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Heat transfer in the FC-72 fluid rivulet flowing down a vertical heated foil

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Abstract. The paper deals with the experimental study of heat transfer in FC-72 fluid revulet flowing down the vertical heated foil with the length of 80, width of 35 mm, and thickness of 25 microns, made of constantan. Employing infrared thermography, we have obtained data on temperature distribution on the foil from the opposite side of the rivulet flow. Further we will calculate the heat flux on the foil surface. It is experimentally revealed that the rivulet width reduces with increase in thermal power due to evaporation, while it increases with increasing fluid flow rate. The FC-72 fluid has good wettability and low latent heat of evaporation. Thus this fluid is recommended for use in cooling systems.

1 Introduction

As of today, one of the main objectives is the design of a highly efficient cooling system. Every year, with each new processor model, the number of transistors increases approximately twice. In modern computer microprocessors, increase in the number of transistors improves many parameters of which processor performance is the main one. However this leads to increase in thermal power that must be removed from the processor. The maximum heat generation in the microprocessor is approximately 500 W/cm^2. Though, microelectronics is only a small part of devices which require a compact and efficient cooling system.

A promising cooling system is a system based on use of rivulet flow, which is a particular case of the film flow between two dividing lines bounding the flow from both sides. The dividing line is a contact line between three phases. Small area between the three-phase contact lines forming a micro-region is characterized by high heat transfer coefficient [1]. Thus, the rivulet flow has high cooling quality.

Maps representing varieties of rivulet flow regimes along an inclined plane were studied in detail in [2, 3]. The increase in liquid flow rate resulted in formation of drip, straight, and winding flow modes, which downstream was transformed into a film flow [2, 4, 5].

Velocity field in a fluid rivulet flowing over a cylinder is obtained in [6] using the PIV (Particle Image Velocimetry) technique.

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Measurements of the local thickness of the rivulets having a wave structure and flowing down a vertical plate were conducted in [7] using LIF method (Laser Induced Fluorescence method). The authors obtained maps representing varieties of wave generation patterns in rivulet flow.

The heat transfer in the water rivulet flowing down a vertical heated foil was studied in [8]. Based on the images obtained from the IR scanner, the authors solved the Cauchy problem for elliptic equation to calculate heat flux on the surface with flowing rivulet. It was proved that in the area of micro-region located near the wetting contact line, heat transfer rate is higher than the average in the rivulet that causes a local temperature reduction in this area.

The main objective of the present study is to determine the heat flux in the area of the three phase contact line of the FC-72 fluid flowing down over a heated surface using data obtained through infrared thermography and solving methods of ill-conditioned problems.

In contrast to the similar experiments already conducted in [8], where highly purified water obtained through a Milli-Q system was used as a test liquid, in this work we use FC-72 fluid designed specifically for cooling supercomputers. Fluorinert Electronic Liquid FC-72 is a fluorocarbon dielectric liquid. It is colorless, transparent, and is thermally and chemically stable cooling agent, compatible with sensitive materials, nonflammable, practically non-toxic, and leaving no residue after evaporation. A special combination of FC-72 properties is ideal for use of this fluid in many areas of electronics, including immersion cooling and film cooling, being currently actively developed.

2 Experimental setup

In the course of the study, the experiments were conducted on a vertical foil with a length $l = 80$ mm, width $w = 35$ mm and thickness $h = 25$ μm made of constantan. The liquid on the foil was fed at a given flow rate within the range 0.1-5 ml/min through a tube with a special nozzle using the Cole-Parmer EW-74905-54 syringe pump. Foil was connected to a source of DC power TTi QPX 1200L through the brass electrode holders. Foil heating was carried out using the power source. Thermal output on the foil was varied within the range from 0.09 to 1.47 watts. The observations were carried out using Nikon D 7000 camera and infrared (IR) 570 M Titanium scanner. The foil was coated with a black graphite paint with an emissivity factor close to 1.

Wetting angle of the FC-72 fluid was measured by a gas (air) bubble technique and was 10±0.4° that indicates good wettability in comparison with satisfactory wettability of water which is 63°.

The experimental setup and the image of the testbench are shown in Figs. 1 a and b.

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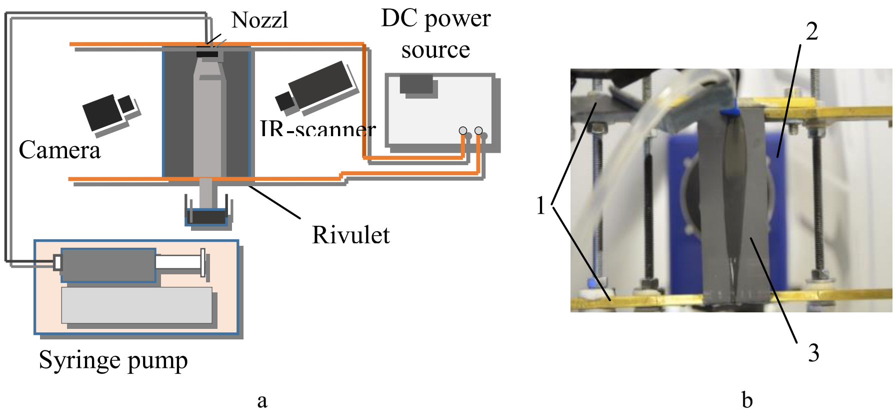


Fig. 1. a – experimental setup; b – FC-72 fluid rivulet flowing down the heated foil at Q = 1 ml/min, P = 0.09 W: 1 – brass electrodes, 2 – IR camera, 3 – foil with flowing rivulet.

3 Experimental results

An infrared scanner was used to measure the temperature distribution over the foil surface from the opposite side of the flowing rivulet (Fig. 2 a-e).

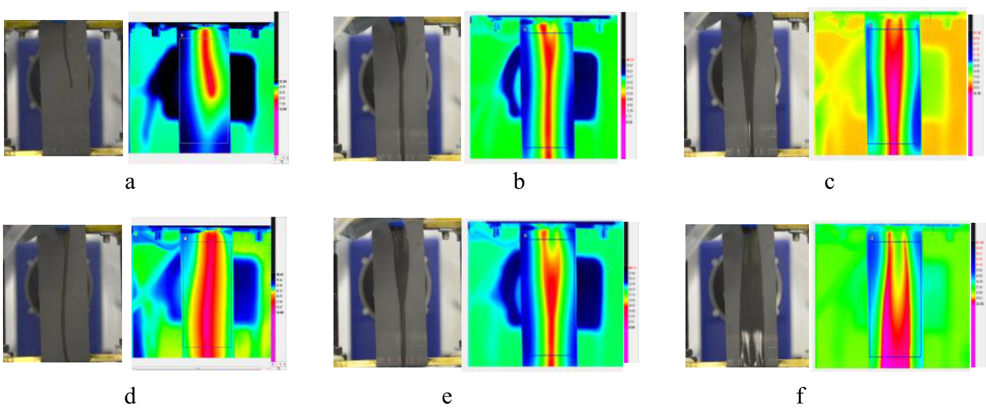
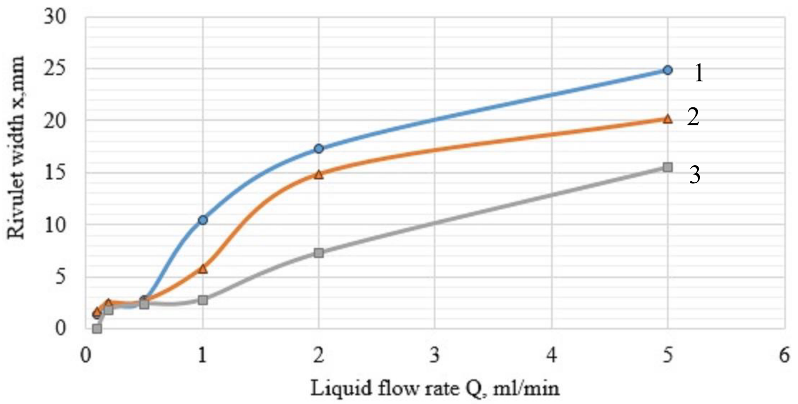


Fig. 2. Images of FC-72 fluid rivulet flowing over a heated foil, and the thermograms from the opposite side of the rivulet:
a – Q = 0.1 ml/min q_{av} = 15.049 W/m^2; b – Q = 0.2 ml/min, q_{av} = 15.049 W/m^2;
c – Q = 0.5 ml/min, q_{av} = 97.45 W/m^2; d – Q = 1 ml/min, q_{av} = 97.45 W/m^2;
e – Q = 2 ml/min, q_{av} = 237.857 W/m^2; f – Q = 5 ml/min, q_{av} = 237.857 W/m^2.

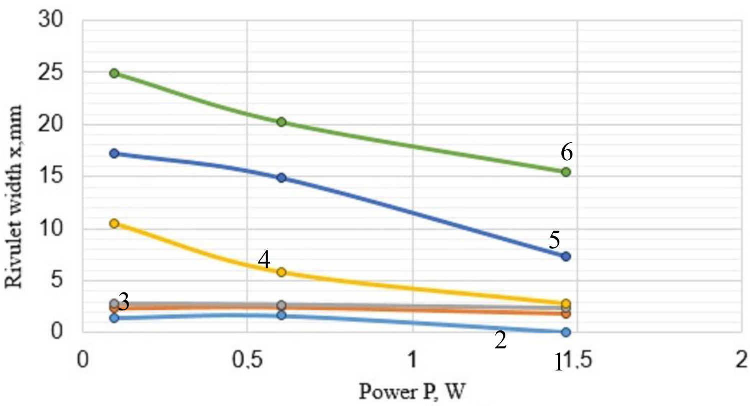
In the future, to calculate evaporation heat flux of a fluid near the contact line, we will use a special method to solve the Cauchy problem for an elliptic equation. In a similar study [8], which was conducted using water, the calculation of the heat flux from the foil was carried out using images from the IR scanner without taking into account heat fluxes in the foil. Alternatively, Cauchy problem describing the thermal conductivity in the foil was solved with due consideration of heat fluxes in the foil. It was shown that the maximum heat flux density takes place in the region near the contact line.

The FC-72 rivulet width was measured from photographs and ranged from 1.4 to 25 mm. Based on the experimental results we plotted dependences of the rivulet width versus applied thermal power at fixed flow rates, as well as dependences of the rivulet width on fluid flow rate at certain thermal power (Figs. 3 a and b).

As is obvious from figures, increasing fluid flow rate leads to increase in the rivulet width, while increasing thermal power leads to reduction in the rivulet width due to the intense evaporation of the FC-72 fluid. At that, latent heat of evaporation of FC-72 fluid is less than that of water.



a



b

Fig. 3: a – the rivulet width versus FC-72 fluid flow rate:
1 – thermal power P=0.09 W; 2 – P=0.6 W; 3 – P=1.47 W;
b – the rivulet width versus thermal power at constant flow rates: 1 – Q = 0.1 ml/min;
2 – Q = 0.2 ml/min; 3 – Q = 0.5 ml/min; 4 – Q = 1 ml/min; 5 – Q = 2 ml/min;
6 – Q = 5 ml/min.

4 CONCLUSIONS

The experimental study on heat transfer in FC-72 fluid rivulet flowing down a vertical heated foil was carried out. It was established experimentally that with the increase in thermal power the width of the rivulet decreases because of evaporation. With increasing fluid flow rate the width of the rivulet increases. Good wettability (maximum contact angle is 10°) and low latent heat of evaporation of the FC-72 fluid facilitates its use when designing effective cooling systems.

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