AN EXPERIMENTAL STUDY OF HEAT TRANSFER IN WATER CONDENSATION INSIDE VERTICAL TUBES

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A function is described which satisfactorily generalizes experimental data on heat transfer in water vapor condensation within vertical steel tubes for various hydrodynamic flow modes of the condensate film.

Currently existing formulas for determination of heat transfer coefficients for condensation within tubes are few in number and contradictory. There are a number of reasons for this situation, one being that in condensation in a tube of vapor moving at variable velocity several different flow modes of condensate film, existing simultaneously within the tube, must be dealt with (turbulent, under the action of vapor viscosity forces at the condensate surface; laminar, under the action of the force of gravity, and others). The combination of such condensate flow modes in the tube will determine the value of the mean heat transfer coefficient.

In order to investigate the effect of these various factors on the mean heat transfer coefficient and to obtain analytical expressions, experiments were performed on condensation of saturated water vapor within vertical tubes of Kh18N10T stainless steel.

The parameters varied during the experiments were: specific thermal flux $\bar{q}$, pressure of condensing vapor P, internal diameter of tube d, and tube length L. These parameters had the following values: $\bar{q} = (19\text{-}820) \cdot 10^3\ \mathrm{W/m^2}$; P = 8, 29.4, 49, and 69 bar; d = 10, 19.3, 20.3 mm; L = 1.5, 3 m. The experiments were performed with practically complete condensation of water within the tube. They permitted determination of the mean coefficient of heat transfer for condensation $\bar{\alpha}$ as a function of the parameters $\bar{q}$, P, d, L. However, it was not possible to generalize the experimental data using any formulas available in the literature. This is because in the traditional form of processing of experimental data on vapor condensation in tubes the curve of the function

$$\mathrm{Nu} = f\left(\mathrm{Re}_f,\ \mathrm{Ga},\ \mathrm{Pr},\ \frac{L}{d}\right)$$

has a minimum, similar to that obtained in condensation of an immobile vapor on a vertical wall with mixed condensate film flow (upward, laminar; downward, turbulent). For tubes of differing diameters the inflection point of the curve occurs at different Re_f. This makes generalization of experimental data and development of formulas for computation difficult.

We offer now a new function for processing of experimental data on heat transfer in condensation of a vapor moving in a tube, with form

$$\mathrm{Nu}_0 = f\left(\mathrm{Fr}_0\,\mathrm{Ga}^{1/3}\,\frac{\mathrm{Pr}'}{\mathrm{Pr}''}\right), \tag{1}$$

where

$$\mathrm{Nu}_0 = \mathrm{Nu}\,\mathrm{Fr}_0 = \frac{\bar{\alpha} l}{\lambda'} \cdot \frac{W_0^2}{gl} = \frac{\bar{\alpha} W_0^2}{\lambda' g}.$$

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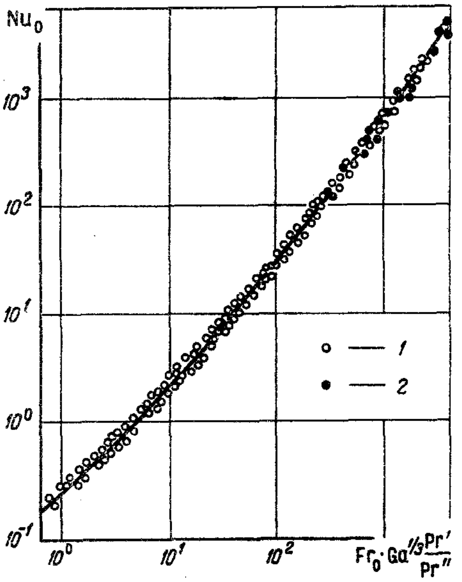

Fig. 1. Nu_0 as a function of $(Fr_0 Ga^{1/3}) \cdot Pr'/Pr''$: 1) authors' data; 2) data of [1].

This function is superior to others in the literature because it may be used not only to generalize experimental data on vapor condensation in tubes, but to generate a single empirical formula for determination of heat transfer coefficient over a wide range of parameter values. Processing of the experimental data in the coordinates of Eq. (1) is depicted in Fig. 1, where points indicate the results of the water vapor condensation experiments performed by the authors. For comparison, Fig. 1 also shows data obtained in [1] for complete condensation of water vapor at a pressure P = 9.8-88 bar within vertical steel tubes, d = 10 mm, L = 2.2, 3.2 m.

As is evident from Fig. 1, the points all group well about a single smooth curve, with scattering not exceeding ±30%. The generalized curve is described by the function

$$Nu_0 = 0.1 \sqrt{7A^{1.7} + 0.2A^{2.8}},$$

where

$$A = Fr_0 Ga^{1/3} \frac{Pr'}{Pr''} = \frac{W_0^2}{g} \left(\frac{g}{\nu'^2}\right)^{1/3} \frac{Pr'}{Pr''}.$$

For low superheating, the ratio Pr'/Pr" may be replaced by the expression $(\mu'/\mu'')^{1/2}$, which also generalizes the experimental data.

NOTATION

$\bar{\alpha}$	is the mean heat transfer coefficient for condensation of moving vapor in the tube;
g	is the acceleration of gravity;
l	is the characteristic linear measure in similarity numbers;
ν'	is the coefficient of the kinematic viscosity of the condensate;
μ' and μ''	are the coefficients of dynamic viscosity of the condensate and vapor;
γ' and γ''	are the specific weights of the condensate and vapor;
λ'	is the coefficient of thermal conductivity of the condensate;
r	is the heat of the phase transition;
W_0	is the corrected condensate velocity at the tube output section;
$Re_f = \bar{q}L/r\gamma'\nu'$;	
$Ga = gl^3/\nu'^2$;	
$Fr_0 = W_0^2/gl$;	
$W_0 = 4\bar{q}L/r\gamma'd$.	

LITERATURE CITED

1. V. V. Konsetov, Candidate's Dissertation [in Russian], TsKTI, Leningrad (1962).