occurring at the liquid–solid boundary under the influence of an electric field.

NOTATION

T, temperature of liquid, °C; P, pressure in the liquid, MPa; U, voltage on the electrodes of the apparatus, V; $\bar{\tau}$, mean lifetime of the heated liquid, sec; t, time, sec.

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TRUE VOLUMETRIC VAPOR CONTENT OF TWO-PHASE FREON FLOWS

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An analysis is made and generalized data presented on the true volumetric vapor content of boiling two-phase flows of Freon-12.

In many heat exchangers, boiling of the refrigerant occurs in horizontal or vertical tubes.

To calculate heat transfer and hydraulic resistance in such units and optimize their operating regimes, it is necessary to know the characteristics of the two-phase flows: volumetric vapor content φ or true phase velocities. The quantity φ makes it possible to most accurately predict flow regimes and to refine physical representations on heat-transfer processes with flows of different structure.

As is known, analytic relations have not found wide use for calculating actual parameters, while the empirical equations obtained have been found mainly in studies of vapor—water (or gas—water) flows circulating at rates $w_0 > 0.2$ m/sec.

There have been practically no studies of the values of φ for refrigerants (we know only of [1]). Of the greatest interest for refrigeration technology are studies at low flow rates $w_0 < 0.2$ m/sec. Flow at these rates is characterized by a number of features. In the case of horizontal tubes, there are zones of laminar and wave flow. In vertical pipes, there are zones of strong pulsations caused by "inversion" of the flow.

We designed and made a stand for experimentally determining the true vapor content of refrigerants and observing flow regimes in horizontal and vertical tubes (with forced flow).

The experimental conditions were as follows: working substance — Freon-12, $w_0 = 0.03$-0.43 m/sec, $q = 2$-20 kW/m^2, $t_0 = -20$ to $+20$°C, $x = 0.005$-0.95, $d_0 = 6$ and 10 mm.

The actual vapor content was determined by the intercept method. The experimental unit consisted of a hydrodynamic stabilization section and thermal and observation sections. The observation section was a tube made of transparent quartz glass 240 mm long. Spherical cutoff valves connected by a tie were installed on both sides of the observation section. The unit, mounted on the rigid frame of a rotation mechanism, was connected to the stand by means of flexible hoses, making it possible to place the entire structure in the horizontal or vertical position.

Vapor content was established by electric heating by one of two methods: in the stand vapor generator or in the thermal section located between the visualization and observation sections. The heater installed in the thermal section was used to study small vapor contents $x < 0.1$ m and allowed us to determine the effect of heat flux on the value of φ.

In the experiments with horizontal tubes, after cutoff the entire unit was turned to the vertical position, and the value of φ was determined from the measured height of the liquid column in the glass tube. The mean accuracy of the determination of φ was ±3%.

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