GENERALIZATION OF EXPERIMENTAL DATA ON THE EFFECT OF THE HEATED LENGTH OF A CHANNEL ON CRITICAL HEAT FLUXES

Table 1

1961

SovietRxiv

Abstract

Full Text

HEAT ENGINEERING

Z. L. MIROPOLSKII and L. E. FAKTOROVICH

GENERALIZATION OF EXPERIMENTAL DATA ON THE EFFECT OF THE HEATED LENGTH OF A CHANNEL ON CRITICAL HEAT FLUXES

(Presented by Academician V. P. Glushko, July 3, 1961)

At the present time, many experimental data have been accumulated showing that, in a certain range of pressures, heat contents, and velocities of motion of a steam-water mixture in channels, the critical heat fluxes depend on the length of the heated section ($^{1-3}$). To clarify the question of the influence of the heated channel length on q^{cr}, the present work gives the results of processing the available experimental data (regimes with limited development of pulsations) by means of the system of dimensionless similarity criteria proposed in work (^{9}).

Table 1

Channel shape	d, mm	l/d_{eqv}	p, ata	w_g, kg/m^2 · s	x	Literature source
Water	Water	Water	Water	Water	Water	Water
Tube	8	20	100	800	0–0.06	(^{2})
Tube	8.2	15–50	100	750	0–0.9	(^{3})
Tube	8	20	180	2000–3030	0–0.45	(^{4})
Tube	7.6	7.5	100–170	384–2200	0–0.3	(^{5})
Tube	6	25	26–100	400	0–0.5	(^{6})
Tube	4.6	50–64.5	39.6–141	1200–3000	0.16–0.5	(^{7})
Tube	8.2	7.9–9.5	40–142	680–5400	0–0.46	(^{8})
Annular channel	6.1/9.7	55	20–100	200–5000	0–0.7	(^{9})*
Ethyl alcohol	Ethyl alcohol	Ethyl alcohol	Ethyl alcohol	Ethyl alcohol	Ethyl alcohol	Ethyl alcohol
Tube	16	6.25	2.0	200–800	0	(^{10})

Fig. 1

Figure 1: Fig. 1

* Experiments with uniform heating of both tubes forming the annular channel were carried out by the authors jointly with M. E. Shitsman and I. L. Mostinskii.

Table 1 gives the geometric characteristics of the channels and the range of the investigated parameters used for the generalization. In this case, data were used that were obtained for tubes with diameter greater than 4.5 mm and annular channels with an equivalent diameter of 3.6 mm, i.e., for such channel cross-section sizes where the influence of this parameter does not exert a substantial effect on q^{cr}.

In work (^{9}), for generalizing experimental data on q^{cr} during forced motion of the medium in channels in the region of lengths where this parameter no longer has a substantial effect on the values of q^{cr} ($l/d \geqslant 100$), the following system of dimensionless complexes was proposed:

$$\frac{q^{\text{cr}}\mu'}{\sigma\gamma' r} = f\left(\frac{w_g\mu'}{\sigma\gamma'}, \frac{r}{c'_p T_s}, \frac{\gamma'}{\gamma''}, \frac{\Delta l}{r}\right). \tag{1}$$

For regimes with limited development of pulsations (i.e., in the absence of a compressible medium in the pre-boiling elements of the circuit located between the heated tube and the throttling device), for $x \geqslant 0$ it was establi···

the following form of relation between the criteria of system (1) was established:

$$\frac{q^{\text{cr}}\mu'}{\sigma\gamma r}\left(\frac{r}{c'_p T_s}\right)^{0.8} = 0.174 K_w^{0.4}(1-x)^n, \tag{2}$$

where

$$K_w = \frac{w_g\mu'}{\sigma\gamma'}\left(\frac{\gamma'}{\gamma''}\right)^{0.2}; \quad n = 0.8, \text{ if } K_w < 1.6{\cdot}10^{-2}; \quad n = 50K_w, \text{ if } 1.6{\cdot}10^{-2} < K_w < 6{\cdot}10^{-2},$$

and $n = 3$, if $K_w > 6 \cdot 10^{-2}$.

Fig. 1. Processing of experimental data in dimensionless coordinates.
1—$l/d_{\text{eq}} = 7.5$; 2—$l/d_{\text{eq}} = 20$; 3—$l/d_{\text{eq}} = 50$; 4—$l/d_{\text{eq}} \geq 100$, corresponding to equation (2).
I. Cylindrical tubes—water: a—$l/d = 20$ (2); b—$l/d = 50$ (3); v—$l/d = 20$ (4); g—$l/d = 7.5$ (5); d—$l/d =$ 50-52 (7); e—$l/d =$ 7.5-9.5 (8).
II. Annular channel—water: zh—$l/d_{\text{eq}} = 55$; data of the authors M. E. Shitsman and I. L. Mostinskii.

Fig. 2

Figure 2: Fig. 2

Fig. 3. Nomogram for determining the coefficient A as a function of p, w_g, x, and l/d_{eq}

Figure 3: Fig. 3. Nomogram for determining the coefficient A as a function of p, w_g, x, and l/d_{eq}

Figure 1 gives the results of processing experimental data on q^{cr} for tubes and annular channels at $l/d_{\text{eq}} < 100$ in the coordinate system

$$\frac{q^{\text{cr}}\mu'}{\sigma\gamma r}\left(\frac{r}{c_p' T_s}\right)^{0.8}; \qquad K_w(1-x)^{2.5n}.$$

It was established that, for values of the complex $K_w(1-x)^{2.5n} < 0.085$ and $l/d_{\text{eq}} < 100$, the points are located above the line corresponding to equation (2). At constant values of the parameter l/d_{eq}, the points lie on lines which, up to a certain value of the complex $K_w(1-x)^{2.5n}$, are parallel to the line corresponding to equation (2), and are bounded by a common horizontal straight line. Moreover, the larger the value of l/d_{eq}, the larger the value of $K_w(1-x)^{2.5n}$ at which the inclined lines pass into the horizontal. For $K_w(1-x)^{2.5n} > 0.085$, in the investigated interval of relative lengths (100-7.5), the influence of l/d_{eq} on q^{cr} is absent, and the horizontal line passes into the straight line corresponding to equation (2).

Fig. 2. Dependence of the coefficient A on l/d_{eq} and $K_w(1-x)^{2.5n}$. The line corresponds to equation (3).

Thus, if the ratio of the critical heat fluxes at a given value of l/d_{eq} and at $l/d_{\text{eq}} \geq 100$ is denoted by A $\left(A = q^{\text{cr}}_{l/d_{\text{eq}}}/q^{\text{cr}}_{l/d_{\text{eq}}\geq 100}\right)$, then in that region of abscissa values where the lines

are inclined, the values of A depend only on l/d_{eq} and can be expressed by the equation

$$A = e^{0.0122(100 - l/d_{\text{eq}})}, \tag{3}$$

and in the region where the lines merge into a common horizontal line, the values of A depend only on the complex $K_w(1-x)^{2.5n}$ and can be expressed by the equation

$$A = 0.373\,[K_w(1-x)^{2.5n}]^{-0.4}. \tag{4}$$

Fig. 4. Processing of experimental data in dimensionless coordinates.

Figure 4: Fig. 4. Processing of experimental data in dimensionless coordinates.

Fig. 3. Nomogram for determining the coefficient A as a function of p, w_g, x, and l/d_{eq}

From consideration of Fig. 1 it is evident that, of the two values of A calculated from equations (3) and (4), the smaller should be selected, since extrapolation of the inclined lines into the range of abscissas where the lines pass into a horizontal straight line, as well as extrapolation of the horizontal straight line into the range of abscissas where the lines are inclined, gives overestimated values of A.

Figure 2 gives the values of A as a function of the parameter l/d_{eq} and the complex $K_w(1-x)^{2.5n}$. To facilitate engineering calculations, Fig. 3 gives a nomogram for determining the values of A as a function of pressure p, mass velocity w_g, steam quality x, and the relative length of the heated section l/d_{eq}. The nomogram is constructed in such a way that first one de-

the value A is determined as a function of p, w_g, and x (from equation (4)), and then as a function of l/d_{eq} (from equation (3)). Of the two obtained values of A, the smaller is taken.

Figure 4 gives the results of processing all the experimental data of Table 1 in the coordinate system

$$\frac{q^{\text{cr}}\mu'}{A\sigma\gamma' r}; \quad K_w\left(\frac{c_p' T_s}{r}\right)^2 (1-x)^{2.5n}.$$

It follows from consideration of Fig. 4 that, for calculating critical heat fluxes in short heated channels (at $l/d_{\text{eq}} < 100$), the following equation may be proposed:

$$\frac{q^{\text{cr}}\mu'}{\sigma\gamma' r} = 0.174\, A K_w^{0.4}\left(\frac{c_p' T_s}{r}\right)^{0.8}(1-x)^n. \tag{5}$$

Fig. 4. Processing of experimental data in dimensionless coordinates.
I. Cylindrical tubes—water: a—$l/d = 20$ (2); —$l/d = 20$ (4); —$l/d = 7.5$ (5); —$l/d = 30$ (3); —$l/d = 50$ (3); —$l/d = 25$ (6); —$l/d = 50$–52 (7); —$l/d = 64$–67 (7); —$l/d = 7.5$–9.5 (8); —$l/d = 15$ (3); —$l/d = 20$ (3).
II. Annular channel—water: —$l/d_{\text{eq}} = 55$, data of Z. L. Miropol' skii, M. E. Shitsman, I. L. Mostinskii, and L. E. Faktorovich.
III. Cylindrical tube—ethyl alcohol: —$l/d = 6.25$ (10).
The line corresponds to equation (5).

Equation (5) agrees satisfactorily with the experimental data when at the inlet to the heated channel $x > 0$, or when the liquid subheating does not exceed 150°.

It is known that, at high vapor contents of the flow, degeneration of the boiling crisis occurs and the permissible heat fluxes may be higher than q^{cr}. Therefore the application of equation (5), as well as of equation (2), is possible only within certain limits of vapor content. In work (9), the following approximate limiting values of vapor content are indicated as a function of pressure, when, at the onset of crisis, the wall temperature rises by more than 150°: $p = 20$ ata—up to 0.9; $p = 100$ ata—up to 0.6; $p = 180$ ata—up to 0.4; $p = 200$ ata—up to 0.25.

Energy Institute named after G. M. Krzhizhanovskii
Academy of Sciences of the USSR

Received
29 VI 1961

REFERENCES

1. M. A. Styrikovich, L. E. Faktorovich, *DAN*, **120**, No. 5 (1958).
2. M. A. Styrikovich, Z. L. Miropol' skii et al., *Teploenergetika*, No. 5 (1960).
3. V. E. Doroshchuk, F. P. Frid, *Teploenergetika*, No. 9 (1959).
4. Z. L. Miropol' skii, M. E. Shitsman, in: *Heat Transfer to Steam and Water Boiling in Tubes at High Pressures*, ed. by N. A. Dollezhal' , 1958.
5. V. E. Doroshchuk, F. P. Frid, in: *Heat Transfer at High Heat Loads and Other Special Conditions*, ed. by A. A. Armand, 1959.
6. I. L. Mostinskii, *Inzh.-fiz. zhurn.*, **3**, No. 10 (1960).
7. A. Cischitti, *Energia Nucleare*, Milano, **6**, No. 10 (1959).
8. I. T. Alad' ev, L. D. Dodonov, V. S. Udalov, *Atomic Energy*, **6**, issue 1 (1959).
9. Z. L. Miropol' skii, M. E. Shitsman, *Atomic Energy*, **11**, issue 6 (1961).
10. L. S. Sterman, N. G. Stiushin, V. G. Morozov, *ZhTF*, **26**, No. 10 (1956).

Note: Figure translations are in progress. See original paper for figures.