

relate respectively to the parameters of the inside and outside contours at the mixer exit, and the parameters at the nozzle exit.

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CAUSES OF ENHANCED BOILING HEAT TRANSFER ON SURFACES COVERED WITH PERFORATED POLYMER FILM

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On the basis of a series of experimental results it is shown that the chief cause of enhanced heat transfer is the concentration of the heat flux in the neighborhood of the perforations.

One of the most efficient methods of enhancing boiling heat transfer in the low-pressure region (below atmospheric) is to cover the heat-transfer surface with perforated polymer film [1, 2].

It is considered [2] that the intensification of heat transfer is achieved mainly as a result of the improved vapor-phase nucleation conditions on the surface of the hydrophobic polymer film. At first glance, this explanation seems quite convincing. However, a careful study of the experimental results [2-10] reveals a very strange fact that cannot be explained from this standpoint. The perforated fluoroplastic (Teflon) film generally employed is, indeed not readily wetted by water ($\theta > 90^\circ$), however, enhanced heat transfer is also observed in connection with the boiling of other liquids: ethanol [2, 3, 5], the refrigerants R 11, R 12, and R 22 [4, 8, 9], acetone [5], and even helium [10]. All these liquids are good wetters not only of metals but also of fluoroplastics, i.e., for them the latter are not hydrophobic materials. Thus, for example, for fluoroplastic surfaces wetted by ethanol, acetone, and cryogenic fluids $\theta = 27^\circ$ [11], 25° [12], and not more than 10° [13] respectively.

But what then causes the enhanced heat transfer when hydrophilic perforated film is employed? The model proposed in [2] does not provide an answer to this question.

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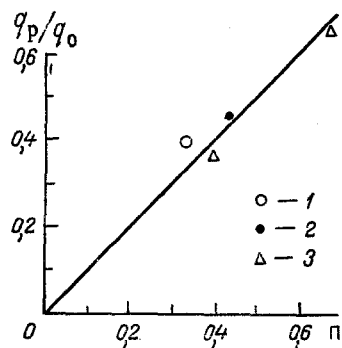


Fig. 1

Fig. 1. Effect of the surface porosity of the film Π on the ratio q_p/q_0 : 1) [2], 2) [4], 3) author's data.

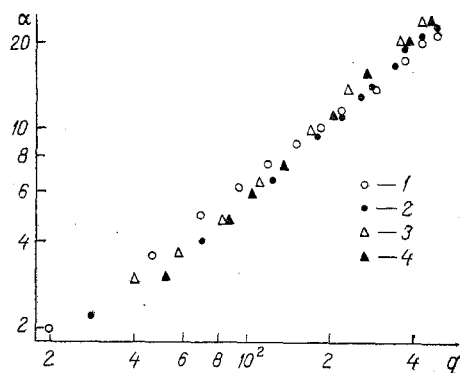


Fig. 2

Fig. 2. Heat transfer coefficient α ($\text{kW/m}^2 \cdot \text{K}$) as a function of q (kW/m^2) for water boiling at 13 kPa: 1) Lavsan mesh ($\Pi = 0.7$); 2) silvered Lavsan mesh; 3) perforated Teflon film ($\Pi = 0.3$); 4) treated Teflon film.

The solution appears to be as follows. All the polymer films investigated have low thermal conductivity, i.e., are essentially thermal insulators. Thanks to this property the heat fluxes are redistributed over the heating surface and are concentrated at the perforations. Thus, at each perforation the heat flux density is higher than the surface average and equal to $q_0 \Pi^{-1}$. As a result of this concentration of the heat flux around the perforations stable vacuum nucleate boiling begins at much lower heat loads (averaged over the surface) and hence lower temperature heads than on bare surfaces. If it is assumed that for a given surface-liquid combination boiling begins at q_0 , then on the same surface covered with a perforated polymer film boiling should begin at a heat flux density q_p equal to $q_0 \Pi < q_0$. Naturally, this earlier boiling leads to enhanced heat transfer.

The above conclusion that the ratio of the heat flux densities at which boiling begins on surfaces with and without a perforated polymer film should be equal (or nearly equal) to the surface porosity of the film is confirmed by the previously published data and by our experiments (Fig. 1).

Of course, the accurate observation of the ratio of the heat flux densities at which boiling begins on surfaces with and without a perforated polymer film q_p/q_0 is not an easy task, since, apart from the basic factor - the concentration of the heat flux in the neighborhood of the perforations - there is a further influence which is difficult to measure. The perforated film does not cling to the heating surface tightly, without leaving a gap, at least intermittently. In this gap convection is nonexistent (or considerably reduced by the structure of the film), as a result of which the superheating stage, corresponding to the onset of boiling, is reached in the gap at lower heat flux densities than on the bare surface. This explains, in particular, why the increase in the heat transfer coefficients is greater for a surface covered with perforated fluoroplastic film than for the same surface covered with patches of fluoroplastic emulsion, which has good adhesion to the heating surface [2].

In order to test this hypothesis we carried out the following experiments. In a first experiment we compared the heat transfer rate with the surface covered with a paraffin-impregnated Lavsan mesh (contact angle for water $\theta = 105^\circ$ [11]) and the heat transfer rate obtained using the same Lavsan mesh with a thin coating of silver ($\theta = 63^\circ$ [12]). In a second experiment we compared the effect of a perforated Teflon film ($\Pi = 0.3$, perforation diameter 0.45 mm, $\theta = 112^\circ$ [11]) with that of the same film after special chemical treatment (sodium-naphthalene complex in accordance with GOST 4.G0-054.210) designed to improve its wettability ($\theta < 90^\circ$). The experiments were carried out on the apparatus described in [14].

From Fig. 2, which shows some results of these experiments, it is clear that using perforated films with identical geometries and thermophysical properties but sharply different wettabilities gives almost equal heat transfer coefficients.

The results convincingly show that the main factor leading to enhanced heat transfer on a surface covered with a perforated polymer film is the concentration of the heat flux in the perforations, the wettability of the film playing only a minor part.

NOTATION

q , heat flux density; q_0 , heat flux density at which boiling begins on the bare surface; q_p , heat flux density at which boiling begins on the surface covered with a perforated film; α , heat-transfer coefficient; θ , contact angle; and Π , surface porosity.

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