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EFFECT OF STATE OF HEAT-TRANSFER SURFACE ON RUPTURE OF THIN FILMS OF BOILING LIQUID

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The effect of roughness of the heat-transfer surface and the presence of a corrosion film on the rupture of stationary films of boiling liquid was experimentally investigated.

The current literature contains hardly any information on the effect of the state of the heat-transfer surface on the rupture of thin boiling liquid films. The known data [1] on the effect of roughness of the surface and the presence of an oxide film on it cannot be extended unreservedly to boiling liquid films.

The generally accepted theories of rupture of thin nonisothermic films [2, 3] ignore the state of the heat-transfer surface.

In this paper we give the results of an experimental investigation of the mechanism of rupture of thin stationary liquid films with highly developed boiling in relation to the roughness of the surface and the presence of a corrosion film on it.

The experiments were conducted on the experimental apparatus described in [4] with distilled water at heat-flux densities of 100–800 kW/m^2 and pressures of 0.1–0.4 MPa on surfaces made of copper, 1Kh18N9T stainless steel, and lead. We compared three kinds of surfaces – a polished surface (treated with diamond paste of grain size 2 μ until a mirror finish was obtained), a technically rough surface [class 5-6 according to GOST (All-Union State Standard) 2.309-68], and a roughened surface (treated with coarse emery paper, class 1-2 according to GOST 2.309-68).

Before the experiments the surfaces were thoroughly washed with ethanol. The polished surface was also boiled for half an hour in butanol, then dried, and washed in ethanol. Experience showed that less thorough treatment of the surface after polishing failed to remove the traces of fat from the diamond paste, which greatly distorted the results of the experiments.

As Fig. 1 shows, surface roughness had no effect on the critical thickness for rupture of a boiling film on a surface made of stainless steel, while the liquid film on copper was more stable on a polished surface, although the difference was not very great (about 20%). Experiments showed that at a pressure of 0.2 MPa surface roughness of any material had hardly any effect.

As we know [4-6], vapor bubbles are the reason for rupture of boiling films. In the case of highly developed boiling the difference in the number of active vapor-forming centers on surfaces prepared in different ways is slight and, hence, the number of potential sites of rupture of the film is almost independent of the roughness. On the viscous copper polishing has a more pronounced effect on the surface relief and, hence, on the number of vapor-forming centers than on a stainless steel surface. Thus, there is less probability of

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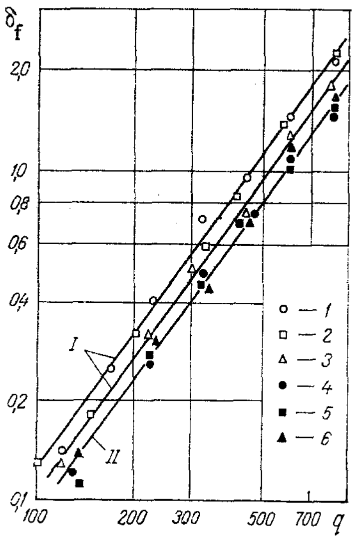

Fig. 1

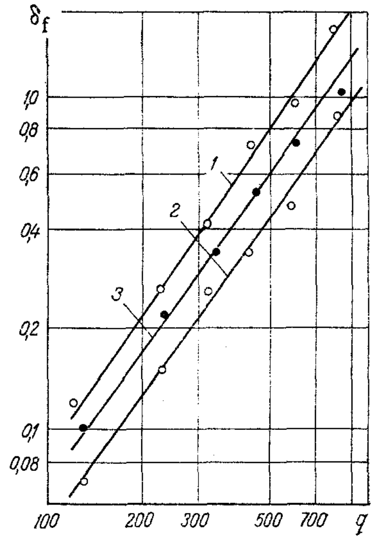

Fig. 2

Fig. 1. Critical thickness for rupture of water film (mm) as function of heat-flux density (kW/m^2) at a pressure of 0.1 MPa: I) copper surface [1) technically rough; 2) roughened; 3) polished]; II) stainless steel surface [4) technically rough; 5) roughened; 6) polished].

Fig. 2. Critical thickness for rupture of water film (mm) as function of heat-flux density (kW/m^2): 1) clean lead surface, pressure 0.1 MPa; 2) oxidized lead surface, 0.1 MPa; 3) oxidized lead surface, 0.4 MPa.

rupture of a film on a copper surface with a reduced number of centers (polished) than on a rough surface. This is the reason for the slight increase in stability of the water film on a polished copper surface. An increase in pressure increases the number of active vapor-forming centers and, hence, the effect of surface roughness is reduced, as was confirmed by experiments.

A lead surface was used to investigate the effect of an oxide film on the rupture of thin boiling liquid films. The presence of an oxide film reduces the critical thicknesses for rupture of a water film by a factor of almost 2 (at atmospheric pressure) (Fig. 2) in comparison with a clean unoxidized surface, owing to the much better wettability of the friable oxide layer.

With increase in pressure the critical thickness for rupture on an oxidized surface increases (Fig. 2) in contrast to clean surfaces, where it is reduced [4]. Experiments [4] showed that under certain conditions the material of the heat-transfer surface, its roughness, and the pressure have hardly any effect on the critical thickness for film rupture. In these conditions it depends only on the heat-flux density (in the investigated range 0.1-1.0 MPa). With increase in pressure the critical thickness for rupture on an oxidized lead surface also tended to the limiting value common to all surfaces and at a pressure of 0.4 MPa was close to this value. Complete coincidence could not be obtained, however, owing to the fact that at high pressures rapid oxidation of the lead was initiated by the start of chemical interaction with the highly heated water and steam, i.e., there was no point in continuing the experiment.

The obtained experimental data can be useful not only for an understanding of the laws underlying the rupture of boiling liquid films, but also for the construction of new thin-film heat exchangers, the selection of the best operating conditions for them, and for the better performance of heat exchangers in service.

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GROWTH OF A BUBBLE OF NONCONDENSING GAS INJECTED INTO A LIQUID

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The solution of the problem of growth of a gas–vapor bubble injected into a liquid is obtained. The growth of the bubble depends on mass transfer in the gas phase and heat transfer in the liquid phase. Experimental and theoretical data are compared.

The solution of the problem of growth of a gas–vapor bubble is essential for investigation of the cooling of a liquid by bubbling gas through it and by other processes. Attempts to solve this problem are described in [1-3]. Neglecting the convective terms in the energy and diffusion equations, the authors of [1] found a solution of the problem of unsteady heat conduction with the aid of the Green function for the case of a stationary boundary. In [2, 3] a solution was obtained by assignment of the radial distribution of vapor concentration in the gas and the temperature in the liquid in the form of a quadratic parabola, which led to distortion of the values of the heat and mass fluxes. There are also errors in [3]. The listed solutions are approximate.

The main factors governing bubble growth are diffusion of vapor into the gas cavity and the redistribution of temperature in the liquid layer adjacent to the bubble. These factors act simultaneously, but, to begin with, it is better to consider them separately. It should be noted that since the thermal diffusivity in gases is greater than the diffusion coefficient, we can assume that heat transfer in the gas has no effect on diffusion.

We will solve the problem of vapor diffusion into a spherical cavity of prescribed variable radius R(t) with a prescribed variable concentration $x_s(t)$ on its boundary. Let the gas be insoluble and noncondensing, the pressure constant everywhere throughout the process, and the vapor in the cavity have nonzero velocity at the moment of entry. We have to solve the equation

$$\frac{\partial x}{\partial t}=D\left(\frac{\partial^2 x}{\partial r^2}+\frac{2}{r}\cdot\frac{\partial x}{\partial r}\right);\ 0\leqslant r\leqslant R(t);\ t\geqslant 0 \tag{1}$$

with initial condition

$$x(r,\ 0)=x_0(r)=0;\ 0\leqslant r\leqslant R_0 \tag{2}$$

and boundary condition

$$x_S=x_S[R(t),\ t]. \tag{3}$$

Standard replacement of the variable

$$v(r,\ t)=rx(r,\ t) \tag{4}$$

leads to the equation

$$\frac{\partial v}{\partial t}=D\frac{\partial^2 v}{\partial r^2} \tag{5}$$

with initial condition

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