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Effects of the Gap on Microchannels Heat Sink Cooling Performance

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Abstract **-** With the surge in electronic systems' performance, the demand for efficient electronic cooling to facilitate high heat dissipation is becoming more imminent. Hence liquid cooling with phase change becomes imperative as far as high-flux electronics systems are employed. Among the cooling devices, a microchannel is commonly adopted. This research evaluates plain microchannel cold plates with a gap above the microchannels. The present study examines the effect of the gap above straight fin microchannels in the cold plate using the dielectric Novec 7000 as the working fluid. Two cold plates are made with a transparency cover. One has a gap above the microchannels (GAM) 1/3 of fin height, and another one with no gap above the microchannels (NGAM); the mass flux ranges from 25 to 260 kg/m^2·s, while the heat flux spans from 50 to 150 W/cm^2. The results show quite an improvement in performance with this space gap above the microchannels. The test results showed that the design of the GAM shows a superior heat transfer coefficient (HTC), which is enhanced by 90% compared to that of NCBM. Moreover, the GAM design has a much lower pressure drop by about 7~24% compared to the NGAM design at different mass flux and heat flux at the fully liquid inlet. The proposed space gap of 33% of fin height above the microchannels, thereby enabling the reduction of surface temperature by around 3~7 °C compared to no gap above the microchannels. This phenomenon becomes even more pronounced in high heat-flux regions.

Keywords**:** Microchannels; gap; pressure drop; enhanced performance; electronic cooling.

1. Introduction

Flow boiling in heat sinks microchannel has demonstrated significantly high heat transfer performance, considered a promising solution for cooling electronics to dissipate large quantities of heat from a small area. Flow boiling can transfer more significant amounts of heat energy through the latent heat of vaporization. The conventional heat sinks microchannels with straight fin array show instabilities in the flow boiling process, which many researchers observe [1-2]. Furthermore, many researchers observed that flow reversal occurs in the flow boiling at high heat flux for microchannels. That is because the bubbles rapidly grow and extend in downstream and upstream regions; the upstream expansion rejects the inflow backward to cause this phenomenon. Therefore, the fluctuations in the pressure drop and temperature are associated with the reversed flow in the flow boiling process [3-4].

For augmentation of flow boiling, devoted research aims to promote the onset of boiling (ONB) at a lower heat flux, to increase the critical heat flux (CHF), or increase the heat transfer coefficient [5]. Many researchers proposed and implemented particular microchannel designs to improve heat transfer performance. For example, Lu and Pan [6] implemented three diverging microchannels with artificial nucleation sites (ANS). The study significantly reduces the wall superheat, thereby enhancing the boiling heat transfer performance with ANS in parallel diverging microchannels. Sulaiman and Wang [7] introduced a contraction before straight-fin microchannels in a cold plate, which improved the performance of microchannels heat sinks significantly for various cooling applications. Ramakrishnan et al. [8] implemented a jet impingement arrangement in microchannels using a dielectric fluid Novec/HFE-7000. Two-phase flow boiling in cold plates, which strongly depends on surface geometry, was carefully studied at various levels of inlet subcooling, heat flux, and flow rates.

The present study proposes plain microchannel cold plates with a space gap above the microchannels to study the effects of operating parameters on the performance of flow boiling in the microchannel cold plate with working fluid Novec HFE-7000.

2. Experimental setup

Fig.1 shows the layouts of the experimental design. The experimental setup is made up of a condenser plate heat exchanger, a stainless steel tank to house the working fluid, filter driers, sight glass, the gear pump, which controls the flow rate by a variable speed gear pump drive, the mass flow meter, pressure transducer for system pressure, the pressure drop in the test section was measured by differential pressure transmitter and the test section parts. The test section consisted of a heating Aluminium block with two cartridge heaters, threaded bottom frame, top frame, gasket rubber, transparent acrylic cover, insulator type (PEEK) at the bottom of the heater and around all parts, and microchannels as shown in Fig. 2. The cold plate placed on the heating Aluminium block and metal thermal interface material used between them. The microchannel heat sink contains an overall dimension of 49 mm × 52 mm with 3 mm fin height, and the test section is made from copper; the test sections of the microchannel heat sink with two different Acrylic covers were tested and designated as gap above the microchannel (GAM) and no gap (NGAM) above the microchannel as shown in Fig. 3.

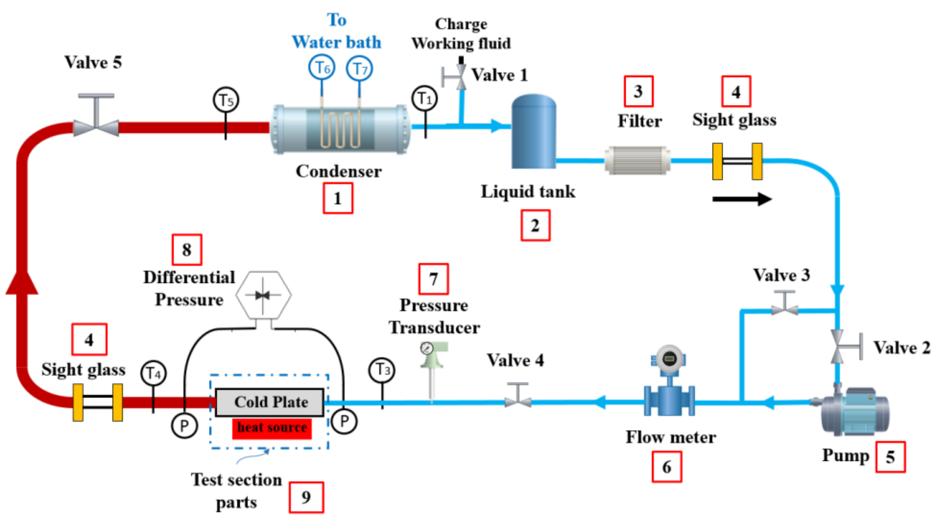

Fig. 1: Schematic diagram of the experimental setup.

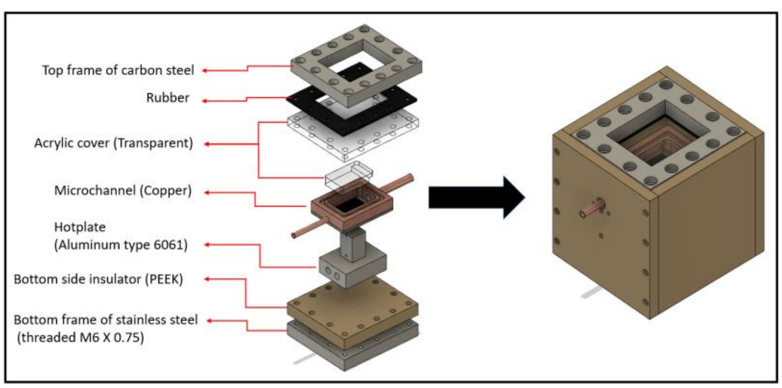

Fig. 2: Exploded view of the Test Section parts.

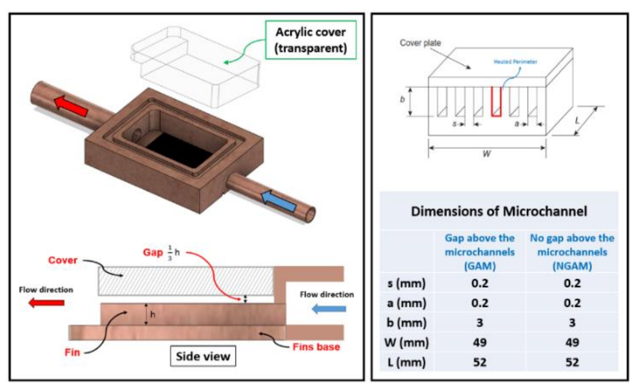

Fig. 3: Illustration pictures for the gap and dimensions.

3. Results and discussion

The pressure drop across the microchannels is plotted as a function of the mass flux in Fig. 4 for the microchannels cross-section at different mass fluxes. In the two-phase flow, the pressure drop is strongly dependent on mass flux and heat flux, so it increases exponentially with increasing mass flux due to the acceleration of vapor and the two-phase frictional pressure drop. Fig. 4 shows the variation in pressure drop at different input heat flux conditions at different mass flux ranges (30-260 kg/m^2·s) using a dielectric fluid Novec 7000 at a saturation temperature of 33°C. The test section results with a gap 1 mm above the microchannels (GAM) show some 7 % ~ 24% lower pressure drop compared to that with no gap above the microchannels (NGAM). Yet, the surface temperature is decreased by around 3~8 °C depending on the supplied mass flux and heat flux. A gap in this study was designed to provide an additional cross-section area in the microchannels along the flow direction to accommodate the vapor flow to be separated from the heating surface, which eventually reduces the pressure drop considerably.

Fig. 5 shows quite an improvement in HTC with this opening area above the microchannels. The GAM test section offers 50-90% higher HTC than the NGAM test section. Unstable operating conditions are responsible for the comparatively low values of HTC in the conventional NGAM compared to the GAM, as shown in Fig. 6. Consequently, flow reversal and significant instability occur, and the bubbles expand to repel against the main flow. The vapor bubble growth is very rapid, which induces high pressure; as a result, the bubble interface extends toward the inlet and outlet, which leads to flow reversal. The expanding channel facilitates automatic vapor removal by taking advantage of the unbalanced surface tension force between the tail and front of the vapor bubbles; when the inlet fluid's flow inertia is inadequate to overcome the bubble's evaporative momentum, the unbalanced surface tension force assists the elongated bubble in leaving the channel quickly to the downstream direction.

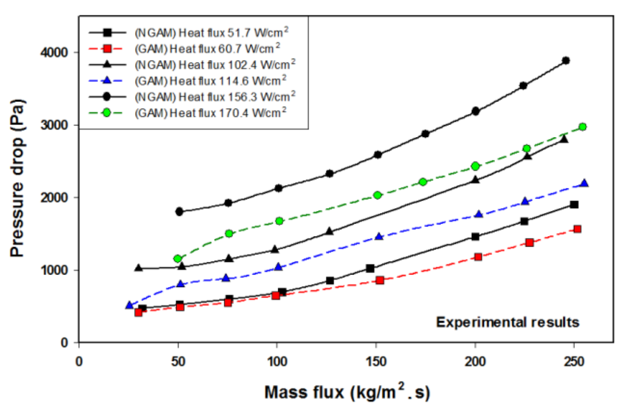

Fig. 4: The pressure drop at different heat fluxes

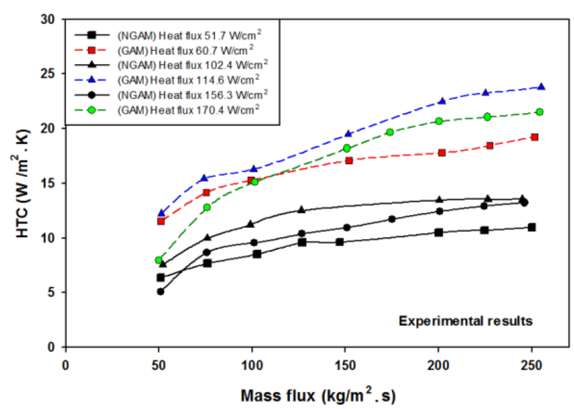

Fig. 5: The heat transfer coefficient at different heat fluxes

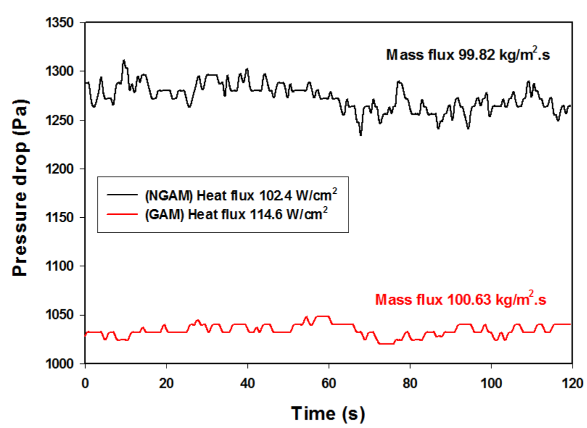

Fig. 6: Pressure drop fluctuations in the microchannels.

4. Conclusion

This study proposes a novel design to improve the 2-phase cold plate subject to the concentrated heat source. The plate is of microchannel configuration, and Novec 7000 is used as the working fluid. Experiments are conducted at a saturation temperature of 33 °C with mass flux ranging from 25 to 260 kg/m^2·s and supplied heat flux spanning from 50 150 W/cm^2. The results show significant improvement in performance with this gap area above the microchannels compared with no gap above the microchannels. The GAM design provided a 7~24% lower pressure drop than the NGAM design, and the HTC performance for GAM showed significant improvement about two times. So the gap with 1/3 height of fins above the microchannels provides a more improvement in pressure drop, heat transfer coefficient, and surface temperature. Expanding the cross-section above the microchannel facilitates automatic vapor removal by taking advantage of the unbalanced surface tension force between the tail and front of the vapor bubbles.

Acknowledgments

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