Experimental investigation of heat transfer in three-phase contact line

T G Ponomarenko\textsuperscript{1, 2} and C Fournely\textsuperscript{1, 3}

\textsuperscript{1} Kutateladze Institute of Thermophysics SB RAS, 630090, Russia, Novosibirsk, 1 Lavrentev Avenue
\textsuperscript{2} Novosibirsk State Technical University, 630073, Russia, Novosibirsk, 20 K. Marks Avenue
\textsuperscript{3} Polytech Clermont-Ferrand, 63100, France, Aubiere, Avenue Blaise Pascal 2

E-mail: t.evans2010@yandex.kz

Abstract. The temperature distribution for one drop on a horizontal heated constantan foil is investigated. The temperature distribution for different time moments of the bottom foil surface was measured by the FLIR infrared (IR) camera. In the future the heat flux distribution near the contact line of drop will be calculated by numerical solution of the Cauchy problem.

1. Introduction

Liquid droplets are widely distributed in industry, technology and nature \cite{1, 2}. The wetting angle is a fundamental macroscopic characteristic of the contact line. The Young equation determines the wetting (contact) angle, \cite{3}. Analysis of papers where drop is placed on the heated substrate with different level of gravity shows that there is not enough information about the process of evaporation and wetting of a solid substrate for variable levels of gravity \cite{4}.

The research team predicted the abnormally high heat transfer coefficient in the three-phase contact line \cite{5}. It was confirmed by experimental and theoretical studies that heat transfer near the contact line (in the micro-region) can be more than an order of magnitude higher than average \cite{6, 7}. It is impossible to perform the direct measurements of heat flux density in the micro-region because of its small cross size (about 10 \textmu m). Various indirect methods and numerical procedures are used to estimate the heat flux in microregion. The meniscus of HFE7100 liquid between two vertical plates which are heated electrically was studied in \cite{8}. The infrared scanner with resolution of 14.8 microns is used to measure temperature distribution, and the local heat flux to evaporating meniscus is calculated using the energy balance for each pixel element and solving Fourier’s heat conduction equation. It was demonstrated that the local heat flux density in the region of the contact line is 3 times higher than the average heat flux density on the surface. The problem of heat transfer of evaporating droplet for stationary conditions on a horizontal constantan foil heated by a DC power source was studied in \cite{9}. The heat flux density on the surface with the droplet was calculated by solving the stationary Cauchy problem for the elliptic equation using the temperature measurements obtained by IR-scanner by the method suggested in \cite{10}. It was demonstrated that in contact line the heat flux is higher than the average one in a droplet. The heat flux in the contact line for stationary sessile drop is determined using Matlab software functions for heat transfer in thin foil \cite{11}.
2. Experimental setup and technique of measurement
The scheme and photo of our setup is shown in figure 1. A constantan foil (CuNi) of the thickness of 25 μm, size of 80 × 35 mm² and heat conductivity λ of 23 W/mK is soldered to the two brass electrodes (3). The electrodes are connected to electrical power supply (2) - TTI QPX 1200L. The temperature of the foil surface is measured by IR camera Titanium 570M (6) with help of gold mirror (1). The video camera (5) is used to observe a drop (4) from top view. The heat transfer coefficient from the foil surface to surrounding air is about 25 W/m²K. These measurements were performed without droplets on the foil surface with the same heat flux. Heat fluxes were not very high and natural convection did not disturb temperature distribution on the foil. Heat fluxes were taken into account only from top and bottom surfaces, while fluxes from lateral walls were neglected. Average temperature was measured and the heat transfer coefficient was calculated. Two different liquids (water and FC-72) for drops were used as working liquids. The drop image and temperature distribution of the bottom foil surface were measured each 10 seconds. The wetting contact angle of constantan foil by water was about 73.5° (measured by goniometer) (figure 2).

Figure 1. Scheme and photos of the experimental setup for the study of heat transfer and the dynamics of the evaporating liquid drop on the heated foil, where 1 - gold mirror, 2 - power source, 3 - brass electrodes with a constantan-foil stretched between them, 4 - evaporating drop of liquid, 5 - video camera, 6 - IR scanner Titanium 570M.

Figure 2. Photo of the sessile water drop on the constantan foil (contact angle is about 73.5°).
3. Experimental results
The IR-pictures from the bottom side of foil and photo of drop for different times (figures 3 and 4). The FC-72 is liquid with low surface tension and low wetting contact angle. So, the diameter of this drop is larger than for the same volume of water drop. One can see that evaporation rate for FC-72 drop (figure 5) is higher than for water drop due to low heat capacity and heat of vaporization of FC-72 liquid. These data will be used to solve Cauchy problem for heat transfer equation in thin constantan foil to find heat flux near the contact line of this drop:

\[ \lambda \Delta T + q_v = 0, \]

with boundary conditions – constant heat flux and temperature distribution for bottom side of foil for different moments of time, where \( \lambda \) is the heat conductive coefficient, and \( q_v \) is the volume heat flux in thin foil.

\[ 0 \text{ min.} \quad \begin{array}{c} \text{2 min.} \\ \end{array} \]

\[ 4 \text{ min.} \quad \begin{array}{c} \text{6 min.} \\ \end{array} \]

\[ 8 \text{ min.} \quad \begin{array}{c} \text{12 min.} \\ \end{array} \]

Figure 3. Thermal images of water drop 0.5 ml, \( q_S = 489.56 \text{ W/m}^2 \).
Figure 4. Thermal images of FC-72 drop and temperature profile from opposite side of the drop for the first picture for the line 1, 0.5 ml, $q_s = 62.61 \text{ W/m}^2$. 
4. Conclusion
In the present paper heat transfer in a sessile liquid drop on the heated constantan foil has been studied experimentally. It is demonstrated that evaporation time is shorter for highly volatile FC-72 liquid drop than for water drop. Substrate temperature under the drop is lower than for water drop due to strong evaporation of FC-72 liquid. These data will be used to find heat flux distribution in the contact line of the studied drop.

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