Droplets evaporation in an insulated chamber with controlled concentrations of water vapor and temperatures

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Abstract**—The experimental study results of the relative humidity (RH) distribution over an evaporating water droplet from the heated surface (323 Kelvin) inside an insulated chamber were presented. Registration of the evaporation process was carried out using an optical system. The concentration of water vapor was determined by hygrometers. It has been established that the water vapor inside is not evenly distributed due to the temperature gradient resulting from the supply of heat to the bottom and the loss through the side and top walls of the chamber. RH increased by 20–40% in comparison with the initial value at a distance of 2-20 mm from the sample surface during the evaporation of the droplets. At the same time water vapor in the insulated chamber condensed on its upper and side walls. After evaporation of the droplets, RH in the whole space of the chamber assumed the initial value.**

Keywords— relative humidity, droplet, evaporate, insulated chamber

I. Introduction

The development of scientific and technical potential is aimed at the transition to new design principles. In particular, new ways to reduce the size of power engineering electronics products with simultaneously increasing their energy efficiency are searched [1]. It initiates intense local heat generation with constantly changing spatial location which varies depending on the tasks of the device and the conditions of its operation [2]. One of the methods of heat removal from heat-loaded areas is the use of droplet cooling, implemented in microfluidic devices [3] and evaporation chambers (Vapor Chamber Technology) [4]. Evaporation chambers are used for any inclination of the device and gravity conditions. It is possible due to the return of the refrigerant to the evaporator using the “bouncing” effect resulting from the release of excess energy when two drops merge on a superhydrophobic condenser [5]. It should be noted that the race is directed perpendicular to the surface and does not depend on the inclination of the evaporation chamber. During the evaporation of water in an isolated chamber RH in space can vary significantly [5], which affects the characteristics of the process of mass transfer of steam from the surface of the droplets as a result of a phase transition (speed, times, modes) [6].However, the industrial application of this technology is constrained by the lack of basic scientific research on the process of evaporation of droplets in an isolated chamber, in particular, the patterns of distribution of water vapor concentration over a drop. Despite the fact that the evaporation process in the contact area of the three phases “liquid – gas – solid” has been studied for 50 years, starting from P.C. Wayner (Rensselaer Polytechnic Institute, USA) of the 1970s [5], this problem is still poorly understood and relevant due to the technical limitations of the recording equipment of the time used for experimental research. The improvement of computer technology, optical methods (high-speed video cameras with a shooting frequency of up to several thousand frames per second, high-resolution lenses and optical zoom), measuring and control devices (for example, low-inertia thermocouples with a junction diameter of less than 6 microns) significantly develop the theory of wetting, spreading and evaporation of droplets on a solid surface in micro and nanosystems.

In connection with the current situation, the purpose of this work was to study the characteristics of the process of evaporation of droplets from a solid surface in an isolated chamber.

II. Matherials and Methods

A. Insulated Chamber Design

The experiments were carried out to the setup, which is present in Fig. 1.

A polished aluminum alloy substrate with a diameter of 55 mm and a thickness of 5 mm (1) was placed inside the insulated chamber. The sample was covered with a box (2) made of transparent plexiglass. A droplet of distilled water (3) with a volume of 10 μl was “placed” into the center of the substrate surface heated to 323 Kelvin with an electronic dispenser Lenpipet (Fisher Scientific, Russia) (4) through a hole in the upper of the box. The hole was closed with adhesive tape, which was pierced with a dispenser tip equal to the diameter of the hole to prevent air from entering the laboratory room. The temperature was controlled by a thermocouple type K (5) “SA1-K” (OMEGA, USA) with an accuracy of ± 0.1 K. The thermocouple was installed at a distance of 2, 12, 20 millimeter from sample surface.

The concentration of water vapor was recorded by a capacitive hygrometer “HIH-4000-004” (Honeywell, Russia) (6) with an accuracy of 3.5% and a polling time of 3 seconds, a response of 15 seconds. The hygrometer was placed at a distance of 2, 12, 20 millimeter from the center of the substrate. The room temperature ranged from 299 to 301 K. The experiments were carried out at atmospheric pressure. The relative humidity (RH) in the insulated chamber until the droplet evaporated was regulated by tanks (7) with a saturated aqueous solution of sodium chloride. The constant value of water vapor concentration is established over the salt solution.

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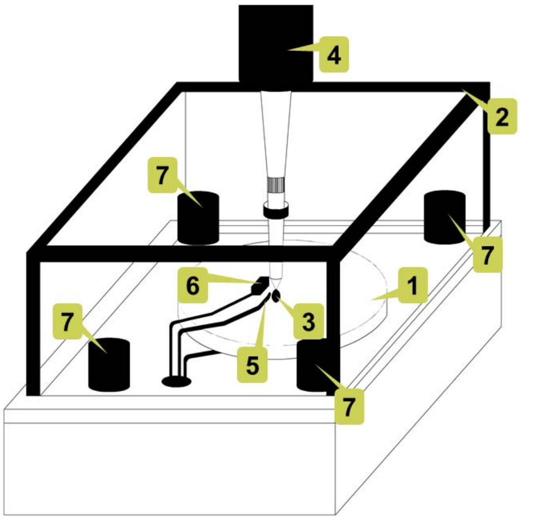

Fig. 1. The experimental setup: 1 - sample of aluminum alloy; 2 –box of plexiglass; 3 - drop; 4 - electronic dispenser; 5 - thermocouple; 6 - hygrometer; 7 - tanks with a saturated salt solution.

B. *Visualization of the evaporation process*

The change in the geometric characteristics of the droplets was recorded using an optical system consisting of a high-speed video camera “FastVideo 500M” (with a frequency of 10 frames per second) and a source of plane-parallel light. Evaporating droplets shadow images on an aluminum alloy substrate were obtained. The geometric parameters of the drop (contact angle, volume) are determined by the Young – Laplace method (LB-ADSA) in the “Drop shape analysis (DSA)” software package (Kruss, Germany) using drop shadow images.

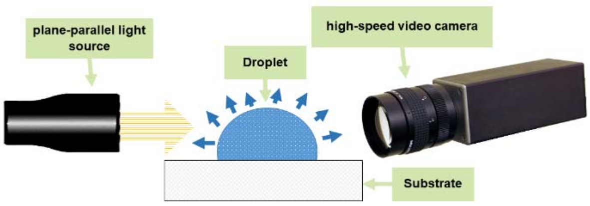

Fig. 2. Visualization of the evaporation process.

III. Resalts and Discussion

A. *Humidity distribution*

The constant water vapor concentration of 75% was established in the absence of temperature convection in the insulated chamber. However, the presence of heat flux from the aluminum alloy substrate initiated the appearance of a temperature gradient. RH was not distributed uniformly in height of the insulated chamber. Fig. 3 show typical distributions of RH with substrate temperature 323 Kelvin.

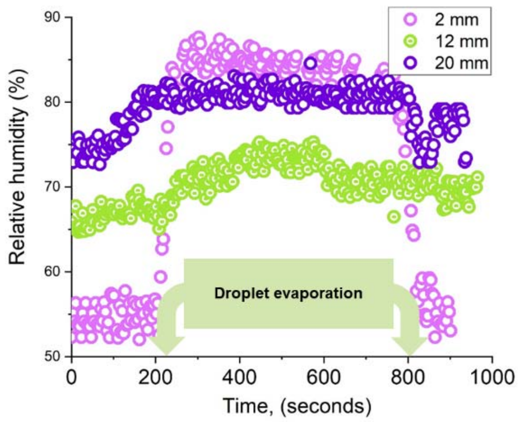

Fig. 3. typical distributions of water vapor concentration (RH) in a closed box (b) in height (substrate temperature 323 K)

Air temperature was reduced due to heat dissipation through the side and top walls of the box into the laboratory room with an increase in distance from 2 to 20 millimeters from the surface.

The quasistationary distribution of RH before the drop is placed inside the insulated chamber are showed between 0 to 200 seconds (fig. 3). With increasing distance from the center of the substrate to the measuring devices from 2 to 20 millimeters RH increased from 55 % to 75 %. The water vapor began to condense on the side walls of the box at a height of 20 millimeters. The concentration of water vapor near the condensate was 100%.

RH increased within 10 seconds, which corresponds to the warm-up time of the drop after dosing the droplet (from 200 to 800 seconds) (Fig. 4). Then it took the maximum value equal to 88 ± 3.5%. After that RH decreased by 3-5% during evaporation process. It can be concluded that hygrometers installed at different heights in a insulated chambers will register a different RH.

RH decreased to the original value as before placing it in the chamber after complete evaporation of the drop (from 800 to 1000 seconds). All volatile liquid condensed on the top and side walls of the insulated chamber.

B. *Droplet geometry*

Geometric parameters (volume) of an evaporating drop were obtained (Fig. 5). The volume linearly decreases during the evaporation of the water drop.

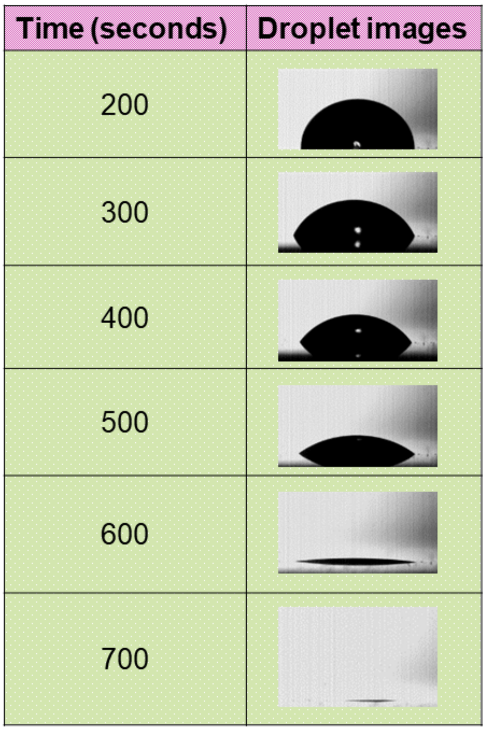

Fig. 4. Evoporating droplet "evolution".

The dependence of the drop volume on the evaporation time (τ) is described by a linear function (V_0 – initial volume):

$$y = \frac{V_0}{\tau} \cdot x + V_0 \,. \qquad (1)$$

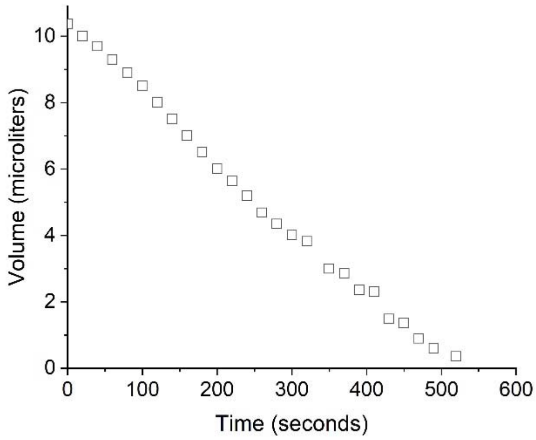

Fig. 5. The dependence of the volume on the evaporation time.

The rate of volume change (w) can be estimated from the shadow images of the drop (Fig. 4) and is equal to the ratio of the initial volume to the time of complete evaporation (Fig. 6):

$$w = V_0 / \tau \qquad (2)$$

The rate of change in volume obtained using drop shadow images increases linearly over the entire time range under study. The rate increased due to the heating and reduction of the droplet size (Fig. 4) during the mass transfer of the liquid as a result of the phase transition.

IV. Conclusion

Experiments were carried out to determine the regularities of the distribution of RH over an evaporating drop of water on the surface of a heated metal substrate in an insulated chamber.

It was established that water vapor is not evenly distributed. RH increases due to a decrease in air temperature due to heat dissipation through the walls of the box with increasing distance above the substrate. The concentration of water vapor at different points in an isolated chamber with the presence of a temperature gradient will not be the same.

RH increased by 32% to the initial value at a distance of 2 millimeter from the substrate during the evaporation of a liquid. RH decreased by 3-5% to the value corresponding to the onset of evaporation with a decrease in the height of the drop due to the loss of liquid as a result of the phase transition.

RH took on value before dropping it inside the chamber after evaporation of the liquid,. Water vapor condensed on the surface of the side walls of insulated chamber.

It was found that the dependence of the drop volume on the evaporation time (τ) is described by a linear function.

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