HEAT TRANSFER CHARACTERISTICS OF HYBRID MICROJET – MICROCHANNEL COOLING MODULE

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AbstractThe paper presents the experimental investigation of heat transfer intensification in a microjet-microchannel cooling module. Applied technology takes benefits from two very attractive heat removal techniques. When jets are impinging on the surface, they have a very high kinetic energy at the stagnation point, also in microchannels boundary layer is very thin allowing to obtain very high heat fluxes.

Main objective of this paper was to experimentally investigate the performance of a microjet-microchannel cooling module. Intense heat transfer in the test section has been examined and described with precise measurements of thermal and flow conditions. Reported tests were conducted under steady state conditions for single phase liquid cooling.

Obtained database of experimental data were compared to standard cooling techniques, and compared with superposed semi-empirical models for minichannels and microjet cooling, Mikielewicz and Muszynski (2009). Gathered data with analytical solutions and numerical computer simulation allows the rational design and calculation of hybrid modules and optimum performance of these modules for various industrial applications.

Keywords:microjets, heat transfer intensification, microchannels

1. Introduction

The paper presents the experimental investigation of heat transfer intensification in a microjet-microchannel cooling module. Applied technology takes benefits from two very attractive heat removal techniques. When jets are impinging on the surface, they have a very high kinetic energy at the stagnation point, also in microchannels boundary layer is very thin allowing to obtain very high heat Accurate control of cooling parameters is required in ever wider range of technical applications. Achieving of high heat fluxes can be obtained by means of numerous technologies. Using liquids such as water, boiling is likely to occur when the surface temperature exceeds the coolant saturation temperature. Boiling is associated with large rates of heat transfer because of the latent heat of evaporation and because of the enhancement of the level of turbulence between the liquid and the solid surface. This enhancement is due to the mixing action associated with the cyclic nucleation, growth, and departure or collapse of vapour bubbles on the surface.

In the case of heat transfer enhancement techniques, such as impinging microjets and microchannels, significant rates of heat transfer can be achieved (Garimella and Rice 1995). In the past years, many reports concerning the heat transfer and pressure drop behavior inside circular and noncircular microchannels have been published for example: Choi et al. (1991), Yu et al. (1995), Adams et al. (1997, 1999), Mala and Li (1999), Celata et al. (2002). But there are only a few papers on the subject undertaken.

It is known that reducing the dimensions of the size of nozzle leads to an increase in the economy of cooling and improves its quality (Mikielewicz and Muszyński 2009). Present study describes results of research related to the design and construction of the hybrid microjet – microchannel , which may be applied as a cooling module in electronics.

2.Experimental setup

Present study shows results of steady state heat transfer experiments, conducted for single phase cooling in order to obtain wall temperature and heat fluxes. Fig. 1 shows the view of the test section diagram with data acquisition apparatus.

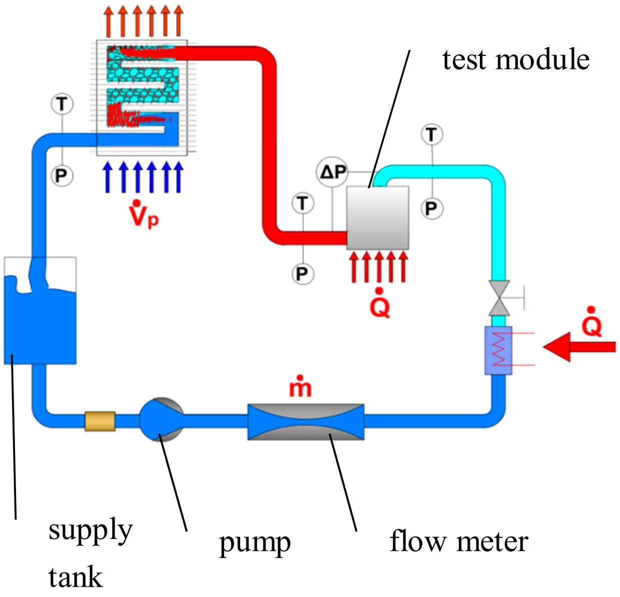

Fig.1 The schematic diagram of test section

It consisted of the probe, fluid supplying system, the measuring devices and DC power supply. Working fluid was fed by a pulsation free gear pump from a supply tank. Desired fluid flow rate was obtained by means of power inverter and flow control valve. In order to reduce pressure drop necessary to create a steady laminar jet, nozzles were created as orifices in a 1mm thick steel plate.Detailed view of test module is presented on fig. 2.

The water jets impinged on the bottom of 2mm high, 2mm wide and 10 mm long microchannels. Every channel was supplied by single water microjet with a hydraulic diameter of 500µm. The cooled surface was made from cast aluminum with 10x10mm bottom surface. Temperature was measured at the bottom surface of hybrid module by single T-type thermocouple. Heat is supplied by a kanthal heater mounted at the bottom of the module. The heater is powered by a DC power supply and the total power input is determined by measuring current intensity and voltage. During tests heater was capable of dissipating up to 240W.The whole set is thermally insulated.The all sensors, such as thermocouple pressure transducers, flowmeter are connected to data acquisitions which is controlled by the National Instruments data acquisition set. The signal from thermocouples was processed with the aid of the LabVIEW application.

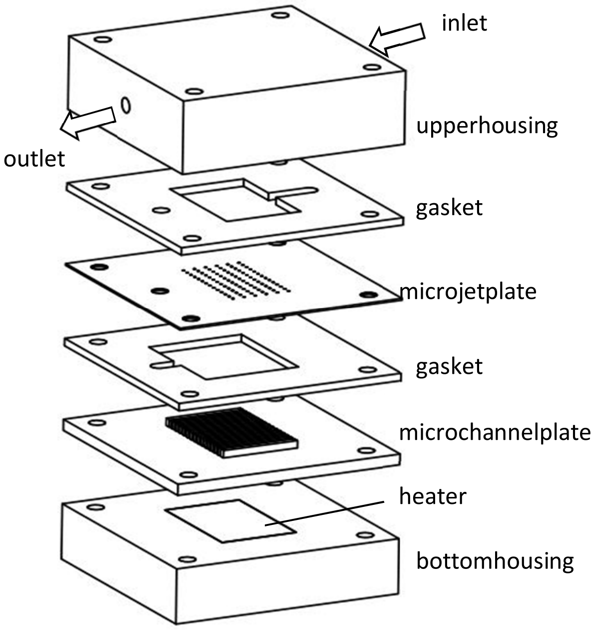

Fig. 1. Hybrid microjet - microchannel module construction

Heater operating power values are precisely controlled and measured. The applied power losses through conduction into the insulation and radiation to the surroundings are accurately calculated according to the following procedure. Air side heat transfer coefficient was determined for case of natural convection,(Incropera DeWitt, 2007).

$$\alpha_{air} = 1{,}18\frac{\lambda_p}{d}\cdot\left(\frac{\frac{1}{T_{av}}\cdot g\cdot d^3}{\nu^2}\left(T_s - T_p\right)Pr\right)^{\frac{1}{8}} \quad (1)$$

The characteristic dimension d was the casing insulation width. The thermodynamic properties of air were determined for average temperature, between casing and ambient:

$$T_{av} = \frac{T_{cas}+T_{air}}{2} \qquad (2)$$

The influences of radiation heat transfer was omitted in calculations. The total thermal resistance was calculatedas:

$$R_c = \frac{1}{\alpha_{air}} + \frac{\delta_i}{\lambda_i} \qquad (3)$$

where the thermal conductivity of insulation is λ_i=0,03 W/m-K.Finally the total loss was calculated as:

$$\dot{Q}_{loss} = \frac{1}{R_c} \cdot A \cdot (T_w - T_o) \qquad (4)$$

In all cases the total heat looses were smaller than 5% of power of heat.

Experimental data points were taken for a steady state in order to exclude heat capacity of the installation. Due to low flow rate of coolant it was measured by means of a Coriolis type – mass flow meter. To allow continuous operation of the cooling system, heat is removed by efficient microchannel heat sink.

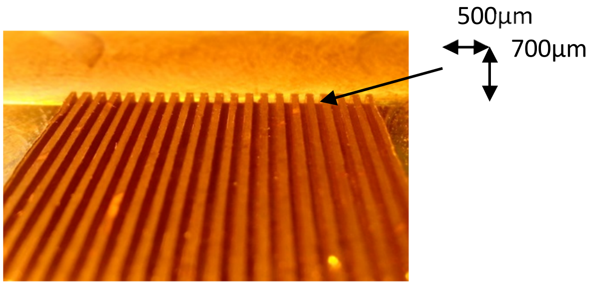

Fig. 2. Microchannelplate view

Test module construction allows to modify both channel and jets dimensions, fig 3. presents one of created microchannel test plates.

3. Correlation of heat transfer data

In the analysis of carried out experiments the simple superpositioning technique is used to correlate single-phase heat transfer data.

The schematic of microjet impingement in a channel is presented in fig. 5. The channel portion on which the microjet heat transfer mechanisms are dominant in can be determined from the energy balance on the element of the cooled channel.

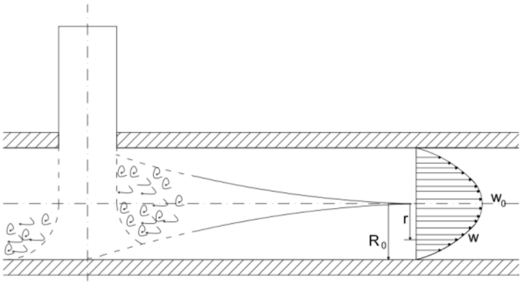

Fig. 4. Fluid flow regimes for a jet impingement in minichannel.

The superimposing technique consists of applying different correlations of general form to the different surface regions. The surface consists of an impingement region and channel flow region.

Assuming surface temperature is uniform along entire microchannel length, overall heat transfer coefficient can be written as:

$$\overline{h_L} L = \overline{h_{jet}} L_{jet} + \overline{h_{mch}} (L - L_{jet}) \qquad (5)$$

Heat transfer in microchannel $\overline{h_{mch}}$ can be found from Dittus-Boelter (1930) correlation:

$$\overline{Nu} = 0.023 \cdot Re^{0.8} \cdot Pr^{0.4} \qquad (6)$$

impingement heat transfer coefficientis taken from authors previous work (Mikielewicz (2009)) :

$$\overline{Nu} = 0.9871 \cdot \mathrm{Re}^{0.8843} \cdot \mathrm{Pr}^{1.776} \cdot \left(\frac{D}{d}\right)^{1.897} \qquad (7)$$

where D[m] is jet orifice diameter and d[m] is surface diameter on which jet impinges.

The Reynolds numbers used to characterize heat transfer are defined as :

$$\mathrm{Re}_{jet} = \frac{G_{jet} D_{jet}}{\mu} \qquad (8)$$

and

$$\mathrm{Re}_{mch} = \frac{G_{jet} D_{mch}}{\mu} \qquad (9)$$

4.Experimental results

In the course of performed experiments data of transferred heat amount along with surface temperatures have been recorded. Data were taken for water as a test fluid.Total heat transfer coefficient recorded during tests is presented on fig.5.

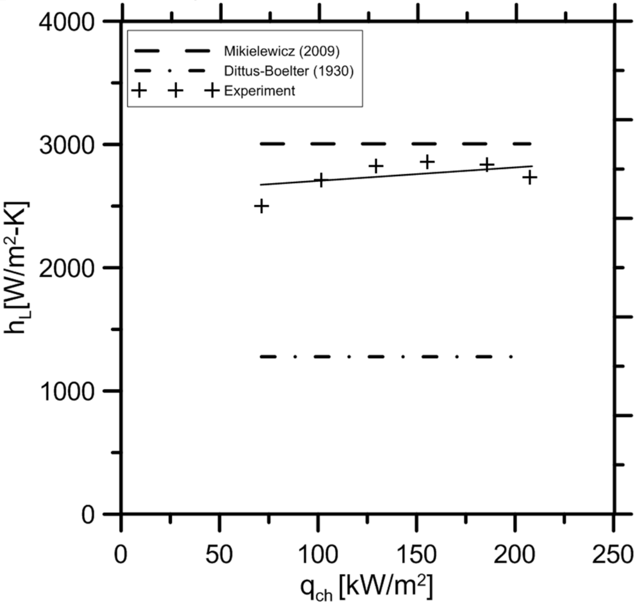

Fig. 5. Total heat transfer coefficient of hybrid microjet - microchannel module

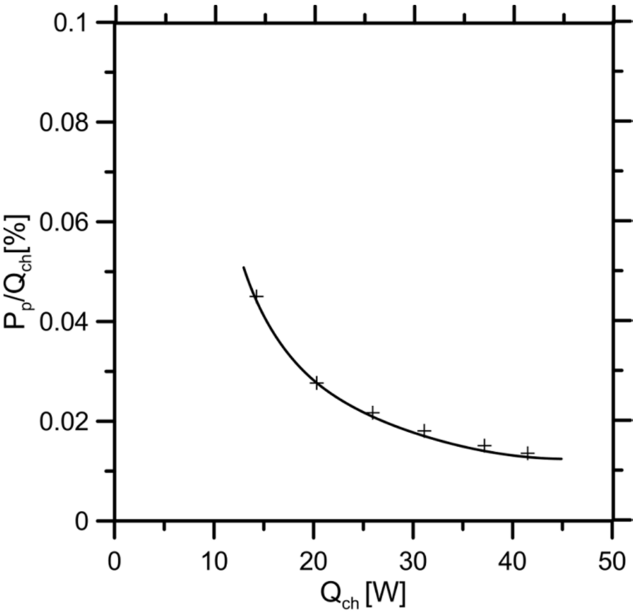

Fig. 6. Effectiveness of heat removal of hybrid microjet - microchannel module

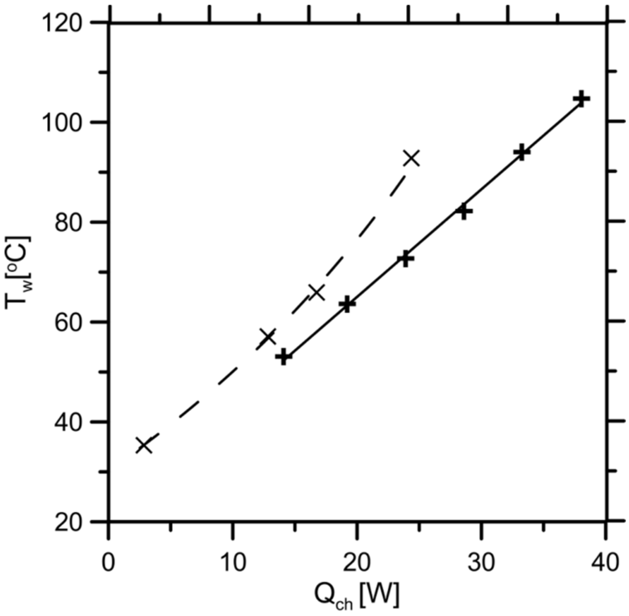

Fig. 7. Comparison of heat removal of hybrid microjet - microchannel module (+) with traditional heat sink (x)

From comparison of experimental results with values of heat transfer predicted by eq. 6 and 7, it is found that according with superposition technique, jet impingement heat transfer is dominant in 90% of total channel length.

Fig.6 shows cooling performance of cooling device. Pumping power was calculated as total pressure drop in cooling module times volumetric flow rate of coolant. Amount of heat removed from the system Q_{ch} was calculated by accounting heat loses to electric power supplied to heater.

Fig.7 presents comparison of the heat removal by hybrid microjet – microchannel module and traditional heat sink. Both were mounted with aid of thermal grease on the contact surface.

Much better performance of the microjet-microchannel module is manifested by lower temperatures of cooled surface. Unfortunately, it appears that the heat fluxes above 40 W/cm^2 for hybrid module approaches the temperature of above 90°C, thus making it impossible to implement in system with such requirements. Ultimately, the system described in the paper is designed to work with fluids such as HFE 7100 and HFE7000 and ethanol in a two-phase flow conditions. Optimal in this respect seems to use HFE 7100 at a normal boiling point of

60^{o}C, which gives hope to obtain the greatest heat flux removal at this temperature.

5. Conclusions

Preliminary experimental data of hybrid microjet - microchannel cooling device were presented. Superimposition technique used in data analysis, showed that jet impingement heat transfer is dominant in 90% of total channel length. This information will be used in future in order to optimize hybrid module geometry, in order to increase its performance.Obtained data are compared to available "on the market" solutions. During measurements a significant difference in the surface temperature was observed for that of proposed cooling device. Unfortunately, it appears that the heat fluxes above 40 W/cm^2 for hybrid module approaches the temperature of above 90°C, thus making it impossible to implement in system with such requirements. Ultimately, the system described in the paper is designed to work with fluids such as HFE 7100 and HFE7000 and ethanol in a two-phase flow conditions. at a normal boiling point of 60 C.

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