MICROSCLAE EVAPORATION HEAT TRANSFER

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1. Introduction

In this work, microscale evaporation heat transfer and capillary phenomena for ultra thin liquid film area are presented. The interface shapes of curved liquid film in rectangular minichannel and in vicinity of liquid-vapor-solid contact line are determined by a numerical solution of simplified models as derived from Navier-Stokes equations. The local heat transfer is analyzed in term of conduction through liquid layer. The data of numerical calculation of local heat transfer in rectangular channel and for rivulet evaporation are presented. The experimental techniques are described which were used to measure the local heat transfer coefficients in rectangular minichannel and thermal contact angle for rivulet evaporation. A satisfactory agreement between the theory and experiments is obtained.

Microscale evaporative heat transfer has grown to an important research field in last decade, it can be considered as important area of microscale thermophysical sciences. The reasons for this trend are the miniaturization of systems and the recognition that microscale phenomena can be important for the understanding and performance prediction of microscopic and macroscopic devices. Micromechanical and microthermal systems are widely used now in computer technology, biological, medical and process engineering. The evaporative heat transfer often plays an important role in performance of miniaturized systems, such as micro heat exchangers or micro reactors as far as macroscopic devices such as heat pipes, falling film evaporators, boilers etc., which used mini structures on the surface to enhanced heat transfer. At last case the mini structures on heat transfer surface deform liquid interface to produce a very thin liquid layer or contact line and microscale evaporative heat transfer peculiarities becomes important to predict the overall system performance.

There have been many analytical and experimental investigations on microscale evaporation heat transfer as can be found in the text books and review papers [1], [2], [3], [4] and [5]. A microscale modelling of the evaporating extended meniscus focused on the role of the intermolecular forces on the phase change processes in thin liquid films and experimental study of thickness profiles of the evaporating meniscus has been developed in [5], [6], [7], [8], [9] and [10]. In the modelling, the wall temperature, the conductive resistance of the liquid film, the surface tension, the disjoining pressure, and the interfacial heat resistance are taken into account to describe the interface shape of the evaporating meniscus and defined the apparent contact angle. Using similar approach in [10], [11] was shown that the apparent contact angle is determined mostly by the capillary number based on the liquid surface tension, liquid viscosity, and the velocity scale set by the evaporation kinetics, so that the molecular forces have a minor effect on the apparent contact angle by evaporation. The study of microscale heat transfer and dynamic of evaporating thin films spreading on solid surfaces was done at [12], [13]. The effect of the local surface curvature and the disjoining pressure on the evaporation rate had been taken into account. In [14] the formation of a
locally thinned liquid film near the corners of a vertical open channel has been demonstrated experimentally. They also solved numerically the governing equations for the thickness of the liquid film to predict a locally thin film produced by the capillary action in the trough. The distribution of liquid film around perimeter of vertical rectangular minichannel has been studied in [15]. The non-uniform nature of the local heat transfer around the perimeter has been discussed. It was shown also that dry spots are characteristic of liquid evaporation in non-circular channel for small liquid flow rate. The dry spots formation supplied by contact line on heat transfer surface were observed in [16] just before boiling crises in narrow annular channels.

In the reviewed paper, it was shown that microscale transport phenomena at liquid-vapor interface can be stronger influenced by external and internal forces, such as capillary forces, intermolecular forces, or by temperature and concentration gradients. These phenomena are still not fully understood and are the subject of future study. The objective of this work is to study theoretically and experimentally the interface shape pattern and heat transfer characteristic of curved evaporating liquid film. We will discuss non-uniform nature of the evaporating heat transfer around the perimeter of minichannel, theory of fluid flow and evaporation heat transfer in a small rectangular channel, experiments on evaporating flow of refrigerant R21 in a small rectangular channel, peculiarities of evaporation heat transfer for liquid rivulet spreading and the nature of microscale heat transfer augmentation.

2. Mathematical Modeling of the Interface Shape for Gravity Induced Film Flow in Rectangular Minichannel

2.1. MODEL DEVELOPMENT

When a liquid flows down in a vertical rectangular channel under the action of gravity the flow characterizes by the formation of two zones: thin film flow along the sides of the channel and meniscus flow of a constant curvature in the corners of the channel [15], see Figure 1. Direct numerical flow modeling based on CFD codes cannot be applied for this case. The reason is the existing of the area where film thickness trends to zero in the solution. To avoid this singularity the flow model based on distinguishing of two specific areas of flow, which are the corner flow and film flow, was proposed in [15]. At corner flow, the interface has constant in cross section and variable along channel length the radius of curvature. At film area, the interface has variable along transversal direction the radius of curvature. The solutions for these areas are matched to each other near the channel corner to produce the total solution. For this case the flow problem has a small parameter which is $\varepsilon = \delta_0/a \ll 1$ ($\delta_0$ is initial liquid layer thickness and $a$ is half width of the channel wall).

To modeling the film flow, let us introduce the Cartesian coordinates shown in Figure 1 as follows: x-axis along the liquid flow direction, y-axis crosswise on the channel's surface and z-axis.

![Figure 1. Coordinate system and scheme of the liquid flow.](image-url)