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Comparative Study of Heat Transfer and Friction Factor Characteristics of Nanofluids in Rectangular Channel

U. K. Ahmad[a]*, M. Hasreen[a], N. A. Yahaya, B. Rosnadiah

[a]*Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia*

Abstract

This paper reports numerical study of heat transfer and friction factor of laminar flow nanofluids characteristics in a rectangular channel. The effectiveness of metal oxide nanoparticles (Al_2O_3), metal nanoparticles (Cu) and semiconductor nanoparticles (SiO_2) in enhancing heat transfer rate were studied by varying volume fractions in the range of 0.5% to 2.5 % with constant nanoparticle diameter of 25 nm. Numerical method was used to solve the three-dimensional laminar flow and heat transfer governing equation. The computations were performed under constant heat flux (18,000 W/cm²) over range of Reynolds number (Re) 100 –1,000 laminar flow. The performances of nanofluids were evaluated in terms of velocity profile, heat transfer coefficient, pressure drop, and friction factor. The numerical results show that the heat transfer coefficients, thermal conductivity, pressure drop and mean velocity for all nanofluids increased with increasing Reynolds number as well as particle volume concentration, while the friction factor decreased.

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Keywords: Nanofluids; heat transfer; friction factor; rectangular channel; laminar flow

1. Introduction

Researchers are attracted in nanofluid capability of transmitting heat extra than the conventional fluids which valuable in many applications including microchannels, refrigeration, air conditioning even in automotive systems. Xuan and Li [1] experimental studies of heat transfer properties of nanofluids emphasized that adding up nanoparticles to base fluid increases the convective heat transfer coefficient. The heat transfer fluid plays as a critical role in heat transfer performance of heat exchange system.

Conventional heat transfer fluids such as water, ethylene glycol and oil usually have relatively poor thermal conductivity in evaluation with metal or metal oxide [2]. To enhance the heat transfer rate, the addition of solid particles into conventional heat transfer fluids has been well known in many years ago as one of the useful techniques [3]. Nevertheless, the fouling and wear problems of the solid–liquid suspension consisting micrometer or millimeter sized particles limit their application. To get to the bottom of these problems, a new class of heat transfer fluids named nanofluids is developed by dispersing nanoparticles in traditional heat transfer fluids [4].

The purpose of this project is to compare the effectiveness between metal oxide nanoparticles, metal nanoparticles and semiconductor nanoparticles in order to enhance the heat transfer rate and investigate the friction factor. There were no experimental set up for this project. The analysis focused on the effect of velocity, heat transfer coefficient, pressure drop, temperature and friction factor when range of volume fraction were varied from *0.5 %* to *2.5 %*.The nanoparticles used are alumina (Al_2O_3), silicon dioxide (SiO_2), and copper (Cu) with constant nanoparticles diameter ($25nm$).

* Corresponding author. Tel.: +6-035-543-5278; fax: +6-035-543-5160.
E-mail address: umikalsom@salam.uitm.edu.my

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2. Methodology

Vital consideration have been made to search the effective way in applying new cooling technologies to meet the requirement of dissipation rate and retain the low temperature region of electronic devices[6]. The performance of Cu/H_2O and SiO_2/H_2O nanofluids has been scrutinized by using mathematical formulation to compare the cooling performance. The 1.0 m long channel with a rectangular cross section area of 4.5 cm^2 heat sink operation is analyzed with the nanofluids serve as a working fluid. Thermophysical properties of the water and nanoparticles (Al_2O_3, Cu and SiO_2) at 30^{o}C, are shown in Table 1.

Table 1. Thermophysical properties of based fluid and nanoparticles.

Property	Water	Al_2O_3	SiO_2	Cu
Density, ρ (kg/m^3)	998.2	3970	2200	8933
Specific heat, Cp ($J/kg{\cdot}K$)	4182	765	703	385
Thermal conductivity, k ($W/m{\cdot}K$)	0.6	40	1.2	401
Dynamic viscosity, μ (kg/ms)	0.000598	-	-	-

2.1. Mathematical modeling

This study is greatly connected with heat transfer in closed system process. There are many equations with assumptions to apply in the investigation. The assumptions occur for the reason that of the design of channel has been produced. Laminar flow of Al_2O_3/H_2O, SiO_2/H_2O and Cu/H_2O nanofluid in a rectangular channel was studied numerically. The model presented was assumed to be fully developed, steady-state, laminar flow, homogeneous mixture, constant heat flux, neglecting x and y direction convective terms, and negligible radiation heat transfer.

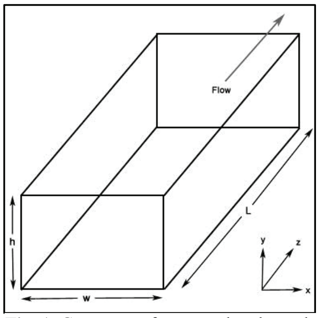

Fig. 1. Geometry of rectangular channel.

The subsequent non-linear governing equations stand for the mathematical formulation of the single phase model, which is contain conservation of mass, momentum, as well as energy meant for the nanofluids flow inside the rectangular channel.

Conservation of mass: $$div\,(\rho_{nf}\vec{\boldsymbol{V}}) = 0, \qquad (1)$$

Conservation of momentum: $$div\,(\rho_{nf}\vec{\boldsymbol{V}}\vec{\boldsymbol{V}}) = -\nabla P + \mu_{nf}\nabla^2\vec{\boldsymbol{V}}, \qquad (2)$$

Conservation of energy: $$div(\rho_{nf}\vec{\boldsymbol{V}}C_{nf}T) = div\,(k_{nf}\nabla T), \qquad (3)$$

Where $\boldsymbol{P}$, $\vec{\boldsymbol{V}}$ and $\boldsymbol{T}$ are corresponding to the fluid pressure, velocity vector and temperature; $\boldsymbol{\mu}$, $\boldsymbol{\rho}$, $\boldsymbol{C}$ and $\boldsymbol{k}$ are the dynamic viscosity, density, specific heat capacity and thermal conductivity respectively; subscript ***nf*** represent a nanofluid property. Every part of fluid properties is considered on the reference temperature.