SUMMARY OF EXPERIMENTAL DATA OBTAINED DURING ACETONE AND ETHANOL BOILING ON FINNED SURFACE

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Abstract

Half-empiric criterion equations have been obtained enabling to analyze the intensity of acetone and ethanol heat transfer in the range of heat fluxes of supporting surface of 8-63 kW/m^2 for horizontal pipes with longitudinal and cross finning at the atmospheric pressure in the conditions of pool boiling.

INTRODUCTION

Characteristic feature of heat exchange during boiling on finned surface is non-isothermality of heat releasing surface. Because of final heat conduction of a fin a temperature field is set up on its surface featuring temperature reduction from the bottom to the vertex of the fin. In consequence of this various boiling modes may coexist on the fin, that largely impedes heat transfer analysis. At present there are no analytical methods enabling to reliably analyze heat exchange intensity during developed boiling on such a surface. Consequently half empirical dependencies confirmed experimentally gain practical importance.

1. Presentation of a Problem

When analyzing and solving the problem of heat exchange intensity during liquid boiling on finned surfaces it is necessary to handle problems concerning the choice of independent variables influencing the heat transfer and to establish the extent of their influence. In order to simplify the problem it is allowable to single out a mode out of the variety of conditions of heat transfer during boiling within the limits of which relations between the parameters determining predominant effect of this or that mechanism of heat transfer (or their combined effect) characteristic for this mode are established.

The process of heat transfer on finned surface can be considered as heat transfer during nucleate boiling in the conditions of free convection on heat releasing surfaces, differently oriented in the space and the relation for determining heat exchange intensity in general form can be written as [1]

$$Nu = f(Pe, Fo, Pr, l_*, X), \quad (1)$$

where l_* is characteristic linear dimension; X is a parameter allowing for a surface geometry.

The process of heat exchange during boiling differs from convective heat exchange by the presence of two phase wall layer. In this case it is necessary to take into account surface forces, that can be taken into account with the use of capillary constant liquid:

$$l_0 = \sqrt{\frac{\sigma}{g(\rho_l - \rho_v)}}. \quad (2)$$

Then Nusselt criterion for heat releasing surface takes the form:

$$Nu = \frac{a\, l_0}{\lambda_l}. \quad (3)$$

The values having greatest influence on the intensity of heat exchange (at constant pressure) out of the values under the function sign are heat flux density, thermophysical properties of liquid and fin geometrical parameters. At the same time one of the main problems arising when determining similarity criteria is the problem of selecting a characteristic linear dimension. It cannot be linear dimension of heating surface since it is usual practice to consider boiling problem on a large surface much greater than the size of vapor bubbles. Absence of considerable influence of liquid layer depth on the intensity of heat exchange during boiling also has been proved in a number of experimental works. Critical radius of nucleus R_{cr} depends on temperature head (or on heat flux density) and consequently cannot be regarded as the characteristic linear dimension as well. The only possible magnitude practically not affected by heat flux density, to the opinion of the authors [2, 3], is the average value of bubble detachment diameter d_0. Following this the criterion equation in general form can be written as:

$$\mathrm{Nu} = f(\mathrm{K}, \mathrm{Pr}, \mathrm{X}), \tag{4}$$

where

$$\mathrm{K} = \mathrm{Pe} \cdot \mathrm{Fo} = \frac{q}{r\rho_v d_0 f} = \frac{q}{r\rho_v \omega''}, \tag{5}$$

where d_0 – bubble detachment diameter; f – vapor bubble detachment rate; ω'' – vapor bubble growth rate, characterizing average rate of growth of the bubbles at a given point and steam generating capacity at one evaporation center [1].

Principle difference of this criterion is in that it includes inner characteristics of the process of nucleate bubbling, showing specific features of the process. Averaged values of inner characteristics d_0, f, and to greater extent of ω'' as shown in [2, 3] can be regarded as practically independent of heat flux density q in the wide range of change of the latter.

As a parameter taking into account the shape and the size of the fin it is recommended to use the fin profile function related to the fin height [4].

$$X = \frac{f_f}{h_f}, \tag{6}$$

where $f_f = \dfrac{\delta_0}{2}\left(\dfrac{x}{h_f}\right)^{(1-2n)/(1-n)}$, x – current coordinate.

Following this an independent variable, characterizing geometrical characteristics of the fin is:

for rectangular

$$X = \frac{f_f(x)}{h_f} = \frac{\delta_0}{2 \cdot h_f}, \tag{7}$$

for trapezoid

$$X = \frac{f_f(x)}{h_f} = \frac{\delta_0}{2 \cdot h_f}, \tag{8}$$

for parabolic

$$X = \frac{f_f(x)}{h_f} \approx \frac{\delta_0}{6 \cdot h_f}, \tag{9}$$

for triangular

$$X = \frac{f_f(x)}{h_f} = \frac{\delta_0}{4 \cdot h_f}. \tag{10}$$

Then the equation (4) may be re-written as

$$Nu_f = CX^b K_f^{\,m} Pr^n. \tag{11}$$

2. Results Generalization

When calculating the heat transfer from finned surface a reduced heat transfer coefficient is usually determined.

$$\alpha_{red} = \alpha_f \cdot E \cdot \frac{F_f}{F_{i\text{-}f} + F_f} + \alpha_{i\text{-}f} \cdot \frac{F_{i\text{-}f}}{F_{i\text{-}f} + F_f}, \tag{12}$$

where $E = \dfrac{\mathrm{th}\left(\dfrac{h_f}{\delta_0}\sqrt{2\mathrm{Bi}}\right)}{\dfrac{h_f}{\delta_0}\sqrt{2\mathrm{Bi}}}$ - fin efficiency coefficient;

$\mathrm{Bi} = \dfrac{\alpha_f (F_f / P_f)}{\lambda_m}$ reduced Bio criterion;

P_f - fin perimeter.

Assuming isothermal nature (as first approximation) of sample basic surface heat balance equation may be written

$$Q = Q_{i\text{-}f} + Q_f, \tag{13}$$

where $Q_f = Q \cdot \dfrac{F_0 - F_{i\text{-}f}}{F_0}$, $Q_{i\text{-}f} = Q \cdot \dfrac{F_{i\text{-}f}}{F_0}$,

Where F_0 - area of the basic (supporting) surface.

Heat flux density values on the fin and on the inter-fin surface respectively are:

$$q_f = \frac{Q_f}{F_f}, \quad q_{i\text{-}f} = \frac{Q_{i\text{-}f}}{F_{i\text{-}f}}. \tag{14}$$

Following the generalization of experimental data on the fin heat transfer [5, 6] from the formula (11) the following equation has been obtained:

$$Nu_f = 21 \cdot X^{-0.1} K_f^{\,0.3} Pr^{-0.2}. \tag{15}$$

Experimental results are described by the dependence obtained with the error of ±15% (Fig.1), that confirms the correctness of the method chosen. Apart from this it is necessary to note an interesting fact that the given relation is true both for longitudinal as well as for cross finning.

When generalizing experimental values of heat transfer coefficients on inter-fin surface equation (4) also was used and the following dependencies have been obtained:

for cross finning

$$Nu_{i\text{-}f} = 115 \cdot K_{i\text{-}f}^{\,0.4} Pr^{-0.2}, \tag{16}$$

for longitudinal finning

$$Nu_{i\text{-}f} = 85 \cdot K_{i\text{-}f}^{\ 0.4} Pr^{-0.2}. \qquad (17)$$

The difference in constant *C* values can be explained by the deterioration of conditions of abstraction of vapor phase from sample lower surface due to surface steaming because of longitudinal fin positioning. The error in determination of $\alpha_{i\text{-}f}$ is also within ±15% (Fig.2, 3). The error in determination of heat transfer reduced coefficient when using criterion equations obtained was also within ±15%.

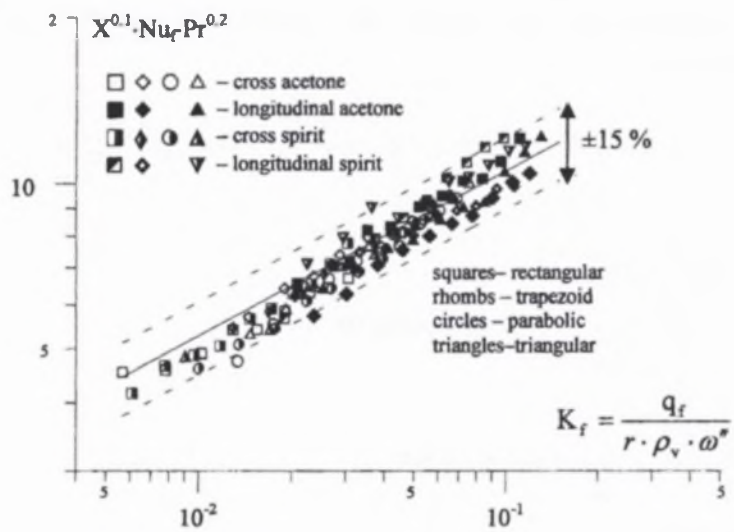

Fig. 1. Generalization of experimental data on the intensity of heat transfer on the fin

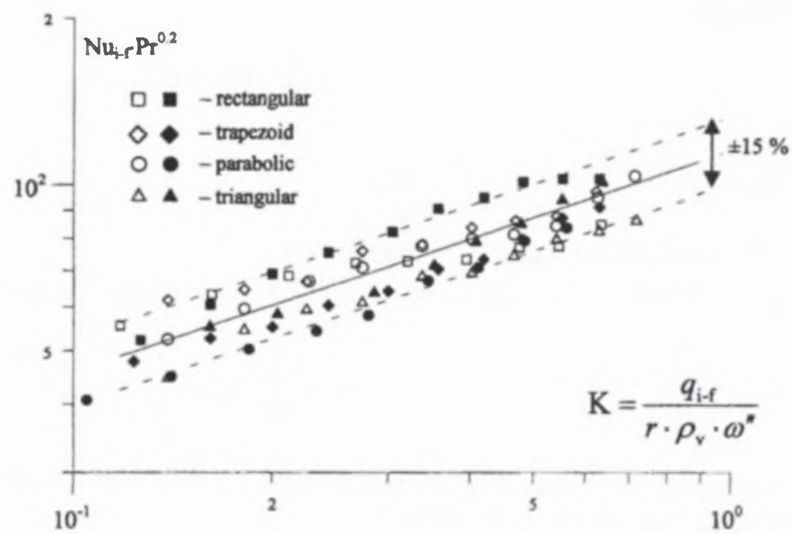

Fig. 2. Generalization of experimental data on the intensity of heat transfer on the inter-fin surface for cross finning (black – ethanol, blank – acetone)

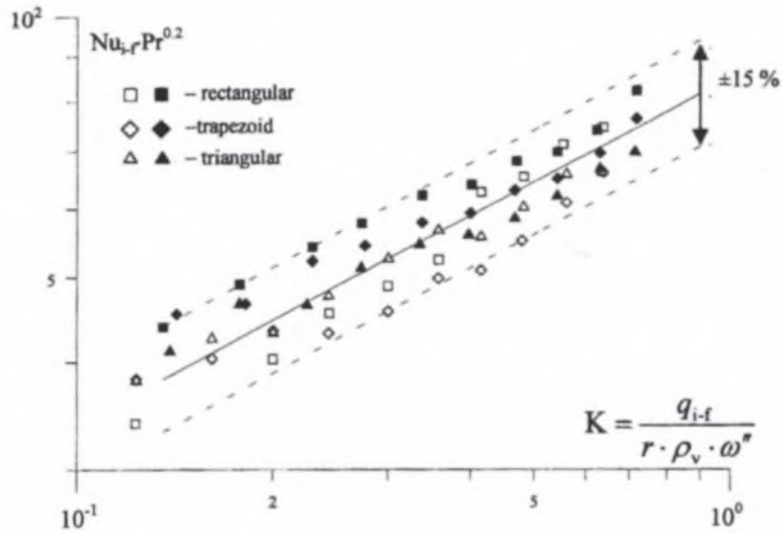

Fig. 3. Generalization of experimental data on the intensity of heat transfer on the inter-fin surface for longitudinal finning (black – acetone, blank – ethanol)

CONCLUSIONS

The criterion equation has been obtained enabling to calculate heat transfer coefficient at all elements of finned surface during acetone and ethanol developed nucleate boiling in the heat flux range of 8-63 kW/m^2 at the atmospheric pressure.

The results of the analysis and experiments show that at the developed nucleate boiling the average heat transfer coefficient on the fin at equal inter-fin distance and fin height is practically independent of the fin profile in the range of operating conditions studied.

Symbol Definition

α — heat transfer coefficient, W/(m^2·K);
d — diameter, mm;
F — surface area, m^2;
h — fin height, mm;
L — length, mm;
p — pressure, N/m^2;
s — fin pitch, mm;
T — temperature, deg;
q — heat flux density, W/m^2.

Indexes:

v — vapor;
l — liquid;
i-f — inter-fin surface;
s — conditions of saturation;
o — basic surface;
fnd — finned surface;
f — fin.

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