Characterization of a Short Microchannel Device for Surface Cooling

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Graphical abstract

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 cm2. 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.

Keywords: Short microchannel, characteristic map, thermal resistance, pumping power

Abstrak

Pembangunan peranti bersaliran mikro dikembangkan secara meluas disbebabkan permintaan untuk peranti elektronik berskala kecil. Dalam usaha untuk meningkatkan keupayaan peranti elektronik, penyejuk yang mempunyai prestasi pemindahan haba yang tinggi dengan penggunaan tenaga yang rendah amat diperlukan. Kajian ini memberi tumpuan kepada pencirian untuk saluran mikro pendek yang baru bagi tujuan penyejukan permukaan dengan saluran berdimensi 800 mikron lebar, 200 mikron panjang, 100 mikron dalam dan keluasan satu sentimeter persegi. Air ternyahion digunakan sebagai medium pengangkutan. Sebuah peta yang menunjukkan sifat atau ciri-ciri saluran mikro seperti purata rintangan haba, kuasa pam, kuasa yang dibekalkan dan kadar aliran jisim bendalir telah diplotkan. Dari pemetaan ini, ia menunjukkan bahawa penurunan kadar rintangan haba menyebabkan kuasa pengepaman berkurang. Keputusan kajian ini juga menunjukkan bahawa fluks haba tidak mempengaruhi nilai kuasa pam. Perbezaan kuasa pam bagi setiap nilai fluks haba adalah antara 3 hingga 4%. Pemetaan yang dipersembahkan dalam kajian ini menunjukkan maklumat mengenai ciri ciri potensi dan keadaan dimana saluran mikro ini dapat diaplikasikan bagi tujuan penyejukan permukaan.

Kata kunci: Saluran miro pendek, peta sifat, rintangan haba, kuasa pam

1.0 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 the relationship between microchannel parameters with thermal resistance, Naphorn *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.* [6] 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. Therefore, this study aims to provide a characteristic map that relates the relationship between average thermal resistances, pumping power, power supplied and mass flow rate of the fluid. This characteristic map provides potential characteristics information and conditions to apply this particular microchannel for surface cooling.

characteristic map for thermal resistance and pumping power. The microchannel is 800 μm wide, 200 μm length and 100 μm depth. The detail diagram of microchannel is shown in Figure 2. The following Table 1 show the thermal properties for the copper.
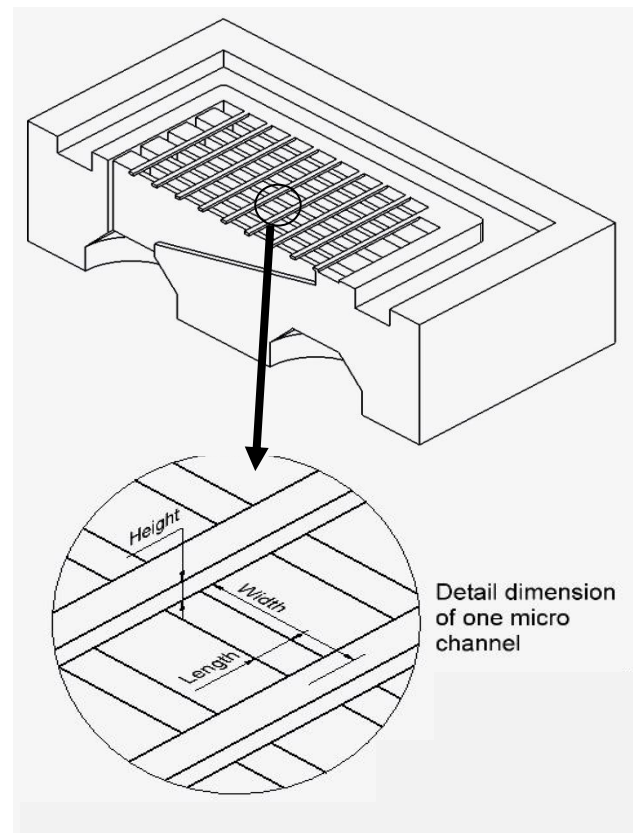

Figure 1 Tested microcooler with structured area

Figure 2 The detail design of microchannel dimensions

2.0 EXPERIMENTAL SETUP

As shown in Figure 1, a one cm^2 copper device consist of 128 microchannels is used to obtain the

Table 1 Thermal properties for copper device

| Density	8940 kg/m³
Thermal conductivity	401 W/m.K (at 300K)
Specific heat	385 J/kg.K (at 298 K)

This device is attached to the experimental rig as shown in Figure 3. 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 °C. 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 2.

Table 2 Measurement uncertainties of 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
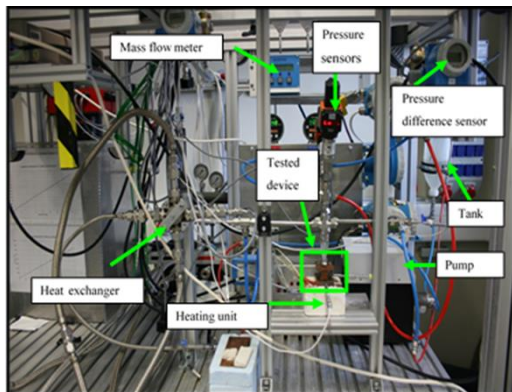
Figure 3 Experimental setup

The experiment data has been analysed based on the following convection heat transfer formulas by assuming that thermal properties of the flow is constant due to the small difference in temperature . Thermal power 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 Equation (3),

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

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 thermal conductivity of the device and $T_{blockupper}$ 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 (Equation (4)).

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

The thermal resistance is calculated by:

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

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).

$$\Omega = \Delta P \dot{V} \qquad (6)$$

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

3.0 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 4. 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 temperature difference of 18 °C is calculated for the maximum tested heat flux of 4500 kW/m^2.
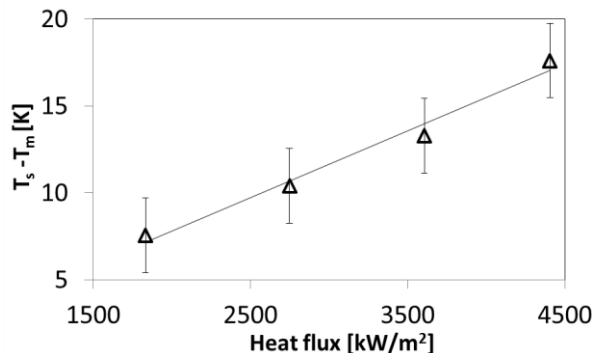

Figure 4 Heat transfer performance for a short microchannel device at rate of 80 kg/h

Figure 5 shows 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 increases 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. The results proved that 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 6 shows that the pressure drop also increase with the increment of mass flow rate. This increment is mainly due to the increment of fluid

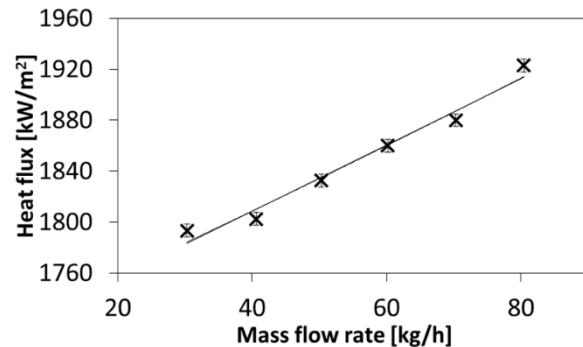velocity as described in the theory presented by Blasius [7].

Figure 5 Variation of heat flux with 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.
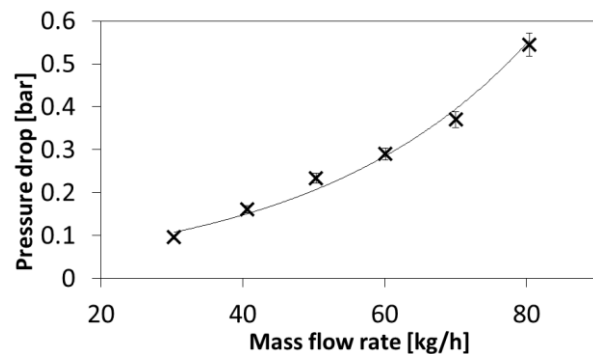

Figure 6 Variation of pressure drop with the increment of mass flow rate at 200 W supplied power

Figure 7 presents the relationship among four different parameters, which are pumping power, total thermal resistance, mass flow rate and thermal power for current device. Each curve represents the different value of thermal power. The result in Figure 7 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 Equation (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 differs only 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 increases 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 agrees well with study done by Wong *et al.* [6]. The difference is that current study using a short microchannel, which is 0.2 mm, while Wong *et al.* [6] was 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.
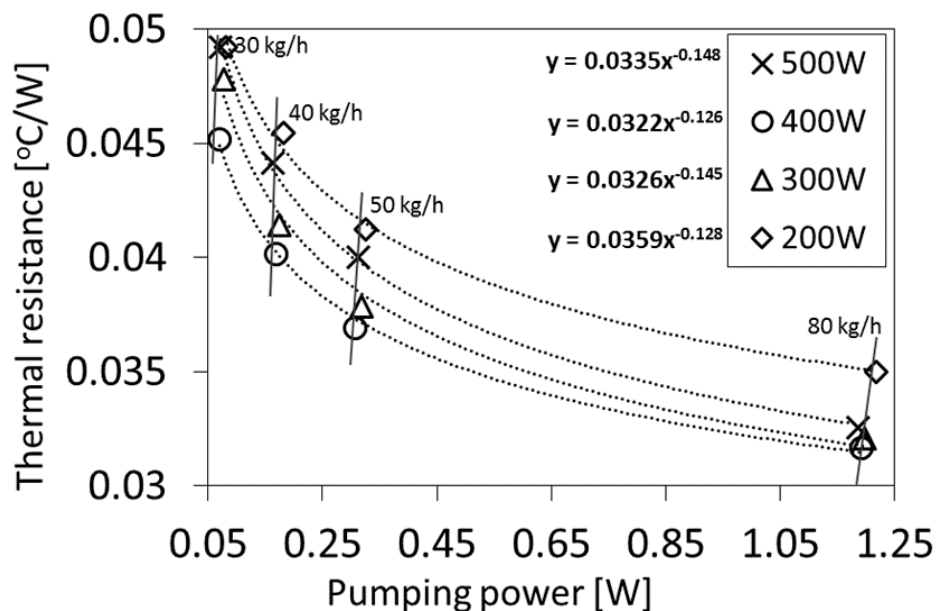

Figure 7 Thermal resistance of a copper device based on different pumping power.

4.0 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 was 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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