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Model of the Heat Exchange in Boiling Emulsions with Low-Boiling Disperse Phase at the Solid Wall

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Abstract

Comparison of the calculated dependencies obtained for boiling emulsion with low-boiling dispersed phase based on the model of Labuntsov [1] for an advanced boiling homogeneous liquid at the solid wall, have been compared with the experimental data presented in [3]. The obtained model curve was in good agreement with measurements of heat flux in boiling water emulsion is heated platinum wire. It has been determined, that all the experimental points are grouped around two curves with different model constants that can be interpreted as the presence of two modes the nucleate boiling.

Keywords: liquid emulsion, heat transfer, low-boiling droplets, initiation of nucleation, vapor bubbles, mechanisms of boiling

1 INTRODUCTION

The nature of evaporation in emulsions with low-boiling dispersed phase is complex, fast-flowing and defies the visualization. The heating surface for the drops of the dispersed phase is the interfacial surface area low-boiling continuous medium of the emulsion, through which the heat transfer from solid heating surfaces. This contributes to the localization of low-boiling liquids in the volume of the droplets in the stream of the emulsion, which delays the onset of the crisis boiling and leads to an increase in efficiency of heat exchange. However, physical ideas about the mechanisms of boiling in the volume of the droplets of the dispersed phase, restricted to the interfacial surface, are not yet clear. Also only few experimental researches of heat changes in liquid emulsions are available.

The further analysis is based on the results of the research of the developed nucleate boiling homogeneous fluid at the heating surface, made by Labuntsov [1]. He proposed an approximate theory of the nucleate boiling and derived the correlations for the heat flux density at boiling homogeneous liquid. According to the concepts of Labuntsov, the density of heat flow rate q that is transferred from the heated surface to boiling on it homogeneous fluid consists of two components:

$$q = q_1 + q_2 , \tag{1}$$

where q_1 is the value determined by the phenomenon of heat conduction through the viscous sublayer thickness δ

$$q_1 \sim \lambda \frac{\Delta T}{\delta} . \tag{2}$$

Here, the value of δ is calculated by analogy with the "wall" turbulence [2]

$$\delta \sim \frac{\nu}{\bar{u}} , \tag{3}$$

where ν is the kinematic viscosity, $\bar{u}$ is some average pulse rate, identify shared in such a way that calculated on the basis of the average kinetic energy of pulse movement $\rho_l \bar{u}^2$ was equal to the energy transferred to the liquid growing on the surface of the vapor bubbles. It is determined from the ratio

$$\rho_l \left(\frac{dR}{dt} \right)^2 R^2 n_s^* \sim \rho_l \bar{u}^2 , \tag{4}$$

where R is the current radius of the vapor bubble, n_s^* is the number of active centers boiling on a heated surface.

Component q_2 is determined by the heat exchange in the evaporation process of liquid

$$q_2 = r \rho_v \bar{u} . \tag{5}$$

2 BOILING EMULSIONS WITH LOW BOILING DISPERSED PHASE

Let’s consider the formal generalization of the model Labuntsov boiling homogeneus liquid at the solid wall in the conditions evaporating emulsion with low-boiling dispersed phase. Assessment of the theoretical dependencies validity, obtained such a way, is performed by comparison with the data of experimental studies, which are presented in [3].

Based on the nature of the process of boiling a liquid emulsion, model representation limited to, the following simplifying assumptions:

1. Drops low-boiling dispersed phase of the emulsion are centers of vaporization. Their initiation occurs due to the interaction of the surface of each droplet with pulsations high-boiling continuous medium, resulting from boiling of

the neighboring droplets in thin commensurate with the size of the droplets, the boundary layer near the surface heating.

2. The growth of emerging bubbles to the low-boiling droplets occurs due to the heat supplied by continuous medium of emulsion to the interfacial surface similar growth “surface” of bubbles in a uniform liquid [1].

3. The thickness of the wall layer is comparable with the maximum diameter of the growing bubble, so condensation of the growing bubble is possible only after full evaporation and outside of the hot part of the thermal boundary layer.

Based on these assumptions, consider the consequences of ideas about identity processes in boiling homogeneous liquid on the surface of the heating with boiling droplets of the emulsion at the surface heating. For this model Labuntsov parameter n_s^* (the number of operating centers boiling on the unit heating surface) needs to be replaced by n_{se}^* (the number of drops of boiling thin superheated layer per unit surface heating).

Finally, in equation (4) instead of the parameter n_s^* is used parameter n_{se}^*, which is determined by taking into account the impact of pulsations of a continuous medium [4]

$$n_{se}^* = n_{se}\left(\frac{\rho_c \overline{w}^2 R_0^3}{W_0}\right)^{\alpha}, \tag{6}$$

where W_0 is full the excess energy of nucleation of the critical embryo vapor phase [5], n_{se} - the number of drops in a thin overheated emulsion layer per unit surface, ρ_c is the density continuous medium, $\overline{w}$ is the root mean square speed of the pulsations of a continuous medium, R_0 is the initial radius of the droplet.

The value of the exponent α is found by final according to a priori accepted views about important characteristics of nucleation under the influence of external pulses. For example, for $\alpha \to 0$, when droplets are gas bubbles critical size [6, 7], the relation (6) is applicable for aqueous emulsions. The other limiting case $\alpha = 1$ corresponds to the emulsions containing organic liquids [8], where there are no gas bubbles.

The value of the "surface concentration" n_{se} can be defined, generalizing counting concentration drops n the original emulsion as $n_{se} \sim \sqrt[3]{n^2}$ [9]. Then, equation (6) would look like:

$$n_{se}^* \sim \sqrt[3]{n^2}\left(\frac{\rho_c \overline{w}^2 R_0^3}{W_0}\right)^{\alpha}. \tag{7}$$

In this case, equation (4) is modified as follows:

$$\rho_c \left(\frac{dR}{dt}\right)^2 R^2 \sqrt[3]{n^2} \left(\frac{\rho_c \bar{w}^2 R_0^3}{W_0}\right)^{\alpha} \sim \rho_c \bar{u}^2 . \qquad (8)$$

The formation and growth of a vapor bubbles in the drop found in overheated layer high-boiling continuous medium at the heating surface, is assumed, to be largely similar to the formation and growth of a vapor bubble in a uniform liquid on heating surfaces. Given that the heat-conducting medium is a continuous medium [2], we get

$$R \sim \sqrt{\frac{\lambda_c \Delta T}{r \rho_v}} \sqrt{t} \, , \qquad (9)$$

where *r* is the specific heat of vaporization, ρ_v is the vapor density.

For determination, $\bar{u}$ we use equations (8) and (9):

$$\bar{u} \sim \frac{\lambda_c}{r \rho_v} \sqrt[3]{n} \left(\frac{\rho_c \bar{w}^2 R_0^3}{W_0}\right)^{\frac{\alpha}{2}} \cdot \Delta T \cdot \qquad (10)$$

The density of the heat flow from the heating surface will be determined as

$$q = \frac{\lambda_c}{r \rho_v} \sqrt[3]{n} \left(\frac{\rho_c \bar{w}^2 R_0^3}{W_0}\right)^{\frac{\alpha}{2}} \left(C_2 \frac{\lambda_c}{\nu_c} \Delta T^2 + C_1 r \rho_v \Delta T\right), \qquad (11)$$

where C_1 and C_2 is the experimental constants.

3 MODEL OF HEAT TRANSFER BOILING EMULSIONS WITH EXPERIMENTAL DATA

In the work [3] presents the results of the study, boiling aqueous emulsions with low boiling phase on a heated platinum wire of length l =56 mm and a diameter d of about 100 μ and the average droplet size 35 - 40 μm. However, the boundary conditions of heat transfer were different from model representations, in which boiling was considered in two-dimensional solid surface.

To compare theoretical models with experimental data transform formula (11) for the number of drops of boiled emulsion n_s per unit one-dimensional surface of the heated wire. The number of superheated drops in overheated layer of the heated wire of length *l* corresponds to $n_l \sim \sqrt[3]{nl}$. Then the number of drops per unit surface area of the heated wire will be corresponds $n_s \sim \frac{\sqrt[3]{nl}}{dl} = \frac{\sqrt[3]{n}}{d}$, and the number of boiled drops per unit surface on condition that $\alpha \to 0$ will be equal $n_{se}^{*} \sim \frac{\sqrt[3]{n}}{d}$.

Taking into account the changing relationship between counting concentration *n* and the volume concentration *F* of the droplets of the dispersed phase, equation (11) takes the following form:

$$q = \frac{\lambda_c}{r\rho_v}\frac{\sqrt[6]{F}}{\sqrt{R_0 d}}\left(C_2\frac{\lambda_c}{\nu_c}\Delta T^2 + C_1 r\rho_v \Delta T\right) \qquad (12)$$

Fig. 1 and 2 shows the calculated curves of $\frac{q}{\sqrt[6]{F}}$ on *ΔT* for the two emulsions: water - silicon organic liquid PES-5 (1) and water - silicone fluid PMS - 300 (2), obtained by the formula (12). Dots mark the experimental data presented in [3].

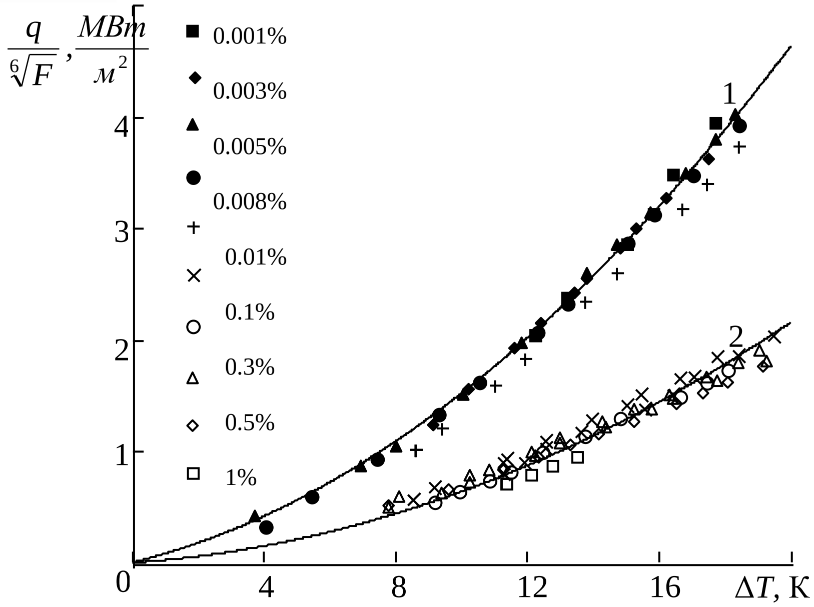

Fig. 1. The dependence of the reduced density of the heat flow from overheating emulsion: water - silicone fluid PES-5.

In fig.1 you can see that the experimental points were stratified into two independent groups, the approximated two model curves. Moreover, curve 1 was in good accordance with the experimental points with a volume concentration of 0.001 - 0.01%, and curve 2 - 0.1 - 4%. This type of grouping experimental points, obviously, may indicate a change of character boil, from the first bubble (0.0001-0.01%) to the second bubble mode, but with a steam film (concentration greater than 0.1%).

Thus, there is a dual nature of heat transfer in emulsions with a low-boiling dispersed phase. This feature can be associated with the fact that the vaporization does not take place on the surface of the heat, as when boiling homogeneous fluid, and at some distance from it. But nevertheless the volume of the vapor phase at a certain concentration drops may behave like a steam film and block the flow of heat to the more remote drops. Consequently, this flow of heat to boil those drops, which are behind a steam shroud formed before the heating surface is insufficient.

For the formation of steam fog the contact between the bubbles in the complete evaporation of the dispersed droplets of the low-boiling fluid is required, the limit value of the volume concentration of the droplets is determined from the ratio 0.0006 = 0.06%. This corresponds to the boundary separating boiling modes presented on Fig.1.

Constants *C1* and C_2 obtained using polynomial regression of the second order were equal for curve 1 - 2.24 and 7.53, and for curve 2 - 0.63 and 4.05 respectively.

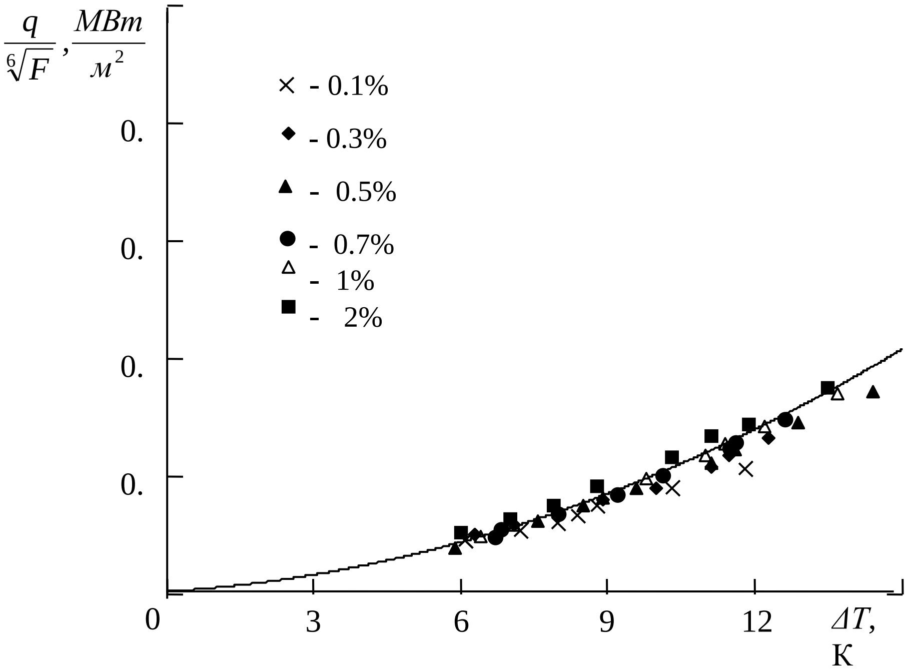

Fig. 2. The dependence of the reduced density of the heat flow from overheating emulsion: water - silicone fluid PMS - 300.

Similar results for the other emulsions of a different physical nature shown in Fig.2. It is shown, that the experimental data are well approximated by a single criterion by equation (12). Due to differences in the physico-chemical properties of the liquid phases of the emulsion in it of course turned out to be different values of the empirical constants. Constants C_1 and C_2 obtained respectively, equal to 0.68 and 4.96.

4 CONCLUSIONS

It is shown, that the calculated dependences, generalizing theoretically grounded model Labuntsov well approximate the experimental data to a boiling in the volume of the dispersed phase, which is limited to the interfacial surface. This fact may testify in favor of the existence of common mechanisms of heat transfer in a homogeneous liquid and the emulsion surface heating. It found that the characteristic boiling emulsions with low dispersed phase is the presence of two modes of the nucleate boiling. Thus, the formal generalization gives grounds for extension of the theoretical concepts relevant to the heat transfer in low-boiling disperse phase of the emulsion.

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