Abstract— Suspensions of nano-sized particles (<100 nm) in base fluid are termed as Nanofluids, which are believed to be the promising coolant in heat transfer applications due to their enhanced thermal conductivity. In this study, the enhancement in heat transfer of CNT nanofluids under turbulent flow conditions was investigated experimentally. Carbon nanotube (CNTs) nanofluids of 0.051-0.085 wt%, stabilized by optimum concentrations of gum Arabic were used as hot fluid in a concentric tube turbulent flow heat exchanger. The flow rates of cold fluid (water) was varied from 1.7 - 3 L/min and flow rates of the hot fluid (nanofluid) is varied between 2 - 3.5 L/min. Thermal conductivity, density and viscosity of the nanofluids were also studied as a function of temperature and CNT concentration. Enhancements in the heat transfer were validated with conventional heat transfer correlations for turbulent flow available in the literature. Results showed an enhancement in heat transfer range between 9 - 67% as a function of temperature and CNT concentration.

Keywords— Nanofluids, Carbon nanotubes (CNT), gum Arabic, heat transfer enhancement, heat exchanger

1. Introduction

In the past decade, researchers had discovered the techniques to disperse ultrafine particles or nano-sized particles in conventional base fluids. Examples of nanoparticles are metals, metal oxides, graphene and CNT [1, 2]. Presence of these nanoparticles with high thermal conductivity enhanced the thermal properties of conventional heat transfer fluid/coolant such as water, ethylene glycol (EG) and oil, eliminating the need of increasing the power or extending the heat transfer surface. Nano-sized particles are preferable compared to micro-sized particles which are prone to clogging, erosion, and sedimentation.

2. Experimental

2.1. Preparation of Nanofluids

Three different concentrations (0.051 wt%, 0.068 wt%, and 0.085 wt%) of CNT nanofluids stabilized with optimum concentration of gum Arabic (GA) as dispersant are used in this experimental study. Nanofluids were homogenized for 10 minutes using a high speed homogenizer (IKA-T18, ULTRA-TURRAX, Germany) and sonication of 4 hours in a ultrasonic bath (Crest Ultrasonics, USA) to obtain stable suspensions.

2.2. Thermophysical Properties

Convective heat transfer performance is related to the thermophysical properties of nanofluids. The thermal conductivity, viscosity, and the density of nanofluids were studied with respect particle concentration and temperatures (25 to 55 °C). Thermal conductivity was measured using a thermal conductivity meter (KD2 Pro, Decagon device, USA).

A viscometer (DV-11+Pro, Brookfield, USA) was used for viscosity measurement. Density of nanofluids were measured using a density meter (DA-130N, Kyoto Electronics, Mexico).

2.3. Convective Heat Transfer Experimental Setup

Experimental studies of convective heat transfer were carried out in a concentric tube heat exchanger as shown in Fig. 1. Inlet of cold fluid (tap water) is connected to the water tap and outlet is left to drain, whereas the hot fluid (nanofluid) is stored in a built-in reservoir. Flow rates of both cold and hot stream were controlled by two built-in flow meters. Setup consists of six thermometers mounted on the inlet, middle, and the outlet of both cold and hot tubes. Experiments were carried out with respect to concentration by varying the flow rates of cold and hot fluids from 1.7 L/min – 3 L/min and 2 L/min – 3.5 L/min, respectively.

3. Results and Discussion

3.1. Thermophysical Properties

(a) Thermal Conductivity

Fig. 1 below shows the thermal conductivity ratio of nanofluids to base fluid water with respect to temperatures at three different CNT concentrations. It can be concluded that thermal conductivity increases with increasing temperature and CNT concentration. Thermal conductivity enhancement of 69 – 250% is observed compared to water, mainly due to the presence of high thermal conductivity of CNT nanoparticles.

(b) Viscosity

From Fig. 2 below it is observed that viscosity decreases with increasing temperature. Viscosity is slightly higher for higher concentration nanofluids, however viscosity of nanofluids are significantly higher when compared to water due to presence of nano-sized particles. At higher temperatures, the forces between the CNT nanoparticles and the base fluid weakened, causing a decrease in viscosity value [1].
(c) Density

Referring to Fig. 3 below, there is a negligible decrease in density with temperature. Nanofluids have slightly higher density than water due to the presence of low concentration of CNT nanoparticles and GA.

3.2. Convective Heat Transfer Experiment

Prior to conducting heat transfer studies using nanofluids, experimental results conducted using water is compared to the theoretical Gnielinski correlation [3] to determine the reliability of the experimental set-up. Analysis is performed by comparing the Nusselt number between the experimental values and theoretical values obtained from Gnielinski correlation. An acceptable error within 15% is observed as shown in Fig. 4.

An overall enhancement of 9 – 67% in heat transfer rate is achieved for the three nanofluid concentrations at 0.085, 0.068 and 0.051 wt%. Fig. 5 shows that Nusselt number increases with increasing Reynolds number and nanofluid concentrations. Enhancement of heat transfer can be associated with the enhancement of thermal conductivity.

3.3. Theoretical studies

Referring to Fig. 7 below, experimental Nusselt number obtained showed a good agreement with the Gnielinski [3] and Pak & Cho [4] correlation, but differs significantly when compared with Duangthongsok and Wongwises [5] correlation. Differences can be explained by the effect type nanoparticles, shape of nanoparticles, as well as the range of temperature measured [1].

4. Conclusion

Stable CNT nanofluids were prepared using GA as a dispersant. An overall enhancement of 69-250% in thermal conductivity was observed as a function of CNT concentration and temperature compared to water. However, viscosity increases due to presence of nanoparticles and GA. Negligible increase in density is observed. 7-202% enhancement in heat transfer is observed using CNT nanofluids compared to water. Experimental results validated with available correlation showed good agreement.

References