Numerical Modeling of Fluid Flow and Thermal Transport in Gravity-Dominated 3D Microchannels

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ABSTRACT

The success recorded by the usage of microchannel in high flux cooling application, has led to several studies aimed at advancement in microchannel fluid flow and heat transfer technology. A recent study area with promising breakthrough is the effects of gravity on microscale flow. Numerical simulations were conducted to study single phase flow and heat transfer in 3D microchannels. A priori, the 3D models were validated with experimental results and showed agreement. Two different aspects were simulated: firstly a microchannel with hydraulic diameter of Dh =199 μm for gravity effects on heat transfer. Secondly, gravity effects on friction factor with hydraulic diameter Dh = 1587 μm. The 3D model confirmed the existence of gravity effects and scaled with significant factors previous 2D model predictions. This result realistically presents the potential of microchannel angular orientation as a passive tool for flow optimization and heat enhancement in portable electronics devices and compact-sized biomedical devices.

Keywords: ***Friction factor, Single Phase flow, Nusselt number, Inclination Angle***
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Introduction

Tukerman and Pease [1] pioneered the application of micro-channels as suitable heat sinks for electronic cooling. The investigation successfully dissipated high heat flux (as high as $800W/m^2$) using micro-channels. This major milestone has opened the door for future research in the field of microscale flow and heat transfer. Fluid flow and heat transfer in microchannel has been found to be influenced by Microchannel configuration, geometry, and aspect ratio [2], [3], [4]. Pega and Xiao [5] investigated rectangular microchannel with hydraulic diameter (69.5 μm - 304.7 μm), and aspect ratios (0.09 to 0.24) using R134a as the working fluid. With the present trend of smart electronics, the reduction in the size of components and the thermal load from processors, the need to study microchannels in manipulated configurations is recently becoming worthwhile in some researches.

In our previous study [6] gravity force was identified as a passive tool for microscale fluid flow optimization and convective heat flow enhancement in, this has the potential for the design configurations for microfluidic systems. Its influence was profound on friction factor for microchannels whose Dh = 1587 μm, similarly for the Nusselt number, gravity effects was influential for microchannels Dh = 199 μm. This work aims at investigating the 3D flow structures for the same dimensions using the same dimensions. This is necessary to obtain more realistic gravity effects when micro and or minichannels are employed for thermal dissipation in minute-sized electronic devices.

Methodology

We adopted the finite volume method as the computational approach, it involves the formulation of a control volume where the governing equations are linearized and integrated over each cell nodes. The working fluid adopted for this study was water, its thermo-physical properties at room temperature were obtained from the material database of FLUENT.

Results and Findings

The accuracy of the 3D model was validated with the experimental results of Mcphail for selected microchannel hydraulic diameters. Thereafter, predictive modelling was undertaken and presented in Fig. 1 and Fig. 2 for hydraulic diameters of Dh=1587 μm and Dh=199 μm respectively.

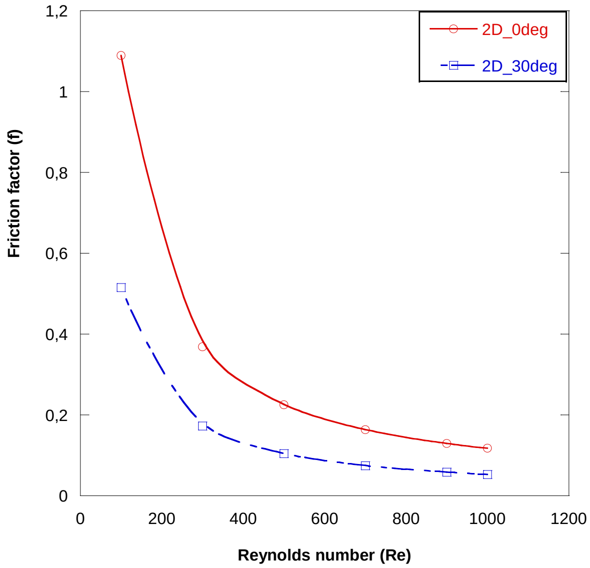

Fig.2: Friction factor for 3D Microchannels (Dh=1587 μm) inclined at 0° and 30°

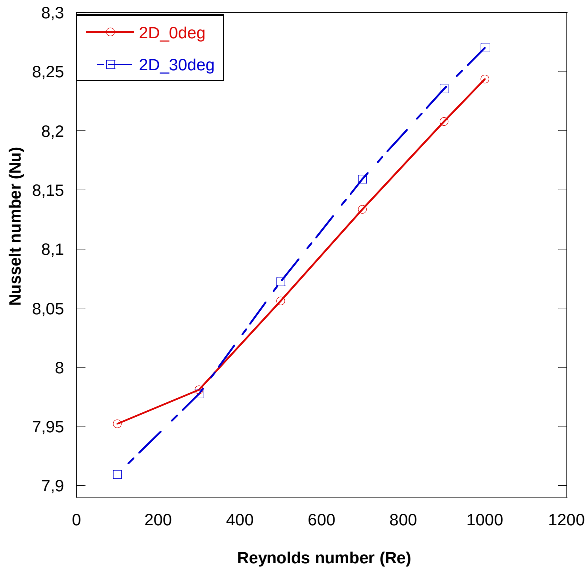

Fig.3: Nusselt number for 3D Microchannels (Dh=199 μm) inclined at 0° and 30°

Conclusion

The conclusion obtained from the study are highlighted as follows: microchannel of Dh=1587 μm was used in studying the fluid flow and Dh=199 μm was adopted for the heat transfer. In both cases, the existence of gravity effects on both phenomena was confirmed. It was discovered that the 2D model overpredicts the impact of gravity in both instances and the 3D model downplayed the impact of gravity by reduction with a factor of 2 for heat transfer, and 0.2 for the friction factor. The benefit of these findings could find suitable utilization in design of cooling systems for portable electronic devices and point of care medical devices.

References

[1] P. R. Tukermann DB, "High performance heat sinking for VLSI," *IEEE Electr Dev Lett,* vol. 2, pp. 126-129, 1981.

[2] S.G. Kandlikar, Heat transfer and fluid flow in minichannels and microchannels, Ed. S.G. Kandlikar, Elsevier, 2014.

[3] M. E Steinke, S. G Kandlikar 2004. Single-phase heat transfer enhancement techniques in microchannel and minichannel flows ASME 2004 2nd International Conference on Microchannels and Minichannels 141-148.

[4] D.B. Mirmanto, R Kenning, J S Lewis and T G Karayiannis 2012. Pressure drop and heat transfer characteristics for single-phase developing flow of water in rectangular microchannels *J. Phys.: Conf. Ser*. 395 012085. doi.org/10.1088/1742-6596/395/1/012085.

[5] X. T. Pega Hrnjak, "Single Phase pressure drop in microchannels," *International journal of Heat and Fluid Flow*, vol. 28, pp. 2-14, 2007.

[6]I. F. Odesola, A. Ashaju and E.O. Ige, "Simulation of Fluid flow and Thermal Transport in Gravity-dominated Microchannel," *International Journal of Scientific & Engineering Research*, vol. 8, no. 1, pp. 994 - 1001, 2017