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Fig. 1

Figure 1: Fig. 1

Abstract

Full Text

HEAT ENGINEERING

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THE INFLUENCE OF TUBE LENGTH ON THE MAGNITUDE OF CRITICAL HEAT FLUXES DURING FORCED FLOW OF A STEAM-WATER MIXTURE

Many works have been devoted to the study of the process by which a boiling crisis arises during the forced flow of a steam-water mixture and of water subcooled below the saturation temperature in heated vertical tubes. In most of these works, the influence of the length and diameter of the experimental section on the magnitude of the critical specific heat flux was not considered ([1], [2]).

In the experiments of B. A. Zenkevich and V. I. Subbotin ([3]), the tube diameter was varied from 4 to 12 mm, and the length from 340 to 600 mm; however, no influence of the geometrical dimensions on the value of q_{cr} was found. Meanwhile, in works ([1], [2]), at the same pressures, mass velocities, and steam contents, different values of the critical heat fluxes were obtained. The only difference in the conditions under which these experiments were carried out was the different lengths of the experimental sections, i.e., different ratios l/d.

On the other hand, at low pressures and mass velocities up to 3000 kg/m^2·sec, as is known, with an increase in steam content from zero to some value x, depending on the pressure and mass velocity, the values of q_{cr} increase; consequently, at a constant value of q along the tube length, the boiling crisis should have arisen in the lower section of the tube. However, in the experiments of work ([1]) the crisis, as a rule, arose in the upper part of the tube. This circumstance also confirms the assumption that there is a dependence of q_{cr} on l/d.

Fig. 1. Dependence of q_{cr} on $\dfrac{i-i'}{r}$ and l/d at $p = 26$ ata and $w_\zeta = 850$ kg/m^2·sec.
a $-l/d = 50$, b $-l/d = 11$

In the laboratory of in-boiler processes of the Power Engineering Institute of the Academy of Sciences of the USSR, work was carried out to study the influence of the length of the experimental section on the magnitude of critical heat fluxes. The experiments were conducted during forced flow of a steam–water mixture and of water subcooled below boiling, at pressures of 26 and 180 ata, mass flow velocities of 850 and 3000 kg/m^2 · sec, and relative enthalpy from −0.3 to +1.

The experimental section was made of a seamless tube of ÉYa1T stainless steel, 3 mm in diameter and 150 and 35 mm long; i.e., l/d was, respectively, 50 and 11. The tube was heated by alternating current.

The experiments were carried out on a stand installed in the boiler room of the CHP plant of the All-Union [[unclear: continuation on next page]]

of the All-Union Thermal Engineering Institute. A description of the experimental setup* is given in work ([1]).

The results of the experiments confirmed the dependences obtained in works ([1], [2]).

1. At low pressures and mass velocities up to 3000 kg/m^2 · s, and at steam contents above zero, the critical heat fluxes increase with increasing relative enthalpy and then begin to decrease. At a steam content equal to unity, $q_{\text{cr}} = 0$.
2. At high pressures, as the steam content increases, the value of q_{cr} decreases monotonically.
3. With decreasing subcooling, at all pressures and mass velocities the critical heat fluxes decrease. In this case, q_{cr} was taken to be the value of the heat flux at which an abrupt increase in the wall temperature was observed. For water subcooled to the saturation temperature and for moderate steam contents, the magnitudes of which depend on the pressure and mass velocity, when q_{cr} was reached the jump in wall temperature was very considerable, which led to automatic shutdown of the power transformer.

At large steam contents, q_{cr} was taken to be the load at which an abrupt increase in wall temperature occurred, associated with the transition from nucleate boiling to a stable film regime, even if this jump was small in magnitude.

At a pressure of 26 ata and a mass velocity of 850 kg/m^2 · s, the boundary separating these regions is a steam content equal to 0.8. At the same pressure, but at a mass velocity of 3000 kg/m^2 · s, $x = 0.45$. At a pressure of 180 ata and the same velocities, this boundary is, respectively, at steam contents of 0.5 and 0.3.

However, during the motion of a steam-water mixture in a heated tube 3 mm in diameter at pressures of 26 and 180 ata and mass velocities of 850 and 3000 kg/m^2 · s, before the onset of the crisis understood in this way, oscillations of the tube-wall temperature were observed, with an oscillation amplitude of several tens of degrees and a frequency of the order of 3–4 s^{-1}.

Figure 2

Figure 2: Figure 2

Fig. 3

Figure 3: Fig. 3

Fig. 2. Dependence of q_{cr} on $\frac{i-i'}{r}$ and l/d at $p = 26$ ata, $w_g = 3000$ kg/m$^2 \cdot$ s. The designations are the same

Figure 1 presents the values of the critical heat fluxes at $p = 26$ ata and $w_g = 850$ kg/m$^2 \cdot$ s as a function of the relative enthalpy and l/d. In this case the values of $\frac{i-i'}{r}$ and l/d referred to the place where the crisis occurred. As is seen from examination of the graph, in longer tubes, all other conditions being equal, the crisis occurs at values of q_{cr} smaller by a factor of 2–2.2.

Figure 2 presents the values of q_{cr} in the same coordinates, but at $w_g = 3000$ kg/m$^2 \cdot$ s. Examination of this graph shows that, as the length of the experimental section is reduced within the same limits, the values of the critical heat fluxes increase by approximately a factor of 1.6. It may therefore be concluded that, with increasing mass velocity of the working medium, the influence of the length of the heated section on q_{cr} decreases.

* I. L. Mostinskii, A. A. Stavrovskii, M. A. Kalashnikova, I. S. Shagov, M. M. Egorov, and M. I. Petukhov took part in carrying out the experiments.

The amount of experimental data for water subcooled below the saturation temperature and for steam contents near zero proved insufficient for determining the course of the curve.

Figs. 3 and 4 show the dependences of the value q_{cr} on $\frac{i-i'}{r}$ and l/d at a pressure of 180 ata and $w_g = 850$ and 3000 kg/m$^2 \cdot$ s in heated tubes 150 and 35 mm long. A decrease in the length of the heated tube under these parameters also leads to an increase in the critical heat fluxes.

From a comparison of the data presented in Figs. 1–4, it may be concluded that with increasing pressure the influence of length on q_{cr} decreases.

Thus, as a result of the present investigation it has been established:

Fig. 3. Dependence of q_{cr} on $\frac{i-i'}{r}$ and l/d at $p = 180$ ata and $w_g = 850$ kg/m$^2 \cdot$s. The designations are the same

Fig. 4. Dependence of q_{cr} on $\frac{i-i'}{r}$ and l/d at $p = 180$ ata and $w_g = 3000$ kg/m$^2 \cdot$ s. The designations are the same

Fig. 4

Figure 4: Fig. 4

1. With forced motion of a steam-water mixture in a vertical steam-generating tube of diameter 3 mm, at w_g = 850 and 3000 kg/m$^2 \cdot$ s, p = 26 ata, and relative enthalpy from 0.1-0.2 to 0.8-0.9, decreasing the length of the heated tube from 150 to 35 mm (l/d, respectively, 50 and 11) increases the value of q_{cr} by a factor of 1.5-2. At 180 ata, with the same values of w_g and relative enthalpy from −0.2 to +0.5-0.6, an increase of the critical heat fluxes by a factor of 1.4-1.8 was observed.
2. Since, as a rule, the length of tubes or the ratio l/d in industrial devices is considerably greater than in experimental installations, there is a need to carry out further investigations of the influence of the length and diameter of the heated tube on the value of q_{cr}.

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