Research of water boiling in microchannel

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Abstract. Boiling of water was investigated in a flat rectangular microchannel with dimensions 13.5x3x0.2 mm. Boiling curves are constructed by processing thermograms obtained by a thermal imager. Data on heat transfer are compared with known results, and the effect of the output section length has been investigated on the critical heat flux in the microchannel.

1. Introduction
The main advantage of microchannel heat exchangers is the large ratio of heat exchange surface area to the volume of the device. Along with the noted advantage in the microchannel heat exchanger, instabilities may arise, which will lead to a decrease in the critical heat flux. This stimulates the search for a method of intensification of heat transfer in microchannel heat exchangers. For example, one of such methods is the use of nanofluid or coating from nanoparticles [9]-[13]. The hydrodynamics of fluid in microchannels was investigated in [1] - [8].

In [14], water boiling was investigated in a single microchannel with similar geometry. As a result, it was found that with increasing speed, heat transfer improves and the critical heat flux increases.

In [15]-[17], the effect of mass flux on critical heat flux was studied during the flow of subcooled water in a different channel. This study is aimed at expanding the data base on boiling in a microchannel.

2. Experimental setup and procedure
The experimental setup is a circuit, the circulation in which is created by a DLX VFT / MBB pump. The working area is a microchannel with dimensions of 13.5x3x0.2 mm, assembled from two glass plates, and a copper wedge, which serves to supply heat to the microchannel.

Unlike the previous one, this installation uses hard supply lines instead of flexible ones [14]. This improving made it possible to reduce pulsations of operating parameters.

The installation has two tubes for the supply and removal of fluid, two lines - for the pressure selection (Fig. 1)
The height of the channel was provided by a wire with a diameter of 0.2 mm, laid along the interface of microchannel between the heating surface and the glass top plate. The work area was compacted by sealant.

Copper block (thermal wedge) and a thermogram of its surface in one of the experiments showed on Figure 3. Heat transfer in a microchannel was determined by measuring the temperature gradient in a copper block using a thermal imager. Surface of copper block is covered by a layer of TiN particles, that ensures the stability of the emissivity over time (the surface does not oxidize) and in space. Before the experiments, the imager is calibrated (determination of the emissivity of the surface) by measuring the temperature of the copper block with a thermocouple. To calculate the heat flux density, a linear approximation of the temperature distribution in the working section was decided(Figure 4).
Then, in accordance with the law of Fourier:

\[ q = \lambda \cdot K \]  

(1)

where \( \lambda \) is the coefficient of thermal conductivity of the work area (copper), K is the angular coefficient obtained by linear approximation of the temperature distribution in the copper block. The temperature of the microchannel is calculated by extrapolating the temperature in the copper block.

The greatest errors in the measurement of heat flux and wall temperature at boiling are caused by the inaccuracy of the correlation of the measured temperature in the copper block to the coordinates.
The average image scale was 0.15–0.17 mm / pixel, which made it possible to obtain a higher accuracy of measuring temperature and coordinates than using a 200 μm thermocouple.

With an increase in the heat flux in the working area, the measurement error decreases: for example, \( q = 0.5 \text{ MW/m}^2 \) \( \delta q = 50\% \), and at \( q = 4\text{ MW/m}^2 \) \( \delta q = 13\%-17\% \). The error in determining the temperature of the microchannel was taken to be \( \Delta T = 6 \text{ C} \).

3. Results
Figure 5 shows the obtained data and the boiling curves of various authors. As the speed increases, heat transfer increases.

Curves 1 and 3 were obtained by Shustov M.V [14]. Boiling curves 2 and 4 were obtained at present study.

![Boiling curves according to known data and obtained in this study.](image1)

Fig. 5. Boiling curves according to known data and obtained in this study. 1- [14], Shustov M.V., \( w = 0.1 \text{ m/s} \), channel 13.7x3x0.2 mm, \( \Delta T_{\text{sub}} = 80 \text{ C} \); 2- This study, \( w = 0.28 \text{ m/s} \), \( \Delta T_{\text{sub}} = 80 \text{ C} \); 3- [14], Shustov M.V., \( w = 0.3 \text{ m/s} \), \( \Delta T_{\text{sub}} = 80 \text{ C} \); channel 13.7x3x0.2 4- This study, \( w = 0.29 \text{ m/s} \), \( \Delta T_{\text{sub}} = 82 \text{ C} \).

Thanks to the improvement of the installation, thermal stresses are reduced due to the temperature difference between the coolant, the inlet and the outlet to the microchannel. In this paper boiling curves were obtained in a microchannel with smaller deviations (Figure 6), as the flow and pressure fluctuations were decreased.

![Boiling curves of water in a microchannel obtained in [14] (1) and this study (2).](image2)

Fig. 6. Boiling curves of water in a microchannel obtained in [14] (1) and this study (2). TL - Leidenfrost temperature. \( \Delta T_{\text{sub}}=80 \text{ C} \), \( w = 0.1 \text{ m/s} \).
Figure 7 shows the microchannel boiling curves for various mass flux.

![Figure 7. Water boiling curves in a microchannel: 1 - 0.62 m/s, 2 - 0.5 m/s, 3 - 0.15 m/s. ΔТsub = 77 С.](image)

In this paper was obtained, that heat transfer and critical heat flux are increased, when mass speed increases. For investigated conditions, Leidenfrost Temperature was calculated by formula [16]. As seen on Fig.7, data on heat transfer were obtained in the range of temperature and pressures covering the nuclear, transitional and film boiling regimes.

During the experiments, it was observed that the length of the output tube affects the critical heat flux in the microchannel. This was explained by the increase in hydraulic resistance at the exit of the microchannel. To test this assumption, boiling curves were obtained for three different lengths of the output section: 4, 14, 24 cm, at a water velocity of 0.3 m / s, subcooling ΔТsub = 77 С (Figure 8). To compare the obtained data with those known on the same graph, the critical heat flux according to Shustov [14] is presented.

![Figure 8. Dependence of the critical heat flux in a microchannel on the length of the output section](image)

1) Shustov’s study (W = 0.3 m / s, ΔTned = 80 С) [14]
2) The present study (W = 0.3 m / s, ΔTned = 77 С)

It was found that with an increase in the length of the output section, the critical heat flux decreases.
4. Conclusions

- To study the heat transfer during boiling of water in a microchannel with dimensions of 13.5x3x0.2 mm, an improved working area was created in which the liquid inlet and outlet are made of a glass tube. Thanks to this, it was possible to achieve more stable boiling regimes in the microchannel.
- The influence of the length of the output section on the critical heat flux was found: with an increase in the length of the output section, the critical thermal flux decreases.
- The obtained data on heat transfer during boiling in a microchannel are consistent with known results.

Aknowlegment

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