Experimental investigation of picoliter liquid drops evaporation on a heated solid surface

To cite this article: D P Kirichenko et al 2017 J. Phys.: Conf. Ser. 925 012026

View the article online for updates and enhancements.

You may also like
- Microengineering methods for cell-based microarrays and high-throughput drug-screening applications
- Wafer scale interdigitated nanoelectrode devices functionalized using a MEMS-based deposition system
- Drop on demand in a microfluidic chip
Experimental investigation of picoliter liquid drops evaporation on a heated solid surface

D P Kirichenko\textsuperscript{1,2}, D V Zaitsev\textsuperscript{1,2}, O A Kabov\textsuperscript{1,2}

\textsuperscript{1}Kutateladze Institute of Thermophysics, Siberian Branch of Russian Academy of Sciences, 630090, Novosibirsk, Russia
\textsuperscript{2}Novosibirsk State University, 630090, Novosibirsk, Russia

E-mail: Dmitriy_kirichenko@mail.ru

Abstract. This paper presents a study of the evaporation of sessile picoliter liquid drops on a heated solid surface. It has been shown that during evaporation diameter of the drop is almost constant (the contact line is pinned) and starts to decrease only at the final moment of drop life. It has been shown that the specific evaporation rate of a droplet (droplet weight loss per unit time per unit droplet surface area) is not constant over time: it gradually grows with time up to a maximum, but at the final stage, when the height of the drop becomes on the order of 1 µm, it decreases rapidly.

1. Introduction
The process of liquid drop evaporation, which takes place in a variety of technological systems in power engineering, medicine, agriculture, chemical and other industries, has been actively investigated during the last decade. Effective solutions for removing high-density heat fluxes are systems based on gas-droplet flows or sprays \cite{1, 2} as well as systems using two-phase flow in a microchannel \cite{3, 4}, where evaporation of liquid drops in contact with hot wall may occur. Most experimental and theoretical studies deal with evaporation of isothermal water drops. There are many publications studying evaporation of drops with volume from 1 to 1000 µl. In \cite{5, 6} it is found that at the final stage of the drop life specific evaporation rate abruptly increases especially for drops with small and moderate contact angle hysteresis. Studies of nonisothermal evaporation of liquid drops of picoliter (pl = 10^{-12} l) volume are almost absent in the literature.

The objective of this work were to study the evaporation of sessile water drops with initial volume of 10-50 pl on a heated solid surface.

2. Experimental setup and methods
The experimental setup is shown schematically in Fig. 1. The working section is made of stainless steel with an embedded copper rod with dimensions of 10x10 mm\textsuperscript{2}. The surface was heated by a nichrome coil supplied with current from a power source. Substrate surface temperature was measured by thermocouples embedded in the copper rod. The surface temperature of the copper rod was 134 °C. The experiments were performed in the working section open to the atmosphere at an air temperature of 25–27 °C. Liquid microdroplets with a size of the order 10 µm were applied on the working surface.
by a spray device placed a few centimeters above the heating area. Droplets were examined over the surface of the copper rod. Room-temperature nanofiltered distilled water was used as the working fluid. The droplets were imaged from side using a FASTCAM SA1.1 high-speed camera (5600 fps at a resolution of 1024x1024 pixels) coupled with a microscope objective. The optical resolution of the system was 0.8 µm/pixel. The morphology of the surface was analyzed using scanning electron microscope (JEOL JSM6700F) and atomic force microscope (Solver Pro NT MDT), Fig. 2. The root mean square (RMS) surface roughness was found to be 0.50 µm.

**Figure 1.** Schematic diagram of the experimental setup

**Figure 2.** Results of heater surface characterization studies: (left) an image obtained using scanning electron microscope; (right) height histogram obtained using atomic force microscope

### 3. Results

Figure 3 shows change of the liquid drop profile during evaporation for a liquid drop with initial volume of 51.4 pl. Due to evaporation, the droplet size decreases with time. Depending on the initial size of the drop, life time changes from 0.006 to 0.016 s.

**Figure 3.** Change of drop shape (side view) during sessile droplet evaporation on a heated substrate, $T_w=134$ °C
It has been found that during evaporation diameter of the drop is almost constant (the contact line is pinned) and starts to decrease only at the final moment of drop life. Figure 4 shows plots of the diameter of an evaporating droplet versus time for different initial droplet sizes.

![Figure 4](image-url)

**Figure 4.** Diameter of wetted area versus time for three different sessile drops (lines 1, 2 and 3), $T_w=134 \, ^\circ$C

Figure 5 shows the volume of an evaporating droplet versus time for different initial droplet sizes. It has been found that volume decreases with time almost linear, but at the final stage of the drop evaporation, the volume starts to decrease much slower. Figure 6 shows the specific evaporation rate of a droplet (droplet weight loss per unit time per unit droplet surface area) versus time. It is seen that the specific evaporation rate is not constant over time: it gradually grows with time up to a maximum, but at the final stage, when the height of the drop becomes on the order of 1 µm, it decreases rapidly. Such decrease of the specific evaporation rate has been observed for the first time. In previous works with evaporation of large drops [5,6] only an increase of the evaporation rate at the final stage was registered.

![Figure 5](image-url)

**Figure 5:** Volume versus time for three different sessile drops (lines 1, 2 and 3), $T_w=134 \, ^\circ$C
Figure 6: Specific evaporation rate versus time for three different sessile drops (lines 1, 2 and 3), $T_w=134 \, ^\circ C$

4. Conclusions
Evaporation of sessile picoliter liquid drops on a heated solid surface has been studied experimentally and the following results have been obtained.

(1) During the process of evaporation, diameter of the drop is almost constant (the contact line is pinned) and starts to decrease only at the final moment of the drop life.

(2) Specific evaporation rate is not constant over time: it gradually grows with time up to a maximum, but at the final stage, when the height of the drop becomes on the order of 1 µm, it decreases rapidly.

Acknowledgements
This work was supported by the Russian Science Foundation (project 15-19-20049).

References
[1] Jungho Kim 2006 International Journal of Heat and Fluid Flow 28 753
[2] Srikar R, Gambaryan-Roisman T, Steffes C, Stephan P, Tropea C, Yarin A L 2009 International Journal of Heat and Mass Transfer 52 5814
[3] Kabov O A, Lyulin Yu V, Marchuk I V and Zaitsev D V, 2007 International Journal of Heat and Fluid Flow 28 103
[4] Zaitsev D V, Rodionov D A and Kabov O A 2009 Technical Physics letters 35 680
[5] Elizaveta Ya Gatapova, Andrey A Semenov, Dmitry V Zaitsev, Oleg A Kabov 2014 Colloids and Surfaces A: Physicochemical and Engineering Aspects 441 776
[6] A A Semenov, D V Feoktistov, D V Zaitsev, G V Kuznetsov, and O A Kabov 2015 Thermophysics and Aeromechanics 22 771