Contact angle dynamics for evaporating droplet on contrast nano-structured surface

E M Bochkareva¹, M K Lei², N B Miskiv¹, S V Starinsky¹ and V V Terekhov¹

¹Kutateladze Institute of Thermophysics, Acad. Lavrentyev Ave. 1, Novosibirsk, 630090, Russia
²Dalian University of Technology, School of Materials Science, Linggong Road, 2, Ganjingzi District, Dalian City, Liaoning Province, 116024, P.R.C

E-mail: prefous-lm@yandex.ru

Abstract. In this work, a series of experiments was carried out to study the evaporation rate of sessile and suspended droplets. The basic geometric characteristics of an evaporating drop from a biphilic surface are investigated. Evaporation dynamics data have been obtained, showing that evaporation from an inverted substrate is faster than evaporation of a sessile drop.

1. Introduction
The study of the processes that occur during the evaporation of liquid droplets onto a solid surface occupies a special place in energy, nanotechnology, due to the great applied potential. However, when studying problems of this kind, a number of difficulties arise associated with surface properties: roughness, thermal conductivity, wettability, etc. It should be noted that the evaporation process of a drop on a hydrophobic surface differs significantly from evaporation on a hydrophilic surface. There are practically no studies of processes involving the interaction of pure liquid droplets on biphilic surfaces [1].

In this work, a series of experiments was carried out to study the evaporation rate of sessile and suspended droplets. The main geometric characteristics (droplet diameter \(d_{\text{drop}}\), contact line diameter \(d_{\text{base}}\), droplet height \(h_{\text{drop}}\), contact angle \(\theta\)) of an evaporating drop from a biphilic surface are investigated. The contact angle is one of the most important characteristics of selective wetting and is defined as the angle between the solid surface and the tangent at the point of contact of the phases [2].

2. Experimental conditions
To prepare the substrates, the HW CVD method was used for the subsequent fictionalization of the material with a fluoropolymer coating. To fix a droplet on a substrate, its surface was irradiated with 10 laser pulses with an energy density less than 0.5 J/cm², which ensured local ablation of the fluoropolymer film from a spot with a diameter approximately 0.2 mm without damaging the substrate. Thus, the “seats” for drops were organized on the surface (Fig. 1). This material allows us to conduct experiments on the study of heat and mass transfer processes that occur during the evaporation of droplets, varying the orientation of the droplet relative to the gravitational forces.
The experiments on the evaporation of droplets were carried out on a facility (Fig. 2) developed at the IT SB RAS. The experimental setup is designed to study the dynamics of evaporation of liquid droplets. This setup allows one to vary the rotation angle of the surface (6) relative to the horizon due to the rotary mechanism (8). The surface on which the substrate was mounted is a copper plate (7) fixed by brackets. The substrate was attached to the copper surface using thermal paste, then the necessary angle was set and the drop “sat down” in the seat. The conditions around the droplet were measured with anemometer (4) to ensure control of humidity and ambient temperature. The evaporation process was recorded with a Thermo Tracer thermal imaging camera (1), Nikon D5300 camera (2) and Digi Scope II v3 digital microscope (3).

The obtained experimental data were processed by Digi Scope II v3 and Thermo Tracer software. The accuracy of measuring the size of the droplet was approximately 50 μm, the accuracy of measuring the temperature of the surface of the droplet was 0.08°C. To measure the relative air humidity φ in the drop suspension region, the stand was equipped with a Model 872 hygrometer with measurement uncertainty of 4%.

3. Results
As it is known, the process of droplet evaporation on a hydrophobic surface differs significantly from evaporation on a hydrophilic surface. Drops evaporation on a hydrophobic surface occurs in three
stages: at the first stage of evaporation, the contact angle decreases, and the radius and area of the contact remain constant; at the second stage, the radius of the surface of the droplet contact decreases, and the contact angle remains constant; the third stage is mixed, where both the contact angle and the contact area change.

Evaporation on nano-structured surfaces occurs in a completely different way (Fig. 3): the contact angle changes only at the last stages of evaporation, while the droplet height and radius change throughout the evaporation. It is worth noting that the contact angle is one of the most important characteristics of selective wetting and is defined as the angle between the solid surface and the tangent at the point of contact of the phases.

![Figure 3. Change in the geometric parameters of a water droplet during evaporation from a substrate under normal conditions.](image)

It is well known that the dynamics of evaporation of sessile and suspended droplets are significantly different [3], which is usually associated with the vapor delay effect near the suspended droplet. The obtained data on the dynamics of evaporation confirm the above statement, indeed, evaporation from an inverted substrate occurs faster than sessile drop evaporation. However, some authors believe that a more important factor is the difference in the movement of the contact line in suspended and sessile drops [4]. In the case of evaporation on a surface with contrasting wettability, this factor can be neglected.

Conclusion

In the framework of this work, experimental studies of the process of evaporation of liquid droplets on structured surfaces were carried out. In the experiments, a non-contact infrared thermography method was used to measure the droplet temperature. At the same time, in experiments a change in the geometric dimensions of the droplet during evaporation was recorded using digital microscopy.

An important section in this work is the setting up of experimental studies of droplet evaporation on a surface with contrast wettability. This material allows us to conduct experiments on the study of heat and mass transfer processes that occur during the evaporation of droplets, varying the orientation of the droplet relative to gravitational forces. As a result of the studies, data on mass transfer and dynamics of the droplet geometry were obtained.
Acknowledgments
The manufacture of superhydrophobic coatings was carried out with the support of the Russian Science Foundation (agreement No. 18-79-10119). The study of the droplet evaporation process was carried out with the financial support of the Russian Foundation for Basic Research, grant GFEN No. 17-58-53168.

References
[1] Ghannam M T and Esmail M N 1997 Chem. Eng. Commun. 158
[2] Mollaret R, Sefiane K, Christy J R E and Veyret D 2004 Chem. Eng. Res. Des. 82
[3] Li W, Lan D, Sun H and Wang Y 2018 Langmuir 34 16
[4] Chen R, Jiao L, Zhu X, Liao Q and Li D 2018 Appl. Thermal Eng. 144 5