EVALUATION OF CRITICAL HEAT FLOW IN THE CASE OF A BOILING MIXTURE OF LARGE VOLUME

Sh. A. Gaidarov

UDC 536.423.1

An equation is obtained in this article for finding the value of the critical heat flow in the case of boiling binary mixture of large volume under conditions of natural convection; an equation is obtained from the hydrodynamic theory of critical fluid boiling. The obtained result provides a suitable description of experimental data on the critical boiling of the ethanol–water and methanol–water mixture.

According to the hydrodynamic theory of critical boiling of large-volume fluids [1] the stability criterion is given by the expression

$$K=\frac{W_{\text{crit}}}{\sqrt{\frac{q}{\gamma''}\left(1+\frac{\gamma''}{\gamma'}\right)}\sqrt[4]{\sigma(\gamma'-\gamma'')}},\qquad (1)$$

where $W_{\text{crit}}=q_{\text{stem}}/r\gamma''$ is the average rate of steam formation when film boiling arises.

In the case of critical boiling of a mixture the value W_{crit} depends on the composition of the mixture. Indeed, as shown by the experimental and theoretical investigations [2-5] the growth rate of bubbles is slower for mixtures than for single-component fluids. One must, therefore, assume that for mixtures the value of W_{crit} should be lower than for individual components of a binary system.

The results in [5] show that the growth rate of bubbles on heated surfaces during the boiling of binary mixtures is given by the equation

$$\dot{R}=\frac{\Delta T}{\gamma'' r\psi(\theta)}\sqrt{\frac{c_p\gamma'\lambda}{\pi}}\,[1-\Phi(x)]\,\tau^{-\frac{1}{2}},\qquad (2)$$

where $\Phi(x)=\frac{2r}{c_p\Delta T}\sqrt{\frac{D}{a}}\,\frac{x_2-x_1}{x_2}$.

One can see from this expression that the radius of a bubble depends on the physical properties of the steam and fluid as well as on the composition of the mixture x_2 and x_1.

For $x_2 = x_1$ one has $\Phi(x) = 0$ and for a single-component fluid Eq. (2) gives $\dot{R}$ as a function of τ.

Thus, the dimensionless parameter $[1-\Phi(x)]$ in (2) takes into account the effect of composition and of diffusion process on the growth rate of a bubble in the mixture. If what was stated above is adopted as a basis, one assumes that the effect of the composition on the average rate of steam generation for critical boiling of mixtures is taken into account by the same parameter, that is, one can write

$$W_{\text{crit}}\approx\frac{q_{\text{crit}}}{r\gamma''}[1-\Phi(x)].$$

Makhachkala. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 4, pp. 146-148, July-August, 1975. Original article submitted October 21, 1974.

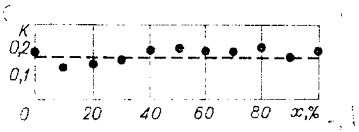

Fig. 1

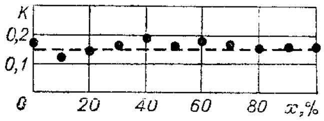

Fig. 2

To determine q_{crit} for boiling mixtures it is indispensable that the value $\Phi(x)$ be known. It can be seen that three dimensionless complexes appear in $\Phi(x)$: $K_s = r/c_p\Delta T$, $K_D = D/a$ and $K_x = (x_2-x_1)/x_2$, where K_s is the criterion of phase transformation; K_D is the Lewis diffusion criterion, and K_x is the concentration criterion. For practical calculations one modifies K_s and K_x.

According to [6] one should put instead of ΔT the saturation temperature T_s in the phase-transformation criterion K_s when the temperature thrust $\Delta T = T_w - T_s$ is unknown.

In the K_x criterion x_1 and x_2 should be replaced by x' and x'' respectively, the latter being fluid or steam concentrations for the equilibrium state.

Having made these modifications one can rewrite Eq. (1) as follows:

$$q_{crit} = Kr\sqrt{g\gamma''\left(1+\frac{\gamma''}{\gamma'}\right)}\sqrt[4]{\sigma(\gamma'-\gamma'')}\left[1-\frac{2r}{c_pT_s}\sqrt{\frac{D}{a}}\frac{x''-x'}{x''}\right]^{-1}. \quad (3)$$

For $x' = x''$ the above equation can be employed for calculating a single-component fluid. The same is also true for the azeatrope point at which the composition of steam and liquid is the same.

To verify Eqs. (3) experimental data have been used on critical heat flows of the ethanol–water and methanol–water mixtures obtained by the authors in [7, 8] when horizontal flat heaters were used.

In Figs. 1 and 2 the data obtained from (3) are shown for the methanol–water and ethanol–water mixtures, respectively. In these diagrams the stability criterion K is shown on the ordinate axis and the corresponding mixture concentration in volume percentages on the abscissa axis.

It can be seen from Figs. 1 and 2 that if the value of K remains constant, as required by the theory, it is clearly sufficient even in the case of critical boiling of the mixture. The average value K = 0.15 shown by dashed lines in Figs. 1,2 is found to be in good agreement with the theoretical value K = 0.147 calculated for critical boiling in the case of flat horizontal heaters [9]. Some deviations in the magnitude from the average value of K for different mixture concentrations is, of course, due to the assumption made for calculating the criterion $\Phi(x)$.

LITERATURE CITED

1. S. S. Kutateladze, Principles of the Theory of Heat Exchange [in Russian], Mashgiz, Moscow–Leningrad (1962).
2. S. J. O. Van Stralen, "Bubble growth rates in boiling binary mixtures," Brit. Chem. Eng., 12, No. 3, 390-394 (1967).
3. L. E. Scziven, "On the dynamics of phase growth," Chem. Eng. Sci., 10, 1-13 (1959).
4. V. I. Tolubinskii, Yu. N. Ostrovskii, and A. A. Kriveshko, "Heat exchange for boiling binary mixtures," Teplo Massoperenos, 2, 211-218 (1968).
5. Sh. A. Gaidarov, "Growth of bubbles on heated surface for boiling fluid mixture," Teplo Massoobmen Khimich. Tekhn., No. 1, 74-77 (1973).
6. A. A. Glukhman, Application of Similarity Theory to Processes of Heat and Mass Exchange [in Russian], Moscow (1967).
7. S. S. Kutateladze, et al., "Some problems of the hydrodynamic theory of heat exchange in boiling," in: Transactions of the Central Scientific-Research, Planning and Design Boiler and Turbine Institute [in Russian], No. 58, Kotlotturbostroenie, Leningrad (1965), pp. 1-14.

8. I. N. Chernobyl'skii and M. N. Pavlishchev, "Investigation of critical boiling of solutions," in: Transactions of the Central Scientific-Research, Planning, and Design Boiler and Turbine Institute [in Russian], No. 58, Kotlotturbostroenie, Leningrad (1965), pp. 29-32.
9. Dir. Linard, "Hydrodynamic evaluation of maximal heat flow for large volume boiling on heaters of finite dimensions," Heat Exchange, Trans. ASME Ser. C, 95, No. 2 (1973).