Dynamics of heat transfer at the coalition of the drops on a horizontal heated surface

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Abstract. An experimental study was carried out to investigate heat transfer during the coalition of two drops of the same volume. The falling of a water drop to other drop sitting on a heated horizontal foil made of constantan with a thickness of 25 μm from a distance of 10 mm was recorded with a high-speed video camera. An infrared scanner was used to measure the temperature field on the surface of the foil. Measurements taken with the infrared scanner will be used to determine the heat flux density in the region of the dynamic contact wetting line at the coalition of drops.

1. Introduction
Within past few decades of the rapid development of the electronic industry many changes have happened in its structure. Now, the main share of the industry products includes the various types of computing equipment used in the industrial, military and other production. Modern electronics strives to reduce the size of devices, but increase the performance, that, in turn, leads to the growth of the thermal power, which must be removed for the stable operation. Thus, one of the main problems in this area is to widen the possibility of the equipment operation without a failure when a certain critical temperature is exceeded for a certain time, that is, until a thermal failure. However, currently used cooling technologies, such as natural convection, air cooling systems, liquid-immersion and film cooling, do not possess sufficiently effective heat-removing ability. It makes the creation of a cooling system corresponding to the trends of constant technology improvement one of the urgent tasks of modern science.

The spray liquid cooling system, when a liquid film forms as a result of a directional flow of drops and partially or completely wets the heating surface, is one of the most promising cooling systems. Accordingly, there is a necessity of a deeper study of the heat transfer dynamics when drops fall on a solid surface and coalesce together. This is associated with many factors: surface tension, wettability, geometry of the surface, etc. [1, 2].

A lot of international research is aimed at exploring the various aspects of the drop flow and spread of the drops on a solid surface. Some of them [3–5] were performed under conditions of the different levels of gravity. Others were devoted to studying heat transfer in the region of a three-phase wetting contact line of the drop. It was experimentally and theoretically shown that heat transfer near the contact line is more intensive than over the entire surface with a drop [6, 7]. Because of the relatively small cross size of the contact line microregion, it is impossible to measure the heat flux density in this area directly. Therefore, the indirect computational methods are used to estimate the heat flux in the field of
the contact of three phases. Heat transfer in a drop sitting on a thin foil heated by a constant current source was considered in the work [8]. To determine the heat flux density in the region of the contact line of the drop, the stationary Cauchy problem for the elliptic equation was solved with using the temperature values at each point of the surface obtained by an infrared camera [9]. In the present investigation the same way for measuring the heat flux in the region of the contact line at the coalition of two drops will be used.

2. Experimental setup
To study heat transfer when a drop falls to the other drop sitting on a heated horizontal surface, an experimental setup is designed (Fig. 1). The main part of it is a foil made of constantan with thickness of 25 μm. The constantan foil is coated with a fluoropolymer film with thickness of 100 nm. The information about coating you can find in [10].

![Experimental setup diagram]

Fig. 1. The scheme of the experimental setup

A horizontally positioned foil with a length of 80 mm and a width of 35 mm is connected to the TTi QPX 1200L power source with the help of the brass electrode holders. The wetting contact angle is about 80°. The thermal power released on the foil is regulated in the range from 0.41 to 1.64 W by means of the constant current source. Such heat fluxes are quite low and natural convection does not disturb the temperature distribution on the foil. The drop of 12.2 μl is positioned on the other drop of the same volume sitting on the heated foil surface from a distance of 10 mm through a syringe by a syringe pump Cole-Parmer EW-74905-54. The moment of the drop fall and two drops coalition is recorded by a high-speed camera FastVideo 500M. The surface temperature of the foil is measured by an infrared (IR) camera Titanium 570M on the opposite side of the foil with the help of a metal mirror. Ultrapurified water obtained in the Milli-Q system is used as a work liquid. This system combines several purification steps: distillation, water purification in the special cartridges on the ion-exchange resins and activated carbon, as well as UV-irradiation.

3. Results
The temperature fields on the foil side opposite to the drop obtained using the IR-scanner and the video frames made by a high-speed video camera are shown in figure 2. The plots of the temperature distribution along the line crossing the foil in the middle section, when a drop falls and coalesces with the other drop, are demonstrated in figure 3. The curves are built for the certain moments of the coalition process.
Figure 2. The video frames and the thermograms (of the opposite side of the foil from the drop) at the coalition of two drops of the volume of 12.2 μl each: a – the thermal power released on the foil \( P = 0.41 \) W, the average heat flux density \( q_{av} = 73.21 \) W/m\(^2\); b – \( P = 0.92 \) W, \( q_{av} = 163.29 \) W/m\(^2\); c – \( P = 1.64 \) W, \( q_{av} = 292.86 \) W/m\(^2\).
Figure 3. The graphs of the temperature distribution in the middle section of the foil at the coalition of two drops: a – $P = 0.41$ W, $q_{av} = 73.21$ W/m$^2$; b – $P = 0.92$ W, $q_{av} = 163.29$ W/m$^2$; c – $P = 1.64$ W, $q_{av} = 292.86$ W/m$^2$. 
As it can be seen from the above graphs, when two drops are in contact the surface temperature of
the foil under the first drop reduces sharply. It is especially obvious in the case of a higher heating of
the foil. After the process of the drops coalition into one new drop, the surface temperature under the
resulting drop begins to increase due to the heating of the drop and its further evaporation.

The data obtained using the IR-camera will be used to calculate the heat flux density on the surface
of the foil. The determination of the heat flux density in the region of the dynamic contact wetting line
at interaction of two drops is of a particular interest. It is assumed that the maximum heat flux will be
observed in this region because the thickness of the liquid layer is minimal there, so the heat transfer
will occur more intensively.

Conclusions
The temperature distributions on the foil side opposite to the drop and the video frames from a high-
speed video camera were obtained as a result of the experimental study of the heat transfer dynamics
when one drop falls and coalesces with another drop sitting on a heated horizontal surface. The infrared
thermography data will be used further to determine the heat flux density in the region of the dynamic
contact wetting line.

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