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THERMAL ENGINEERING

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Abstract

Full Text

THERMAL ENGINEERING { : style= "text-align: right;" }

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THE EFFECT OF LOCAL INCREASES IN HEAT FLUXES ALONG THE LENGTH OF A CHANNEL ON THE BOILING CRISIS

In most published works devoted to the study of the boiling crisis under forced motion of the working medium in channels, only the case of a uniform distribution of heat fluxes along the length of the channel is considered. However, in a number of technical devices there is a clearly expressed nonuniform distribution of heat fluxes along the channel length; in particular, local increases in heat fluxes— “hot spots” —are observed (1-4).

In (5) the conclusion is drawn that “hot spots” affect the value of q_{cr} . In (6) an increase of q_{cr} at a “hot spot” 35 mm long is noted as a function of the heat content of the working medium at the place of crisis (an increase of 100% at $i = 306$ kcal/kg and of 4% at $i = 510$ kcal/kg). The experiments were carried out at $p = 141$ ata and a ratio of heat fluxes at the “spot” and in the remaining part of the rectangular channel $\varepsilon = 2$.

In order to study this question in greater detail, the authors carried out experiments on the experimental stand of the G. M. Krzhizhanovskii Power Engineering Institute, located at the Heat and Power Center of the All-Union Thermal Engineering Institute (a detailed description of the stand is given in (7)). The experiments were carried out under conditions with restricted and free development of pulsations, i.e., both in the absence and in the presence of a compressible medium in the elements of the circuit situated between the heated tube and the inlet throttle. The experimental sections were made from a seamless tube 10/8 mm in diameter of stainless steel 1Kh18N9T and were installed vertically. Heating was effected by alternating electric current over the length l . The “hot spot” was simulated on a section of tube with a thinned wall of length l_1 , located 10 mm from the end of the tube. The bulk of the experiments was carried out with the “hot spot” located at the upper, outlet end of the tube. The heat fluxes on it were distributed uniformly, and the ratio of the heat fluxes in the “hot spot” zone to the heat fluxes on the remaining part of the tube was 2 and 1.35. The experiments were carried out at a pressure of 100 ata, mass velocities of 2000, 850, and 400 kg/m²·sec, and upward motion of the working medium. The relative enthalpy of the medium at the outlet from the experimental section

Fig. 1

Figure 1: Fig. 1

Fig. 2

Figure 2: Fig. 2

$$x = \frac{i - i'}{r}$$

varied from 1.0 to -0.2 . The crisis was recorded by a sharp jump in wall temperature, determined from thermocouple readings or visually—from reddening of the tube wall.

Figure 1 gives summary curves of the experimental data for regimes with restricted development of pulsations in the form of the dependence of q_{cr} on the steam content at the outlet from the experimental section x_{out} , the mass velocity w_g , and the length of the “hot spot” l_1 , with the ratio of heat fluxes at the “spot” and in the tube $\varepsilon = 2$. From consideration of Fig. 1 it is seen that, at all investigated mass velocities, the value of q_{cr} depends substantially on the length of the “hot spot,” this influence being strong at low steam contents and almost disappearing in the region of large x_{out} . With increasing mass velocity w_g , the region of influence of the length l_1 on q_{cr} narrows noticeably.

In the experiments, some decrease in q_{cr} was observed in the region $x_{out} = 0$; however, this effect was insignificant, since even at $w_g = 400 \text{ kg/m}^2 \cdot \text{s}$, where the strongest influence of pulsations is observed, the decrease in q_{cr} in the region $x_{out} = 0$ was only 17%. The discontinuity of the curve $q_{cr} = f(x_{out})$, which

Fig. 1. Effect of the length of the “hot spot” l_1 on the value of q_{cr} under conditions of limited development of pulsations: $p = 100 \text{ ata}$, $\varepsilon = 2$, $l = 160 \text{ mm}$, $d = 8 \text{ mm}$; a — $w_g = 2000 \text{ kg/m}^2 \cdot \text{s}$; b — $w_g = 850$; c — $w_g = 400$; 1 — $l_1 = 64 \text{ mm}$; 2 — $l_1 = 16 \text{ mm}$; 3 — $l_1 = 4 \text{ mm}$.

Fig. 2. Effect of the total channel length l on the value of q_{cr} under conditions of limited development of pulsations in the presence of a “hot spot” and with uniform heating. $p = 100 \text{ ata}$, $d = 8 \text{ mm}$. a , d — $w_g = 2000 \text{ kg/m}^2 \cdot \text{s}$; b , e — $w_g = 850$; c , f — $w_g = 400$. 1 — $l = 160 \text{ mm}$, $\varepsilon = 2$; 2 — $l = 500 \text{ mm}$, $\varepsilon = 2$; 3 — $l = 945 \text{ mm}$, $\varepsilon = 2$; 4 — $l = 160 \text{ mm}$, $\varepsilon = 1$; 5 — $l/d \geq 100$, $\varepsilon = 1$.

was observed in works (⁸, ⁹) at 100 ata and $w_g = 400$ and $850 \text{ kg/m}^2 \cdot \text{s}$, when the steam content of the working medium at the inlet to the experimental tube reached zero values, was preserved in our experiments only at $w_g = 400 \text{ kg/m}^2 \cdot \text{s}$.

Figure 2 presents data obtained under the same conditions as in Fig. 1, with different total heated tube lengths ($l = 160$; 500 ; 945 mm).

Fig. 3

Figure 3: Fig. 3

The data obtained at $l = 500$ and 945 mm differ little, whereas in experiments with shorter tubes ($l = 160$ mm), in the region of high steam qualities, higher values of q_{cr} were obtained. This difference, reaching about 100% at $w_g = 2000$ kg/m² · s, $l_1 = 64$ mm, and $x_{out} = 0.45$, decreases as the steam quality decreases and is more pronounced

Fig. 3. Effect of the length l_1 , l , and intensity ε of the “hot spot” on the value of q_{cr} , and comparison with q_{cr} under uniform heating in conditions of free development of pulsations. $p = 100$ ata, $d = 8$ mm. 1– $l_1 = 64$ mm; 2– $l_1 = 16$ mm; 3–uniform heating ($\varepsilon = 1$). a – $w_g = 2000$ kg/m² · s; b, c, d – $w_g = 850$; v – $w_g = 400$. a, b, v – $\varepsilon = 2$, $l = 160$ mm; c – $\varepsilon = 2$; d – $\varepsilon = 1.35$. A – $l = 160$; B – $l = 500$ mm.

at greater lengths of the “hot spot” and high w_g . In the region of low steam qualities ($x_{out} = 0.0 \div 0.5$) at $w_g = 850$, and $x_{out} = 0.0 \div 0.25$ at $w_g = 2000$ kg/m² · s, all the data obtained for channel lengths from 160 to 945 mm practically coincide; i.e., heating of the pre-included section has no substantial effect on q_{cr} . This is also confirmed by the data obtained in experiments with an unheated pre-included section ($w_g = 850$ kg/m² · s, $\varepsilon = 2$, $l_1 = 64$ mm). The range of steam qualities in which heating of the section located before the “hot spot” does not affect q_{cr} widens as w_g decreases.

Figure 2 also shows curves obtained under conditions of uniform heating at $l = 160$ mm⁽⁹⁾ and $l/d \geq 100$ ⁽¹⁰⁾. At $l_1 = 64$ mm the values of q_{cr} slightly exceed the data obtained at $l = 160$ mm (by up to 30%), and exceed by as much as 3.5 times the q_{cr} values obtained at $l/d \geq 100$. With increasing w_g and l_1 , this effect decreases; thus, for example, at $w_g = 2000$ kg/m² · s and $l_1 = 64$ mm this increase is about 50%, while at $l_1 = 16$ mm it is 2.5-fold (in comparison with data for a uniformly heated tube at $l/d \geq 100$).

Figure 3 presents data obtained in experiments with free development of pulsations, with and without a “spot.” In tubes

of small length ($l = 160$ mm), in the region of small x_{out} , the influence of l_1 is clearly noticeable. The crisis occurs at heat fluxes considerably greater than in the case of uniform heating (an increase by a factor of 2.7 at $l_1 = 16$ mm). With increasing w_g this influence weakens, especially when x_{out} is increased. Increasing the total length of the tube to $l = 500$ mm noticeably reduces q_{cr} (by approximately a factor of 2); moreover, at $l_1 = 64$ and 16 mm and $w_g = 850$ kg/m² · sec, the values of the critical heat fluxes practically coincide. However, q_{cr} on the “spot” is nevertheless substantially higher than under conditions of uniform heating. This increase is about 50% at $\varepsilon = 2$ and about 30% at $\varepsilon = 1.35$. In the experiments at $w_g = 850$ kg/m² · sec, $\varepsilon = 1.35$, $l = 160$ m, $l_1 = 16$ and 64

mm, almost identical values of q_{cr} were obtained, although the presence of the “spot” increased q_{cr} by more than one and a half times ($x_{out} = 0$) in comparison with uniform heating.

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