Experimental study of evaporation of distilled water and 10% NaCl and $CaCl_2$ aqueous salt solutions droplets under their free falling on a heated surface

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Abstract. The paper presents the experimental results of evaporation of distilled water and 10% aqueous salt solutions of NaCl and $CaCl_2$ droplets under their free falling on a heated surface. It is proved that it is more expedient to conduct the experimental research in this field according to classical multifactorial experiment. Laser treatment of surfaces is found to increase the evaporation rate and to biases the point of boiling crisis in the region of lower surface temperatures. In this case, in the conditions of boiling crisis the frequency of contact of a droplet with a heated surface will decrease.

1. Introduction

There are many experimental and numerical studies of falling, spreading and evaporating droplets on a heated surface [1-12]. However, it is worth noting that there are few studies in this field with using laser patterned surfaces. The processing of metal surfaces is known to change their properties; it can improve both hydrophilic and hydrophobic properties [13, 14]. The effect of this method of patterning on the spreading (changes in the geometric shape of the droplet) and evaporation when droplets free-fall on a heated surface remains unknown. Experimental study of such processes will expand the available scientific contributions in the wetting field.

This paper presents the experimental results of a study of distilled water and 10% aqueous salt solutions of NaCl and $CaCl_2$ droplets under their free falling on a heated surface.

2. Experimental procedure

When choosing a research procedure, we compared the plan of classical multifactorial experiment, which is a sequence of single-factor experiment (change of one parameter at constant rest parameters, for example, change of the surface temperature at a fixed height, droplets volume, composition of the liquid), and a full factorial plan, which is to find the

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required number of experiments on the number of factors. As a result, a number of important features were highlighted. Several factors are varied in the full factorial experiment (surface temperature, height of dosing, and droplet volume). This leads to the fact that the dispersion in evaluating the coefficients is typically an order of magnitude less than the experimental error. The nature of the dependences between the main studied factors (evaporation rate of a droplet on the surface temperature, as well as the evaporation rate of liquid droplets in different volumes of dosing) are not known in advance and not found the mechanism of influence of these factors. So the use of a full factorial plan can lead to erroneous results. Consequently, it is more expedient to conduct classical multifactorial experiment for studying the processes of falling, spreading and evaporation of droplets onto a heated metal surface.

According to results of preliminary experiments, the main ranges of variable factors were defined (Table 1).

Table 1. Ranges of variable factors.

Factors	Values of factors	
Surface temperature	60, 80, 100, 120, 130 °C	
Surfaces	polished aluminum surface	laser patterned surface
Working liquid	Distilled water 10% aqueous solution of NaCl 10% aqueous solution of $CaCl_2$	
Volume of distilled water droplet	0.015 mL	
Height of the droplet fall	300 mm	

Experimental studies of falling, spreading and evaporation of droplets onto a heated metal surface were conducted on the setup with using the shadow method (Fig.1).

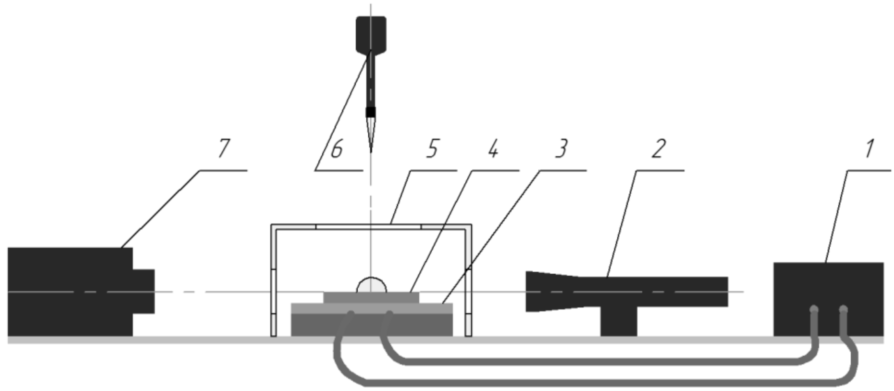
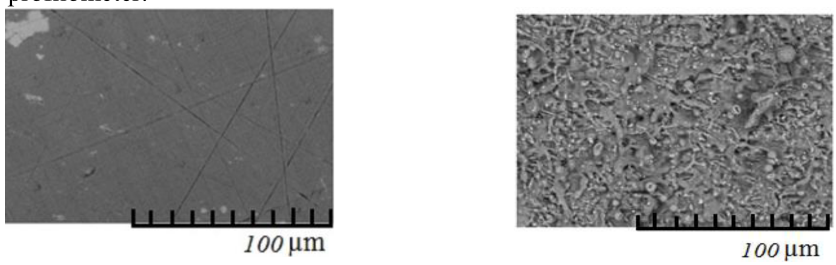


Fig. 1. Sketch of the experimental setup: 1 – power source of electrical heater; 2 – source of plane-parallel light; 3 – heating element; 4 – substrate; 5 – box; 6 – dosing device; 7 – high-speed video camera.

Source of plane-parallel light 2 lighted a droplet on substrate 4. Its shadow was recorded by the lens of high-speed video camera 7. A droplet was squeezed by single-channel electronic dosing device 6 (Lenpipette Stepper ThermoScientific), which was mounted vertically above the substrate at a distance of 300 mm. Substrate temperature was controlled by heating element 3 connected to power source 1. To maintain constant conditions of heat and mass transfer with the environment, the test cell was covered by glass box 5 [15-17].

Experiment was conducted with using two heated surfaces: polished and laser patterned surfaces made of aluminum alloy (AMG-6). Photographic images of surfaces were obtained on the microscope "Hitachi-3000M" (Fig. 2). The parameter of roughness (Ra) was defined on the profilometer.



(a) (b)

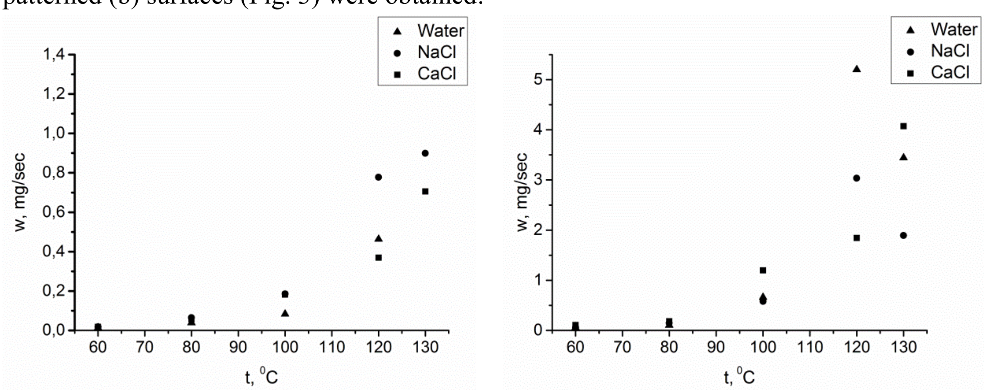
Fig. 2. Photographic images of aluminum alloy surfaces (AMG-6) (magnification×1000): (a) polished (Ra=0.374 µm); (b) laser patterned (Ra=1.290 µm).

Surface of polished substrate (Fig. 2 (a)) is formed by multi-directional grooves obtained after polishing with diamond paste. The width of the grooves is less than 1 mm, the depth is 0.374 µm. There are impurities of arbitrary shape (white – magnesium; gray and black – manganese, iron, silicon, zinc, copper, titanium, and beryllium). Area of one impurity does not exceed 10 µm^2. It is known that the impurity with such size does not affect the behavior of the liquid droplet on a solid surface [5, 6].

After processing the substrate by laser radiation, chaotically arranged structure of molten metal with micro cavities and asperities was formed (Fig. 2 (b)). Local area of asperities does not exceed 10 µm^2. It should be noted that after the laser treatment of the surface, the roughness is increased by 3, 4 times.

3 Results and discussion

According to experimental results dependences of mass evaporation rate of water droplet and 10% aqueous salt solution droplet (NaCl, $CaCl_2$) on the temperature of polished (a) and patterned (b) surfaces (Fig. 3) were obtained.



(a) (b)

Fig. 3. Mass evaporation rate of distilled water and aqueous salt solutions droplets versus surface temperature. Substrate: (a) polished; (b) laser patterned.

After breakdown of the droplet from the tip of dosing device, the droplet moves due to gravity. At the moment of impact of the droplet with substrate attraction force transforms to inertial force directed from the center to the periphery – a droplet spreads to the maximum diameter. In this case, the inertial force is balanced by the surface tension of the liquid. Further, the surface tension of the liquid compresses the droplet to an equilibrium state. After establishing the equilibrium mode, the evaporation of water droplets and salt solution droplets has a similar consistency and depends on the temperature and the substrate structure. This is due to low concentration of salt in its aqueous solution. However, the evaporation of salt solution droplets is accompanied by crystallization of salt on the substrate surface.

According to analyses of the obtained dependences (Fig.3) it can be concluded that the microstructure biases the point of boiling crisis in the region of lower surface temperatures. In this case, in the conditions of boiling crisis the frequency of contact of a droplet with a heated surface will decrease. It means reducing the intensity of heat transfer from the heated metal to the spheroid.

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