

# LEVITATION OF LIQUID MICRODROPLETS ABOVE A SOLID SURFACE SUBCOOLED TO THE LEIDENFROST TEMPERATURE

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**Abstract.** Evaporation of liquid microdroplets that fall on a solid surface with the temperature of below the Leidenfrost temperature is studied. It has been found out that sufficiently small liquid droplets of about 10 microns can suspend at some distance from the surface (levitate) and do not reach the surface; at that, the rate of droplet evaporation is reduced by an order as compared to microdroplets, which touch the surface. It is determined that in contrast to microdroplets, which touch the surface, the specific evaporation rate of levitating droplets is constant in time.

## 1 Introduction

Among the effective solutions for removing high heat flux densities, there are the systems of spray cooling [1] as well as the systems using stratification of a two-phase flow in a microchannel [2, 3]. Under the certain conditions, heat in these systems is removed due to intensive evaporation of liquid microdroplets. However, due to the Leidenfrost effect [4] the liquid microdroplets cannot reach the heating surface [5], and this may reduce the efficiency of apparatus cooling and cause its failure. The behavior of liquid microdroplets falling onto a solid surface, subcooled to the Leidenfrost temperature (about 200°C for water), is studied insufficiently. The phenomenon of droplet levitation at relatively low temperatures [6,7] can have a significant effect on operation efficiency of the two-phase cooling systems.

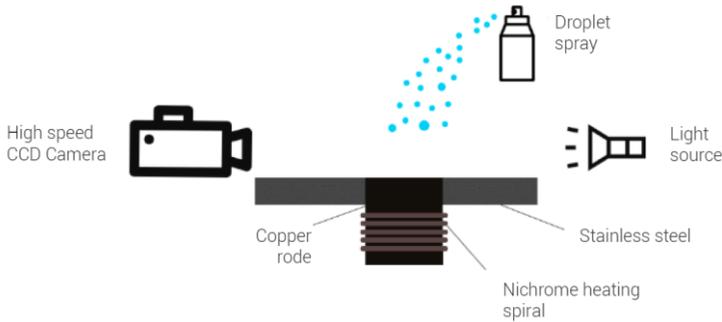
## 2 Experimental setup and research methods

The experimental setup is shown in fig. 1. The working section is made of stainless steel with an embedded copper core of 10x10 mm<sup>2</sup>. The surface is heated using the nichrome tape, where the current from a power source is supplied. The temperature of the substrate surface was controlled by thermocouples mounted in the copper core. The surface temperature of the copper core was 135-155 °C. The experiment was carried out using the working section open to the atmosphere at the air temperature of 25-27 °C. Liquid

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microdroplets with the size of about 10-100 microns were fed to the working surface from a nozzle mounted at some centimeters above the heating area. Deionized nanofiltered distilled water at the room temperature was used as the working liquid. According to images obtained via FASTCAM SA1.1 high-speed camera (5600 f/s with resolution of 1024x1024 pixels), the diameter and height of droplet levitating were measured. Optical resolution of the system was about 1  $\mu\text{m}/\text{pixel}$ .

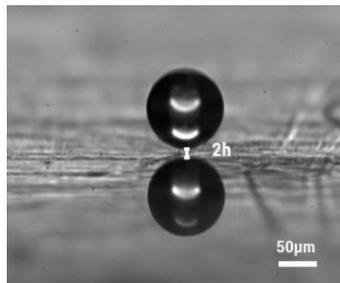


**Fig. 1.** Scheme of experimental section. (*Fastcam, copper core, heating, nichrome spiral, stainless steel, light source, droplet spray*).

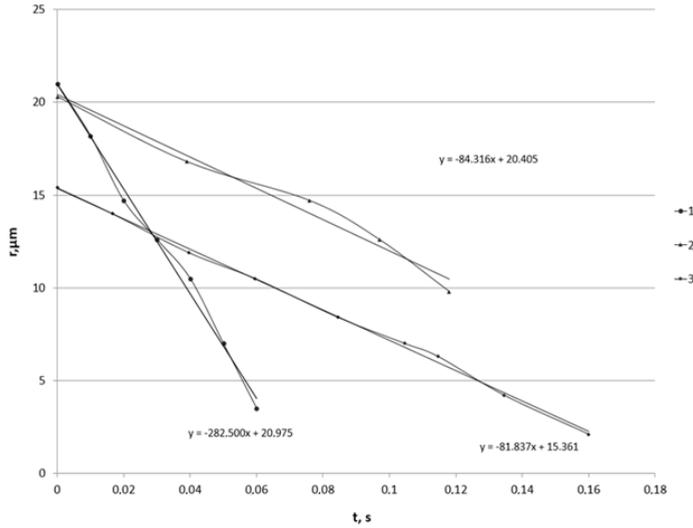
### 3 Investigation results

It has been found out that microdroplets with the size of about 10  $\mu\text{m}$ , falling on a heated surface with relatively low speed, do not touch it, but “suspend” over a solid surface at some distance; at that, the rate of droplet evaporation reduces by an order as compared to the microdroplets, which touch the surface. A photograph of levitating droplet and its reflection from the substrate is shown in fig. 2. Due to evaporation, the droplet size decreases with time. It should be noted that the droplet shape is not changed at evaporation and remains perfectly spherical, in contrast to levitation of large drops at the temperatures above the Leidenfrost temperature.

Dependence of a change in the radius of evaporating droplet on time is shown in fig. 3 for different surface temperatures and initial droplet sizes. Data were approximated with sufficient accuracy by linear relationships. It can be seen that at the same substrate temperature for the droplets with different initial sizes, inclination of lines is close. With an increase in the substrate temperature, the slope of the line increases.

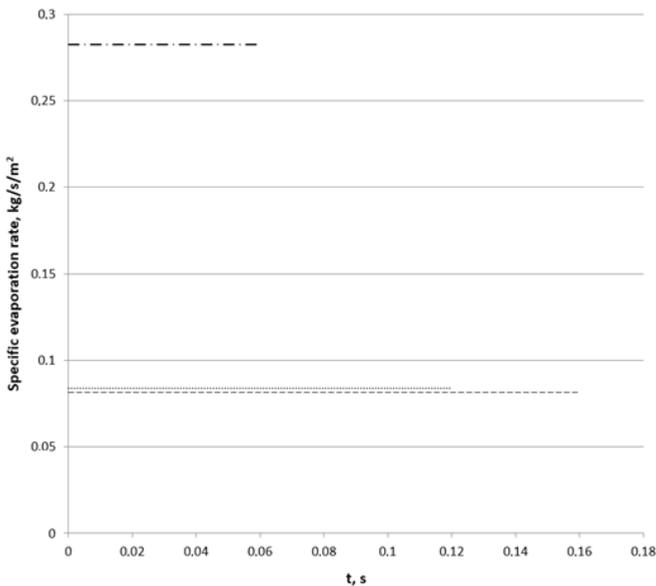


**Fig. 2.** Microdroplet ( $R=50.5 \mu\text{m}$ ), levitating at height  $h=4.2 \mu\text{m}$ . Substrate temperature – 155  $^{\circ}\text{C}$ .



**Fig. 3.** Change in the radius of levitating droplet vs. time. 1 – substrate temperature – 155 °C; 2,3 – substrate temperature T=135 °C.

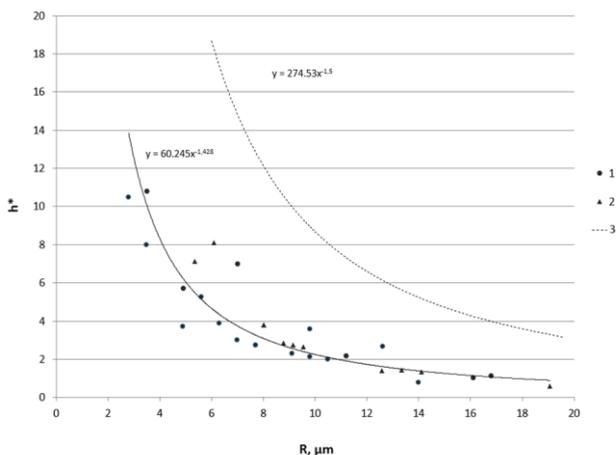
Dependences of specific evaporation rate of a droplet (a loss of the droplet weight per a time unit per a surface area unit) on time, plotted by approximating straight lines shown in fig. 3 are presented in fig. 4. It can be seen that the specific evaporation rate does not change during droplet evaporation, but increases with an increase in temperature. In the case, when the droplet touches the heated surface, the specific evaporation rate is not constant; it increases drastically in the last moments of droplet existence [8, 9].



**Fig. 4.** Specific rate of levitating droplet evaporation. 1 – substrate temperature – 155 °C; 2,3 – substrate temperature – 135 °C.

The height of droplet levitation,  $h$ , was calculated as a half distance between the real droplet and its reflection (fig. 2). The diagram of dependence between dimensionless value  $h^*=h/R$  and droplet radius  $R$  is shown in fig. 5. The obtained results were compared

qualitatively with generalized results of [5] for levitation of water microdroplets over the surface, heated to the temperature of 400 °C. It is evident that the exponents of approximating dependences are close, but dependence of [5] is significantly higher.



**Fig. 5.** Dimensionless height of droplet levitation vs. its radius. 1 – substrate temperature 135 °C; 2 – 155 °C; 3 – substrate temperature 400 °C [5]. Solid line – generalization of data 1 and 2.

## 4. Conclusions

Interaction of the falling liquid microdroplets with the solid surface, whose temperature is lower than the Leidenfrost temperature, was studied experimentally. It has been found out that:

- Microdroplets with the size of about 10 μm, falling on the heated surface with relatively low velocity, do not touch it, but “suspend” over the surface at some distance.
- The time of levitating droplet evaporation becomes an order higher in comparison with the microdroplets, which touch the surface.
- The specific evaporation rate of a levitating droplet is constant in time in contrast to the droplets contacting the surface, whose specific evaporation rate increases drastically with time.

The law of variation of the droplet levitation height vs. its radius is qualitatively similar to the law described in [5] for the substrate with the temperature higher than the Leidenfrost temperature.

## Acknowledgments

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