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CHARACTERISTIC FEATURES OF THE BOILING OF EMULSIONS HAVING A LOW-BOILING DISPERSED PHASE

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The results of investigation of heat transfer from thin wires to a boiling emulsion, the dispersed phase of which is formed from a liquid with a boiling temperature much lower than the boiling temperature of the dispersion medium, are presented. Two variants of boiling of such an emulsion are possible: boiling of the dispersed phase alone and simultaneous boiling of the dispersed phase and dispersion medium. In the present work, only the first variant has been studied; it is distinguished by the following most important features: high superheat of the dispersed-phase droplets ΔT_{sup} *of the emulsion and a wide temperature range of bubble boiling (50–200°C). For conventional heat carriers (pure liquids and solutions), the value of* ΔT_{sup} *does not exceed 1–10°C, with the bubble-boiling interval lying within the range from 5 to 20°C.*

Introduction. The intensity of boiling of any heat carrier depends on the number of boiling centers. With other things being equal, an increase in their number leads to an increase in the heat-flux density and heat-transfer coefficient α. However, when the density of the boiling centers becomes extremely high, the latter coalesce into a continuous film, and a boiling crisis occurs; it is accompanied by a sharp decrease in the heat-transfer coefficient α, superheating, and often by the destruction of the heat-transfer surface.

The nature of the formation of boiling centers still has been inadequately studied. In boiling of the emulsions considered, the heating surface turns out to be wetted by a high-boiling dispersion medium, the temperature of the saturated vapors of which is higher than the surface temperature. Therefore, the appearance of boiling centers on the surface is hampered, and they do not exert any noticeable effect on the process of heat transfer, whereas the effervescence of the dispersed-phase droplets occurs only at the centers that are activated inside these droplets or on their surface and when they reside in the thermal boundary layer. We note that superheatings of the dispersed-phase droplets ($\Delta T_{\rm sup}$) that precede their effervescence are much higher than those usually observed for pure liquids and solutions but they are still extremely low for fluctuational formation of boiling centers [1]. The quantity $\Delta T_{\rm sup}$ is also called the temperature delay in the onset of boiling [2, 3]. None of the well-known models of nucleation is applicable in the case considered. There is a need for developing a new model of the boiling center that could be suitable for the case considered, where, on attainment of a certain superheating $\Delta T_{\rm sup}$, which depends on the average volume of the dispersed-phase droplets of the emulsion $\bar{v}$, there occurs a sharp, jumpwise increase in the frequency of activation of boiling centers. In [4, 5], a model whose principal elements are dissolved gases (air) and solid microscopic particles, both contaminating the liquid, has been suggested. It is noted in the literature [6] that even in the liquid that underwent the most thorough purification, each cubic millimeter of the volume contains several tens of particles contaminating it. The particles are of irregular shape, their average diameter does not exceed 10^{-7} m, they are in constant Brownian motion, do not float up, and do not precipitate onto the vessel bottom under gravity. It is known that solid particles adsorb the gases dissolved in a liquid, and they can combine, forming some unstable aggregates — floccules. As the temperature increases, the solubility of a gas in the liquid decreases, which favors an increase in the volume of the gas adsorbed on the surface of the particles and formation of gas bubbles. When the radius of any of them attains the critical one [1], it becomes a boiling center, but only in the case where its surface directly borders on the superheated liquid and is not screened by particles. Calculations have shown that the time of growth of a vapor bubble to the critical size [5]

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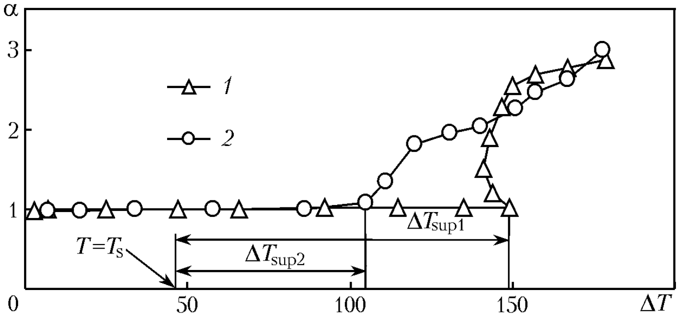

Fig. 1. Heat-transfer coefficient α vs. temperature difference ΔT in convective heat transfer and bubble boiling of the water/PES-5 emulsion on a horizontal platinum wire at atmospheric pressure (C = 1.0 vol.%, T_0 = 60°C): 1) finely dispersed emulsion (d = 1.5 μm); 2) coarsely dispersed emulsion (d = 35 μm). α, in kW/(m^2·°C); ΔT, in °C.

and the time of residence of the dispersed-phase droplets in the thermal boundary layer are of the same magnitude within the error limits, which points to the reliability of the proposed mechanism of activation of boiling centers. Moreover, we assume that the proposed model allows one to explain the experimentally observed sharp transition from convective heat transfer to a vigorous and stable boiling on attainment of a certain superheating of the emulsion ΔT_{sup} in the thermal boundary layer. Indeed, on effervescence of any of the dispersed-phase droplets, a pressure pulse arises [7], which, while moving through the emulsion, destroys the floccules encountered on its path, and they break up into individual particles. The gas that earlier was located between the particles and did not contact the superheated liquid now may come in contact with it. The volume of the gas bubble increases rapidly due to both gas diffusion from the surrounding liquid and evaporation of superheated liquid. On reaching the critical radius, the bubble formed becomes a boiling center and, as a result, a new droplet of the dispersed-phase boils up, and a new pressure pulse appears, and this leads to formation of new boiling centers. This process may be repeated many times causing chain (avalanche) effervescence of the dispersed-phase droplets of the emulsion.

Experimental Checking of the Proposed Model of Activation of Boiling Centers. Figure 1 [8] presents typical experimental data [8–10] on heat transfer of finely (1) and coarsely dispersed (2) emulsions. Attention should be paid to high superheats of the dispersed-phase droplets in the thermal boundary layer ($\Delta T_{\text{sup1}} \approx 100$°C and $\Delta T_{\text{sup2}} \approx 60$°C) preceding the effervescence of the emulsion and the sharp S-like increase in the heat-transfer coefficient α on attainment of the above-noted superheats.

The experiments carried out have shown that the high superheat of the dispersed-phase droplets persists during the entire time of observation and is determined by the dispersed-phase concentration C and by the average volume of droplets $\bar{v}$: the smaller $\bar{v}$, the higher ΔT_{sup} (Fig. 1).

Within the framework of the model adopted, explanations may also be given to the sharp increase in α with ΔT and to the dependence $\Delta T_{\text{sup}} = f(\bar{v})$. Indeed, the smaller the volume of the dispersed-phase droplets, the less thermal energy $Q = c_p \Delta T_{\text{sup}} \rho \bar{v}$ is stored in them and the smaller the amplitude of the pressure pulses that appear in the course of their effervescence. It is evident that the smaller the pressure pulse, the smaller the number of floccules that can be destroyed by that pulse and, consequently, the less intense the boiling of the emulsion.

Influence of Activated Carbon on the Character of Heat Transfer. If carbon powder, the particles of which are good in adsorbing gases from liquids, is put into a water/PES-5-type emulsion, the superheat of the dispersed phase of the emulsion ΔT_{sup} (temperature delay in the onset of boiling) must decrease, and the heat-transfer coefficient must increase. This is confirmed by the experimental data given in Fig. 2 [8]. Attention should be given to the fact that if, on addition of activated carbon in a water/oil-type emulsion, the delay in the onset of boiling is decreased, the addition of activated carbon into an oil/oil-type emulsion (e.g., *n*-pentane/glycerin or diethyl ether/glycerin) must yield and does yields the opposite effect (Fig. 3). Such behavior is attributed to the fact that the adsorption links of the activated carbon with organic liquids turn out to be stronger than with the atmospheric air components. Carbon binds gas strongly only in its fine pores, into which large molecules of organic liquids cannot enter, whereas the large pores and the outer surface of the particles are covered by organic liquids, and the adsorbed gases are displaced en-

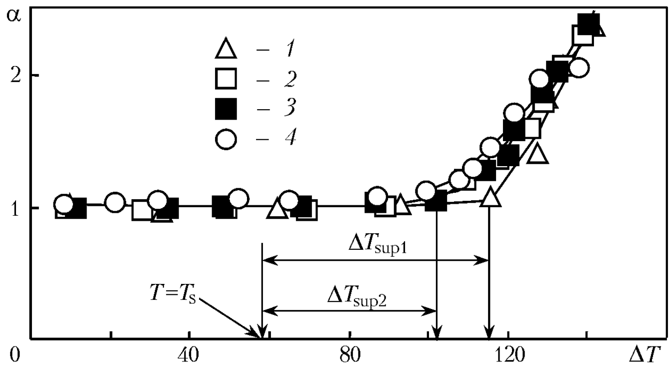

Fig. 2. Influence of activated carbon on the intensity of heat transfer and delay in the onset of boiling of the water/PES-5 emulsion (C = 4.0 vol.%): 1) emulsion without additions of coal; 2, 3, 4) emulsion with additions of activated coal at c = 0.045, 0.09, and 0.3 wt.%. α, in kW/(m^2·^{o}C); ΔT, in ^{o}C.

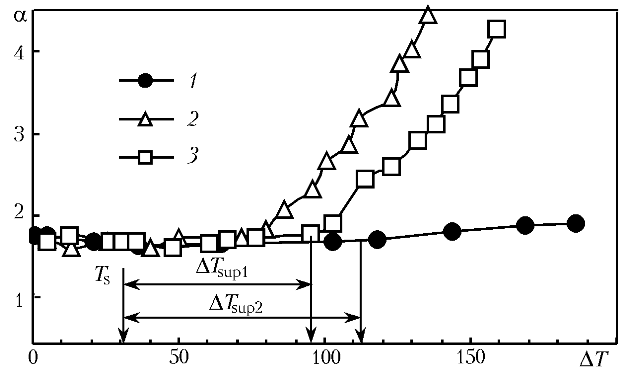

Fig. 3. Influence of activated coal on the intensity of heat transfer and delay in the onset of boiling of the n-pentane/glycerin emulsion (C = 10.0 vol.%, T_0 = 25^{o}C): 1) pure glycerin; 2) emulsion without additions of coal; 3) emulsion with additions of activated coal at c = 0.3 wt.%. α, in kW/(m^2·^{o}C); ΔT, in C^o.

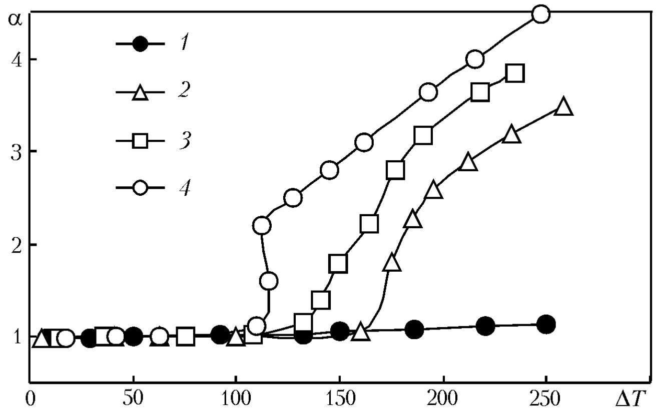

Fig. 4. Influence of a surfactant on the intensity of heat transfer and delay in the onset of emulsion boiling (T_0 = 36^{o}C, C = 1.0 vol.%): 1) pure PES-5; 2) water/PES-5 emulsion with addition of 1.0 wt.% trisodium phosphate; 3) water/PES-5 emulsion with addition of 1.0 wt.% caustic soda; 4) water/PES-5 emulsion without additions. α, in kW/(m^2·^{o}C); ΔT, in ^{o}C.

tirely from them. This leads to a decrease in the number of activated centers and to a lower intensity of boiling, but at the same time the delay in boiling increases.

Influence of Surfactants. Based on the boiling-center model adopted by us, we may assume that the introduction of surfactants into a liquid will lead to an increase of the delay in the onset of boiling and to a decrease in α, since a surfactant is adsorbed by the surface of particles hindering gas adsorption and activation of boiling centers.

Experiments with additions of trisodium phosphate and caustic soda into emulsions [8] were carried out. Caustic soda is not a surfactant as such, but on its introduction into the dispersed phase of the water/PES-5 emulsion it reacts chemically with the dispersed medium of the emulsion, forming a surfactant.

Figure 4 demonstrates the influence of a surfactant on heat transfer and the delay in the onset of boiling (superheating ΔT_{sup}) for the water/PES-5 emulsion on introduction of 1 wt.% of caustic soda or trisodium phosphate into the dispersed phase of the emulsion. It follows from the experimental data that at small concentrations of the dispersed phase C, addition of a surfactant leads to a substantial additional delay in the onset of boiling. With an increase in the concentration C, the influence of a surfactant on the delay in the onset of boiling becomes weaker. However, at high temperature differences and high values of C, addition of a surfactant leads to a noticeable increase in the heat-transfer coefficient and critical heat-flux density, which is explained by the influence of the surfactant on the magnitude of surface tension and does not contradict the model proposed by us.

Conclusions. The characteristic features of the boiling of emulsions involving a low-boiling dispersed phase on addition of activated carbon or a surfactant to them have been studied. It is shown that by introducing additives we can substantially change the temperature value of the delay in the onset of boiling ΔT_{sup} and the heat-transfer coefficient α. The results obtained are explained qualitatively from the standpoints of the proposed model of boiling centers and their chain activation. The following recommendations on regulation of the intensity of heat transfer to the emulsions considered can be given: a gas adsorbent should be introduced into an emulsion if one wishes to increase the heat-transfer coefficient α and decrease the delay in the onset of boiling ΔT_{sup}, whereas a surfactant should be introduced if one wishes to increase α.

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NOTATION

C, concentration of the dispersed phase of the emulsion, vol.%; c, concentration of additions to an emulsion, wt.%; c_p, heat capacity of liquid, J/(kg·$^{\text{o}}$C); d, diameter of the dispersed-phase droplets of emulsion, m; Q, quantity of stored heat, J; T, temperature, $^{\text{o}}$C; α, heat-transfer coefficient, W/(m^2·$^{\text{o}}$C); ν, volume of the dispersed-phase droplets of the emulsion, m^3; ρ, liquid density, kg/m^3. Subscripts: s, parameter of the phase equilibrium line; sup, superheating of liquid above the temperature of saturated vapors; 0, initial value of the parameter; overbar, average value of the parameter.

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