Investigation of boiling heat transfer in microchannel of water and isopropanol

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Abstract. Boiling curves of distilled water and isopropanol in 12.5x3x0.2 mm microchannel with rigid inlet and outlet lines are obtained. Critical heat flux is calculated for isopropanol by using the previously obtained correlation for water.

1. Introduction
In [1] the water boiling in a heat exchanger, which consisted of two 16x2x0.36 mm microchannels, was investigated. It is shown that with a mass velocity increase in the range of 100-600 kg/(m²s) the critical heat flux increases.

When calculating the crisis of heat transfer using the formula from [2], which assumes that a heat transfer crisis of the second kind occurs in the microchannel the difference with the experimental data was up to 40%.

In [3] the boiling of isopropanol and FC-72 was investigated in a large volume. The working area is a copper horizontal plate. To predict the critical heat flux it assumes that the formation of dry spots was proposed. The boiling curves were obtained. At a wall superheat ΔT=40K a maximum heat flux of 0.2 MW/m² was achieved.

H. Auracher obtained the boiling curves of FC-72 (p/p_{crit} = 0.071), isopropanol (p/p_{crit} = 0.007) and water (p/p_{crit}=0.0045) in pool boiling in [4]. The working section is a copper horizontal disk with a diameter of 35 mm. The boiling curves cover all modes. The critical heat flux for isopropanol is 3 times less than for water. The distribution of vapor content was measured at various distances from the wall using a micron optical sensor.

In [5], the heat transfer of water and a mixture of isopropanol and water was studied in a heat pipe with a horizontal evaporator with a finned surface. It was shown that the use of a mixture of isopropanol and water (70%) it allows to increase the heat flux, at which uncoated areas occur in the heat pipe evaporator, up to 90 W/cm² at a pressure of 0.2 MPa. As for water, the critical heat flux was 50 W/cm².

In [6], equations for calculating the critical heat flux in rectilinear and swirling flows for the regions of negative and positive vapor quality are obtained. The data arrays cover the ranges of mass velocities from 30 to 33000 kg/m²s, pressures from 0.1 to 20.1 MPa, twisting coefficient from 1 to 34.5, heating section length from 0.007 to 4.87 m, pipe diameters from 1.6 to 20 mm, located both vertically and horizontally, with their homogeneous and inhomogeneous heating. It is shown that the proposed
equations under the conditions considered describe the experimental data of the formed arrays with deviation \( \pm 30\% \).

In [7], experiments on cooling nickel-copper and stainless-steel balls with a diameter of 30 to 45 mm were carried out in a binary mixture of water-isopropanol with different isopropanol concentrations. The critical heat flux did not exceed 100 kW/m\(^2\) for isopropanol and this value was four times less than for water.

The purpose of this paper is to obtain experimental data heat transfer boiling of water and isopropanol in a rectangular microchannel and calculate the critical heat flux under the conditions considered.

### 2. Experimental setup and research methodology

The experimental setup is a closed loop. The circulation is created by a DLX VFT/MBB pump. The working section is a microchannel with dimensions of 12.5x3x0.2 mm. The bottom side of microchannel is heated by the wedge method, the upper side is made of glass. The pressure of liquid was measured on entrance and output of microchannel (Fig 1).

The working fluids are water and isopropanol. The experimental setup scheme and its general appearance are shown in Figure 2.
The setup includes a working section (1); a heating element (copper block) (2), a condenser (3); pressure gauge in tank (4), the pressure in the drain tank (5) and the pressure drop in the working section (13); a DLX VFT/MBB pipe (6); a drain tank (7); a damping tank (8); a tank with an additional volume designed to reduce pulsations from the vacuum pump (9); a vacuum pump (10); a float flow meter (11); a valve for adjusting the flow (12); a high-speed camera for recording video of the experiment (14).

To calculate the heat flux density, a linear approximation of the temperature distribution in the working area was taken. According to Fourier’s law:

\[ q = \lambda \cdot K, \]

\( \lambda \) is the coefficient of thermal conductivity of the working section (copper), \( K \) is the angular coefficient obtained by linear approximation of the temperature distribution in a copper block. The flow rate in the circuit is determined using a float-type flow meter. The calibration results were shown in Figure 3.

![Figure 3](image)

**Figure 3.** Calibration of the float flow meter

It were shown on Figure 4 the obtained boiling curves of water in the microchannel for the mass velocity \( G=100 \text{ kg/m}^2\text{s}, T_{in}=20^\circ\text{C} \); data [8] for a single microchannel 0.36x5x26 mm, \( G=95.6 \text{ kg/m}^2\text{s}, T_{in}=22^\circ\text{C} \); data [9] for a system of trapezoidal microchannels with a base of 210 microns, an angle at the base 54\(^{\circ}\), length of 10 mm, \( G=116 \text{ kg/m}^2\text{s} \).

![Figure 4](image)

**Figure 4.** Water boiling curves in the microchannel:

1 – the data of this paper, single microchannel 12.5x3x0.2 mm, \( G=100 \text{ kg/m}^2\text{s}, T_{in}=20^\circ\text{C} \);
2 – data [8], single microchannel 0.36x5x26 mm, \( G=95.6 \text{ kg/m}^2\text{s}, T_{in}=22^\circ\text{C} \);
3 – data [9], system of trapezoidal microchannels with a base of 210 microns, an angle at the base 54\(^{\circ}\), length of 10 mm, \( G=116 \text{ kg/m}^2\text{s} \).

As the analyses showed, the obtained boiling curves coincide with the data of the [8,9]. The boiling curves of isopropanol in a microchannel for pressures of 80, 60 and 40 kPa were obtained for the first
time (Figure 5). Wall superheat is calculated from the saturation temperature for inlet pressure. The flow rate in the experiments was 0.46 m/s. In each experiment, a heat transfer crisis has been achieved.

Figure 5. Boiling curves of isopropanol in the microchannel at conditions:
velocity 0.46 m/s, pressure: 1 – 80 kPa; 2 – 60 kPa; 3 – 40 kPa; 4 – the same velocity, but after a week, 80 kPa; 5, 6, 7 – calculations of critical heat flux according to the formula (1): \( p = 80 \text{ kPa} \) (5); \( p = 60 \text{ kPa} \) (6); \( p = 40 \text{ kPa} \) (7)

To check the reproducibility of the experimental data, a boiling curve was obtained again a week later at a pressure of 80 kPa. A satisfactory matching of the experimental results was obtained.

The calculation of the critical heat flux in boiling of isopropanol in the microchannel was carried out by the formula (1) from [10].

\[
q_{crit} = 9.1 \cdot 10^{-3} q_0 \cdot \left( \frac{\rho'}{\rho} \right)^{0.25} \cdot Re_s^{0.26}
\]

where \( Re_s = \frac{\rho W_0 D_t}{\mu_s} \); \( W_0 = \frac{\rho W}{\rho_s} \); \( q_0 = r \sqrt{\frac{\sigma \rho''}{D_t}} \)

Figure 6 shows the obtained data on the critical heat flux in boiling of isopropanol and water in the microchannel. The obtained results are compared with the data of the papers [1], [11], [12]. The deviation of the experimental data from the calculated ones does not exceed 30% under the studied conditions.

Figure 6. Dependence of the critical heat flux on the mass velocity
1 – isopropanol, the data of this paper; 2 – water [10]; 3 – water [1]; 4 – water [11]; 5 – water [12]; 6 – calculation according to equation (1), water; 7 – calculation according to equation (1), isopropanol

3. Conclusion
In this paper, the boiling curves of isopropanol were obtained for the first time in a microchannel with a closed circulation loop for pressures 80, 60 and 40 kPa, at a velocity \( W = 0.46 \text{ m/s} \).

Data on the water boiling in a microchannel at a mass velocity \( G = 100 \text{ kg/m}^2\text{s} \) are presented.

The calculation of the critical heat flux for water and isopropanol is carried out according to the previously obtained equation. The deviation of the experimental data from the calculated ones does not exceed 30% under the studied conditions.
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