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Numerical Simulation of Fluid Flow and Heat Transfer in Wavy Micro-Channel at Different Reynolds Number

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Abstract : *Heat performance and overall characteristics of microchannels can be improved by employing different channel structures. In this study wavy microchannel is analysed for its heat transfer and pressure drop characteristics. A three dimensional analysis is performed for different values of Reynolds number. The geometry is first created in Solidworks and then imported in ANSYS for CFD simulation in CFX package. To ensure the accuracy and reliability of the model the results for straight microchannels have been compared with experimental data. They are found to be in great agreement with the experimental results. A constant heat flux of $2*10^6$ W/m^2 is applied at the heat sink bottom. With water taken as coolant, the heat transfer and pressure drop characteristics are analysed for Reynolds number (600, 1000). It is found that both heat transfer and pressure drop increased with the employment of wavy channel as compared to straight microchannel.*

Keywords: Microchannel, Wavy, CFD, Heat sink

I. INTRODUCTION

With the developments in electronics in the recent years, electronic devices have become more powerful and small. They also produce a large amount of heat. Microchannel heat sinks are used for removal of large amount of heat from a very small surface area. These are challenging the use of conventional coil technology for heat exchange. Over the past few years, smaller scale machining technology is utilized at a huge rate for the improvement of exceptionally productive cooling gadgets known as micro-channel heat sinks as it possesses greater advantages like small size and less coolant requirements.

Tuckerman and Pease [1], first studied heat transfer in microchannels heat sink. They fabricated a 1×1 cm^2 rectangular microchannel with depth 302 µm and width 50 µm and employing water as the cooling fluid. The microchannel heat sink was capable of dissipating 790 W/cm^2 at the expense of a pressure drop of 2.2 bar. Peng and Peterson [2] investigated the single-phase forced convective heat transfer characteristics in microchannels experimentally with small rectangular channels with hydraulic diameters of 0.134–0.367 mm. P. Mohajeri Khameneh [3] illustrated the effects of geometric parameters on the Nusselt number in a single-phase and forced convective heat transfer of water in microchannels to obtain computational Nusselt number in laminar flow. This study stated that the average Nusselt number is increased by increasing the width or decreasing the height of the microchannel. Roy et al. [4] studied heat transfer using nanofluids as a coolant inside a radial channel between two coaxial and parallel discs. Xu et al. [5] investigated the flow characteristics and heat transfer numerically in microchannels with dimples. Different geometric parameters were independently evaluated under constant Reynolds Number of 500 and a constant heat flux of 1 W/mm^2. It was found that in comparison to straight channels, dimpled surface reduced the local flow resistance and also improved thermal performance of microchannel heat sink. Chai, Xia and Wang [6] studied the laminar flow and heat transfer characteristics in the interrupted microchannel heat sink with ribs in the transverse microchambers. In their study they examined the effect of such ribs on pressure distribution, velocity contour, and temperature distribution. They also observed the pressure drop and heat transfer characteristics in such microchannels. Results portrayed that the ribs in the transverse microchambers would prevent the decline of local heat transfer coefficient along the flow direction.

In the present work the heat transfer and pressure drop characteristics are studied for wavy microchannel at Reynolds number (600,1000). It is clear from the above given literature review that wavy channels have not been studied for heat transfer and pressure drop characteristics before and hence this study is important. To make sure that the model produces desired results, the simulation results of straight microchannel heat sinks have been compared and then validated with Qu and Mudawar's experimental work [7].

Heat transfer and pressure drop characteristics for wavy microchannels are computed for Reynolds number (600,1000). These are then compared with results of the rectangular microchannel heat sink. An increase in heat transfer and pressure drop is seen. The results are used to assess the suitability of macro transport models in depicting the transport characteristics of micro-channel heat sinks.

II. MODEL DESCRIPTION

The heat sink was created in Solidworks as per the dimensions given in Table I. The wave dimensions were decided in accordance with the length of the channel which is 44.7 mm. A sinusoidal sine wave (Eqn. 1) was constructed in the solid heat sink. The amplitude of the wave was taken as 0.15 mm while the wavelength was taken as 2 mm. However, fluid channel was created of the same dimensions as of the wavy rectangular slot along the length of heat sink.

$$y = A\sin(2\pi x / \lambda) \qquad \text{-(1)}$$

Here , 'A' is wave amplitude and 'λ' is wave length.The assembly of the heat sink and fluid channel was created and then imported in ANSYS. The mesh was generated in ANSYS.

TABLE I
DIMENSIONS OF THE UNIT CELL USED FOR SIMULATION

W_{wall}(μm)	$W_{channel}$(μm)	H_{wall2}(μm)	$H_{channel}$(μm)	H_{wall1}(μm)	L(mm)
118	231	12700	713	5637	44.7

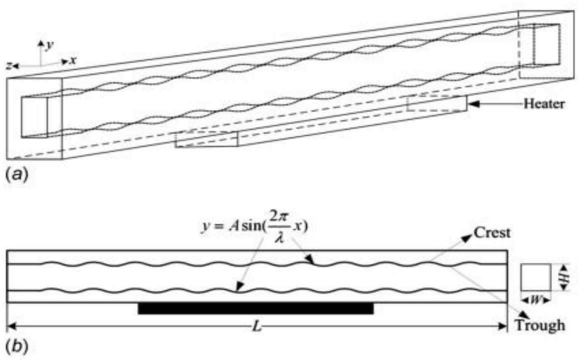

Fig. 1 (a) and (b) Schematic of wavy micro-channel heat sink

As, we have assumed a unitary computational domain, we only need to specify boundary conditions for the unit cell, which are given as: -

Hydraulic Boundary Conditions: -

- Uniform velocity at the inlet of the channel.
- At channel outlet, mass flow rate boundary condition is applied.
- Zero velocity at all other solid boundaries.
- No slip at the surface.

Thermal Boundary Conditions: -

- A uniform heat flux 200 W/ cm^2 of at the bottom wall of the heat sink.

III. MODEL VALIDATION

To ensure that the model is reliable and accurate, the computational results of a straight rectangular microchannel heat sink were compared with that of the experimental results by Qu and Mudawar [7]. These results are shown in Table II. It can be seen that the computational results comply with that of the experimental results. Hence the model and the boundary conditions chosen are reliable and accurate. The model can be used to assess the characteristics of wavy microchannel heat sink.

TABLE II

EXPERIMENTAL AND COMPUTATIONAL PRESSURE DROP AND TEMPERATURE RISE IN RECTANGULAR MICROCHANNEL

Reynolds number	Exp. pressure drop (bar)	Comp. pressure drop (bar)	Exp. Temp. rise (°C)	Comp. temp. rise (°C)
600	0.15	0.16	31	28
1000	0.32	0.29	18	16

IV. RESULTS

In this study heat transfer and pressure drop characteristics were studied for a wavy microchannel.

TABLE III

COMPUTATIONAL TEMPERATURE RISE AND PRESSURE DROP FOR WAVY MICROCHANNEL HEAT SINK

Reynolds number	Computational temperature rise (°C)	Computational pressure drop (bar)
600	39	0.204
1000	26	0.390

A. *Pressure drop*

The pressure drop characteristics were studied for a constant heat flux of 200W/cm^2 for two Reynolds number (600,1000). The results are as shown in Table III.

The pressure contours for the two Reynolds number are as shown below in Fig. 2 and Fig. 3.

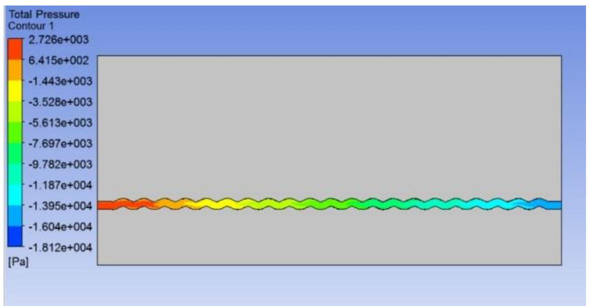

Fig. 2 Pressure contour of water along wavy channel at Re=600

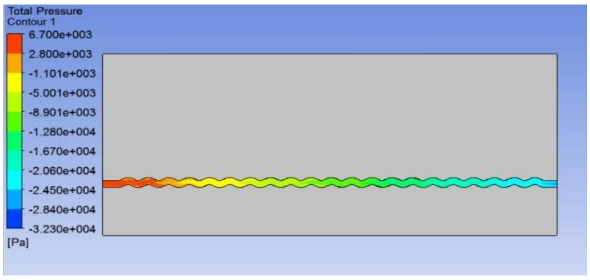

Fig. 3 Pressure contour of water along wavy channel at Re=1000

The pressure drop increases with increase in the Reynolds number. The wavy path obstructs the fluid flow in the direction of motion and hence leads to increased pressure losses as compared to straight microchannel.

B. *Heat Transfer*

The heat transfer characteristics were also studied for a constant heat of 200W/cm^2 for the same Reynolds number (600,1000). The temperature contours for the two Reynolds number are as shown in Fig. 4 and Fig. 5.

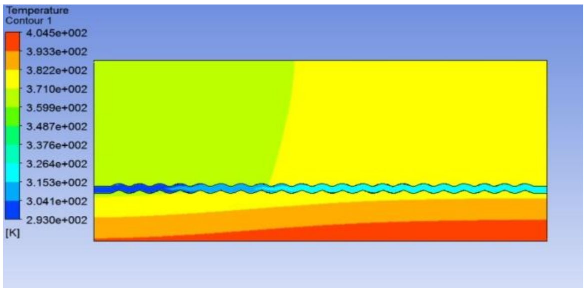

Fig. 4 Temperature contour of water and heat sink at Re=600

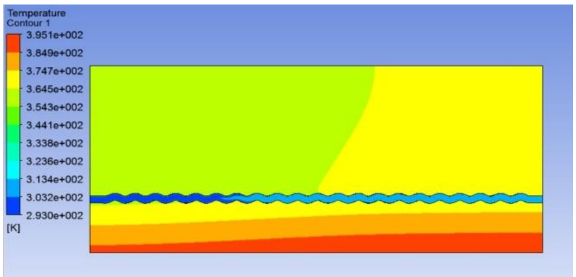

Fig. 5 Temperature contour of water and heat sink at Re=1000

The heat transfer rate decreases with increase in the Reynolds number. Also the heat transfer rate in wavy microchannel is greater than that of straight microchannel for corresponding values of Reynolds number. This can be attributed to the increase in surface area with the help of wavy structure and hence increasing the convective heat transfer.

V. Conclusions

In this paper, we have investigated, the conjugate heat transfer problem in a wavy microchannel geometry with the assumption of single phase flow. Numerical analysis of pressure drop and heat transfer is conducted and results are laid out. These results are compared with that of a rectangular microchannel heat sink to assess the design of the new geometry. Based on the results following conclusions can be made-

- The heat transfer in wavy microchannel heat sink is greater than that of rectangular microchannel heat sink. This wavy structure increases the convection heat transfer area. It also interrupts thermal boundary layer periodically in the flow direction and hence increases the heat transfer.
- The heat transfer decreases with increase in the Reynolds number as the velocity of coolant (water) flow increases.
- The effect of wavy channel on pressure drop is obvious. This structure hinders the fluid flow in the microchannel. These hindrances lead to a higher pressure loss compared to rectangular microchannel heat sink.
- The pressure drop increases with increase in Reynolds number.
- The computational values for pressure drop and heat transfer are found to be in good agreement with that of the experimental values and hence assures the reliability of the chosen model for analysis.

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