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HEAT AND MASS TRANSFER AND PROPERTIES OF WORKING FLUIDS AND MATERIALS

Heat Transfer during the Boiling of Liquid on Microstructured Surfaces. Part 1: Heat Transfer during the Boiling of Water

I. A. Popov[a], N. N. Zubkov[b], S. I. Kas'kov[b], and A. V. Shchelchkov[a]
[a] *Tupolev Kazan National Research Technical University, ul. K. Marksa 10, Kazan, 420111 Russia*
[b] *Bauman Moscow State Technical University, Vtoraya Baumanskaya ul. 5, Moscow, 105005 Russia*

Abstract—Results from an experimental investigation of heat transfer on microstructured surfaces obtained using the deforming cutting method and having different design shapes and sizes are presented. Heat transfer enhancement by a factor of up to 9 as compared with that on a smooth surface is obtained. Principles for constructing physical models of boiling enhancement are given.

Keywords: pool boiling, heat transfer coefficient, enhancement of heat transfer
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Development of modern technologies generates the need of achieving significantly higher heat transfer coefficients for removing high specific heat fluxes from relatively small areas. This problem can be solved by using the boiling of liquids in cooling systems. Despite the fact that considerable heat transfer coefficients are obtained due to an intense phase transformation process during boiling even on smooth surfaces, there is a need to achieve still higher enhancement of heat transfer.

Heat transfer from a wall to liquid during boiling can be enhanced using different means, namely:

(i) by selecting a suitable working fluid the physical parameters of which allow higher heat transfer coefficients to be obtained;

(ii) by using boiling during the motion of cooling agent; and

(iii) by shaping a microstructure on the heat-transfer surface for enhancing the generation and separation of bubbles.

Microstructured surfaces are understood to mean heat-transfer surfaces with small-scale deformations obtained as a result of subjecting these surfaces to processing or applying coatings and commensurable in their geometrical parameters with roughness. The roughness of such surfaces is small for changing the intensity of single-phase heat transfer; therefore, they are used primarily for boiling processes. The fundamental principle behind the development of structured surfaces for enhancing the boiling process consists in creating a large number of nucleation sites or traps of steam bubbles on the surface, due to which earlier commencement of boiling or boiling at lower temperature differences is obtained. This is especially important for the boiling of liquids that have good well surface wetting properties, e.g., freons, organic and cryogenic liquids, and liquid alkali metals.

The following requirements are imposed on the modern boiling heat-transfer surfaces for development of cooling systems:

(i) Nucleate boiling must begin at smaller differences of temperatures between the hot wall and liquid; i.e., narrower boundaries must be obtained between natural convection and nucleate boiling.

(ii) Higher heat-transfer coefficients must be obtained at the preset difference between the temperatures of wall and liquid.

(iii) A higher critical heat flux identifying the commencement of burnout must be achieved.

In paper [1] written by M. Jakob and W. Fritz, which one of the first works on heat transfer enhancement during nucleate pool boiling achieved through the use of microroughened surfaces with square milled slots and a rough surface obtained by means of a sandblasting machine, the heat transfer coefficients were increased by factors of 7–13 and 1.3–4, respectively. Such results were confirmed by the investigations carried out by C. Corty and A.S. Foust [2], which obtained a heat transfer enhancement ratio during pool boiling on a surface with granular roughness up to 4. That significant enhancement of heat transfer on structured surfaces can be obtained and that the superheating of liquid on a wall can be decreased by an order of magnitude was reported in the works of A.E. Bergles [3], J.R. Thome [4], R.L. Webb [5], S. Yilmaz and J.W. Westwater [6], as well as in the works of many other researchers. Recent years have seen an increased interest in studying the characteristics of boiling with a nanorelief [7, 8]. It was found that the use of nanorelief applied on a heat-transfer surface facilitated a decrease of separating bubble diameter by as much as