Experimental and numerical investigation of evaporative heat transfer in the vicinity of the 3-phase contact line

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Abstract:
An experimental study has been performed with a single liquid-vapor meniscus formed in a vertical channel of 600 µm width between two flat parallel plates. A 10 µm thick stainless steel heating foil forms a part of one of the flat plates. HFE7100 was used as test fluid. Liquid is sucked into the gap between the plates due to capillary forces and evaporates inside the gap under steady state conditions. The high evaporation rates in the vicinity of the 3-phase contact line lead to high temperature gradients along the heating foil. The two-dimensional micro-scale temperature field at the back side of the heating foil is observed with an infrared camera. On the basis of these temperature measurements a local temperature drop at the micro region is defined as the difference between the maximum wall temperature underneath the wetted portion of the foil and the minimal wall temperature in the vicinity of the contact line area. The distribution of the local wall heat flux is calculated from the measured wall temperature field using an energy balance for each pixel element. A numerical model of heat transfer in the vicinity of evaporating contact line has been developed. This model takes into account the heat conduction in the heating foil and in the liquid, the heat generation in the foil due to the Joule effect and the local evaporation phenomena in the micro region. A modular modelling strategy has been applied, where the solution of the energy equation on a macroscopic scale is combined with a solution of the set of highly nonlinear ordinary differential equations describing the phenomena in the micro region. The results of the numerical modeling are in agreement with the experimental observations. The measured and computed temperature drop in the micro region increases linearly with the input heat flux.

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1. Introduction
Boiling and evaporation are very efficient mechanisms of heat transfer. They are used in numerous energy conversion and heat exchanger systems as well as for cooling of high-energy-density electronic components. The evaporative heat transfer performance strongly depends on the local heat

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electronic components. The evaporative heat transfer performance strongly depends on the local heat and mass transfer in the vicinity of a 3-phase contact line, where the liquid-vapor interface approaches the wall [1][2]. Due to very low thermal resistance of an ultrathin film in this tiny region (often referred to as micro region) the local heat fluxes and evaporation rates are extremely high [2]. These high evaporation rates lead to appearance of a considerable temperature drop at the micro region. In spite of the small size of the micro region (usually of the order of $1 \mu\mathrm{m}$) the transport processes in this region significantly contribute to the macro scale heat and mass transfer. The heat flow in the vicinity of the 3-phase contact line is governed by the transverse flow of liquid into the region of intensive evaporation, by the high gradients of the capillary pressure, by the intermolecular forces, and by the molecular-kinetic resistance to evaporation.

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IEEE Keywords
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thin films, capillarity, evaporation, flow visualisation, heat conduction, heat transfer, liquid films, microchannel flow, multiphase flow, nonlinear differential equations, numerical analysis, stainless steel

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size 10 mum, evaporative heat transfer, three-phase contact line, liquid-vapor meniscus, vertical channel, flat parallel plates, stainless steel, heating foil, HFE7100, test fluid, capillary forces, evaporation, two-dimensional microscale temperature field, infrared camera, foil temperature, minimal wall temperature, wall heat flux, energy balance, pixel element, numerical model, heat generation, Joule effect, modular modelling strategy, energy equation, nonlinear ordinary differential equations, numerical modeling, heat conduction, size 600 mum

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