

Evaporation of stationary alcohol layer in minichannel under air flow

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Abstract. This paper presents experimental investigation of effect of the gas flow rate moving parallel to the stationary liquid layer on the evaporation rate under the conditions of formation of a stable plane “liquid-gas” interface. The average evaporation flow rate of liquid layer (ethanol) by the gas flow (air) has been calculated using two independent methods. Obtained results have been compared with previously published data.

1. Introduction

Nowadays there is a growing interest in capillary hydrodynamics and heat-mass exchange in microsystems. It is connected with the miniaturization of devices, advances in medicine, electronics, aerospace and energy industries [1].

2. Relevance of research

A thin layer of liquid entrained in the gas flow in the mini-and micro-channels is a promising way of significant heat flow extraction. Therefore it can be used for cooling of microelectronic equipment [2–4]. Much of the research is aimed at studying the hydrodynamics of liquid and gas in the mini-and micro-channels. Heat and mass transfer in the two-phase flows is poorly studied analytically [5, 7–9] and experimentally [5, 6]. Hence it follows the importance of a systematic study of heat and mass transfer during two-phase flow in mini-and micro-channels.

The purpose of work is studying the dependence of the evaporation rate of the stationary horizontal liquid layer in minichannel under the gas flow.

3. Research techniques

Experimental setup consists of the following components (Figs. 1, 2):

1. Test cell.
2. Gas and liquid supply circuits: gas cylinder, flow controller, flow meter, peristaltic pump.

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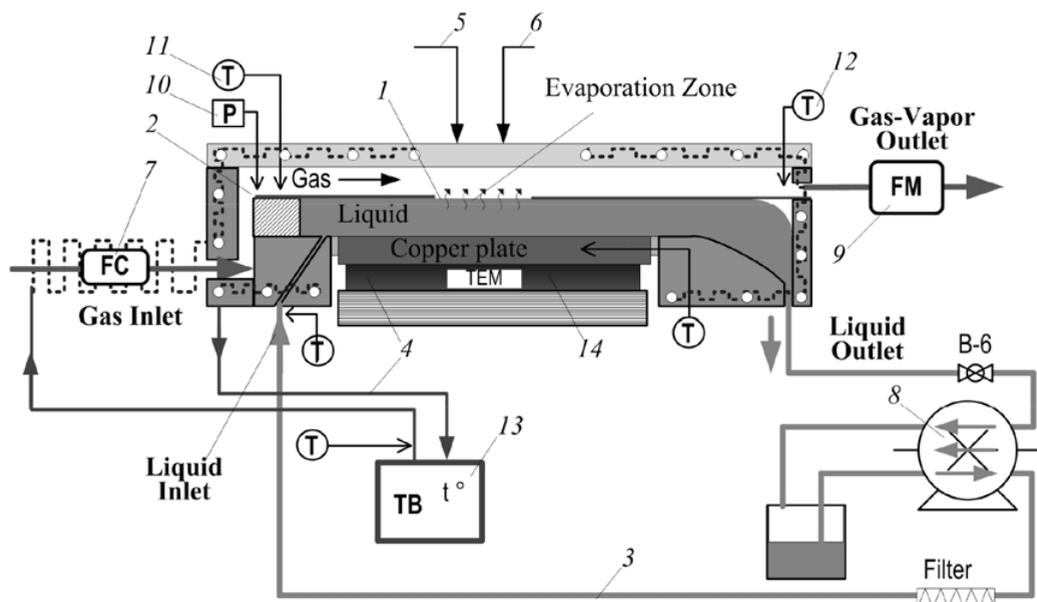


Figure 1. A schematic view of the experimental rig: 1 – test cell; 2 – gas supply circuit; 3 – liquid supply circuit; 4 – thermal stabilization system; 5 – test-and-measurement system; 6 –Schlieren system; 7 – flow controller; 8 – peristaltic pump; 9 – flow meter; 10 – pressure sensor; 11 – gas temperature sensor; 12 – gas-vapor mixture temperature sensor; 13 – thermostatic bath; 14 –Peltier thermoelectric module.

3. Thermostatic system: thermostatic bath, thermoelectric construction.

4. Test-and-measurement system: personal computer, data recorder, power-supply source.

5. Schlieren system.

Procedure for the experiment: gas from the cylinder enters the test cell. Mass flow of gas is controlled at the inlet to the test cell by the flow controller. The peristaltic pump was used for liquid supply to the test cell using. Also, the pump is needed to keep a constant level of vaporizing liquid layer. Then the gas-vapor mixture leaves the test cell and flows into the vent line. The outlet gas-vapor mixture flow is measured using a mass flow meter. A bypass channel for a gas flow is used for readings synchronization of flow controller and flow meter. The gas pressure in the test cell is measured by a pressure sensor. Gas and gas-vapor mixture temperatures are measured at the inlet and outlet of the test cell. Temperature of the test cell is controlled by means of water which is pumped through special channels in the test cell with a controlled temperature by thermostatic bath. Temperature of the liquid in the test cell is defined by the temperature of the substrate base. Temperature of this base is controlled by a Peltier element. Thus, the temperature difference between the liquid and the gas is maintained not exceeding $0.3\text{ }^{\circ}\text{C}$.

General view and design features of the test cell are shown in Fig. 3. The test cell (Fig. 3) is made of two interconnected blocks from organic glass, which forms a rectangular gas channel with height of 3 mm and a width of 40 mm, and also the rectangular liquid chamber. Liquid chamber is a square cutout ($50 \times 50\text{ mm}$) with variable height. The height of the chamber is changed by means of a vertically-moving substrate base and varies from 1.5 to 8 mm. There is a special channel to measure the pressure in the test cell. The pressure sensor is connected to the channel by a tube and a special fitting embedded into the channel. The transparent optical window with a diameter of 120 mm is installed on center of the cover of the test cell over the liquid reservoir.

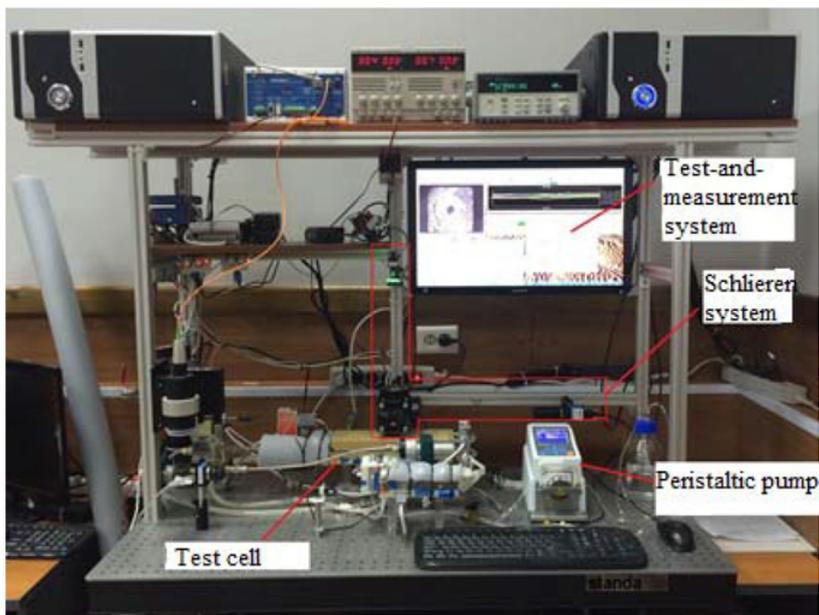


Figure 2. Photo of the experimental setup.

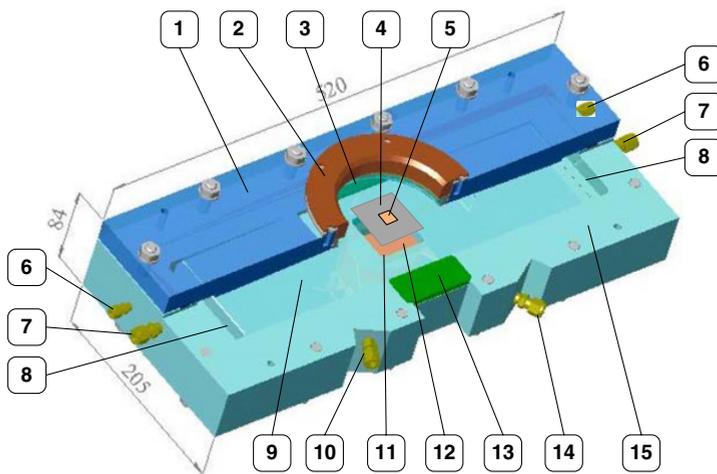


Figure 3. General view of the test cell. Content: 1 – cover, 2 – frame for the top-window, 3 – optical window, 4 – stainless steel wafer with opening and microgroove served as anti-wetting barrier, 5 – opening $10 \times 10 \text{ mm}^2$, 6 – fitting of the temperature sensor, 7 – fitting of the gas loop, 8 – gas distributing camera ($20 \times 20 \text{ mm}^2$), 9 – gas channel ($280 \times 40 \times 3 \text{ mm}^3$), 10 – fitting of the inlet liquid, 11 – liquid reservoir $50 \times 50 \text{ mm}^2$, 12 – moving copper base of substrate, 13 – glass inset (side window), 14 – fitting of the water loop, 15 – case ($520 \times 205 \times 84 \text{ mm}^3$).

The evaporation mass flow rate is determined in the experiment by two methods:

1. The first method is based on evaluation of the average liquid flow in the test cell in order to keep the total liquid volume constant during the evaporation process and planar interphase boundary. The average liquid flow is set using a peristaltic pump in volume units (ml/min).

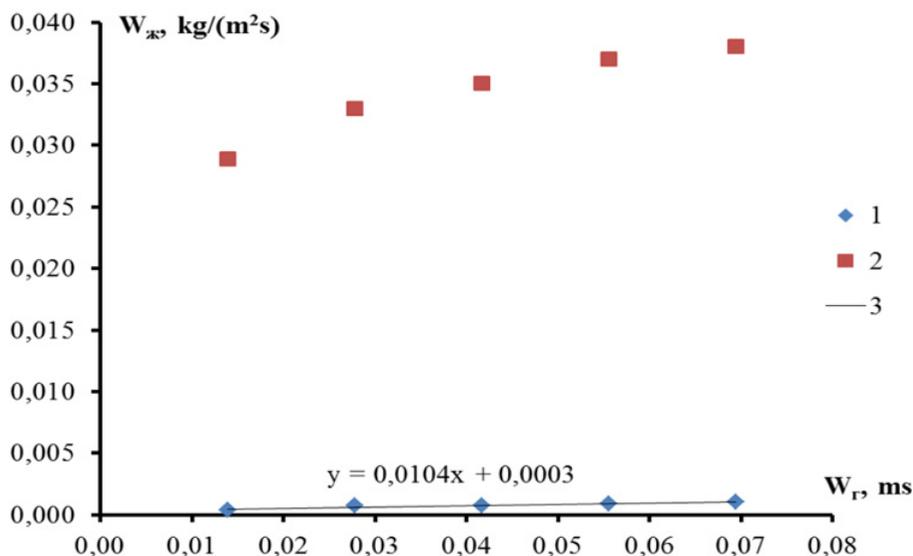


Figure 4. Mass flow rate versus average velocity of gas for series of experiments. Working liquid, gas: 1 – ethanol (95% part by volume), air; 2 – HFE-7100, nitrogen (99.8%) [8]; 3 – trend line.

2. The second method is to measure the difference between the mass flow rate of gas at the inlet of the test cell and at the outlet (gas–vapor mixture). Mass flow rate of gas at the inlet of the test cell is set by flow controller. Mass flow rate of gas–vapor mixture at the outlet is measured by flow meter.

A series of three experiments has been executed. As a working fluid we used ethanol (GOST R 51723-2001), as gas – air. Gas flow entering the test cell is varied from 100 to 500 ml/min every 100 mL/min. Temperature of the liquid and gas was kept constant (25 °C). Layer of liquid with a thick of 3 mm was stationary, surface evaporation was 100 mm². Gas–vapor mixture flow at outlet of the test cell and pumping liquid flow have been fixed for maintaining a flat interphase boundary.

According to the obtained data dependence of mass flow rate from gas velocity was plotted (Fig. 4).

4. Results and discussion

According to the analysis of Fig. 4 it was found that variation of the gas velocity affects the evaporation rate of alcohol in minichannel (sizes: 40 × 3 mm²).

Similar experiments were carried out in [8] with the test cell sizes 100 × 3 mm², but they used hydrofluoroether mixture HFE-7100 at different temperature (20 °C). Nitrogen (99.8%) was used as a parallel moving gas flow. A linear dependence of the mass evaporation rate from gas velocity for alcohol and logarithmic for HFE-7100 were identified. Mass evaporation rate is a characteristic of heat and mass transfer determining intensity of evaporation.

In comparison with the results in [8] it was found that with increasing latent heat of vaporization of the working liquid used for cooling of surface in minichannel at eight times, the evaporation rate decreased by thirty times. It should be noted that the behavior of the evaporation rate of alcohol is linear, but mass evaporation rate varies logarithmically at the replacement of the fluid heat sink and blowing slipstream gas.

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