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Numerical analysis of heat and fluid flow in microchannel heat sink with triangular cavities

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ABSTRACT

In recent years, there has been an increasing interest in heat transfer enhancement using nanofluids in corrugated channels due current devices become smaller and smaller and are expected to perform better. The devices will create hot spot and generate more heat are related to the devices performance are better and inability of current heat sink to remove heat. So, the aim of this project is to stimulate the nanofluids flow in straight channel and corrugated microchannel using ANSYS software with certain specific parameters to be fixed or stated which are hydraulic diameter is 133.3 µm, Knudsen Number will be fixed when flow is continuum, Reynold number will be below than 1400, so that the flow in within laminar region, the inlet temperature will be 300 K, uniform heat flux 100W/cm^2 and inlet velocity will be in the range of 1.0m/s to 4.5m/s. This research will describe the procedure of using ANSYS software and to analysis the heat enhancement, pressure drop, velocity contour of nanofluids happen in straight microchannel compared to triangular cavities microchannel. The analysis proved triangular cavities that using high volume fraction of nanofluid has better performance compared to straight channel with the same volume fraction of nanofluid because the triangular cavities microchannel have the highest nusselt number and lowest friction factor whereby these two factors become indicator to thermal performance.

1. Introduction

The past decade has seen the rapid development of nanotechnology. A longitudinal study by Heera and Shanmugam [1] reports that in the past few decades there has been a considerable research interest in the area of nanotechnology using nanoparticles, such as metals, semiconductors and metal oxides are of great interest for a wide of variety of applications in the field of information, energy, environmental and medical technologies due to their unique or improved properties determined primarily by size, composition and structure along with their self-organized film structures. So, nanotechnology bring us a lot of advantages which may bring us to more advanced

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level and comfort of life. In 2017, Mohammed *et al.* [2] published a paper in which they described that numerical simulation findings of the convective heat transfer with and without nanofluids in the facing step and corrugated channel have been investigated. The result of it is the utilization of nanofluids in the corrugated channel has augmented the heat transfer with slight pressure drop compared with facing step channel.

Detailed examination of nanofluid flow in channels with different shape which is trapezoidal, sinusoidal and straight with different volume fraction by M.A. Ahmed showed that the heat transfer enhancement increase as the nanoparticles volume fraction increases, however at the expense of increasing pressure drop. Furthermore, the trapezoidal-corrugated channel has the highest heat transfer enhancement followed by the sinusoidal-corrugated channel and straight channel[3]. In another major study, Ahmed conducted numerical investigations on the turbulent forced in triangular-corrugated channels with different types of nanofluids which are Al_2O_3, CuO, SiO_2 and ZnO-water with nanoparticles diameters in the range of 30-70nm and the range of nanoparticles volume fraction from 0% to 4%. It is found that the average Nusselt number, pressure drop, heat transfer enhancement, thermal-hydraulic performance increase with the increasing in the volume fraction of nanoparticles and with the decreasing in the diameter if nanoparticles. Furthermore, the SiO_2-water nanofluids provides the highest thermal-hydraulic performance among other types of nanofluid followed by Al_2O_3, ZnO and CuO-water nanofluids.

2. Methodology

2.1 Geometry of microchannel heat sink

Microchannel are defined as flow passages that have hydraulic diameters in the range of 10 µm to 200 µm. After reviewing the advancement in heat transfer technology from a historical perspective, advantages of using microchannel in high heat flux cooling applications is discussed, and research done on various aspects of microchannel heat exchanger performance is reviewed. The word “micro” was embraced enthusiastically with the opening of its newest branch in microscale heat transfer. The classification of small dimensions divides the range from 1µm to 100µm as microchannel, 100µm to 1mm as meso-channel, 1mm to 6mm as compact passages and > 6mm as conventional passages [4].

Figure 1 show the schematic diagram and geometry parameters of the microchannel heat sink with triangular cavities (TC) and conventional straight microchannel (SC). The microchannel heat sink is made of copper. In this simulation only considering one symmetrical part of the whole heat sink due to the symmetry of the structure. As shown in Figure 1, the length L, width W_z, height H_z and the height H of the computational domain is 10mm, 0.2mm, 0.35mm and 0.2mm. All the geometry dimensions of the microchannel in this simulation are shown in Table 1.

2.2 Nanofluid Thermal Properties

Nanoparticles get produced by plants are more stable and the rate of synthesis is faster than that in other case of organism. Nanoparticles get classified mainly into two groups they are organic particles and inorganic particles. There are different ideal methods for nanoparticle to get synthesized. The following aspects involved for synthesizing nanoparticles are neutral pH, low cost and environmental friendly fashion [1]. Inorganic particles is Based on their unique physical properties and particularly in biotechnology of inorganic nanoparticles, they have certain physical properties that mainly include size-dependent optical, magnetic, electronic and catalytic properties. Bio related application are involved for the preparation of these interesting nanoparticles like iron oxide, gold, silver, silica, quantum dots etc. Novel physical properties mainly related because of their size approaches nanometer scale dimension [1]. Polymeric nanoparticle it is a type of nanoparticle which the dispersion of performed polymers and the polymerization of monomers are two strong strategies mainly involved for preparation [1]. Solid lipid nanoparticles played a dominant role which there are certain alternate carrier systems to emulsions, liposomes and polymeric nanoparticles as a colloidal Carrier system [1].

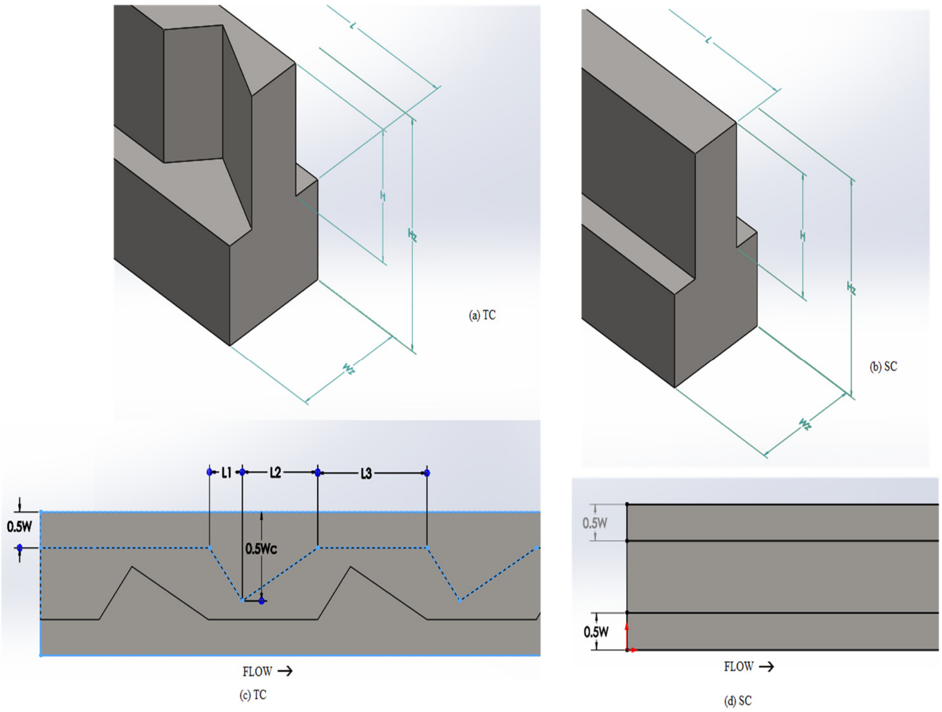

Fig. 1. Schematic diagram and geometry parameters of the microchannel: **(a)** schematic diagram of TC channel; **(b)** schematic diagram for SC channel; **(c)** geometry parameters of TC channel; **(d)** geometry parameters of SC channel

Table 1
The geometry dimensions of the microchannel heat sink

Parameters	W	W_z	W_c	L	L1	L2	L3	Hz	H
Values (μm)	100	200	248	10000	60	140	200	350	200

There have many methods to study the effectiveness of nanofluid in CFD such as single-phase or multiphase method. In the present study, single-phase method is used, therefore, the following assumptions are considered [5]:

a) Nanoparticle that dispersed in base fluid is so fine
b) Nanoparticle is to be easily fluidized so that it can be considered to have no slip motion between base fluid and nanoparticles.
c) homogeneous mixture

Based on these assumptions, the effective thermophysical of nanofluid such as density and heat capacity is used in the simulation analysis [6-10]. The effective density and heat capacity of a nanofluid are shown in equation (1) and (2) respectively.

$$\rho_{nf} = (1-\text{Ø})\rho_f + \text{Ø}\rho_s \tag{1}$$

The heat capacitance of the nanofluid term is

$$(\rho c_p)_{nf} = (1-\text{Ø})(\rho c_p)_f + \text{Ø}(\rho c_p)_s \tag{2}$$

where Ø is the volume fraction of the solid particles, subscripts *f*, *nf* and *s* stand for base fluid, nanofluid and solid respectively.

The Maxwell-Garnetts (MG) model [6] is used to predict the nanofluid viscosity and thermal conductivity can be expressed as follow.

$$\mu_{nf} = \frac{\mu_f}{(1-\text{Ø})^{2.5}} \tag{3}$$

$$\frac{k_{nf}}{k_f} = \frac{k_s+2k_f+2\text{Ø}(k_f-k_s)}{k_s+2k_f-\text{Ø}(k_f-k_s)} \tag{4}$$

Table 2 shows the parameter for effective density, thermal conductivity, heat capacity and viscosity based on volume fraction of nanoparticle in base fluid (water). These parameters are used in FLUENT to analyse the effectiveness of nanoparticle as heat transfer.

Table 2
The nanofluid thermal properties based on the volume fraction of nanoparticles

Nanoparticles	Volume Fraction, Ø	ρ	k	c_p	μ
Copper	0	998.2	0.6	4182	0.001003
	0.010	1077.5	0.6	3867	0.001029
	0.025	1196.6	0.6	3473	0.001069
	0.050	1394.9	0.5	2966	0.001140
	0.100	1791.7	0.4	2289	0.001305
	0.150	2188.4	0.4	1857	0.001506

2.3 Numerical Method
2.3.1 Governing equation and boundary conditions

The ANSYS software is used to capture the characteristics of flow and heat transfer in the three-dimensional model. The flow is continuum if the Knudsen number (Kn) is less than 10^{-3}. Kn is defined as the ratio of the mean free path of fluid molecules to the characteristics dimension which far less than 10^{-3} in this work. So the flow is continuum, the Navier-Stokes (N-S) equation and no-slip boundary condition is reasonable. Several assumptions are made: (1) the fluid is Newtonian fluid, the flow is laminar, incompressible and in steady-state; (2) the solid properties are constant and fluid properties are varying piecewise-linearly with water and nanofluid temperature; (3) the gravitational force and other forms of body forces are neglected; (4) the viscous dissipation cannot be ignored. According to these assumptions, the governing equations including the continuity equation, three-dimensional Navier-Stokes (N-S) equation and energy are represented as follows:

$$\nabla \cdot U = 0 \quad (5)$$

$$\rho U \cdot \nabla U = -\nabla P + \mu \nabla^2 U \quad (6)$$

$$\rho c_p (U \cdot \nabla T) = \lambda_f \nabla^2 T \quad (7)$$

The energy equation for solid par is written as

$$\lambda_s \nabla^2 T_s = 0 \quad (8)$$

The inlet of the microchannel is set as uniform velocity inlet and the inlet temperature is set to 300 K for all cases of the present work. The outlet pressure of microchannel is assumed to be the atmosphere pressure. An uniform heat flux (q_w= 100 W/cm^2) is applied to the bottom of the microchannel heat sink. No-slip and no-penetration condition ($U = 0$; $T_s = T_f$; $-\lambda_s \frac{\partial T_s}{\partial n}$=$-K_f \frac{\partial T_f}{\partial n}$) are assigned to the fluid-solid inter-surface to couple up the fluid convection and solid conduction. The centre planes of the microchannel area set as "Symmetry" boundary condition. All the other walls are applied adiabatic[11].

2.3.2 Mathematical Formulation

The relevant analytical expressions are presented in this work in order to calculate fluid flow and heat transfer characteristics in the microchannel. Hydraulic diameter (Dh) and Reynold Number (Re) are expressed as follow:

$$D_h = \frac{2HW}{H+W} \quad (9)$$

$$Re = \frac{\rho u_m D_h}{\mu} \quad (10)$$

Where μ, ρ, u_m, H and W are the fluid dynamic viscosity, fluid density, flow velocity, the height of the microchannel and the width of the microchannel, respectively. The heat transfer coefficient and Nusselt number are given by:

$$h = \frac{q}{T_f - T_w} \quad (11)$$

$$Nu = \frac{hD_h}{K_f} \quad (12)$$

where T_f, T_w, K_f and q are the temperature of the water/nanofluid, temperature of the copper base, thermal conductivity of the water/nanofluid and the heat flux per area.

The apparent friction factor can be expressed as follow:

$$f = \frac{2\Delta p D_h}{\rho L u_m^2} \quad (13)$$

where Δp and L are the pressure drop and the length of the microchannel.

3. Results and Discussion
3.1 Nusselt Number

Fig. 2 presents the correlational simulation result among the eight (8) measures of Reynold number based various speed range from 1.0m/s, 1.5m/s, 2.0m/s, 2.5m/s, 3.0m/s, 3.5m/s, 4.0m/s and 4.5m/s. There is clear trend increasing of Nusselt number which improve fluid convection when the Reynold number increasing as well. Besides, there was a significant different between two different type of microchannel which is straight channel (SC) and triangular cavities channel (TC) which lead the increasing of Nusselt number. When the small volume fraction for 1% and 2.5% of copper nanoparticles were added in water base fluid, no significant increase of Nusselt number as shown in Fig. 2.

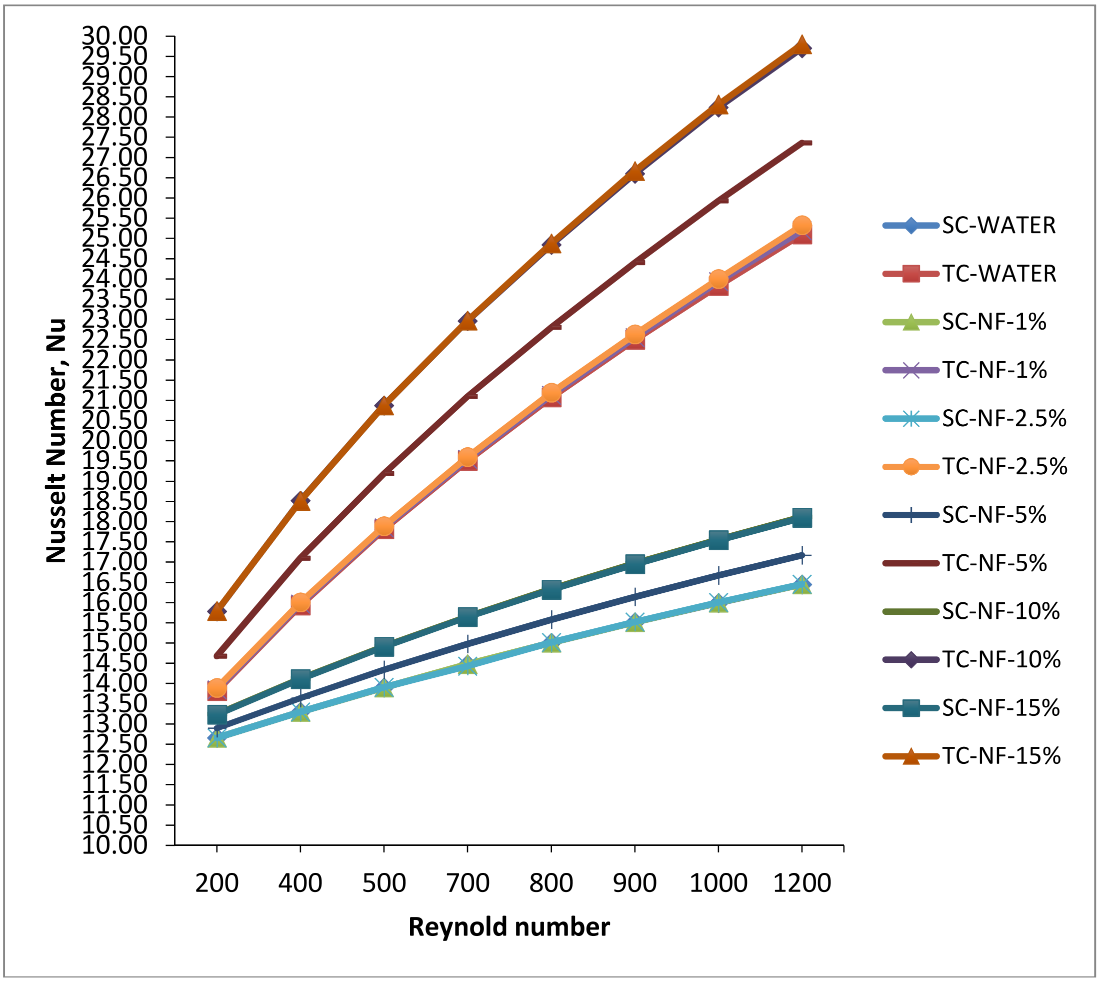

Fig. 2. The Nusselt number of SC and TC vs varying Reynold number (Re)

3.2 Pressure Drop

As shown in Fig. 3, the graph below illustrates the breakdown of pressure drop vs varying Reynold number (Re). The most interesting aspect of this graph is the pressure drop keep in increasing in triangular cavities (TC) compared with straight channel (SC) with varying volume fraction of the nanofluids. But surprisingly, the TC with every volume fraction of copper nanoparticle’s pressure drop is lower than SC but until Reynold number start from 1200 the TC’s pressure drop will more than SC.

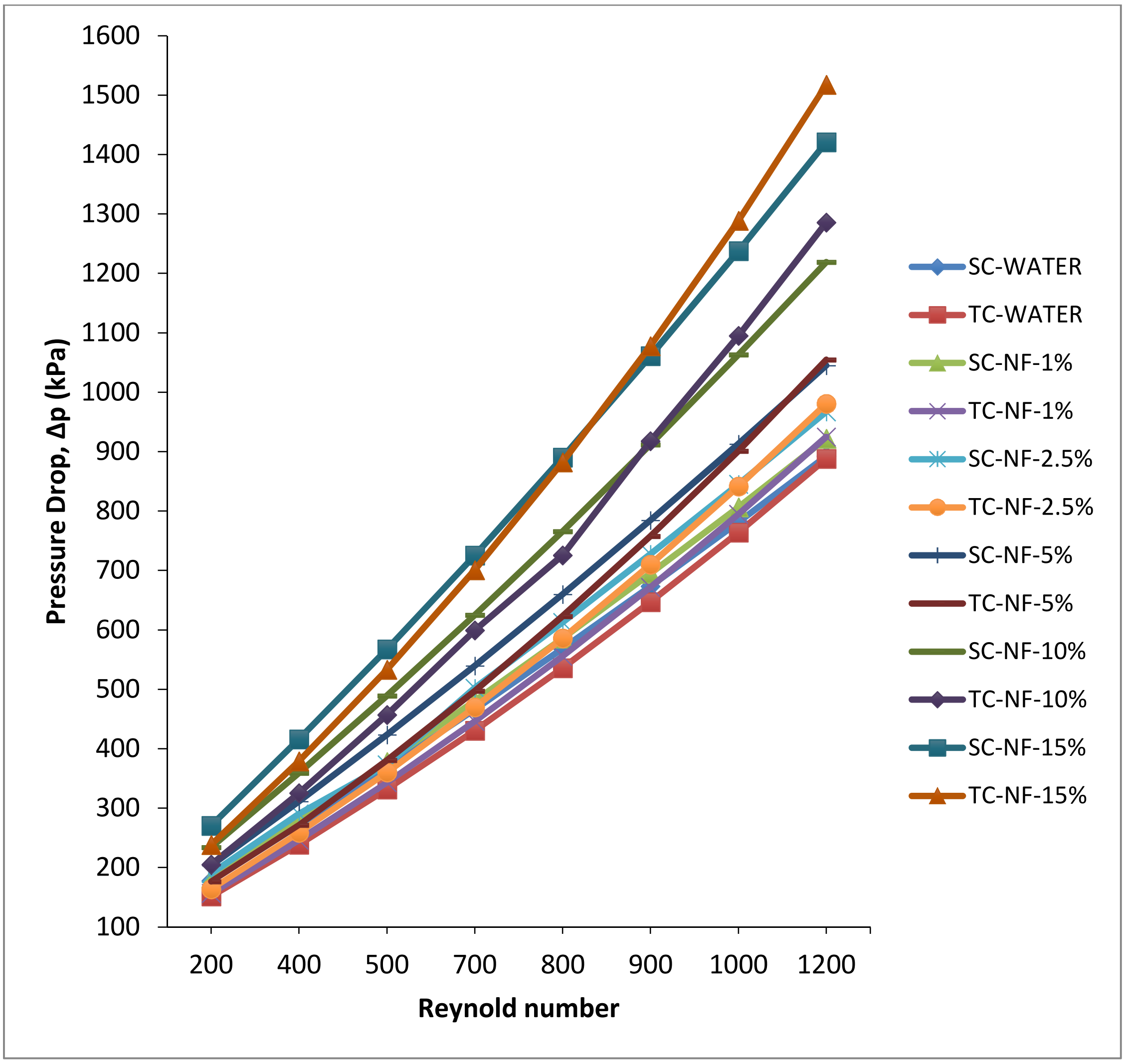

Fig. 3. Pressure drop of SC and TC vs varying Reynold number (Re)

4. Conclusion

This paper was set to determine the effect of triangular cavities and nanofluid on the thermal performance of microchannel heat sink. In general, it seems that triangular cavities channel with the highest volume nanofluids in the present study will lead to maximum increment of Nusselt number.

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