Heat transfer enhancement when boiling on finned surfaces

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Abstract. In this work, we studied the effect of radial surface finning and hydrophobic fluoropolymer coating of finned surfaces on the intensity of heat transfer at boiling. Two samples were used: 16 fins and 32 fins. At first, experiments were carried out without a hydrophobic coating. After that, the samples were covered with a layer of fluoropolymer and a series of experiments were carried out. During these experiments, the state of the fluoropolymer coating was analyzed. Experiments on a sample with 16 fins showed that deposition of fluoropolymer leads to significant intensification of heat transfer. For the sample with 32 fins, the opposite effect was observed: hydrophobization negatively affected the efficiency of heat transfer. Maximal enhancement of heat transfer, in comparison with finely finned and smooth surfaces, was achieved on a surface with large fins coated with fluoropolymer.

1. Introduction

The development of electronics and microelectronics is limited by several factors. One of them is the efficiency of cooling systems. The urgency of the problem increases with an increase in power and miniaturization of microelectronic systems. This can be solved via the development of technologies for surface modification for boiling heat transfer.

At the moment, there are many works dealt with boiling on surfaces with arrays of rods and fins of various shapes. There are many studies on boiling on surfaces with different geometries. A significant number of them are devoted to surfaces, which are the ordered arrays of short rods of different shapes and dimensions (McGillis [1]; Rainey [2]; Yu [3]; Shen [4]).

It is shown in some works (Kaniowski [5], Gheitaghy [6]) that heat transfer enhancement at boiling on finned surfaces is limited. At a too narrow space between the fins with sufficiently high heat fluxes, it is “steamed”, which leads to a drop in the heat transfer coefficient.

Boiling was also studied on surfaces with grooves and fins of more complex shapes: T-shaped, Y-shaped, rounded channels, channels with extended bottom, etc. (Das [7]; Xin [8]; Hübner [9]).

Another field for research is the study of the effect of surface hydrophobicity on boiling heat transfer. There are works that demonstrate its positive effect in some regimes on different surfaces, such as tubes (Safonov [10]) and flat surfaces (Surtanov [11]).

This work is devoted to the study of the intensification of heat transfer during boiling on radially ribbed surfaces, which remain poorly studied. A hydrophobic coating was also applied to the surfaces to study its effect on heat transfer. A fluoropolymer was chosen as the material for the hydrophobic coating, similar to the above works.
2. Experimental setup
The setup used for studying pool boiling has cylindrical symmetry. The main heater was a nichrome wire of 4-ohm resistance wound on a brass rod 5 mm in diameter. The rod was pressed into a Teflon washer 4 mm thick and 15 mm in diameter. To fix the surface temperature and determine the heat flux according to the Fourier law, two thermocouples were installed in the copper core in holes at different depths. A nichrome heater was insulated with several layers of fiberglass. Additionally, the entire core with thermocouples was thermally insulated with foil-coated polyethylene foam.

The walls of test section included a stabilizing heater used to equalize the temperature in the entire volume. Throughout the experiments, the power supplied to the stabilizing heater remained constant and ensured the maintenance of saturation temperature in the volume. This construction was enclosed in Teflon insulated housing.

Distilled, deionized, degassed water was used as a working fluid. The water level was kept constant (30 mm). The temperature was controlled by a thermocouple immersed in the liquid. The coatings were preliminarily applied to the upper finned section of the brass rod. A scheme of the test section with an installed specimen with radial finning is shown in figure 1.

The setup consists of a test section, temperature recording equipment and power sources for Gwinstek GPO-743035 heaters.

All thermocouples used in the setup were individually calibrated from 0°C to 150°C with a step of 10°C. A dry-block calibrator KS 100-1 was used up to 100°C. The Termex VT-8 glycerin thermostat was used in the range from 100°C to 150°C. The temperature was monitored with a V7-99 meter with ETS-100 resistance thermometers. The calibration error was 0.1°C.

![Figure 1. Scheme of setup for studying pool boiling.](image1)

Pool boiling was studied on surfaces with radial finning. The photo of 5-mm diameter brass heater with a finned surface is shown in figure 2. The temperature was measured by thermocouples located inside the core. Two heaters were used: the heater with 16 fins and the heater with 32 fins.

Fluoropolymer coatings were deposited by Hot Wire CVD method. The method and schematic of experimental setup are described in detail in Safonov [12]. The method consists in deposition of fluoropolymer coatings from a precursor gas activated by a heated wire catalyst.

![Figure 2. The photo of finned surface (16 fins). Diameter – 5 mm. Fins height – 1 mm.](image2)
3. Results and discussion
Several series of experiments on pool boiling at saturation temperature were carried out on a heater with 16 fins: without applying a fluoropolymer coating and with a fluoropolymer coating at different time steps. The resistance of the fluoropolymer coating to prolonged boiling has been studied. The contact angle on a surface coated by fluoropolymer is shown in figure 3 (143.4º). Changes in morphology over time can be seen in figure 4, figure 5 and figure 6.

![Contact angle on a surface covered by fluoropolymer](image1.png)

**Figure 3.** Contact angle on a surface covered by fluoropolymer (16 fins).

![Surface before fluoropolymer deposition](image2.png)

**Figure 4.** Surface before fluoropolymer deposition.

![Surface just after fluoropolymer deposition](image3.png)

**Figure 5.** Surface just after fluoropolymer deposition.
Figure 6. Surface with fluoropolymer after several experimental series.

All data for the surface with 16 fins are presented in figure 7. The first experiment (11.11.2018) was carried out before fluoropolymer deposition and did not lead to a noticeable increase in the efficiency of heat transfer in comparison with a smooth surface (Rohsenow [13]). After that, a fluoropolymer was applied to the surface; subsequently this fluoropolymer was gradually disintegrated during the experiments. The surface wettability became inhomogeneous and the heat transfer rate increased.

At the end, an experiment to achieve the maximal thermal loads was carried out (31.07.2019). The heat flux density exceeded 400 W/cm², the overheating value exceeded 35 K. So high value of heat flux density without reaching boiling crisis is explained by complex surfaces geometry, which made it almost impossible to form a stable vapor film (ribs were enough high and the real surfaces area was bigger, then cross-sectional area of heater). The heater coil failed, but the critical heat flux was not reached. Data of subsequent measurements of 2.12.2019 showed that the fluoropolymer coating was completely destroyed. Heat transfer data matched the results obtained for the uncoated surface.

Figure 7. Boiling curves for the surface with 16 fins.
On a finely finned heater (32 fins), the experiments were carried out in a similar way: before deposition of a fluoropolymer, with deposition of a fluoropolymer, and until complete destruction of the applied layer. The opposite effect was observed: hydrophobization negatively affected the efficiency of heat transfer. The contact angle on pure brass surface (a) (60.7°-64.6°) and surface coated with a fluoropolymer (b) (156.8°-156.9°) is shown in figure 8. Before applying the fluoropolymer, the drop flows to the space between the fins. After deposition of a hydrophobic layer, it stays on the tops of the fins.

![Contact angle on pure brass surface (a) and surface coating with fluoropolymer (b)](image)

**Figure 8.** Contact angle on the pure brass surface (a) and surface coating with fluoropolymer (b) (32 fins).

![Boiling curves for the surface with 32 fins](image)

**Figure 9.** Boiling curves for the surface with 32 fins.

### 4. Conclusion
Experiments on boiling on surfaces with different geometries of radial finning (16 and 32 fins on a heater) were carried out. It is shown that the intensity of heat transfer at boiling on a surface with a
The large number of copper fins is higher than that on a surface with 16 brass fins and smooth surfaces (before fluoropolymer deposition on both surfaces).

The fluoropolymer coating has a different effect on boiling heat transfer on finned surfaces. Heat dissipation on an absolutely hydrophobic surface with 32 fins degrades significantly. Further, with degradation of the fluoropolymer coating, an increase in heat transfer occurs. On a surface with 16 brass fins, fluoropolymer coating leads to an increase in heat transfer. It should be noted that degradation of the fluoropolymer coating leads to a significant increase in the heat transfer intensity. After complete removal of the fluoropolymer coating, the intensity of heat transfer decreases to the initial value. This unequal effect of hydrophobization of samples on heat transfer is probably associated with steaming of a narrow space between the fins on the surface of 32 fins. The intensity of removal of steam formed during hydrophobization of this surface is insufficient.

**Acknowledgments**

The study was supported by the Russian Science Foundation (Agreement No. 18-19-00407).

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