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Convective heat transfer characteristics of water–ethylene glycol mixture with silver nanoparticles

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ABSTRACT

We report the convective heat transfer characteristics of water–ethylene glycol mixture fluids seeded with silver nanofluids under laminar, transitional and turbulent regime in this work. The volume concentrations of silver nanoparticles viz. 0.05%, 0.1%, 0.15%, 0.3% and 0.45% are considered. Thermophysical properties measurements such as thermal conductivity, viscosity, density and specific heat capacity were carried out using conventional techniques. Convection measurements were carried out in a tube in tube counter flow heat exchanger using nanofluids as the hot fluid. The effect of nanofluid mass flow rate ranging from 5 g/s to 45 g/s and inlet temperature of nanofluid at 35 °C and 45 °C on the convective heat transfer coefficient were investigated. The convective heat transfer coefficient was considerably increased with increasing Reynolds number, particle concentration and inlet temperature. The maximum enhancement of convective heat transfer coefficient of nanofluid is observed to be ~42% at 0.45 vol% compared with pure basefluid. The pressure drop of nanofluid increases marginally for a nanofluid volume concentration up to 0.15 vol%. When compared with the base fluid, the difference of pressure drop is insignificant so that the use of nanofluid has limited penalty on the pressure drop up to 0.15 vol% loading of silver nanoparticles. However, beyond 0.15 vol% the pressure drop increases significantly which limits the use of these nanofluids at higher concentration for engineering applications.

1. Introduction

Heat removal is a major technical challenge faced by numerous industries such as automobiles, power generation, HVAC, electronics and manufacturing. New technological developments are increasing the thermal loads and require faster cooling. The traditional methods in increasing the cooling rate (use of fins, mini/micro channels, etc.) are already stretched to a great extent. Today, the automobile industry continuously faces the challenges to obtain best automobile design in the aspects of performance, fuel consumption, safety, etc. The thermal performance of an automobile radiator plays a significant role in the performance of the cooling system and all other associated systems.

Ethylene glycol has been popularly used as an antifreeze heat transfer fluid in chillers because of its compatibility with metals and better heat transfer characteristics. A simple method of reducing the freezing point of water is to dissolve ethylene glycol in the water. Water (H_2O) and ethylene glycol (EG) mixtures are used to cooling the engines in automotive applications [1] and widely used as a secondary refrigerant in industrial refrigeration systems (chillers) [2]. Generally it is recommended to have at least 30% concentration of ethylene glycol for automotive application [3]. Choi et al. [4] described a new class of heat transfer fluids (nanofluids) that exhibit thermal properties superior to those of the conventional heat transfer fluids. Although pure ethylene glycol and water–ethylene glycol mixture has been used for over several decades as a heat transfer fluid and there is only limited information available in the published literature on its heat transfer characteristics with different nanoparticles. A comprehensive understanding of the trends and the dominant factors affecting the heat transfer and transport process in nanofluids is essential for design and development.

Peyghambarzadeh et al. [1] studied the Nusselt number of Al_2O_3/water, Al_2O_3/EG and Al_2O_3/H_2O–EG ($\varphi = 0.05\%$, 0.15% and 0.3%, 0.7%, 1%) nanofluids in the car radiator. Water and ethylene glycol mixture was used as the basefluid, with 5%, 10% and 20% volume fractions of ethylene glycol. The maximum enhancement of Nusselt number was reported to be 40% for 1 vol% of Al_2O_3. Authors suggested that addition of nanoparticles to the coolant has the prospect to improve heavy-duty and automotive engine cooling rates

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Nomenclature

Cp	specific heat (J/kg K)
k	thermal conductivity (W/m K)
T	temperature (°C)
ΔT	change in temperature (°C)
T_{hi}, T_{ho}	hot fluid inlet and outlet temperatures (°C)
T_{ci}, T_{co}	cold fluid inlet and outlet temperatures (°C)
Q	heat transfer rate (W)
d_i, d_o	inside and outside diameter of the inner tube (m)
A_i, A_o	surface area of the inner tube and outer tube (m^2)
L	length of the tube (m)
D_h	hydraulic diameter (m)
m	mass flow rate (kg/s)
V	velocity (m/s)
g	size of the particle
w	weight fraction of the particle (%)

Greek symbols

μ	dynamic viscosity (kg/m s)
υ	kinematic viscosity (cSt)
ρ	density (g/cm^3)
φ	volume fraction (%)
α	thermal diffusivity (m^2/s)

Subscript

bf	base fluid
nf	nanofluid
P	particle

Abbreviation

Ag	silver
Ag/H_2O–EG	silver/water–ethylene glycol mixture nanofluid
EG	ethylene glycol
H_2O	water
MWCNT	multi walled carbon nanotubes
CHTC	convective heat transfer coefficient
Nu	Nusselt number
vol%	volume fraction of the nanoparticles

and equally removes the engine heat with a compact cooling system.

Ding et al. [5] studied the heat transfer characteristics of aqueous/spherical titania, ethylene glycol/spherical titania, and aqueous based carbon nanotubes, titanate nanotubes, and nanodiamond nanofluids. The results show that the enhancement of heat transfer coefficient for aqueous/titania nanofluids, carbon and titanate nanotubes nanofluids was exceeded by a large margin to the extent of the thermal conduction enhancement. The enhancement of thermal conductivity and effects of particle migration on the thermal boundary layer thickness are reported to be possible mechanism for the heat transfer enhancement.

Some studies have been carried out by several researchers [6–12] on the heat transfer characteristics of water–ethylene glycol mixture and ethylene glycol based nanofluids with oxide nanoparticles and found that convective heat transfer coefficient (CHTC) significantly increases with respect to particle volume concentration. The maximum enhancement of convective heat transfer coefficient was observed to be 105% for the H_2O–EG (60:40) based nanofluid with volume fraction of TiO_2 at $\varphi = 0.5\%$ [11]. Minimum enhancements of convective heat transfer coefficient were observed for other oxide nanoparticles at higher volume concentration. Studies on convective heat transfer characteristics of pure water and ethylene glycol with metallic nanoparticles have been carried out by several researchers [13–15]. Kumaresan et al. [16] performed the heat transfer characteristics of MWCNT/H_2O–EG (70:30) nanofluids and reported that the convective heat transfer coefficient was enhanced to a maximum of 160% for 0.45 vol% MWCNT.

From the published literature, it is clearly seen that convective heat transfer co efficient enhancement is higher with presence of pure metallic nanoparticles and high aspect ratio nanoparticles (CNT) compared with the metallic oxide nanoparticles. This is due to the fact that high thermal conductivity of metallic particle and high aspect ratio nanoparticle (CNT) significantly enhances the thermal conductivity of nanofluid than metallic oxide nanoparticles. Thermal conductivity and heat transfer coefficient significantly increases with higher volume concentration of metallic oxide nanoparticles but this will increase the viscosity of the nanofluid. Hence the use of metallic nanoparticles with low volume concentration overcomes this problem. It is also observed that limited work has been done using ethylene glycol–water based metallic nanofluids. However, no work has been reported till date by using pure silver metal nanoparticles suspended in water–ethylene glycol mixture. The convective heat transfer characteristics of nanofluids suspended with metallic nanoparticles namely silver with low volume concentration suspended in water–ethylene glycol mixture will be the aim of this study. Silver nanoparticle has been selected due to its high thermal conductivity when compared to other metallic nanoparticles. In this study, the enhancement of convective heat transfer characteristics of a Silver/H_2O–EG nanofluid flowing in the tube side of a tube in tube counter flow heat exchanger was experimentally studied.

2. Experimentation

2.1. Preparation of nanofluids

In the present study, two-step method was used for preparation of Ag/H_2O–EG nanofluid. Water and ethylene glycol mixture containing 70% volume of water and 30% volume of ethylene glycol was used as a basefluid in this study. Generally, for automobile applications it is recommended to have at least 30% volume concentration of ethylene glycol in water to reduce the freezing point of water. Addition of more ethylene glycol in the water will increase the viscosity significantly. Hence, we used 30% volume concentration of ethylene glycol in water to reduce the freezing point with minimum increase in viscosity value. Silver nanoparticles were purchased from Sigma Aldrich, India (product number 576,832, silver nanopowder, size <100 nm, 99.5% metals). As per the specifications provided by the manufacturer, the size of silver nanoparticles lies below <100 nm. Independent verification using Scanning electron microscope indicated that the size distribution of the nanoparticles lies in the range of 30–90 nm. Scanning electron microscope visualization (SEM) and X-ray diffraction (XRD) pattern of silver nanoparticles are shown in Fig. 1. The high intensity peak for FCC materials is generally (1 1 1) reflection and is shown by the silver nanoparticles. The intensity of the peaks reflected the crystalline characteristic of the silver nanoparticles. The XRD pattern shows the four diffraction peaks at 38.74°, 44.95°, 65.06° and 77.81° corresponding to (1 1 1), (2 0 0), (2 2 0) and (3 1 1) reflections of FCC silver respectively.