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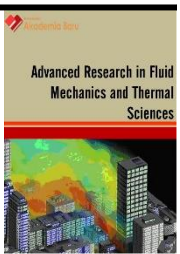

Experimental Study on the Effect of Multilayer Microchannel Arrangement to the Thermal Hydraulic Performance of Microchannel Arrays

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ABSTRACT

Devices such as Insulated Gate Bipolar Transistor (IGBT), supercomputers and microcontroller depend on the heat sink ability of a microchannel. The present study focuses on the experimental study on the effect of multilayer microchannel arrangement to the thermal hydraulic performance of microchannel arrays. The main objective of the study is to design /develop array of micro channel with different layer arrangement and to experimentally investigate the effect of layer arrangement in microchannel arrays performance. A microchannel heat sink with two layers configuration were designed and developed to study the thermal hydraulic performance. The data collected were used to find the heat flux dissipated by the microchannel, the pressure drop of the system, and dimensionless parameter (Nusselt number and Reynolds number). Analysis of experimental results presented the thermal hydraulic performance of short microchannel heat sink and discussed the effect of mass flow rate, heat flux and temperature difference of the flow to the heat transfer performance. The data obtained in this study revealed that 128 short multilayer microchannel structured on area of 1 cm^2 could dissipate a maximum of 260 W/cm^2 heat with maximum substrate temperature to inlet water temperature difference of 5^{o}C. This was achieved by a pressure loss of only 1.71 bar. The comparative study was done for the results obtained for the double layer with the single layer where the heat flux, pressure drop and Nusselt number was compared.

1. Introduction

Microchannel cooling system or better known as microchannel heat sink is a widely used solution to alternative heat transfer devices due to having a desirable higher heat transfer rate but a lower pressure drops simultaneously. These has been the basis to the interest of many researchers who contemplate on the effectiveness of the microchannel heat sink devices in comparison to the other

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heat transfer devices that are being developed. Till date, it has been a challenge to find the best compromise value for the heat transfer rate and the pressure drop [1].

Studies made by some researchers recently shows that the multilayer design for microchannel heat sink shows an increase in efficiency in terms of heat transfer rate and pressure drop although the thermal performance heavily still depends on the geometry (channel depth, width and length), materials and operation conditions such as flow rate) [2, 3]. Ning *et al.,* [4] in their research studied about the heat transfer for comparison of single layer and multilayer microchannel. The study yielded that the multilayer copper heat sinks had smaller average surface temperature than their single-layer counterparts at low heat flux. Shao *et al.,* [5] investigated the effect of long channel multilayer arrangement on the heat transfer. They found that the use of double layer channel could reduce thermal resistance and enhance heat transfer inside the microchannel.

Multilayer with developing flow profile microchannel was developed due to some long microchannels having space constraints and these will be the solution as the smaller size will allow for easier installation and removal, not forgetting that the short microchannel provides a more realistic study when compared from simulation and calculation [6]. Recent studies have been more on the combination of microchannels or to simply sum it up, the multilayer microchannels have been an interest of researchers when the early channel cooling researcher was able to identify that the multilayer microchannel is able to dissipate heat better than a single layer microchannel [2,7-13]. Researches on geometrical shape have also included other shapes such as deep rectangular channels, wavy microchannels, and triangular microchannels [9,14-15]. Optimization studies by the researchers were done to enhance the effect of the multilayer microchannel cooling. The current designs were numerically simulated and were calculated to optimize the desired output [5,8,14, 16,17]. Although the numerical simulations are able to produce such high amount of optimization it usually is not the case when the multilayer microchannel is run experimentally.

The capability of multilayer micro channels should be explored further so that better heat transfer devices could be developed. Studies that are more intensive should be performed on multilayer with developing flow profile microchannels considering that the future of this kind of microchannel seems promising. Therefore, this study focuses on the multilayer short microchannel length that is less than 0.5 mm which were developed and experimentally tested to obtain higher heat transfer rate and lower pressure drop. This kind of multilayer microchannel is practical since it could be scalable and easily fit to any surface area since the multilayers are embedded into the MCHS. Experimental study is performed to obtain the characteristics of multilayer short microchannel arrangement device and to determine its thermal hydraulic performance.

2. Methodology

The experiments on the thermal hydraulic performance of a microchannel array to the effect of multilayer microchannel heat sink device arrangement was conducted on experimental rig that was designed and built after careful study of available literature. The main components of the rig are the heating system, water distribution system, secondary cooling system and the instrumentation system. The rig was developed in such a way that it would mimic an actual electronic device. Figure 1 shows the schematic diagram of experimental setup. The actual experimental setup was presented in Figure 2. The water distribution consists of water tank, pump, water flow meter, cooler, secondary water source and microstructure device. While heating unit consist of a copper block, heating cartridges, and power supply. The measurement devices consist of two absolute pressure transducers, a unit of differential pressure transducer and data acquisition system. The variable parameters are namely mass flow rate, power supply and inlet temperature. Table 1 shows the setup parameter for the experiment. The thermal hydraulic performance is analyzed based on the temperature difference between substrate and flow, and pressure drop of the system. The study is performed under laminar flow condition.

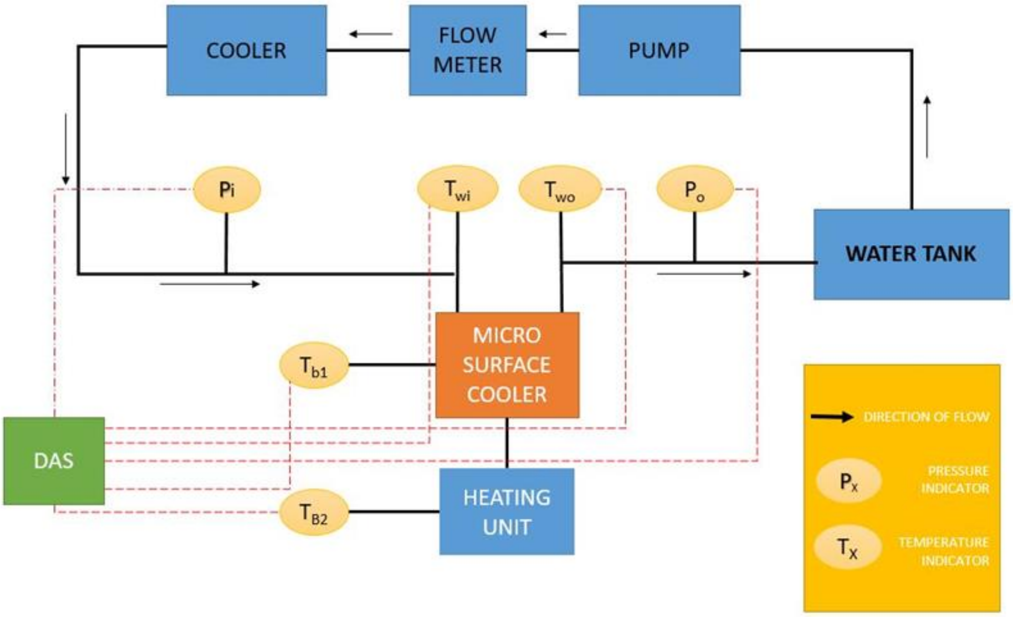

Fig. 1. Schematic diagram of experimental setup

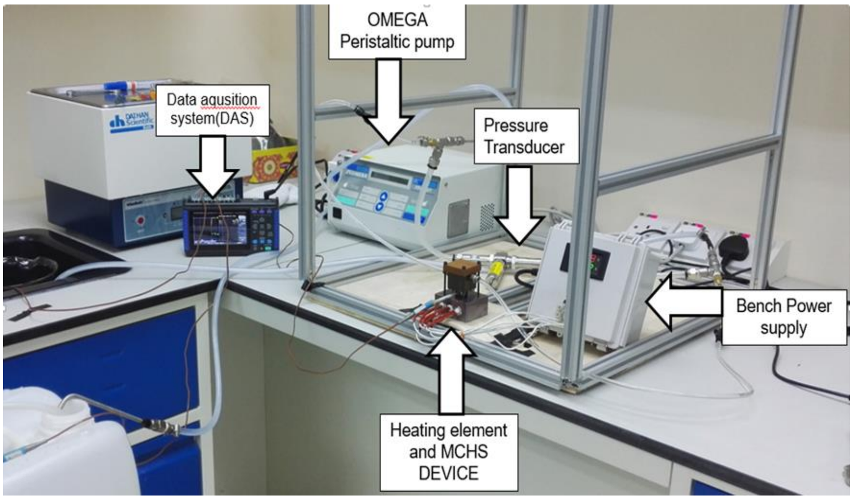

Fig. 2. Experimental rig setup

Table 1
Experimental setup parameter

Water inlet temperature, T_{in} [°C]	27 °C
Water mass flow rate, $\dot{m}$ [kg/h]	27, 40, 54, 67, 81
Heat flux, $\dot{q}$ [kW/m^2]	412, 740, 350

In the flow distribution unit, firstly deionized water is supplied from a tank to the secondary cooling unit using an OMEGA Peristaltic pump. The pump capacity of water delivery is from 20 - 80 kg/h. Then the water is flowed to the test device and back to the tank. The secondary cooling unit has a cooler where the water flows through the cooler to cool down the fluid. The process was conducted to ensure similar inlet temperature for each cycle. Determination of thermal properties of the fluid requires constant inlet temperature. Heat was supplied from a power supply with a maximum heating capacity of 2000 W. The power supply was connected to three high power resistor-heating cartridges inserted into a copper block. Each of the cartridges was able to handle a heating power of up to 200W. The heating block is attached to the test device using screws and a thermal interconnecting material.

3.1 Device Geometry

A device with a total length of 3.0 cm has been designed. The device is fabricated using micromachining technique. The material used is copper with a density of 8940 kg/m^3, thermal conductivity of 401 W/m.K at 300K.

The device consists of eight inlet flow distributors and nine outlet flow distributors. A row of eight microchannels was located between each inlet and outlet distributor. 256 microchannels is present in the microstructure where divided equally in two layers. Each layer consists of total 128 microchannels. The microchannel has a dimension of 800 µm width, 100 µm depths and 200 µm lengths. The design of this microchannels and distribution channel is based on the design by Kamaruzaman *et al.,* [18] The multilayers in the microchannel is illustrated Figure 3(a) shows the details of device including microchannel dimensions and Figure 3(b) shows the fabricated final product.

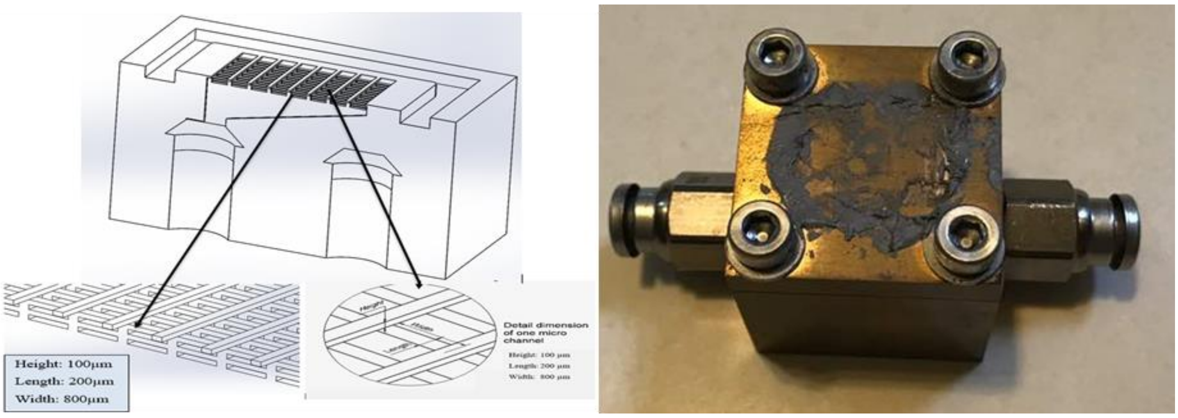

Fig. 3. (a) Schematic of double layer microchannel heat sink device showing the microchannels. (b) Fabricated double layer microchannel heat sink device

3.2 Heat Transfer Analysis

Assuming the flow as steady and neglecting the kinetic and potential energy of the flow, the experiment data was analyzed based on the following formulas. Thermal power is calculated as

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

where $\dot{m}$ is the 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

$$\dot{q} = \frac{\dot{Q}_{therm}}{A_{hts}} \tag{2}$$

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

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

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 $T_{blockupper}$ 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.

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

The average inlet velocity $\vec{u}$ is calculated using

$$\vec{u} = \frac{\dot{m}}{\rho A_{cs}} \tag{5}$$

where ρ is water density and A_{cs} is the cross-sectional area of microchannel heat sink's inlet

4. Results

4.1 Thermal Hydraulic Performance of Double Layer Microchannels

The experimental data of heat flux against mass flow rate for double layer channel is shown in Figure 4 to study the influence of mass flow rate to the heat removed. The heat flux has been calculated in accordance to Eq. (2) and the value shown in the graph was calculated from average heat flux and the device base's area. The heat supplied was 200 W.

From the results, it is clear that increasing the mass flow rate increases the heat removal from the device. An increase in the mass flow rate means that the number of particles also increases at that time and therefore a higher heat removal is achieved.

The next parameter that is crucial in microchannel device is pressure drop. Figure 5 shows a relationship between pressure drop and the device inlet mass flow rate for double layer microchannel device and it clearly shows that the pressure drop increases while mass flow rate increases. The mass flow rate also influences the velocity of the flow and the resistance towards the flow.

The resistance is the contributing factor in the pressure drop although the pressure drop of flow inside a channel is proportional to the fluid viscosity. There is another reason that impacts the viscosity of the fluid which is the microchannel dimension and shape where there maybe variations in the manufacturing of the MCHS device. The flow in microchannel depends highly on the channel geometry and a slight change in dimensions might be responsible for the flow characteristics.

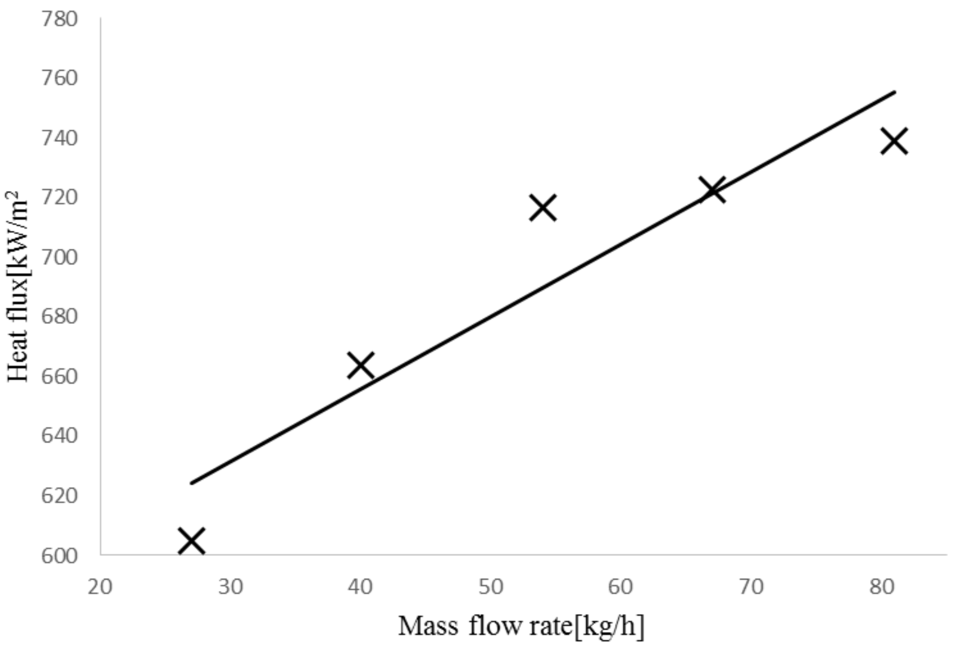

Fig. 4. Variation of heat flux with mass flow rate

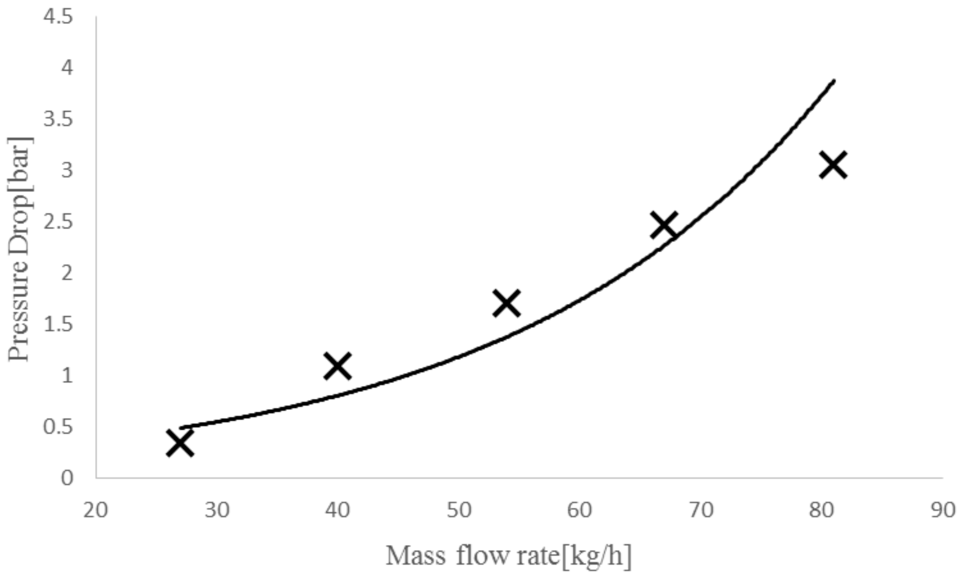

Fig. 5. Pressure drop for double layer device for different mass flow rate

4.2 Comparison for Single Layer and Double Layer Devices

Figure 6 shows the variation of Nusselt number against the Reynolds number for a single layer device (data taken from Kamaruzaman *et al.,* [18]) and double layer device (the experimental results). It is important to mention that both parameters being studied here is dimensionless thus the comparison in between both parameters is not biased. The Reynolds number is the ratio between momentum inertia of fluid flow against the viscosity of fluid and the Nusselt number is the ratio between heat of convection against heat of conduction. From the graph, it could be seen that the single layer has a better Nusselt number against the Reynolds number as it is increasing significantly compared to second layer devices. This result is contradicted with the study presented by some of previous researchers [13,19].

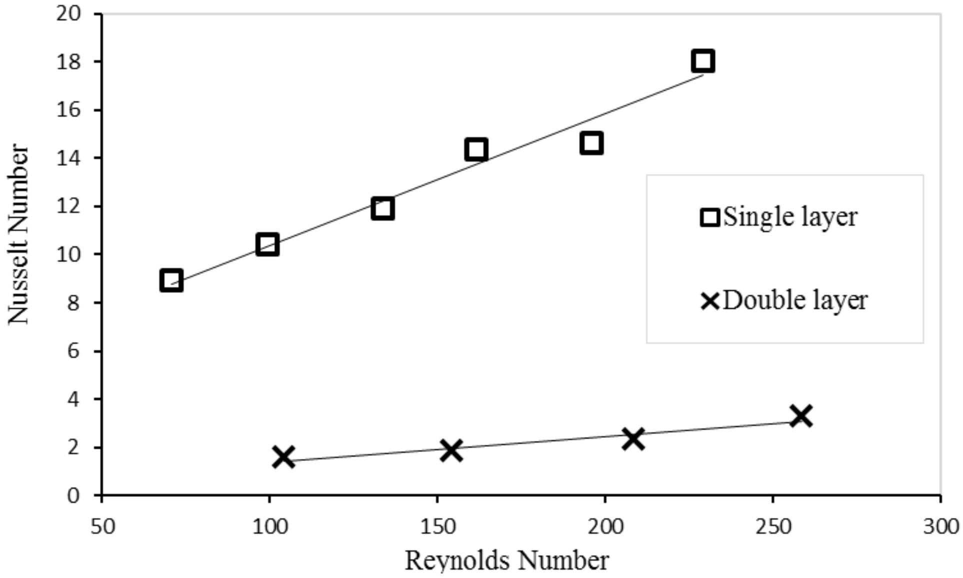

Fig. 6. Nusselt number for different Reynolds number in single layer [18] and double layer channel

The cause for the difference is most likely due to major heat loss during the experiment. Figure 7 shows the difference between thermal power and electrical power supplied. The graph should be a straight linear line starting at the origin. However, the graph deviated from the theory. This proved that most of the power supplied to the device is lost to environment and caused the lower value of Nusselt number in double layer channel. In this experiment, the most heat loss occurred due to device insulation problem. In addition to that, the connection problem between heating unit and the heat sink device might be the cause of air resistance between the surface and resulting lower heat transfer from the heating unit to the heat sink.

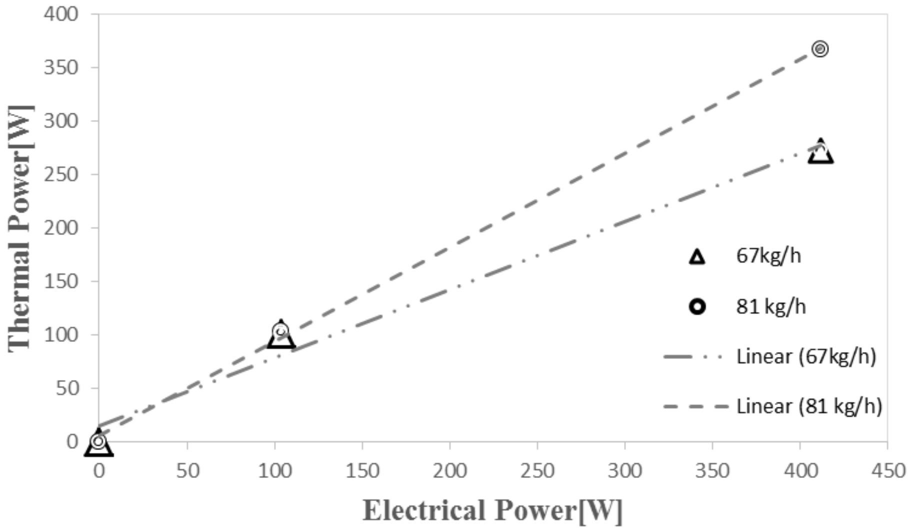

Fig. 7. Comparison between electrical power supplied with calculated thermal power

As to compare the hydraulic performance of the devices, pressure drop between inlet and outlet for both single (data taken from Kamaruzaman *et al.,* [18]) and double layer (the experimental results) is plotted against the mass flow rate. From the results shown in Figure 8, single layer device shows a slight increase in the pressure drop as the flow rate is increased for a constant electrical input, but an exponential increase in the pressure drop occurred for the double layer that does not follow the trend that was speculated earlier. This may be due to the device geometry and the fluid flow pattern. The cause might be due to the manufacturing of the double layer device which has a small radius at each edge of microchannel that could cause a higher resistance. The high resistance could be the major contribution to the increment of pressure drop.

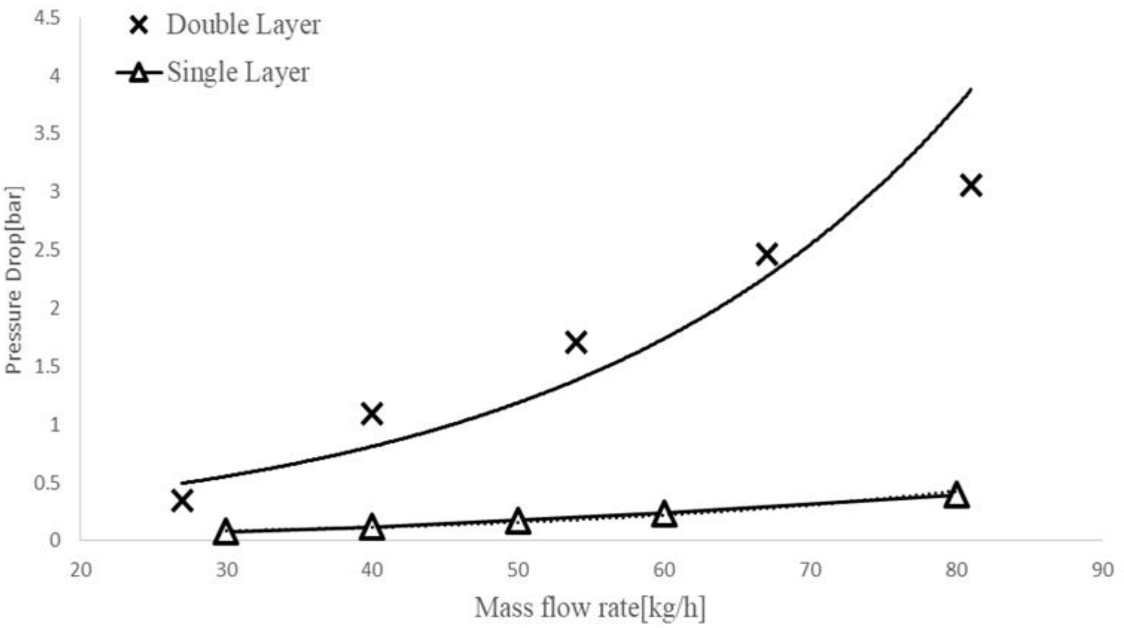

Fig. 8. Comparison of pressure drop between single layer [18] and double layer device

4. Conclusions

An experimental study on the double layer microchannel device with a developing flow profile was performed. The result shows that the thermal hydraulic performance obtained in the double layer channel is lower compared to single layer channel which contradicts with most of the previous research. The deviation could be caused by the manufacturing limitation and due to the major heat loss in double layer device. A further study should be done with consideration to solve the heat loss problem and to increase the manufacturing precision. The study on effect of more layers to the thermal hydraulic performance of the device should be conducted to investigate whether a different result could be obtained.

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