Rivulet deflection in the heated liquid film with different initial characteristics

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Abstract. Analysis of rivulet movement across flow direction in vertical flowing heated liquid film at different Reynolds numbers and initial temperatures was carried out. It is shown, that amplitude of deflection increases substantially at heat fluxes corresponding to the appearance of thermocapillary structures of type A.

1. Introduction
During the gravitational flow of liquid films along a heater, instabilities of different types develop, leading to the formation of regular structures. The study of rivulet flows on the surface of heated liquid films is important for the understanding of heat transfer processes and the development of crisis phenomena.

Formation of regular structures was firstly detected in [1, 2], where the flow of 25% alcohol solution along a small size heater of 6.5 x 13 mm was investigated. At heat flux density higher than the threshold value, a horizontal roller was formed on the upper edge of the heater, and this led to liquid movement in the form of vertical rivulets and a thin film between them. At that, the resistance of the liquid film to breakdown increased sharply. In [3], two types of regular structures (A and B) were distinguished in heated liquid films. Flows of water and dielectric liquid FC-72 along the heater with a size of 150x150 mm. The reason to division rivulet flows into two types was the distance between rivulets, which increases of type A with the growth of heat flux density, and decreases for type B. The effects of instabilities and structures of different types on water film breakdown was investigated in [4].

The aim of the present work is the investigation of the transverse movement of rivulets in vertical flowing heated liquid film at different Reynolds numbers (Re) and initial temperatures (T0).

2. Experimental setup
The experimental setup was a closed circulation circuit, including a working section, thermostat with a pump, pipelines, rotameter, and stop valve.

The working section made of a textolite plate with liquid nozzle, thermostabilizer, and heater located on this plate. The length of heat exchanger is 100 mm and width 150 mm, where heated water was pumped through the channels, was used as a heater. The average heat flux was calculated by the difference of temperature for water at the inlet and outlet of the heat exchanger and the mass flow rate of water.
Distilled water with the addition of a dye was used as a working liquid. The working liquid was fed by the pump to the film former, which included a storage chamber, dispenser, and nozzle with a calibrated flat slit. The setup is described in more detail in [5].

The thickness field was determined by the modified fluorescence method. Rhodamine 6Zh was used as a fluorescent dye. Temperature distribution on the water film surface was measured by the Titanium 570M infrared scanner [5].

3. Discussion

Because of wave interaction with thermocapillary waves, the rivulets are formed on the liquid film surface and move across the flow (deflection). A maximal amplitude was used as a numerical characteristic of deflection. The maximum amplitude of deviation was defined as the distance between the extreme right and extreme left positions of the rivulet crest during thermal imaging (600 frames, 6 seconds) [6]. For more details, the calculating procedure of this parameter is illustrated in Fig. 1. Point 1 corresponds to the rivulet crest position in the Figure averaged by 600 frames. Points 2 and 3 correspond to the extreme left and extreme right positions. The maximum amplitude of rivulet deflection ($A_r$) is equivalent to the distance between points 3 and 2. The maximal amplitude of rivulet deflection was calculated for the area of 25-100 mm from the upper edge of the heater because no upstream structures were observed clearly.

![Figure 1. Thermogram of the film surface with a rivulet. Points 1, 2, and 3 are at a distance of 50 mm from the upper edge of the heater. Re=33, $T_0$=30 °C, $q$=2.66 W/cm². The arrow indicates flow direction.](image)

Function of the maximal amplitude of rivulet deviation on the heat flux ($q$) at various distances from the upper edge of the heater for different values of Re and $T_0$ is shown in Fig. 2. For all cases, threshold growth of the maximal amplitude of rivulet deflection was observed upon reaching specific values of heat flux density. These values correspond to the appearance of type A structures in the upper part of the heater. Rivulet deflects exactly as a result of the interaction of three-dimensional waves with these structures. At that, at lower and higher values of the heat flux, $A_r$ is almost equal for all values of $q$, Re, and $T_0$. 
Figure 2. Dependence of maximal amplitude of rivulet deflection on heat flux.

Besides, a change of the nature of the function of the maximal amplitude of rivulet deflection on the distance along the heater is observed at the increase of heat flux density (Fig. 3). At low heat flux densities, \( A_r \) almost does not change along the heater. However, at high heat flux densities, \( A_r \) increased along the heater.

Figure 3. Function of maximal amplitude of rivulet deflection on the distance along the heater at different heat fluxes and Re=33; a - \( T_0=23^\circ \text{C} \), b - \( T_0=30^\circ \text{C} \).
Deflection at transitional values of heat flux density, corresponding to the appearance of type A structures and threshold growth of $A_r$, is of particular interest. Figure 4 shows the dependence of the maximal amplitude of rivulet deflection on the distance along the heater for different rivulets at the same values of $Re$, $T_0$, and $q$. As it is seen, at a given value of heat flux density this dependence is different for each rivulet and does not follow any regularities.

**Figure 4.** Dependence of maximal amplitude of rivulet deflection on the distance along the heater for different rivulets $Re=33$, $T_0=23^\circ C$, $q=2.37$ W/cm$^2$.

### 4. Conclusions

For any Reynolds numbers and initial film temperature growth of the maximal amplitude of rivulet, its deflection occurs at heat flux densities, corresponding to the appearance of type A structures. Also, the nature of the dependence of rivulet deflection on the distance along the heater changes.

At that, in the case of transitional values of heat flux density (corresponding to the appearance of type A structures), the dependence of the maximal amplitude of rivulet deflection on the distance changes from rivulet to a rivulet.

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