Characterization of a Short Microchannel Device for Surface Cooling

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Abstract. The development of microchannel devices is expanded widely due to the demand for small scale electronic devices. In order to increase the capability of the electronic devices, high heat transfer performance with low energy consumption cooler is required. This study is focusing on the characterization of new short microchannel for surface cooling purposes with the channel dimension of 800 µm wide, 200 µm length, 100 µm depth and total area of one cm^2. Deionized water is used as the transport medium. A map of microchannel characteristics is plotted in term of average thermal resistance, pumping power, power supplied and mass flow rate of the fluid. From this mapping, it is shown that the thermal resistance decreased as the pumping power decreased. The results also show that the heat flux has not affected the value of pumping power. The different for each heat flux value is ranged between 3 to 4 %. The mapping presented in this study provides potential characteristics information and conditions to apply this particular microchannel for surface cooling.

Introduction

Characterizations of microchannel for cooling devices are performed by many researchers using variable parameters such as Nusselts number, heat flux value, pressure drop and many more. Among them, the thermal resistance and pumping power is widely used in the industry to characterize the cooling devices. The relationship between thermal resistance and pumping power with other variables such as Reynolds number and channel parameters were presented by many researchers. The effect of Reynolds number is well known, where the increment could reduce the thermal resistance of the device to some asymptote value [1].

In term of relationship between microchannel parameters with thermal resistance, Naphon et. al. [2], investigation on rectangular microchannel using nano-fluid revealed that thermal resistance increases with the increment of microchannel height.While, in other study, Wei et. al. [3] suggested that the use of a short microchannel and the increments of the number of layers within microchannel arrangement could reduce thermal resistance. This is supported by the study done by Kamaruzaman et. al [4] where, they found that short microchannel increase the heat transfer capability compare to long microchannel.

Obtaining higher heat transfer does not always contribute to an optimized microchannel. Hung Yan et. al. [5], in his numerical study for 1 cm^2 rectangular microchannel with heat flux of 100 W/cm^2 that was applied at the bottom of the channel has found that the thermal resistance could be reduced rapidly by increasing the pumping power. This method is not practical especially when associate with regards to energy usage.

A similar result was obtained by Wong et. al [6] which through their study also revealed that the increment of pumping power reduces thermal resistance. Wong et. al. also discovered that the aspect ratio range from 3.7 to 4.1 are the optimum values for microchannels which are defined based on the thermal resistance and pumping power values. However, this result was only limited to microchannel with the length of 10 mm.

From studies described above, it is important to determine the relationship between thermal resistance and pumping power for each microcooling device before applying it to any potential area.

Experimental Setup and Procedure

As shown in Figure 1, a one cm^2 copper device consist of 128 microchannels is used to obtain the characteristic map for thermal resistance and pumping power. The microchannel is 800 µm wide, 200 µm length and 100 µm depth. This device is attached to the experimental rig as shown in Figure 2. Deionized water is pumped from the tank to the device and flow out through the secondary cooling system before circulate back to the tank. The secondary cooling unit consist of a heat exchanger to maintain the temperature of the inlet water at 10 degree Celcius. The device is heated using three electrical cartridges with power supply range of 100 W to 500 W. The flow rate of the deionized water is varied from 20 kg/h to 80 kg/h. Temperature and pressure drop is measured using PT100 temperature sensor and 0-1 bar Kobold absolute pressure sensor. Measurements are taken at the inlet and outlet of the device and at a distance of one mm from the heated surface. The measurement uncertainties are summarized in the Table 1.

Figure 1: Tested microcooler with structured area of one cm^2

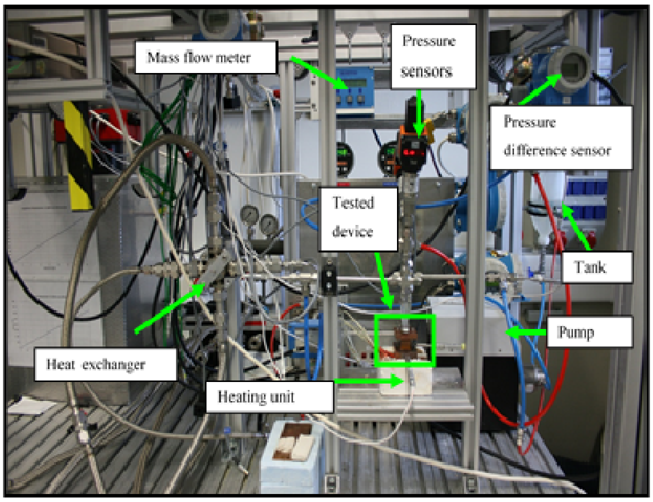

Figure 2: Experimental Setup

Table 1: Measurement uncertainties for the experiment

PT100	T=±(0.3+0.005t) t: measured temperature
Mass flow meter	±0.16 % from measured value
Power supply unit	±0.5% from measured value
Pressure sensor	±0.005 bar
Differential pressure transducer	± 0.075 % from measured value

The experiment data has been analyzed based on the following formulas. Thermal power $\dot{Q}_{therm}$, is calculated as:

$$\dot{Q}_{therm} = \dot{m} c_p (T_{in} - T_{out}) \qquad (1)$$

where $\dot{m}$ is a water mass flow rate, c_p is the specific heat of water and T_{in} and T_{out} are inlet and outlet temperature respectively.Heat flux of the system $\dot{q}$, is calculated as:

$$\dot{q} = \frac{\dot{Q}_{therm}}{A_{hts}} \qquad (2)$$

where A_{hts} is the total area of heat transfer surface.Since the measured surface temperature is taken at 1 mm from the heat transfer surface, the surface temperature is calculated based on the heat conduction formula in Eq. 3.3:

$$T_s = \frac{Q_{therm}}{A_{hts}} \frac{\Delta x}{k} + T_{blockupper} \tag{3}$$

where T_s is the temperature at the heat transfer surface, Δx is the distance (in this experimental study is 1 mm), k is the heat conductivity of the device and $T_{blockuppe}$ is the temperature of block where the temperature sensor is located.

To obtain the relationship between fluid and heating surface, a fluid bulk mean temperature, T_m has been used to represent the temperature of the fluid (Eq. 4).

$$T_m = \frac{(T_{in} + T_{out})}{2} \tag{4}$$

The thermal resistance is calculated by:

$$R_t = \frac{T_{\max} - T_{in}}{\dot{q} A_{hts}} \tag{5}$$

where $T_{\max}$ is the maximum temperature at the heat transfer surface. The pumping power of the device is calculated from the following equation 6.

$$\Omega = \Delta P \dot{V} \tag{6}$$

Where ΔP is the pressure drop and $\dot{V}$ is the volume flow rate.

Results and Discussion

The heat transfer performance of current microchannel device at mass flow rate of 80 kg/h and varied power supplied is presented in Figure 3. In this figure, heat flux is plotted against the temperature difference between heat transfer surface and average temperature of fluid inlet and outlet. The plot shows a proportional relationship between these two parameters. A difference temperature of 18 degree Celsius is calculated for the maximum tested heat flux of 4500 kW/m^2.

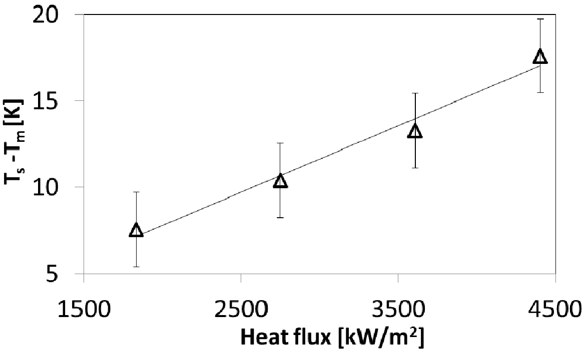

Figure 3: Heat transfer performance for a current short microchannel device at rate of 80 kg/h.

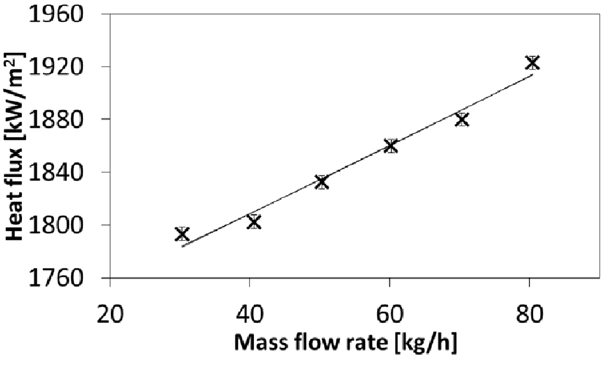

Figure 4: Variation of the heat flux with. increment of mass flow rate at 200 W mass flow supplied power.

Figure 4 presented the relationship between heat flux calculated from the thermal power and mass flow rate of the deionized water. The data is taken at electrical power supplied of 200 W. The result shows that the heat flux of the device increase with the increment of mass flow rate. At 80 kg/h, a maximum of 1920 kW/m^2 heat is removed from one meter squared surface. This results proved that the fluid flow rate or could be said the velocity of the transport medium could enhance the heat transfer process. However, the advantage of higher mass flow rate caused other disadvantage which is pressure drop. Figure 5 shows that the pressure drop also increase with the increment of mass flow rate. This increment is mainly due to the increment of fluid velocity as described in the theory presented by Blasius [7].

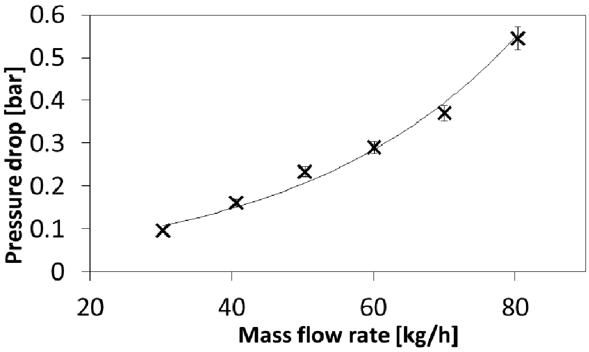

Figure 5: Variation of pressure drop with the increment of mass flow rate at 200 W supplied power.

Therefore, to characterize the current device, a map should be plotted to relate the heat transfer performance and pressure drop of the device simultaneously. Figure 6 presenting the relationship among four different parameters, which are pumping power, total thermal resistance, mass flow rate and thermal power for current device. Each plotted lines represent the different value of thermal power. The result in Fig. 5 shows that total thermal resistance for current device is reversely proportional to the pumping power of the fluid for each thermal power values. The following Eq. 7 relates the thermal resistance to the pumping power:

$$R_t = a\Omega^{-b} \qquad (7)$$

where R_t is a thermal resistance, Ω is the pumping power, a and b are the constant that depending on the how much thermal power is transferred. It is interesting to find out that the thermal resistance of current device shows a unique trend depending on the electrical power supplied.

The thermal resistance is reduced by the increment of power supplied from 200 W to 400 W but started to increased when the power supply increased to 500 W. The increment of thermal resistance is due to conjugate heating. Since the material used is conductive, the heat is transferred to the fluid starting from the distribution channel. When the thermal power is increasing, the heat transferred will decrease due to a lower temperature difference between the heating surface and the fluid flow inside the microchannel.

It is also shown that within the same mass flow rate, pumping power for each thermal power value is only different by 3-4%. This similarity proved that the pumping power is not influenced by the heat transfer value or it could be said that the effect of heating could be ignored when determining the pumping power. Figure 6 also shows that the pumping power increase with the increment of mass flow rate. As the mass flow rate increase, the total pressure drop of the device will increase due to the shear stress between water and wall. The increment of total pressure drop has led to the increment of pumping power. However, a reverse phenomenon is found for thermal resistance. Thermal resistance is decreasing with the increment of pumping power. This result agreed well with study done by Wong et. al[6] . The different is that current study using a short microchannel, which is 0.2 mm, while Wong et. al. using 50 times longer microchannel. The increment of pumping power has contributed to the increment of fluid velocity inside the microchannel. The theory given by Blasius [7] supported this finding. In his theory, the Reynolds number (hence velocity) is reverse proportional to the thermal boundary layer thickness. When the velocity increase the boundary layer thickness will decrease. This means that the heat transfer rate is increasing.

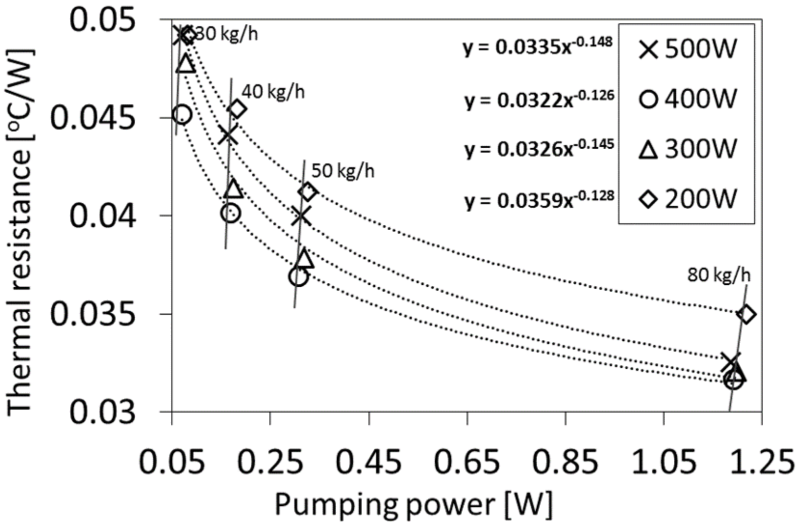

Figure 6: Thermal resistance of a copper device based on different pumping power.

Conclusion

A characteristic map has been drawn for a surface cooler device consist of 128 short microchannel with dimension of 800 µm, 100 µm and 200 µm. Heat supplied to the system and mass flow rate of the coolant fluid is varied and the relationship between thermal resistance and pressure drop is correlated. Lower thermal resistance could be achieved with higher pumping power and vice versa. The results also shows that the total heat dissipated should not exceed 450 W in order to obtain the optimal value for thermal resistance and pumping power for current device.

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