International Communications in Heat and Mass Transfer 95 (2018) 161–170

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

A new approach to evaluate the impact of thermophysical properties of nanofluids on heat transfer and pressure drop

Ali H. Abdelrazek[a,*], Omer A. Alawi[b], S.N. Kazi[a,*], Nukman Yusoff[a,c], Zaira Chowdhury[d], Ahmed A.D. Sarhan[e]

[a] Department of Mechanical Engineering, University Malaya, Kuala Lumpur 50603, Malaysia
[b] Department of Thermofluids, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia UTM, 81310 Skudai, Johor Bahru, Malaysia
[c] Mechanical Engineering Department, College of Engineering, Qassim University, Buraidah 51452, Saudi Arabia
[d] Nanotechnology& Catalysis Research Center (NANOCAT), University Malaya, Kuala Lumpur, Malaysia
[e] Department of Mechanical Engineering, King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia

ARTICLE INFO

Keywords:
Nanofluids
Thermal conductivity
Dynamic viscosity
Thermal diffusivity
Momentum diffusivity
Turbulent flow

ABSTRACT

In this paper, an experimental and numerical study was conducted to evaluate the impacts of momentum and thermal diffusivity comparing to the thermal conductivity of various types of nanofluids on turbulent forced convection heat transfer. 1%, 2%, and 3% volumetric concentrations of different nanofluids such as Al_2O_3-DW, SiO_2-DW, and Cu-DW were considered in this study and their properties were evaluated numerically at the flow inlet temperature of 30 °C. The experimental works were conducted with distilled water as a working fluid to validate the 2-D numerical model. A two-dimensional domain was constructed using ANSYS-Fluent package, and the standard k–ε turbulence model was employed to solve the continuity, momentum, and energy equations. The flow was maintained in the Reynolds range between 6000 and 12,000, and the data obtained experimentally were validated by results from empirical correlations. The numerical solutions for the average Nusselt number and pressure drop presents a good agreement with the experimental results as the average error was less than 5% for both the cases of heat transfer and pressure loss data. The results showed that Al_2O_3-DW nanofluid has the best enhancement in convection heat transfer coefficient compared with the DW and other nanofluids of the same concentration while Cu-DW nanofluids shown the lowest enhancement though it shown the highest value of thermal conductivity. Also, the results showed that the product of kinematic and dynamic viscosities had the greatest effect on pressure drop in the fluid domain.

1. Introduction

Nanofluids consisting of metal oxides particles suspended in the base liquids (typically conventional heat transfer liquids) to enhance the thermal conductivity and convective heat transfer performance of the base liquids. The thermal conductivities of the material particle are typically an order-of-magnitude higher than those of the base fluids such as water, and nanofluids, even at low volume concentrations, resulting in significant increases in thermal performance [1–6]. Nanofluids have the potential to reduce such thermal resistances, where the industrial groups could be benefited from such improved heat transfer fluids.

The nanofluid does not mean a simple mixture of solid particles and the base fluid. The nanoparticles are prepared by dispersing the nanoparticles in a base fluid, proper mixing and stabilization of the particles are required. Basically, nanofluids are dilute suspensions of nanometer-sized particles that are less than 100 nm in diameter dispersed in a liquid. As a result, when compared to the base fluid, the changes in physical properties of such mixtures occur, e.g., viscosity, specific heat, density, and thermal conductivity [7].

Nanofluids contain typically the metal or metal oxide nanoparticles, such as copper (Cu), aluminium oxide–alumina (Al_2O_3), copper oxide (CuO), gold (Ag), silicon carbide (SiC), titanium carbide (TiC), titanium oxide (TiO_2) and the carbon based nanostructured nanomaterials. The most common metal oxide nanoparticles are Al_2O_3 and CuO. The base fluid is usually a conductive fluid, such as water, ethylene glycol or engine oil. Nanofluids commonly contain up to 5% volume fraction of nanoparticles to obtain effective heat transfer enhancements [8,9]. Of all the physical properties of nanofluids, the thermal conductivity is the most complex property, which in applications is the most important one. Interestingly, experimental findings have different results and theories which do not fully explain the mechanisms of elevated thermal

---

[*] Corresponding authors.
E-mail addresses: ali_hassan80@siswa.um.edu.my (A.H. Abdelrazek), salimnewaz@um.edu.my (S.N. Kazi).

https://doi.org/10.1016/j.icheatmasstransfer.2018.05.002

Nomenclature

Al_2O_3	Aluminium Oxide
C_f	Friction coefficient
C_p	Specific Heat, KJ/kg·K
Cu	Copper
D	Tube Diameter, mm
d_p	Nanoparticle Diameter, μm
DW	Distilled Water
f	Friction factor
h	Convection heat transfer coefficient, $W/m^2 \cdot K$
K	Thermal Conductivity, W/m·K
k	Turbulent kinetic energy
L	Annulus Computational Length, mm
n	Empirical shape factor for nanoparticle
Nu	Nusselt number
P	Pressure, Pa
Pr	Prandtl Number
q	Cylinder Heat Flux, W/m^2
Re	Reynolds number
SiO_2	Silicon Oxide
T	Temperature, K
T_b	Fluid bulk temperature, K
T_w	Tube wall temperature, K
u	Velocity component in x direction, m/s
v	Velocity component in y direction, m/s
V	Mean flow velocity, m/s

Greek symbols

α_{th}	Thermal diffusivity of the fluid, m^2/s
ε	Turbulent dissipation rate, m^2/s^2
ν	Momentum diffusivity or Kinematic viscosity, m^2/s
φ	Nanoparticles volume fraction (%)
μ	Dynamic viscosity, N·m/s
μ_t	Eddy viscosity, N·m/s
τ	Shear stress, Pa
ρ	Density, kg/m^3
ψ	Sphericity of nanoparticle

Subscript

b	bulk
bf	Base fluid
nf	Nanofluid
s	Solid
t	turbulence
th	thermal
f	Fluid
p	Particles
w	wall

conductivity.

Concerning theories/correlations which try to explain the thermal conductivity enhancement for all the nanofluids, is not a single model predicting a wide range of experimental data. However, many experimental data sets may fit between the lower and upper mean-field bounds, originally proposed by Maxwell where the static nanoparticle configurations may range from a dispersed phase to a pseudo-continuous phase [9–11].

Many researchers have reported experimental and numerical studies on the forced convection heat transfer using diverse metals and metal oxides nanopowders (Aluminium, Copper, Silicon, Tungsten and Al_2O_3, TiO_2, SiO_2 and their oxides) under different flow regimes. Most of the industrial thermal systems and devices consider constant heat flux approach for heat transfer analysis. So, this review focus on studies related to constant heat flux boundary conditions. This section presents the work done by various researchers, categorizing them into types of flow and further subcategorized on the basis of the nanoparticles used. The outcome from all the existing studies (experimental and numerical) has indicated that nanofluids have significantly augmented the heat transfer than those of base fluids with a moderate pressure drop penalty. An important investigation on turbulent convection of Al_2O_3 nanofluids was conducted by Lotfi et al. [12]. They studied numerically the forced convection in water/Al_2O_3 in the horizontal circular tubes. To show the validity of the results and the precision of their developed model, they validated their data with the existing correlations. They also compared the Nusselt number obtained from their experimental data with the results obtained from the previously used Gnielinski and Dittus–Boelter formulas. Their experimental study proposed three approaches for simulation of nanofluids, which includes the single-phase model, two-phase mixture model and Two-phase Eulerian model. Their results state that the mixture model was found better in comparison with other two models. Further, they added that the rate of thermal augmentation decreases on increasing volume concentration of nanoparticles.

Bianco et al. [13] used finite volume method to study the steady state turbulent forced convection flow of water/Al_2O_3 nanofluid in a circular tube. Firstly, they synthesized water/Al_2O_3 nanofluid by single phase and mixture models. They performed experiments on 38 nm diametric particles and reported that the addition of nanoparticles may lead to better heat augmentation as compared with the base fluids. An increase in heat transfer was also noticed on increase in Reynolds number and particle loading. Moreover, their results seem quite good when compared with the data from the Pack and Cho correlations. Higher heat transfer was obtained at 6% particle loading.

Thermal characteristics of Water/Ethylene Glycol (60:40)-Al_2O_3 nanofluids in turbulent forced convection were numerically studied by Bayat et al. [14]. Experiments were performed in the Reynolds number of 10^4 to 10^5. Particles volume fraction had much affected the heat transfer rate, pressure drop, Prandtl number, thermal effectiveness of the nanofluids. Also, a rise in heat transfer coefficient was observed with the increase in concentration of nanoparticles and Reynolds number. At a constant pumping power and higher viscosity, heat transfer was found decreased on the addition of nanoparticles.

Sahin et al. [15] performed their numerical study to evaluate the pressure drop and steady state heat transfer behaviour for turbulent flow in a wavy channel with amplitude of 0.005 using Al_2O_3–water nanofluid with volume concentrations of 0.5%, 1%, 2% and 4%. Results demonstrate that the concentrations of Al_2O_3 particles higher than 1 vol % were not appropriate for heat transfer enhancement. At larger concentrations, the viscosity growth of the nanofluids was pre-dominating the thermal conductivity. Heat transfer augmentation was observed with increasing of the Reynolds number and the volume concentration. With the exception of the particle volume concentrations of 2 and 4% and at $Re = 8000$, the enhancement was highest.

Suresh et al. [16] used sol–gel method to synthesize the prepared CuO nanoparticles and stimulated the experimental work to study heat transfer and friction factor characteristics. Firstly, nanofluid with a volume concentration of 0.1%, 0.2% and 0.3% were synthesized. Experiments were conducted to study the effects of nanofluids on the Nusselt number and the friction factor. Studies reported a maximum of 29.63% rise in the heat transfer coefficient. They also developed a correlation which satisfies their experimental results within ± 7.5%.

Coefficient of heat transfer and friction factor with SiO_2/water nanofluid up to 4% particle volume concentration were determined by