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# Numerical Modelling of Nanofluid Based Microchannel Heat Sink

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## Abstract

The current paper presents the effect of heat transfer and fluid flow characteristics in three dimensional rectangular microchannels under laminar flow conditions. The microchannel of widths 500 µm and 300 µm are tested in the presence of water and nanofluid as a cooling medium. In which a two-phase mixture model is used for the modelling of the nanofluid. The research works on the numerical modelling of nanofluids suggest that the multi-phase mixture approach gives better results than the single phase model approach. First, the obtained results for water based heat sink from the numerical simulation are validated with the experimental results taken from the literature. Then, the test was repeated by replacing water with water-$Al_2O_3$ nanofluid. Also, the effect of heat transfer and flow characteristics of nanofluids by varying the particle volume concentrations. Finally, the results from the nanofluids simulations are compared with water based heat sink simulations under similar flow and heat flux conditions to understand the improvements and limitations of using nanofluids as the heat transfer medium.

***Keywords*:** Microchannel, Two-Phase Mixture Model, Nanofluids

## 1. Introduction

Conventional cooling methods like air cooling is not sufficient for satisfying, the increased cooling demands of sophisticated electronic equipment Kandalikar et al [1]. The idea of microchannels heat sink was first instigated by Tuckerman and Pease [2] since 1981. Micro channels provide several advantages like compactness, lighter in weight and large heat transfer surface area to fluid volume ratio which forge them more attractive [3]. Kandalikar et al. [1] has reviewed the possibilities of using channels with smaller dimensions and has suggested the flow passage dimensions in convective heat transfer. Suresh et al. [3] performed experimental analysis to determine the validity of classical correlations based on conventionalized channels. For forecasting the thermo-physical properties of single-phase flow in rectangular microchannels.

Nanofluids, which are advanced heat transfer fluids contains nanometer-sized particles, called nanoparticles. These nanoparticles were suspended in a base fluid like water and ethylene etc. In general ,the nanoparticles added to base fluids are made of metals, metal oxides, carbides, or carbon nanotubes. Wenhua and Routbort et al. [4] reviewed the results of the research and development work forming the current status of nanofluid technology for heat transfer applications. Routbort et al. [5] studied the pumping power of nanofluids through a micro system. Nanofluids have an ability to improve thermal conductivities and heat transfer coefficients than the base fluids. Moreover, the addition of nanoparticles to a base fluid raises the viscosity. So, it requires more pumping power to drive fluid through the channels. Several researchers have worked with nanofluid modelling using various approaches and concluded that two-phase approach gave the most accurate results. Nazififard et al. [6], Davarnejad et al. [7], worked on numerical simulation of nanofluid with $Al_2O_3$

nanoparticles with different particle volume concentrations and obtained satisfactory results close to experimental results.

The domain of interest is only on single phase flows since numerical modelling of two-phase flow through microchannels involving liquid and vapour is out of the scope. However when Nano fluids are considered for numerical simulation. It is modelled as a two-phase mixture where the base fluid is considered as the primary phase and the suspended Nanoparticles as the secondary phase. The improvements and limitations of using nanofluids in microchannel heat sinks are discussed later in this report based on the observations and comparison of results from numerical simulation of both water and nanofluid based heat sinks

## 2. CFD Analysis

### 2. 1. Geometry

Microchannel heat sinks of channel width 500 µm and 300 µm are considered for the present study shown in figure 2.1. Those channels are having same foot print area of 25mm × 25mm and are made of Copper. The number of channels on the top of the heat sink is made by wire cut electro-discharge machining (EDM) method. For all channel widths, one single channel of fluid flow and two half fin widths are considered on either side of the channel as the computational domain shown in figure 2.2. Other geometric details are provided as table 2.1 in this section.

Table 2.1 Specification of microchannel heat sinks (300µm, 500µm)

| **Name** | **Dimensions** |
|---|---|
| Material | Copper |
| Base area of channel | 25mm×25mm |
| Channel width | 300/500(µm) |
| Fin width | 300/500(µm) |
| Channel depth, h | 1500(µm) |
| Aspect ratio, α | 3 |
| Number of fin row, n | 23 |

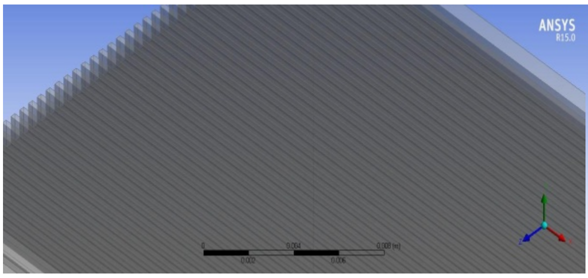


Fig. 2.1 Full model of a heat sink.

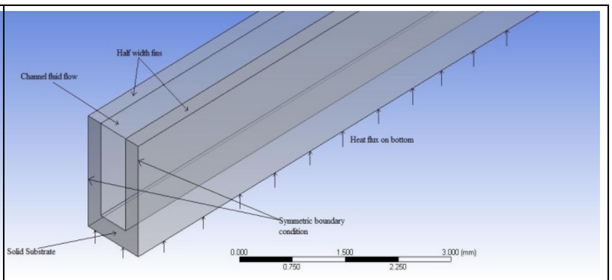


Fig. 2.2 Simplified single channel for computation.

### 2. 2. Grid Generation

CFD preference meshing is done without considering any advanced size function. Since very fine meshing is required in the micro meter range channel width, it is observed that considering any advanced size function reduces the orthogonal quality of mesh and increases the skewness. The edge sizing tool is used to specify the required element size for corresponding edges in microchannel models. Mesh element sizes are determined by doing grid independency test. In 500µm channel, meshing the edges by 0.01mm (width) × 0.02 mm (height) ×0.05 mm (streamwise) spacing (100 × 90 × 500 cells).

### 2. 3. Governing Equations

For single phase approach the governing equations are given are as follows.

$$\nabla\cdot(\rho\vec{v}) = 0 \tag{1}$$

$$\nabla\cdot(\rho\vec{v}\vec{v}) = -\nabla P + \nabla\cdot(\mu\nabla\vec{v}) \tag{2}$$

$$\nabla\cdot(\rho\vec{v}\,Cp\,T) = \nabla\cdot(k\nabla T) \tag{3}$$

$$\nabla\cdot(k\nabla T) = 0 \tag{4}$$

For nanofluid based microchannel heat sink modelling, the working fluid (nanofluid) is considered to be in two-phase where the primary phase is the base liquid (water) and secondary phase is the solid nanoparticles suspended in the base fluid. The governing equations for two-phase mixture model is adopted from nanofluid modelling [8]

$$\nabla.(\rho_m.\vec{v}_m) = 0 \tag{5}$$

$$\nabla.(\rho_m\vec{v}_m\vec{v}_m) = \nabla p_m + \nabla.(\tau_m) + \nabla.\tau_{Dm} + \rho_m\vec{g} \tag{6}$$

$$\nabla.\left[\left(\varphi\rho_p C_{p,p}\vec{v}_p + (1-\varphi)\rho_f C_{p,f}\vec{v}_f\right)T\right] = \nabla.\left(k_{eff}\nabla T\right) + S_e \tag{7}$$

### 2. 4. Boundary Conditions

For all channel width, the volume flow rate through the full model domain is maintained constant. Two such different flow rates are considered which can be generalised as a high flow rate and low flow rate. The flow rates considered for 500 µm and 300 µm channel widths are 311 mL/min and 711 mL/min. For 500 µm and 300 µm channels, the heat flux value of 65 W/cm$^2$ and 100 W/cm$^2$ is applied on the bottom wall respectively. The top surface of the microchannel assumed as adiabatic wall and symmetric boundary condition given at the side walls of the fin. Also, pressure at the outlet boundary taken as atmospheric pressure.

## 3. Validation and Grid Independence Study

The meshes generated in the simulation studies of 500 µm and 300 µm width microchannel heat sinks are compared with the results obtained from grid independent studies. The parameter used for conducting the grid independent study is the average Nusselt number. Three different meshes for 500 µm width channel are 70 × 60 × 350 cells, 100 × 90 × 500 cells and 130 × 120 × 650 cells. An average of Nusselt number obtained for these meshes 7.90, 7.885 and 7.879 respectively. The average Nusselt number increases by 0.19 % from the first to the second mesh, and only by 0.08 % increment for further refinement. Hence, the intermediate grid (100 × 90 × 500 cells) was selected for simulation. Similarly, grid independence study was done for 300 µm width channel.

## 4. Result and Discussion

### 4. 1. Fluid Flow Characteristics

Figure 4.1 shows the velocity contour of water flow inside 500 μm rectangular microchannel at the midplane of fluid in the longitudinal direction. All the velocity profiles for other channel width are also considered at this plane only. It can be clearly observed that in rectangular microchannel constant velocity contour is maintained throughout the channel with large velocity gradient from the channel wall to the fluid core. Since no slip condition is specified at the convention wall boundary, velocity is zero. The parabolic velocity contour that can be identified from the figure 4.1 shows that the velocity boundary layer is fully developed and fused at the centre of the channel. Since the flow is hydrodynamically developed, there won't be any fluid movement between the fluid layers and hence no proper fluid mixing, which reduces the heat transfer and increase the temperature gradient across the flow.The same trend is followed in channel widths of 300 μm microchannels for water and nanofluids as the working fluid. All the above discussions are done for water based microchannels only. The implementation of nanofluids as the working fluid will not have much effect on the fluid flow characteristics because the particle concentrations considered are less than 3 %. Hence water and nanofluids have similar fluid characteristics with the difference in velocity and pressure drop values. Nanofluids mainly have an effect on heat transfer and pressure drop characteristics which are discussed in the following sections

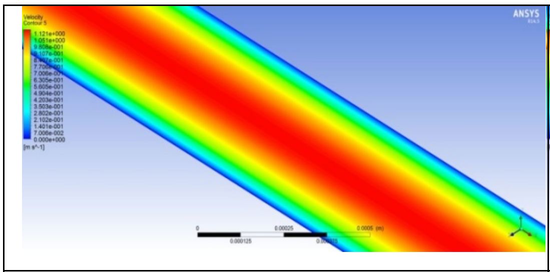


Fig. 4.1 Velocity contour of flow inside microchannel (500 μm)

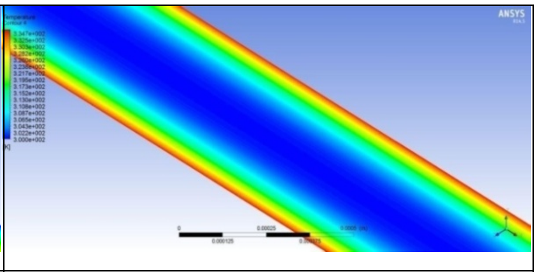


Fig. 4.2 Temperature contour of flow inside microchannel (500 μm)

## 4. 2. Heat Transfer Characteristics

Figure 4.2 shows temperature contour of flow inside 500 μm microchannel heat sinks, when water is replaced by $Al_2O_3$ nanofluid of 1 % particle volume concentration, the maximum fin temperature is reduced from 351.75 K to 341.56 K for a flow rate of 13.5 mL/min. This shows a 10 K reduction in temperature which is very remarkable. For a higher flow rate of 30.89 mL/min, nanofluid 1 % reduces the temperature by 8 K. By increasing the particle volume concentration to 2 %, the temperature is reduced to 336.23 K for 13.5 mL/min flow rate and 325.85 for 30.89 mL/min flow rate. For 3 % particle volume concentration, these temperatures are 332.88 K and 322.97 K respectively. Hence for the 13.5 mL/min flow rate, when nanofluid (3 %) is used as the working fluid, the temperature is reduced to 26 K when compared to water. The Same trend is followed in other channel widths microchannels

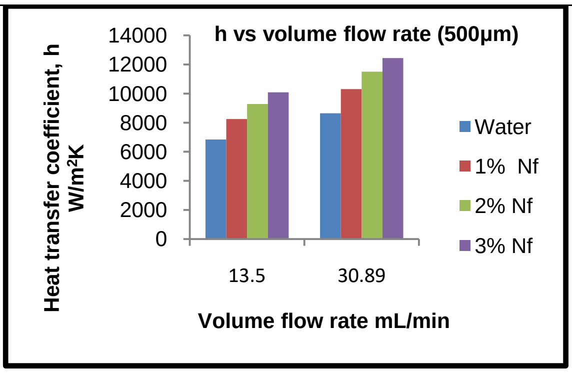


Fig. 4.3: Effect of heat transfer coefficient (500μm conventional channel with water and nanofluids)

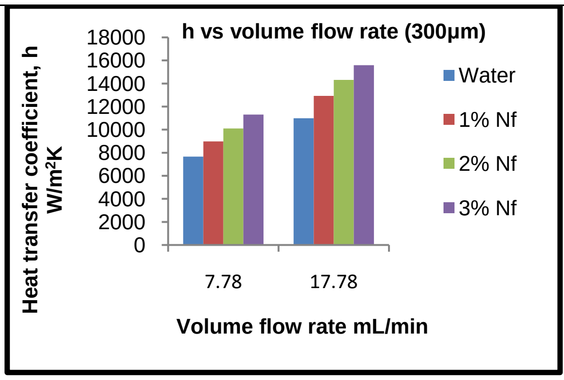


Fig. 4.4: Effect of heat transfer coefficient (300μm conventional channel with water and nanofluids)

Nanofluid indicted as 'Nf'

Figure 4.3 to Figure 4.4 shows the comparison of the heat transfer coefficient in different channel widths for water and nanofluids with different particle concentrations. Considering the effects of nanofluids in 500 µm conventional channels, replacing water with $Al_2O_3$ nanofluid-1 % heat transfer coefficient is improved by 20 % for both lower and higher flow rates. Further replacing the nanofluid 1 % with nanofluid 2 % improves the heat transfer coefficient by 12 % for both the volume flow rates. Significant improvement is observed with nanofluid-3 % also. In 300 µm width channels nanofluid 1 % improves heat transfer coefficient by 17% for higher and lower volume flow rates when compared to water. Further replacing the nanofluid 1 % with nanofluid 2 % and 3% improves the heat transfer coefficient by 9 -12 % for both the volume flow rates. But generalising the trend, nanofluids improve the heat transfer rate considerably compared to the water and increases the heat transfer rate with increasing nanofluid particle volume concentration.

## 4. 3. Pressure Drop Characteristics

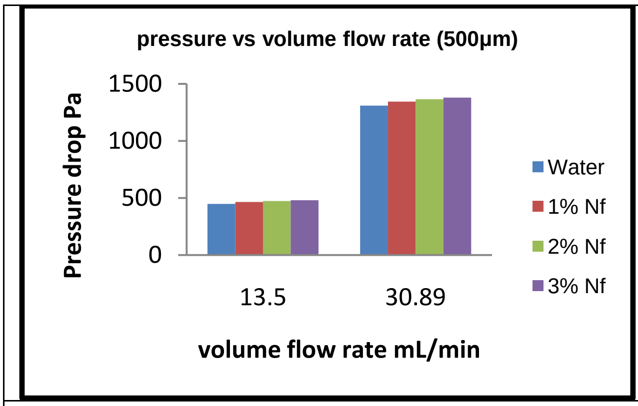


Fig. 4.5 Effect of pressure drop (500µm conventional channel with water and nanofluids)

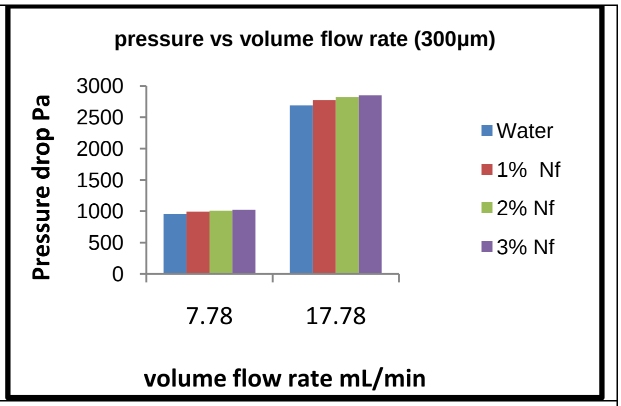


Fig. 4.6 Effect of pressure drop (300µm conventional channel with water and nanofluids)

Nanofluid indicted as 'Nf'

Figure 4.5 to Figure 4.6 shows the comparison of pressure drop in 500 µm and 300 µm width microchannels. The pressure drop is less in 500 µm channels for both water and nanofluid as the working fluid. For microchannel with water, flow at a lower volume flow rate (13.5 mL/min), pressure drop values for 500 µm and 300 µm channel are 448.2 Pa and 995.67 pa respectively. For higher volume flow rate (30.89 mL/min), these values are 1308 Pa and 2689.96 Pa. From the result it is clearly observed that, 300 µm channel with water as the working fluid, increases pressure drop by 2.9 times the pressure drop in 500 µm channels at lower flow rates (2.7 times pressure drop in 500 µm channels at higher flow rates). This increases the pumping power required for 300 µm channels to be very high than 500 µm channels. Thus the heat transfer enhancement caused by 300 µm channels is compromised by the increased pressure drop which makes 300 µm channel not suitable as an enhancement method.

## 5. Conclusion

Numerical simulation and analysis of water and nanofluid based microchannel heat sink of channel width 500 µm and 300 µm with rectangular finned channels are done and results were analysed. Simulation results of water based heatsinks were validated using existing experimental results. Observations from the detailed analysis of fluid characteristics, heat transfer characteristics and pressure drop characteristics for both water and nanofluid of different particle concentrations helps in understanding the underlying physics of fluid flow and heat transfer phenomenon in a microchannel heat sink. So the conclusions from the present study are stated as follows.

- Water based nanofluid with $Al_2O_3$ nanoparticles is found out to be an excellent candidate as the working fluid for a microchannel heat sinks. It provides considerable heat transfer enhancement for all the channel widths without much increase in the pressure drop values.
- When nanofluid is used as the working fluid, a significant temperature drop in the channel. Because there is an enhancement of thermal conductivity of working fluid.
- Maximum heat flux dissipation is offered by 300 μm channels as observed from the simulation. But the pressure drop values in 300 μm channel is very much higher than the pressure drop in 500 μm channel widths, especially at higher flow rates. Usage of nanofluids as working fluids can increase this heat flux dissipation limit by a considerable amount without moving to two-phase heat transfer.

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