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Experimental investigation of nanoparticle mixture ratios on TiO_2–SiO_2 nanofluids heat transfer performance under turbulent flow

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ABSTRACT

The new class of fluids namely nanofluids are highly desirable in the enhancement of thermal properties. Various studies were carried out based on their greater thermal performance. The nanofluids are also beneficial in improving the heat transfer performance of devices or systems that require cooling operations. However, the performance of nanofluids with dispersion of two or more different nanoparticles is limited in the literature. Hence, the present study was carried out to investigate the heat transfer performance of TiO_2–SiO_2 nanofluids for various nanoparticle mixture ratios dispersed in a water/ethylene glycol (W/EG) mixture. The convection heat transfer experiment is conducted under turbulent region with Reynolds number from 3000 to 24,000. Five composite mixtures in volume percent of TiO_2 and SiO_2 nanoparticles are prepared with mixture ratios (TiO_2:SiO_2) of 20:80, 40:60, 50:50, 60:40 and 80:20 for a constant volume concentration of 1.0%. The heat transfer performance and friction factor were evaluated for the bulk temperatures of 30, 50 and 70 °C. High performance was seen at a 40:60 mixture ratio with heat transfer enhancement of 35.32% at 70 °C temperature. The mixture ratio of 50:50 showed the least enhancement of 9.02% in heat transfer coefficient for a working temperature of 30 °C. Furthermore, the friction factor of the nanofluids is practically negligible due to the small increment. As a conclusion, the nanoparticle mixture ratios of TiO_2–SiO_2 nanofluids contributed to the overall performance of heat transfer. It was recommended to use 20:80 and 40:60 mixture ratios of TiO_2–SiO_2 nanofluids in heat transfer systems.

1. Introduction

Nanofluids can be defined as a suspension of nano-sized particles in a conventional base fluid. Earlier studies conducted by Masuda et al. [1] and Choi [2] have initiated the potential of nanofluids as an effective heat transfer fluid. Research on nanofluids that covered from the thermal properties to the heat transfer performance has increased rapidly. The reports revealed that nanofluids are beneficial heat transfer fluids for various engineering applications [3–6]. Meanwhile, the hybrid or composite nanofluids is defined as dispersion of two or more types of nanoparticles into the base fluid. Sundar et al. [7] categorized the hybrid (composite) nanofluid into three main types which are (a) metal matrix nanocomposites, (b) ceramic matrix nanocomposites, and (c) polymer matrix nanocomposites. The preparation methods of hybrid nanofluid can be varied and combined with several chemical processes since it consists of two (or more) elements of nanoparticles. Previous studies used preparation methods such as chemical reduction techniques, ball milling, mechanical milling, plasma treatment and chemical vapour deposition [8–12].

Hybrid nanofluids have novel properties which have been studied at various concentrations and temperatures. Several reviews associated with thermo-physical properties were presented by Sundar et al. [7], Ganvir et al. [13] and Nabil et al. [14]. Some studies conducted on the investigation of thermal conductivity with several factors affected the properties. Han et al. [15] studied hybrid carbon nanotubes (CNT) attached to alumina/iron oxide sphere and dispersed in poly-alpha-olefin. The measurement was undertaken for temperatures ranging from 10 to 90 °C. They obtained an enhancement of 21% for a volume concentration of 0.2%. The diffusive heat conduction and thermal conductivity of CNT contributed to the augmentation. Suresh et al. [16] studied the Al_2O_3–Cu/water nanofluids of volume concentrations from

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Nomenclature

A	area
$\overline{A}_r$	absorbance ratio (ratio of final absorbance, $\overline{A}$ to initial absorbance, $\overline{A}_0$)
ASHRAE	American Society of Heating, Refrigeration and Air-conditioning Engineer
C	specific heat
d	diameter
EG	ethylene glycol
f	friction factor
h	heat transfer coefficient
k	thermal conductivity
L	length
$\dot{m}$	mass flow rate
Nu	Nusselt number
ΔP	pressure drop
Pr	Prandtl number
$\dot{Q}$	power
R	volume fraction of single TiO_2 or SiO_2 nanofluid in mixture TiO_2-SiO_2
Re	Reynolds number
T	temperature
TEM	transmission electron microscopy
UV–Vis	ultraviolet visible
V	voltage
v	velocity
W	water

Greek symbols

ϕ	volume concentration, %
μ	dynamic viscosity, mPa·s
ϕ	volume fraction
ρ	density, kg/m^3
ω	weight concentration, %

Subscript

b	bulk
bf	base fluid
Bl	Blasius
DB	Dittus-Boelter
nf	nanofluid
exp	experimental
p	nanoparticle
r	ratio
s	surface

0.1 to 2%. Al_2O_3 and Cu nanoparticles were mixed together with the weight ratio of 90:10. At 2% concentration, the maximum enhancement of thermal conductivity was observed to be up to 12.11% compared to single Al_2O_3-water nanofluids. The study also obtained a significant increase in thermal conductivity ratios with increasing concentration. They stated that the formation of larger particle-free regions in the liquid offer greater thermal resistances by the agglomerated particles. For that reason, the thermal conductivity of Al_2O_3–Cu/water nanofluids improved significantly.

In another study, Madhesh and Kalaiselvam [17] used Cu–TiO_2 hybrid nanoparticles and dispersed in water-based coolants. The thermal conductivity of the coolant is improved by about 48.4% with 0.7% concentration and resulted in enhancement of conductive heat transfer. They found that the surface functionalized and the highly crystalline nature of the hybrid nanofluid contributed to the enhancement of thermal conductivity. Furthermore, several studies on the viscosity of hybrid nanofluids were conducted in the recent years [10,18–23]. Minea et al. [18] conducted a numerical investigation on Al_2O_3, TiO_2 and SiO_2 nanoparticles in water-based fluids. They used a constant ratio of Al_2O_3 (25%) mixed with TiO_2 (75%) or SiO_2 (75%) for nanofluid preparations of 0.5, 1.0 and 1.5% volume concentration. The discrepancy appeared between those combination mixtures due to the method of calculation. Bahrami et al. [19] conducted a study on the rheological behaviour of Fe–CuO nanofluids in water-ethylene glycol (EG) at proportions of 20:80 (vol.%). The range of concentrations and temperatures studied were 0.05–1.5% and 25–50 °C, respectively. The results showed that the nanofluid samples exhibited Newtonian behaviour at low concentrations. However, the shear thinning occurred for high concentrations thus indicating non-Newtonian behaviour.

Previous researchers have conducted investigations on the heat transfer performance of single nanofluids and hybrid nanofluids [5,24–27]. They studied the heat transfer performance with variations of different parameters such as concentration, flow region either laminar or turbulent, as well as the nanofluid properties. For single TiO_2 nanofluids, an experimental study was conducted by Duangthongsuk and Wongwises [28] and they used a horizontal double-tube counter flow heat exchanger. They prepared TiO_2/water nanofluids at 0.2% volume concentration. Their investigations were conducted at Reynolds number range of 4000 and 18,000. They found that the heat transfer performance of TiO_2 nanofluids in their study was about 6–11% higher than the base fluids of water. Suresh et al. [25] investigated the convective heat transfer using Al_2O_3-Cu/water nanofluid for laminar regions. The maximum enhancement of Nusselt number was reported to be up to 13.6% in comparison with water. In another study, Takabi et al. [26] conducted heat transfer investigations of Al_2O_3–Cu/water nanofluid for Reynolds number of up to 100,000 and a concentration range of $0\% \le \phi \le 2\%$. The heat transfer enhancement approached 32.1% higher than the base fluid. Later, a numerical study by Moghadassi et al. [29] using Al_2O_3–Cu/water nanofluids obtained up to 13.5% heat transfer enhancement in comparison with water. Their CFD modelling was investigated in the laminar region for Reynolds number of less than 2500 and a constant heat flux of 9549 W/m^2.

From the authors' knowledge, there is no comprehensive study in literature for forced convection heat transfer that has conducted various ratios of the two nanoparticle components in hybrid or composite nanofluids. Therefore, the present study is carried out for the investigation of the effects of two nanoparticle mixture ratios on the overall heat transfer performance of TiO_2–SiO_2 nanofluids. The experimental study is conducted for 1.0% volume concentration with five nanoparticle mixture ratios (TiO_2:SiO_2) of 20:80, 40:60, 50:50, 60:40 and 80:20. The experimental working temperature was set from 30 to 70 °C to widen the temperature effect on the heat transfer performance.

2. Methodology

This section describes the preparation of TiO_2-SiO_2 nanofluids. Further, the measurement and estimation of thermo-physical properties, and experimental method for forced convection heat transfer are explained in details. Lastly, the pressure drop and fric-