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Shear driven FC-72 liquid film flow on the heater with microgrooves

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Abstract. The crisis in a FC-72 liquid film moving under the action of a gas flow through a smooth and micro-grooved heater was experimentally investigated. It is shown that the use of micro-grooves leads to an increase of the critical heat flux.

1 Introduction

When the microprocessor is cooled, the local heat flux is estimated at 1 kW/cm^2 [1]. A two-phase flow in a channel is promising solution of this problem. The flow regimes map inside the microchannel has been constructed in the papers []. The formation of dry spots in the horizontal layer of the isothermal liquid depends on the contact angle of the wetting and the thickness of the film has been studied in [2]. The heat transfer and rupture of a liquid film on horizontal, slightly inclined and vertical surfaces with local heating is investigated in [3, 4, 5]. It is shown that the destruction of the water film is carried out in two stages: after the film is ruptured, a film with a thickness much less than the initial film is observed on the heating element. Then, this thin film of the liquid breaks and the surface is completely dried.

Improvement of heat transfer is observed due to the creation of various structures on heated surfaces, in particular, due to improved wetting of the working surface [6]. The use of different structures (for example, micro-finning) on a heated surface is a good alternative to more complex factors of stabilization (gas flow, electric field, etc.) of the film flow on heating surfaces [7]. Heat transfer in a liquid film flowing along the surface with micro-grooves was experimentally investigated by the authors [8]. It is shown that the heat transfer crisis on the surface with microgrooves is tightened in comparison with the smooth surface. The deformation of a locally heated liquid film (25% ethyl alcohol in water) moving under the action of a gas stream under ground conditions and with different level of gravity was investigated numerically in [9]. The three-dimensional nonstationary problem was solved. The formation of thermocapillary deformations is shown.

2 Experimental setup

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An open contour is used for the experiments (Fig.1). During the experiment, liquid and gas nitrogen are supplied from the tanks. With the help of Bronkhorst regulators, gas flow and pressure are maintained in the test cell. With the help of a syringe pump, degassed liquid is supplied into the work area. To maintain a constant temperature of the liquid and gas at the entrance to the work area, heat-stabilizing systems based on Peltier elements are used. Using a membrane pump, a two-phase mixture is evacuated to the atmosphere. Separation and recovery systems using liquid nitrogen are used to separate the FC-72 liquid from the gas phase. Using the program developed in the LabView system, all parameters of the experiment are recorded and monitored.

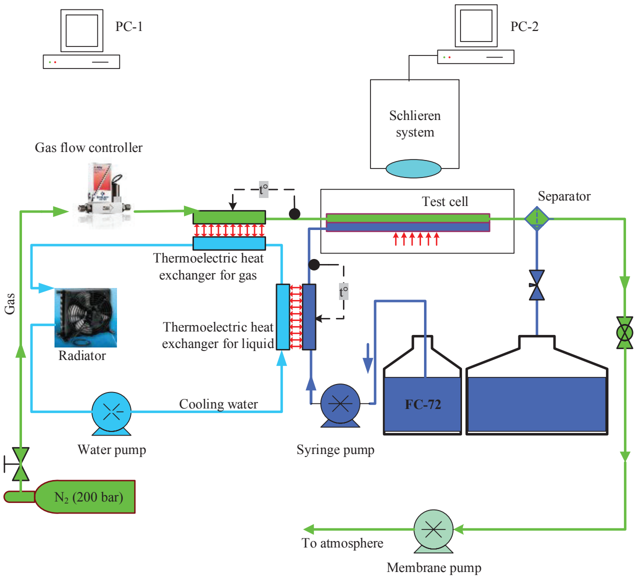
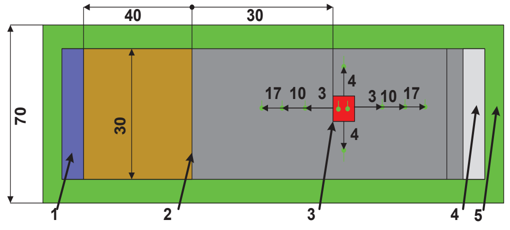
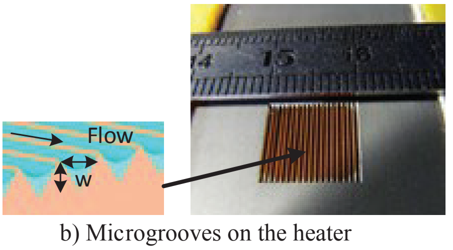


Fig. 1. Scheme of the experimental setup.

The test cell (Fig. 2a) consists of a base made of stainless steel and a textolite plate. The side of the substrate on which the liquid flows is treated with an abrasive M40 for better wetting. The frame from the textolite is attached to textolite plate, and from above is covered with optical glass, thereby creating a minicall with a height of 1.5 mm and a width of 30 mm. Using a liquid nozzle with height 150 microns and with width 30 mm a liquid film is formed. The gas flow enters the minichannel and entrains the film of liquid. A copper rod with a size of 10 x 10 mm^2 was pressed into the substrate. A ceramic heater is attached to the rod. The surface of the rod, which is located in the minichannel, can be smooth (w = 0 mm) or with microgrooves (w = 0.3 and 0.5 mm) (Fig. 2b). The microgrooves are oriented along the flow with the width of the individual structure w = 0.3 or 0.5 mm (Fig. 1b). The temperature of the substrate is measured by 10 K-type thermocouples (Fig. 2a), the distances are in millimeters.



a) Top view of the test cell



b) Microgrooves on the heater

Fig. 2. Scheme of the experimental setup.

Visualization of deformations on the film surface is carried out using a high-speed schlieren system, including a high-speed Optronis CL600x2 video camera, IDT 8 LED light source and optical elements.

3 Experimental results

The heat transfer crisis was experimentally studied for FC-72 shear driven liquid film by gas flow in a minichannel with smooth heater and microgrooved heater (the width and height of the micro-finning are equal to w = 0.3 mm) under the action of a nitrogen gas. The dynamics of the flow along a substrate with a smooth heater and on a substrate with microgrooves is significantly different. The critical heat flux on a smooth heater (w = 0) is 3.1 W / cm^2 at Rel = 7.6, Reg = 183.8. The thermocapillary effect has a determining effect. Under the action of thermocapillary forces, liquid is forced out from the heating element, a thickening of the film is formed in the region of the leading edge of the heater with respect to the oncoming flow.

On the heater with microgrooves, the liquid continues to wet the heater due to the capillary effect in the grooves, even for sufficiently high heat fluxes. Comparison of the critical heat fluxes (q_{CHF}) on smooth-surface and micro-finned heaters at different gas and liquid flows shows that the critical heat flux is lower on a smooth heater than on a heater with w = 0.3 mm (Fig. 3). Experimental data show that as the flow of liquids and gases increases, the critical heat flux increases.

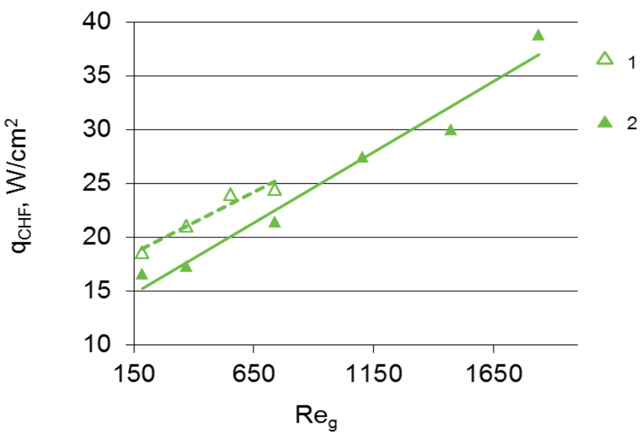


Fig. 3. The critical heat flux for smooth heater and for heater with microgrooves (height 0.3 mm), 1) w=0.3 мм, Re_l=30.2; 2) w=0, Re_l=30.2.

Conclusion

The work shows an increase of the critical heat flux for the FC-72 liquid film flow in a minichannel by a gas flow when using microgrooves on the heating surface.

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