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Boiling Heat Transfer Enhancement on Micro- and Nanoscales

Yuriy Kuzma-Kichta and Alexander Lavrikov

ABSTRACT

Microchannel heat exchangers for future electronics, air conditioning systems and heat pipes must provide an extremely high heat flux. Conventional heat transfer enhancement methods may not be applicable due to the small size of these heat exchangers. The present investigation is directed to solve problems of an effective cooling at high heat flux in microchannels and CHF increasing with help of an artificial nanorelief of the surface. The relief is formed by alumina nanoparticles which are deposited on the heating surface of the channel.

INTRODUCTION

Many methods of heat transfer enhancement under boiling are well-known nowadays. Heat transfer surface modification methods are probably the most effective of them. In [1] it was shown that porous coating of the surface increases CHF and heat transfer coefficients both for nucleate, transition and film boiling . There are no difficulties to form this relief inside or outside a pipe but it is not so simple to use it in microchannels.

Actually the heat transfer enhancement in a microchannel is not a trivial [2]. Suzuki and others [3] investigated microbubble emission boiling (MEB) in mini- and microchannels as a heat transfer enhancement method. The MEB allows to increase the CHF in subcooled boiling, but occur of the boiling crisis depends on a flow velocity and liquid subcooling.

Moscow Power Engineering Institute, 14 Krasnokazarmennaya Street, Moscow, 111250, Russia

Microchannel surface can be covered with a layer of nanoparticles which deposit from a colloidal solution (also known as nanoliquid or nanofluid). This relief of nanoparticles can increase the CHF and the boiling heat transfer coefficient [4]. At first researchers used nanoliquid as a heat carrier and the relief of nanoparticles was formed all along the experiment.

The present study is aimed at studying of the heat transfer on the surface with artificial relief of alumina (Al_2O_3) nanoparticles.

PROPERTIES OF THE INVESTIGATED RELIEF

These nanoparticles are deposited on the inner surface of the microchannel before the experiment [5]. The thickness of the nanoparticles layer, its properties depend much from the deposition method, initial surface roughness and other factors. The relief of nanoparticles seems to be a perspective heat transfer enhancement method but poor theory is developed nowadays in spite of the fact that many investigations were provided.

As shown in [6-9] the mechanism of CHF increase is connected with a contact angle reduction. Analysis of pool boiling data for different surfaces (with different contact angles) allowed selecting relief of alumina nanoparticles as one of the most effective for the heat transfer enhancement.

The test setup is aimed for investigations of water-based fluids boiling in a single microchannel[7]. The heating surface of the channel (3mm width, 13.7mm length, 0.2mm height) is made of copper. The distribution of temperature in the test section and the heat flux are measured using the IR-camera, it allows to make 30 frames per second IR-recordings. The high-speed video recording is provided to monitor bubble formation and growth.

Calculation of heat flux is provided according to the Fourier law by the measured temperature distribution along the height of the test section. The heat conduction coefficient of the test section is supposed to be known. The heating surface temperature is approximated by values of temperature inside the test section. Thus the accuracy of heat flux and wall temperature depends much on the distance measurement accuracy and temperature measurement accuracy. The relative heat losses are small enough and can be neglected. The absolute error of temperature measurement is 1-3 ^{O}C, the relative error of the heat flux is assumed to be 10-15%.

During the experiment the flow rate is measured by a rotameter and it can be checked using mass-measuring method on a precision laboratory balances.

The Al_2O_3-water nanofluid is applied to obtain the artificial nano-scale relief of the test section. Nanoparticles deposit on the heating surface during boiling of nanofluid before the main experiment and form the artificial relief where the average size of nanoparticles is 50-100 nm. The relief will be discussed below.

Two properties of the nanoparticles layer are very important in its application but poor investigated: its thickness and durability. These two characteristics are interrelated and depend on many factors.

As it was already said before, the nanoparticles layer on the heating surface is obtained during boiling of nanoliquid. The layer thickness can be measured from SEM pictures of the heating surface (Figure 1). This coating thickness varies from 1 to 10 micrometers. In some parts of the surface one can see bald spots which look free from nanoparticles, but it is possible to find a very thin layer of nanoparticles in a greater magnification.

Thus we can assume the next way of nanoparticles deposition on the heating surface during boiling of nanoliquid based on deionized water. Nanoparticles aggregate (deposite on the surface) only in a three-phase line which exists on the border of a dry spot under the bubble. According to the theory of microlayer the liquid film exists under the bubble, vapor is above this layer and the heating surface is below.

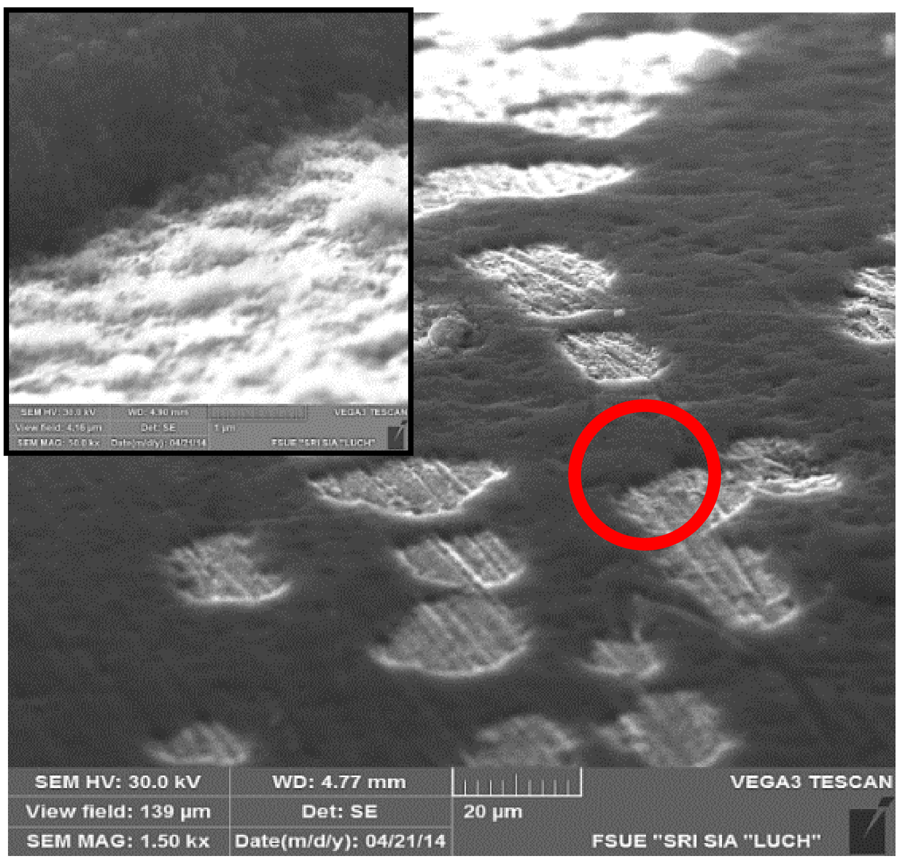
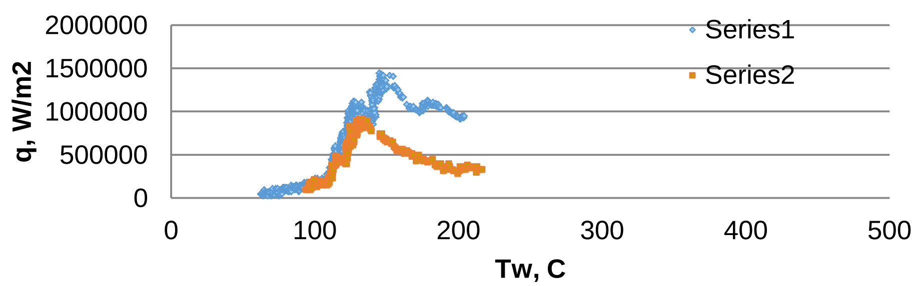


Figure 1. Nikel surface with coating from nanoparticles Al_2O_3.

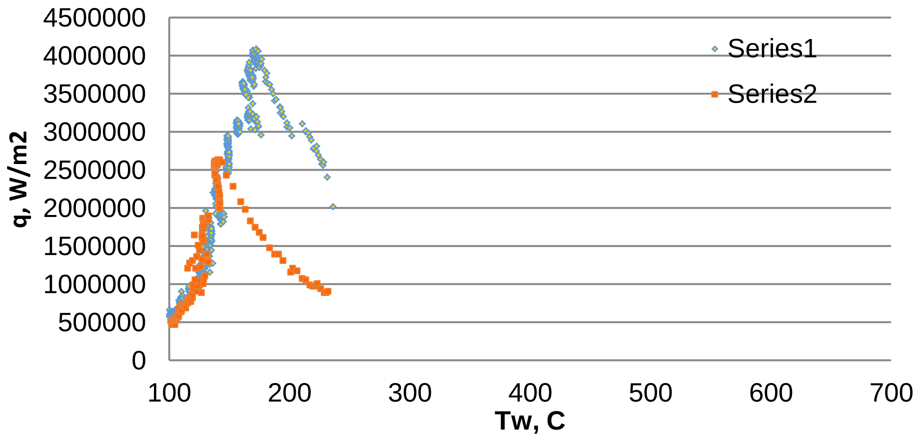
RESEARCHES ON BOILING IN MICROCHANNEL

Researches on boiling in a single microchannel were conducted for different heating surfaces: clean copper and copper with an artificial nano-relief [10-17]. Experiments were provided in quasi-stationary conditions. Quasi-stationary conditions of the experiment allowed to provide measurements in different regimes of boiling: nucleate boiling, transition boiling and even film boiling.

Boiling curves for a clean microchannel and the microchannel with the coating of nanoparticles are shown on Figure 2. The critical heat flux is higher in the channel with nanoparticles rellief. Also the heat transfer coefficient in the transition boiling is higher in the channel with the nanorelief than in a clean channel. The CHF depends much on the contact angle (clear surface θ=81º, nano-relief θ=9º). The heat transfer coefficient in the transition boiling also depends on the contact angle. It can be explained by a better contact of fluid with the heating surface in the case of a small contact angle (better wettability).



a) mass velocity 100 kg/m^{2}s



b) mass velocity 300 kg/m^{2}s

Figure 2. Boiling curves for the microchannel with nanorelief and for a clean channel. Series 1- boiling curve 1(microchannel with nanorelief), Series 2- boiling curve 2 (microchannel with clean surface). Water, Tsub=80K, atmospheric pressure.

CONCLUSIONS

Nanorelief in microchannel can be obtained by nanoparticles deposition from the nanoliquid. This relief changes the contact angle, the CHF and the heat transfer coefficient in transition boiling.

The contact angle decreases on the surface with alumina nanorelief in comparison with the contact angle on a clear surface. The CHF at water boiling is 30% higher on the surface with alumina nanorelief.

The transition boiling heat transfer coefficient is twice higher for the channel with alumina nanorelief than for the channel without coating.

ACKNOWLEDGMENT

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TABLE I. NOMENCLATURE

CHF	Critical heat flux	(W/m^2)	t	Time	(s)
F	Channel cross section	(m^2)	W	Velocity	(m/s)
G	Mass flux	(kg/s)	ΔP	Pressure drop	(Pa)
q	Heat flux	(W/m^2)	ΔT	Temperature difference	(^OC)
T	Temperature	(^OC)	Θ	Contact angle	(deg)
T_w	Wall temperature	(^OC)	ρ	Density	(kg/m^3)
T_{sub}	Subcooling temperature	(^OC)			

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