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THE EFFECT OF THE SUBSTRATE TEMPERATURE AND THE HEIGHT OF THE MINI-CHANNEL ON THE EVAPORATION OF LIQUID DROPLET BLOWN BY THE GAS FLOW

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Abstract. The experimental setup has been designed and fabricated to study the evaporation of liquid droplets, blown by the gas flow in a mini-channel with a height of 6 and 9 mm. Substrates were removable, and the surface temperature of the substrate was maintained at a constant level. The shadow method was the main method of measurement. A series of experiments with a water drop of 100 µl volume settled on a polished stainless substrate were carried out. As a result the dependences for the droplet evaporation rate were obtained in the range of temperatures 25-70 °C and Reynolds numbers of gas 0-2000.

1 Introduction

Drop is a fairly simple physical object, including complex physical processes and interactions. Evaporation of liquid droplets on solid surfaces is a key point in many processes such as: painting, coating, air humidification, irrigation in agriculture, cooling of hot surfaces, etc. The evaporation of droplets has been widely studied numerically and experimentally, but mostly in motionless air. The studies show that the contact angle and its hysteresis have a significant impact on droplet evaporation [1, 2, 3]. Authors of [4] studied the effect of gravity on the drop spreading over a solid surface. In work [5] it is shown that Marangoni effect (flow driven by surface tension gradient) modifies the drop interface shape and impacts on evaporation. The influence of gas flow on droplet evaporation is known, but all these studies were conducted in the open air with insufficiently controlled conditions [6]. This paper presents the experimental results for evaporation of the droplet under gas action, placed on a heated substrate in a mini-channel.

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2 The experimental setup and conditions

The scheme of experimental setup is shown in figure 1. It includes a channel with height varying from 3 mm to 20 mm, removable substrates, the temperature regulation system of the substrate, and the air supply system. The side walls and the upper cover were equipped with optical windows for visualization. The aim of this work is to study the effect of the substrate temperature and the Reynolds number of the air flow on the drop evaporation rate in a channel with height of 6 and 9 mm. The working fluid was ultrapure water, obtained through a Milli-Q system. The drop was placed into the channel using a syringe. The initial drop volume was about 100 µl. The experiments were conducted on the stainless steel substrate with a polished surface. The Reynolds number of the gas flow varied from 0 to 2000. The gas temperature was maintained equal to 25 °C. Heating of the substrate was carried out by Peltier elements contacting with the substrate. The substrate temperature during the experiment was regulated with a precision of 0.20 °C with the help of the controller PR-59. The experiments were conducted for three temperature values 25.0, 50.0 and 70.0 °C.

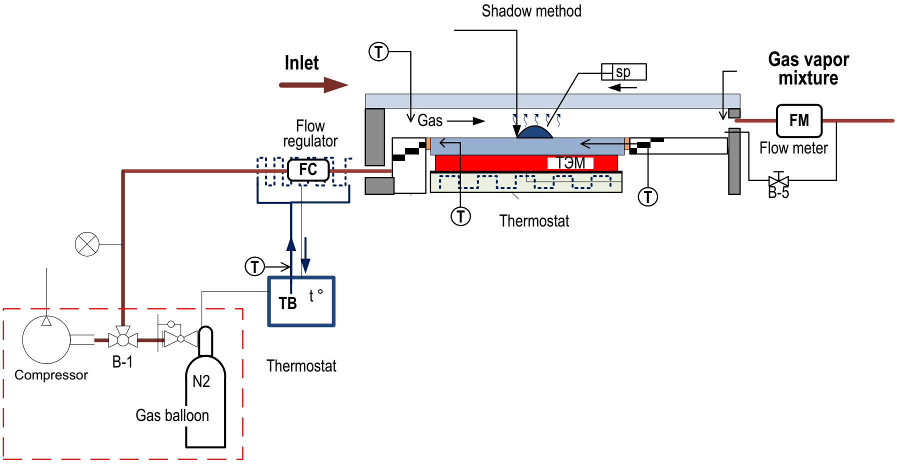

Fig. 1. Scheme of the setup.

To register the contour of the sessile drop on the solid substrate the shadow method was used. Its principle is based on the lighting of the physical object by a parallel light beam, whose shadow is recorded by the camera, as shown in figure 2. Optical equipment allows obtaining images with a resolution of 6 µm/pixel (see figure 3). The obtained images were processed by different methods with the help of software (the Drop Shape Analysis by KRÜSS), including on the basis of the solution to the Young-Laplace equation [7]. The most suitable for measuring the contact wetting angle in the experiments was the tangential method, since the drop has a slightly asymmetric shape due to the air flow impact. The principle of the tangential method is based on the adjustment of the contour according to the equation of conical sectors. Then at the point of intersection of the contour line and the baseline, the derivative of this equation equal to the contact angle is taken.

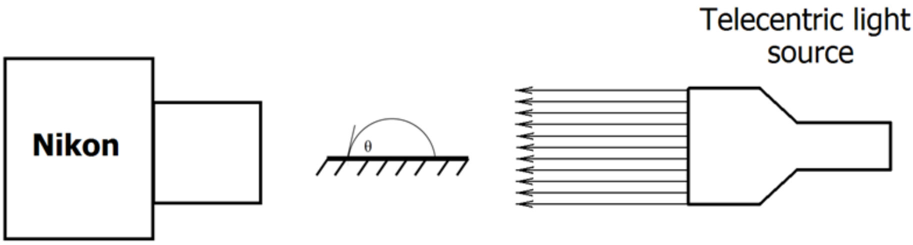

Fig. 2. Shadow method.

Fig. 3. Photo of the drop using the shadow method. The interval between frame is 2 minutes. T = 70 °C, Re = 1140, channel 9 mm.

3 Results

The first series of experimental data was obtained at constant substrate temperature of 25 °C and at different air flow velocities in the channel of 6 mm and 9 mm height (see figure 4). It is seen that the channel height does not affect the nature of the curve. In the 6 mm channel, the drop lifetime is significantly less than in the 9 mm channel. This may be explained by the fact that at the same Reynolds numbers, the gas velocity in the 6 mm channel is higher than in the 9 mm channel. The superficial velocity in the 6 mm channel at maximum Re number = 2000 corresponds to 5 m/s.

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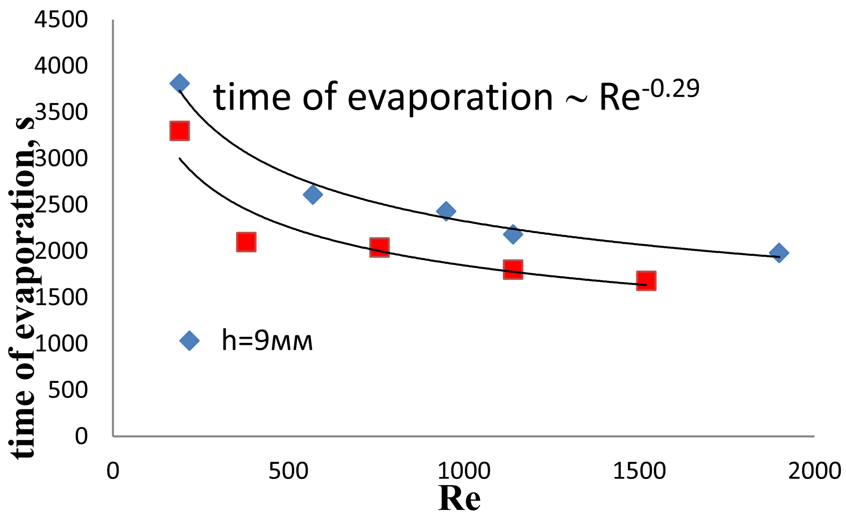

Fig. 4. Drop lifetime depending on the Reynolds number. $T_{substrate}$ = 25 ºC.

Analyzing the results of the experiment shown in figure 5, it may be concluded that in the range Re = 1140-1900 the evaporation rate is determined by the substrate temperature and less depends on the height of the channel and the Reynolds numbers of the gas.

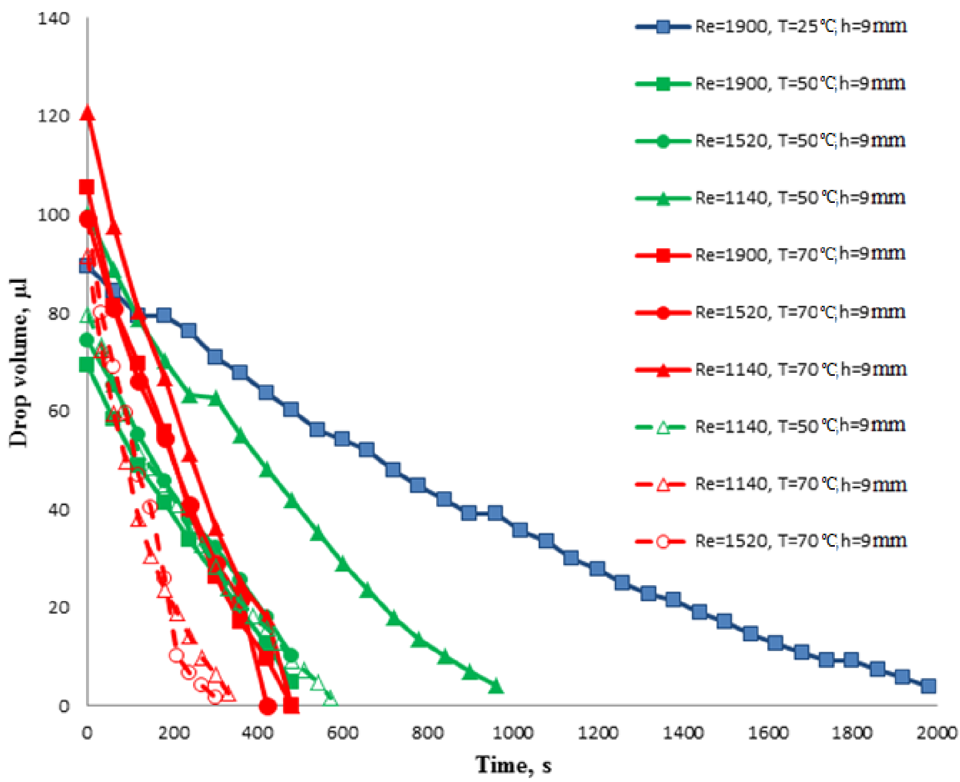

Fig. 5. The effect of temperature and height of the channel on the evaporation of droplets for different Reynolds numbers of the gas.

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Figure 6 shows the results of the evaporation rate Q, related to the drop base. Despite the fact that there is some scatter in the data, it is visible that the evaporation rate is weakly dependent on time. The height of the channel affects the rate of evaporation, as well as in the case with the experiment without the substrate heating. It can be noted that before the disappearance of the drop, i.e. its complete evaporation, some curves show intensification of evaporation, which may be explained by the fact that the drop becomes almost flat (see. figure 3). Since the interval between frames is large enough (30 seconds), then further analysis is required, and new measurements performed with a smaller time interval between frames.

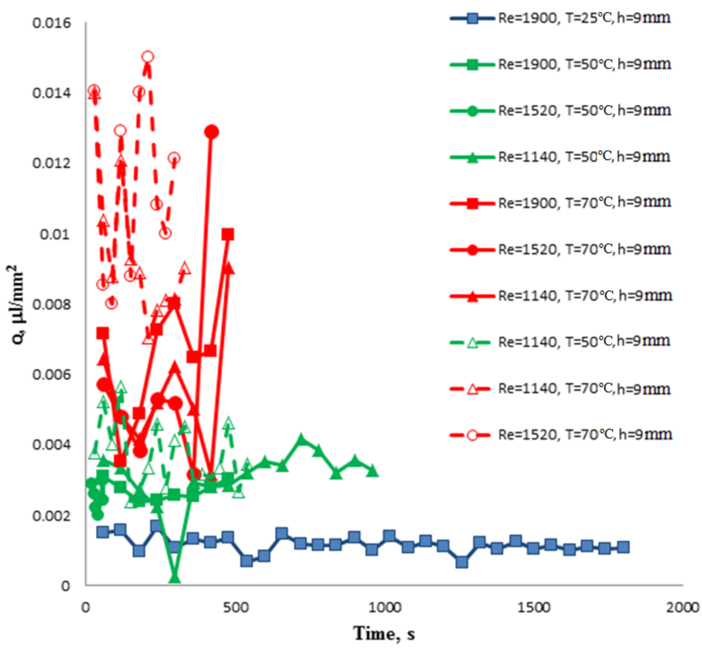

Fig. 6. Evaporation rate of water droplet via time.

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