

Effect of Channel Arrangement on the Thermal Hydraulic Performance of Multilayer Microchannel Arrays

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ABSTRACT

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Thermal hydraulic performance of microchannel device is affected mainly by its geometrical parameter. The purpose of this study is to investigate the effect of multilayer microchannel arrangement to the thermal hydraulic performance of microchannel arrays. Numerical analysis was conducted to simulate three different microchannel arrangements by varying mass flow rate and heat flux imposed on the microchannel device. The simulation model is a simplified version which consists of eight microchannels in a single row and contains four layers for model one while model two has an arrangement of eight-seven-eight-seven microchannels in four layers and model three has an arrangement of seven-eight-seven-eight microchannels in four layers. The boundary condition that was set for heat flux ranged between 200 W/cm^2 to 1000 W/cm^2 while mass flow rate that flow into the device was varied between 20 kg/h to 80 kg/h . From the simulation result, it is shown that certain arrangement of microchannel in multilayer channels contribute to the enhancement of heat transfer and at the same time reducing the pressure drop of the system.

Keywords:

Multilayer microchannel; heat transfer; thermal

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1. Introduction

Nowadays microchannel cooling devices have become a cooling solution especially for portable and miniature devices with high heat generation. Till now, the research on microchannel devices are still focusing on heat transfer performance as the main objective but in the same time, pressure drop is another main issue to be solved where both parameters are contradicting to each other [1]. As the heat transfer performance increases, there will be high pressure drop which needs additional pumping system to overcome. Researchers aim to remove the additional pumping system because

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the microchannel cooling devices are getting complex and consume more energy in terms of electricity and space. There are several approaches and modifications towards microchannel cooling devices to attain better outcome for both high heat transfer performance and low pressure drop [2-5].

The modification taken by researchers involves the geometry of the microchannel in terms of dimensions in height, width and length of the channel where these parameters may contribute to the heat transfer performance and pressure drop [6-8]. Researchers also discover some factors that contribute to high heat transfer with a low-pressure drop by varying the design of MCHS such as the length of the channel, type of flow, types of coolant used and the stacking or known as multilayer microchannel [9-12]. The advantages of multilayer microchannel heat sink are better heat transfer performance, small and compact size. However, the efficiency of multilayer microchannel still depends on the geometry (height, length, and width), types of coolant and operating condition such flow rate and inlet temperature [12,13]. Therefore, the objective of this study is to investigate the effect of different multilayer arrangement on the thermal hydraulic performance of microchannel device. This study is specific on short microchannel that is less than 0.5 mm or flow with developing profile. The results of this study might be applied to design a heat sink device that satisfies both heat transfer and pressure drop needs in industry.

2. Methodology

A simulation study has been performed to study the effect of microchannel arrangement on thermal hydraulic performance of multilayer channel.

2.1 Simulation Model

Three different microchannel arrangements are modelled and simulated using commercial CFD software. The total layer selection is selected based on the study done by Kamaruzaman *et al.*, [1]. All models have microchannels with a height of 100 micrometer, length of 200 micrometer and width of 800 micrometer. The model used is simplified model which represent by one single row of microchannel instead of eight rows of microchannel in actual scale device [3].

Figure 1 shows the arrangement configurations for each model. All three models consist of four layers. Model one consists of total 32 microchannels where each layer is comprised of 8 microchannels. While model two consist of 30 microchannels with the configuration of eight-seven-eight-seven microchannels in each layer. As for Model 3, the number of microchannels is similar as model two but the configuration is set as seven-eight-seven-eight microchannels for each layer.

2.2 Boundary Condition and Solver Selection

Water is chosen as the coolant and copper as material of the device. At the inlet, a mass flow boundary condition with inlet temperature of 27°C is set. The mass flow rate applied is ranged between 20kg/h to 80kg/h. At the outlet the boundary condition of pressure outlet is specified. The value is set as atmospheric pressure. Heat flux boundary condition is set at the heating surface with a range between 200 to 1000 W/cm². Other wall is as symmetry based on actual devices. Figure 2 shows the example of boundary condition in Model 1. The other model also applied the same boundary conditions.

A commercial software is used to solve the mass, momentum, and energy equations to determine the velocity and thermal profile for this problem. Based on the assumptions made previously,

pressure-based solver was selected to solve the pressure equation to achieve the constraint of mass conservation in the velocity field. This pressure equation was derived such that the corrected velocity field fulfilled the continuity equation. Further, solving the problem requires adaptation of the segregation solution method under the pressure-based solver. With this method, the governing equations were solved sequentially.

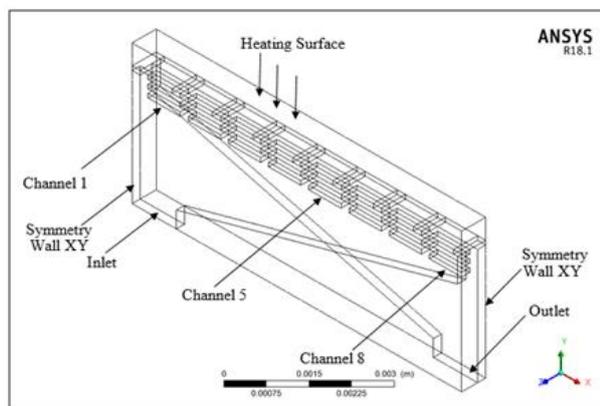
2.3 Mesh Independent Test

Grid independence has been tested on M1 to M3 which varies in term of numbers of nodes. The fine meshing size is selected at microchannel, inlet and outlet of water where this area is the focus to be analyzed. The number of nodes for each model can be refer from the Table 1. M1 to M3 undergo adapted region process to ensure the result obtain is more accurate because adapted region is tuned to make the meshing become finer. The number of nodes increase after the adapted region process undergoes as shown as in table. M3 is consider as grid independence value because the variation with M1 is 1.9% in term of temperature difference and 2.74% in term of pressure drop. The M1 contains half of the number of nodes which contains by M3. Thus, it is assuming that the M3 has achieve grid independence value. The results are shown in Figure 3.

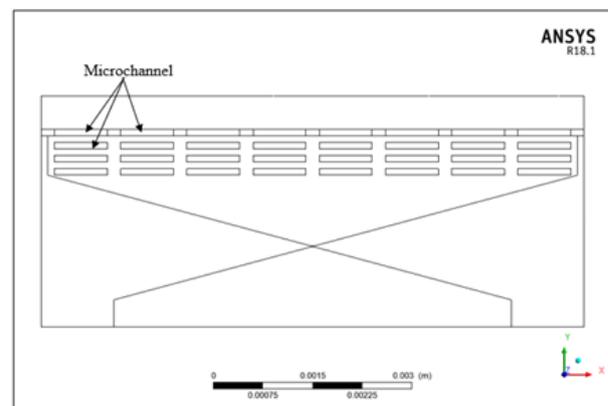
Table 1

The summary of the number of nodes for each model

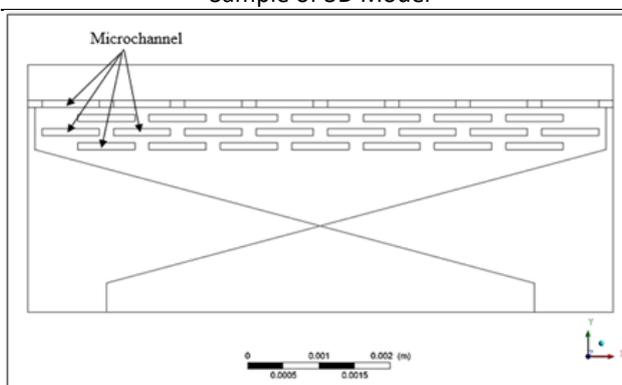
Parameter	M1	M2	M3
Total nodes	99854	141198	220108
Total nodes (after adapt region)	447442	654054	1080308



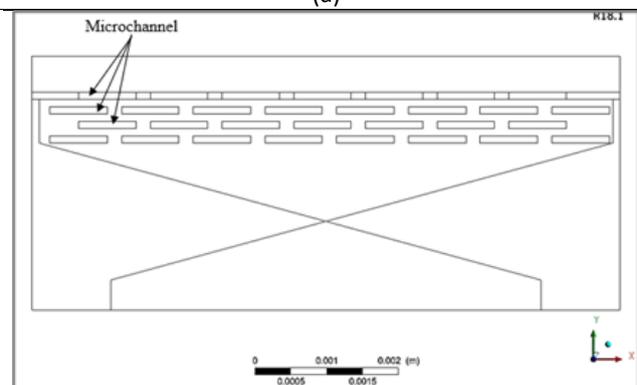
Sample of 3D Model



(a)



(b)



(c)

Fig. 1. Design of different simulation model (a) Model 1, (b) Model 2 and (c) Model 3

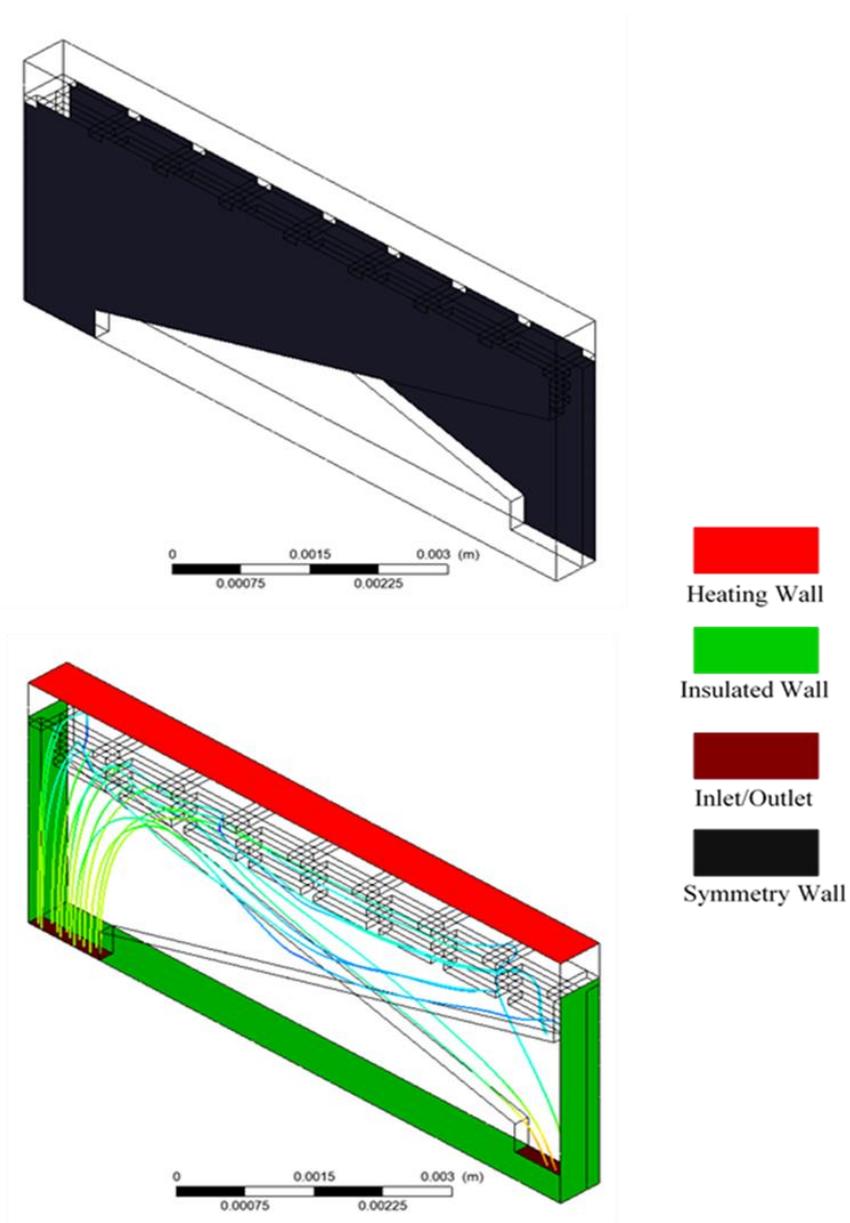


Fig. 2. Example of boundary condition set up

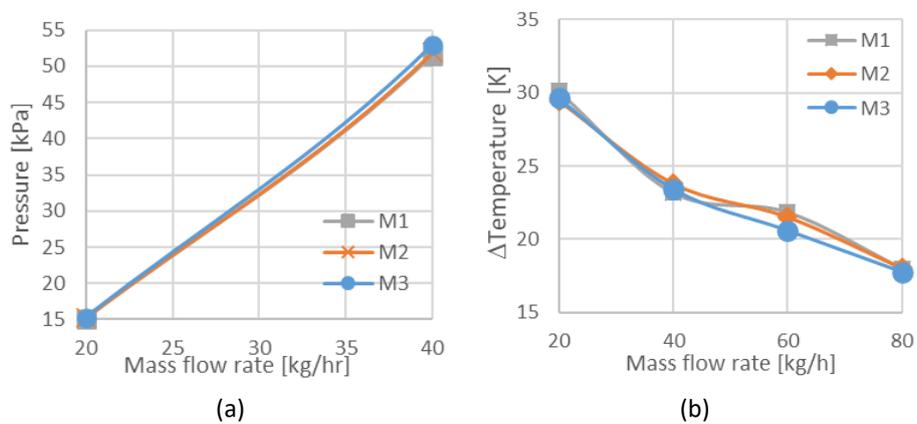


Fig. 3. Grid independent test result for (a) Pressure drop (b) Temperature difference

3. Results

Results for this simulation study is divided into three different sections. The first section is the validation of simulation with previous research. Then, the temperature and flow visualization and the last section is comparison of thermal hydraulic performance.

3.1 Comparison of Friction Factor

The effect of multilayer channel arrangement is compared with single layer results [1,3] and theoretical calculation introduced by previous researchers [14,15]. Figure 4 shows the results of apparent friction factor vs the Reynolds number. The result shows that multilayer channel improves the flow movement and reduced the pressure drop. Therefore, reduced the apparent friction factor of the device. However, the reduction of apparent friction factor is more significant for a lower Reynolds number compared to a higher one.

3.2 Temperature and Flow Visualization

Figure 5 shows the result for temperature distribution along the microchannel with the heat flux of 400 W/cm^2 imposed to the heating block and the water mass flow rate of 40 kg/h . Model 2 recorded better heat transfer performance by creating less heating spot compared to Model 3 and Model 1. Model 1 shows the highest temperature of hot spot compared to the others. The hot spot occurred in this kind of arrangement due to the flow maldistribution through the channels. The affected channels could be seen clearly in Figure 6. The hot spot was formatted as the results of stagnant point at the inlet of the distribution channels as shown in Figure 7. The effect of distribution channel design to the flow uniformity has been discussed by many researchers previously [16-18]. However, by varying the microchannel arrangement, this disadvantage could be minimized.

3.3 Comparison of Thermal Hydraulic Performance

Figure 8 shows the pressure drop and temperature difference between the inlet and heating surface versus the mass flow rate for all three models. From the results, Model 3 has the lowest pressure drop compared to the other design. Even though the total number of microchannels is almost the same for all models, the flow uniformity reduces the pressure drop significantly. Comparing the heat transfer performance of all models, it is cleared that Model 2 and Model 3 is better by 8% than Model 1 especially for a higher mass flow. Even though Model 1 has more surface transferring heat based on number of channels, the water flows into the microchannels in Model 1 is not evenly distributed which caused the lower heat transfer rate compared to the other two models.

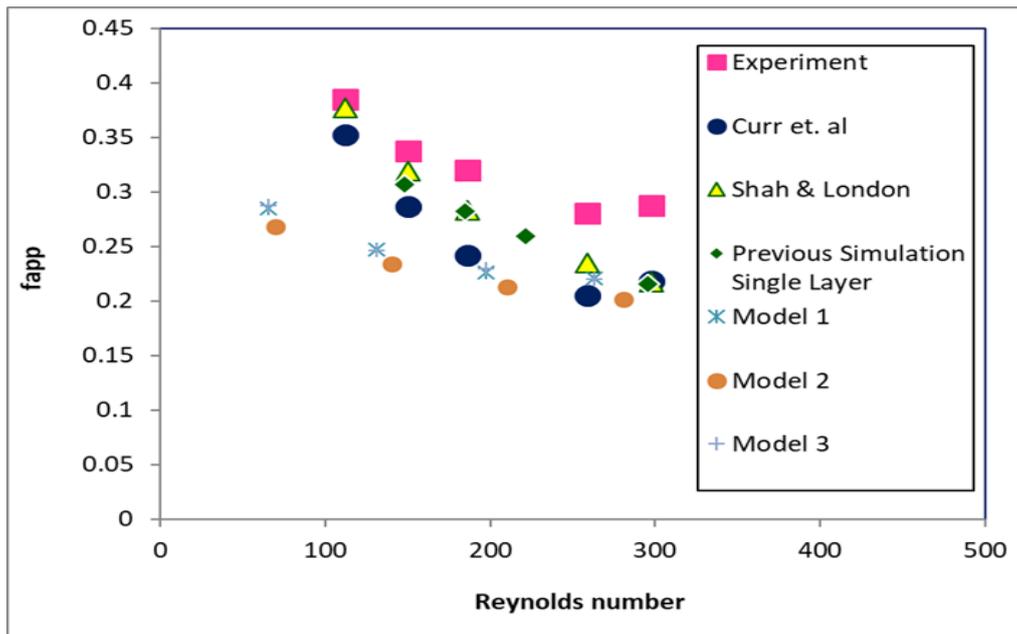


Fig. 4. Comparison of friction factor between models and single layer channel

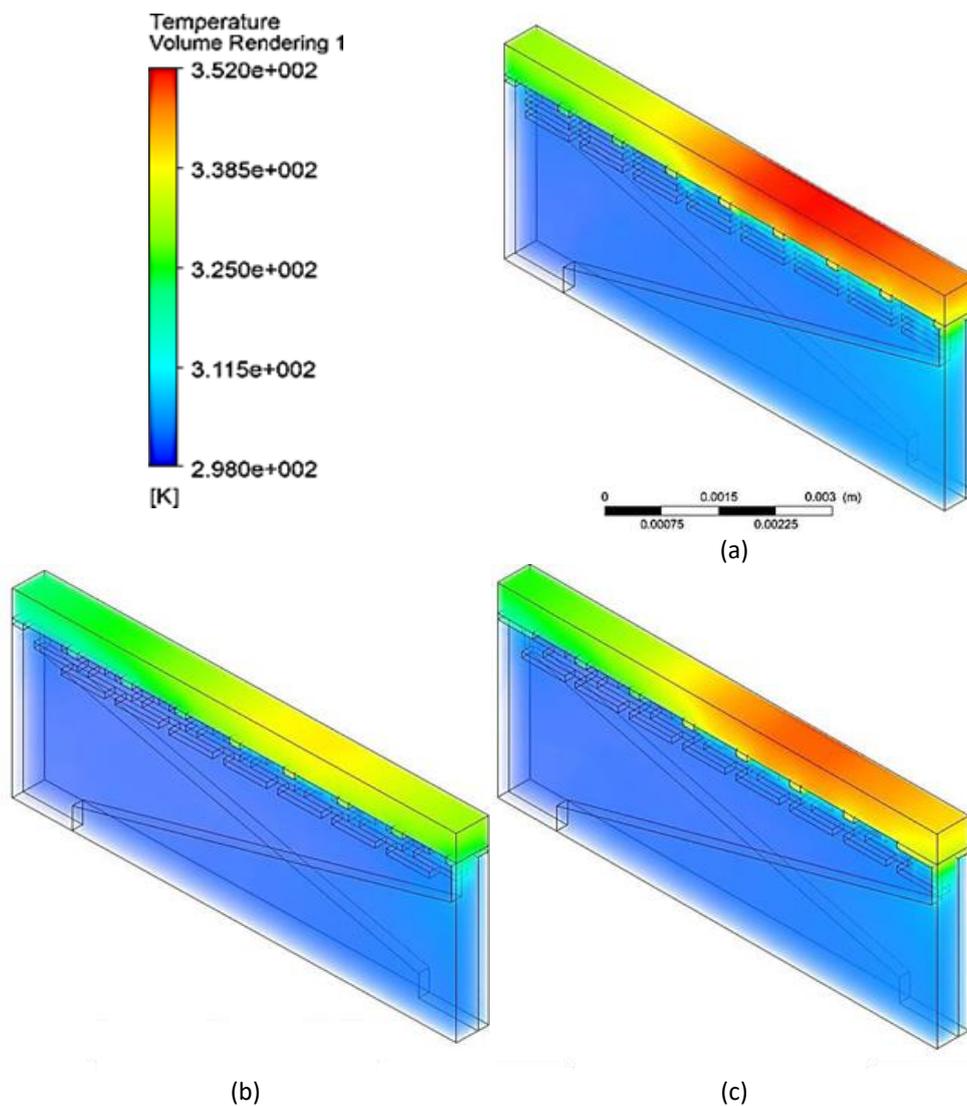


Fig. 5. Temperature distribution for (a) Model 1, (b) Model 2 and (c) Model 3

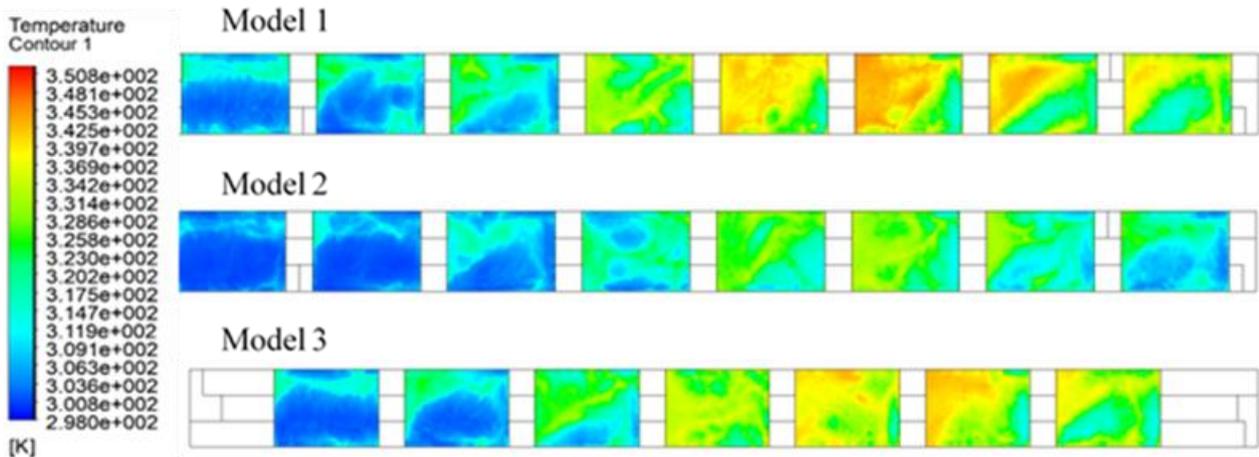


Fig. 6. Temperature distribution at the surface that contact with heating block

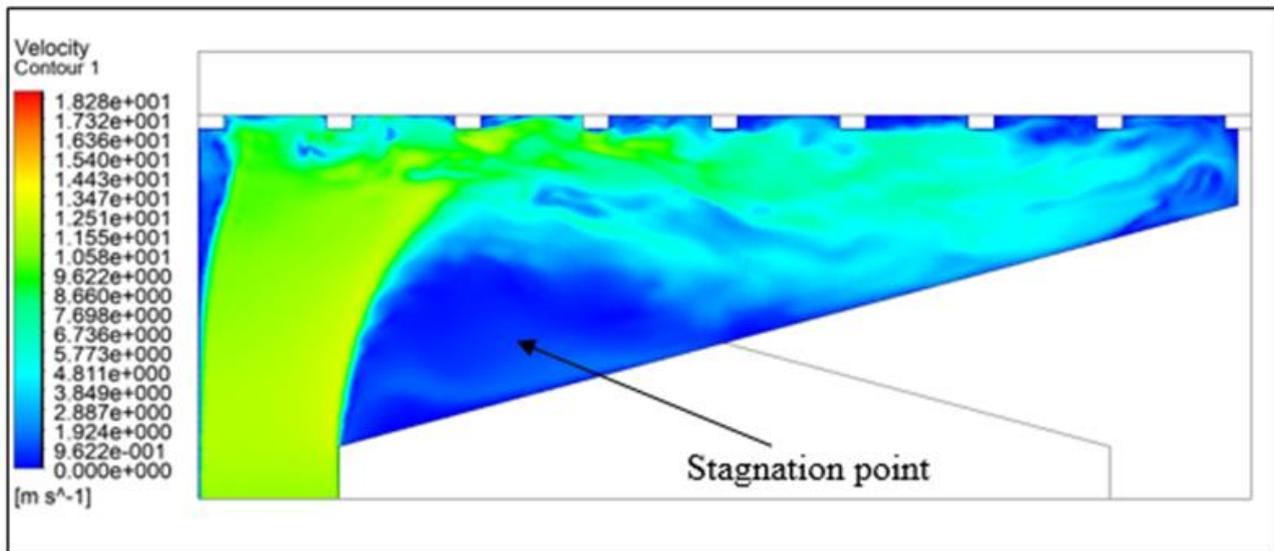


Fig. 7. Velocity profile at the outlet distribution channel

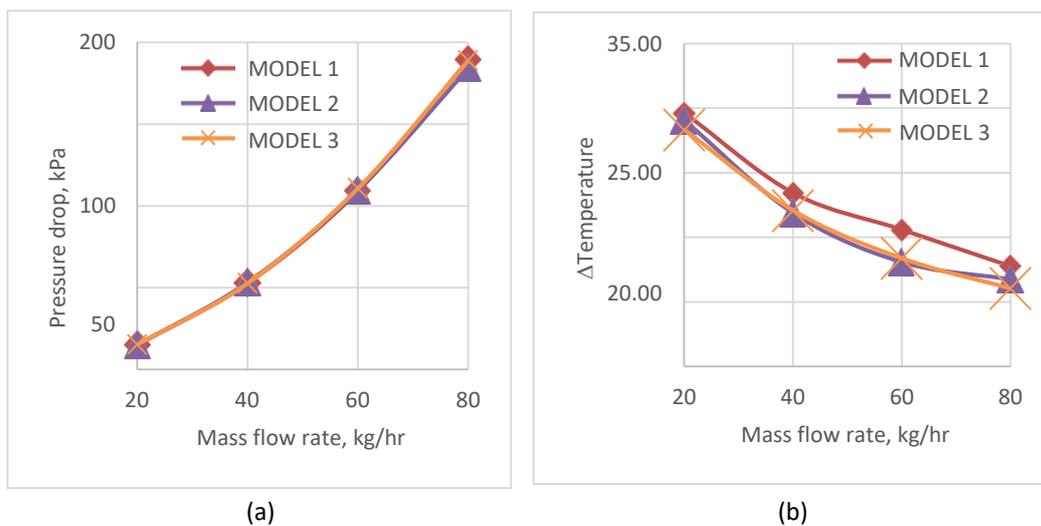


Fig. 8. (a) Comparison of pressure drop for different model, (b) Temperature difference between the inlet and heating surface for each model

4. Conclusions

Investigation of the effect of multilayer channel arrangement on the thermal hydraulic performance of microchannel devices has been performed. The results show that an arrangement of eight-seven-eight-seven microchannels in four layers come out as the best arrangement in current study. This arrangement allowed the water to flow in each microchannels with almost similar velocity. Therefore, the heat transfer is transferred smoothly and preventing the hot spot formation on certain area. Further study should be performed experimentally, to look at the performance of this arrangement in actual devices.

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