Condensation growth of microdroplets levitating over a heated liquid film

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Abstract. This work is devoted to the study of such an interesting phenomenon as levitation of liquid microdroplets above the surface of a heated film. Levitating microdroplets of liquid are formed due to condensation of the upward flow of steam. The height of the drop levitation is comparable to their size. This paper presents new experimental data on the dependence of the droplet diameter on time. Microdroplets of liquid being in a two-dimensional array of microdroplets and levitating above the heated liquid film constantly grow due to condensation. The diameter of the droplets practically linearly increases with time. The obtained non-trivial results require further careful research.

1. Introduction

The study of liquid microdroplets is relevant for some applications. At present, to ensure reliable and stable operation of high-speed electronic components, high-power lasers, and conversion systems, it is required to use efficient methods for removing high heat fluxes. Possible technologies for liquid cooling include two-phase liquid cooling in a microchannel [1, 2, 3, 4], spray cooling [5, 6], jet cooling, thermosyphons and heat pipes. In spray cooling, droplets spread over the surface and evaporate or form a thin liquid film, removing a large amount of energy. The interaction of aerosol droplets with a heated surface is characterized by a huge number of different factors, which are difficult to account for in the theoretical analysis. Liquid microdroplets may not reach the heated surface [7], which may affect the cooling ability. Therefore, when studying heat transfer processes during spray cooling, it is important to know under what conditions the droplets levitate, that is, do not touch the heated surface. Also, microdroplets of liquid can be used as indicators for visualizing micro-scale flows. The use of levitating microdroplets of liquid as tracers for visualizing micro-scale flows in a gas-vapor medium in the immediate vicinity of the liquid-vapor/gas interface, where it is difficult or impossible to apply traditional PIV methods, was experimentally shown in [8, 9, 10].

Levitating microdroplets of liquid, which can be observed in everyday life [10, 11, 12], are formed due to condensation of the upward flow of steam. The initial size of droplets is about 10 $\mu$m. Papers [13, 14] present a theoretical model of microdroplets levitation over a dry and wet surface. The droplets levitate due to the Stokes friction force acting on the drop from the upstream flow that occurs at the liquid - vapor/gas interface. Taking into account the Stefan flows, a new theoretical model was constructed, which is in good agreement with the experimental data.

From the above we can conclude that the mechanism of levitation of microdroplets has been clarified, while the mechanism of interaction of droplets with each other remains unclear. In [15] the geometric
characteristics of the two-dimensional array of liquid microdroplets was investigated for different experiment parameters. In the current paper we investigate the growth of the droplet diameter in time.

2. Experimental setup
A caprolon cylinder base with a radius of 12 mm, in the center of which a copper rod with a radius of 1.5 mm, is used as a working section. This copper rod serves as a heating cell. A snapshot and a scheme of the experimental installation are shown in figures 1, 2. The working fluid in the experiments is degassed and ultra-pure Milli-Q water. A thermocouple was established in the center of the heater to determine the surface temperature of the heated base. The digital camera Nikon D500 was equipped with a Mitutoyo M Plan Apo 10X 0.28 microscopic lens, which allows taking photos and videos with high image quality. Experiment parameters such as the thickness of the liquid layer and the substrate temperature were kept constant in each experiment series.

![Figure 1. A scheme of the experimental installation.](image1)

![Figure 2. A still picture of the experimental setup.](image2)
In the course of this study, a Titanium 570M IR camera manufactured by Flir Systems was used for recording the temperature distribution on the surface of the liquid film. It was detected that the surface temperature does not differ much from the heated plate temperature, figure 3.

![Figure 3](image)

**Figure 3.** The surface temperature of the film in the center of the heater and the corresponding values of the temperature of the substrate, the local thickness of the liquid layer $h_{loc} = 0.8$ mm.

In this paper, the temperature of the base is measured in all series of the research. The liquid surface temperature is measured in some series for monitoring.

3. Experimental results

Microdroplets of liquid that make up a two-dimensional array continuously increase in size due to vapor condensation. Figure 4 shows images of an array with a number of droplets $N = 8$ at a substrate temperature $T_w = 79.8 \, ^\circ C$ during its evolution in time. Shortly after the moment shown in Figure 4c, the array suddenly disappears due to the merging of the monolayer with the surface of the heated thin layer of water. Figures 5 shows the dependence of the drop diameter on time. The graphs show data for different monolayers, with different amounts of droplets, and at different substrate temperatures.

![Figure 4](image)

**Figure 4.** The evolution of a two-dimensional array over time. $t_o$ is the moment the measurement begins. The substrate temperature $T_w = 79.8 \, ^\circ C$, the number of drops $N = 8$, the local layer thickness in the center $h_{loc} = 0.5$ mm.
As can be seen from the graph, the diameter of the droplets practically linearly increases with time. Figure 6 shows the evolutionary dependences of the surface area ($S = \pi d^2$) of the droplets. In addition, Figure 6 shows data from the experiments of Fedorets et.al. [16], which is in good agreement with our data. It is known [17] that under diffusion regime of condensation the droplet surface area has a linear dependence on time. But in our case, the diameter of the droplets almost linearly depends on time. This may be due to the fact that as the droplets approach to the heated surface under the influence of gravity, the vapor concentration increases and, as a result, the droplets condense faster.

**Figure 5.** A plot of the diameter of the droplet ($d$) vs. time. Evolutionary data are shown for different monolayers at different substrate temperatures ($T_w$) and the number of droplets ($N$) in a two-dimensional array. The local thickness of the liquid layer in the centre of the working area for all monolayers $h_{loc} = 0.5$ mm.

**Figure 6.** Graph of the droplet surface area ($S$) vs. time ($t$). The values of the droplet diameter at the beginning of measurement were used for normalization. Red dots correspond to the data from the experiments of Fedorets et. al [16].
Conclusion
It has been found that the diameter of the levitating liquid microdroplets of condensate practically linearly increases with time. Non-trivial results have been obtained that require further careful research. We hope that the presented results will be useful in the future for verification of the developed theoretical model.

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