Experimental Investigations on Thermal Enhancement of Multi Walled Carbon Nanotubes

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ABSTRACT

As multi walled carbon nanotubes exhibit thermal conductivities which are thousands of times greater as compared to the basic fluids used in heat transfer applications, such as water, ethylene glycol, and mineral oil, they proposes an extended capabilities for enhancement in heat transfer. Experimental investigation outcomes for the tests conducted on MWCNT nanofluids are presented in this paper. The volumetric concentration of mineral water based MWCNT nanoparticles were varied from 0.05% to 0.2%. Tests were performed under the criteria of uniform heat flux in the complete flow region from laminar to the turbulent comprising maximum Reynolds number of almost 18,450. Constant temperature was ensured at the inlet of test section by providing adequate cooling system in the outlet of experimental test unit. Maximum enhancement of almost 38% in the heat transfer has been recorded with 0.2% concentration by volume of MWCNT nanofluid at the highest flow rate.

Keyword: - *Heat Transfer Coefficient, MWCNT, Reynolds Number, Nanofluids, Nusselt Number*

1. INTRODUCTION

The introduction of nanofluids was given in the year 1995 by Steve Choi [1] who belongs to Argonne's Division of Energy Technology and Jeff Easterman who belongs to Division of materials science at National laboratory of Argonne. The very first attempt to inserting particles comprising of micrometer size had proposed several problems, few of which includes abrasion, obstruction of channels and settling down of the particles. Modern nanotechnology has provided this opportunity to prepare Nanoparticles and hence the Nanofluids, which were observed to remain in stable form in the suspensions but under specific conditions. In last few decades, the exponential rise which has been observed in regards to the research publications in the field of nanofluid heat transfer clearly certifies the extensive usage of this nanotechnology in recent years.

Base fluids having uniformly dispersed solid particles in it, is termed as nanofluid which exhibits an extended potential in enhancing the thermal performance of base fluids of heat transfer. The maximum enhancement in the thermal conductivity was observed with carbon nanotubes emulsions (CNT), which carries a very high aspect ratio of closely 2000. There are basically two types of carbon nanotubes, as single walled carbon nanotubes (SWCNTs) and multi walled carbon nanotubes (MWCNTs). Out of these two types, SWCNTs have a thermal conductivity of 6000 W/m.K and MWCNTs have a thermal conductivity of 3000 W/m.K., which signifies the potential of carbon nanotubes in improvising thermal conductivities of the heat transfer base fluids which are generally water, ethylene glycol and mineral oil, etc. [2]

2. LITERATURE SURVEY

Apart from MWCNT nanofluids, many researches have conducted their experimentation with oxide forms of nanofluid, a few of which have been included at the start of this section. Heris *et al* [3] and Almohammadi *et al* [4] have studied the thermal behavior of water based Al_2O_3 nanofluid and reported an increase in heat transfer rate by using nanofluid in the tested range of laminar flow pattern. Experimental study of heat transfer enhancement for Al_2O_3 nanofluid in the turbulent flow regime was carried out by Sajadi and Dizaji [5] and M. H. Kayhani *et al* [6]. Kalbasi and Saeedi [7] have conducted numerical analysis of thermal behavior CuO nanofluids with water as base fluid. Experimental as well as numerical analysis of thermal behavior of Al_2O_3, SiO_2, and TiO_2 nanofluids was performed by Hussein *et al* [8]. Hamid *et al* [9] have studied the thermal behavior of TiO_2 nanofluid dispersed in ethylene glycol base fluid. Thermal characteristics of water based Fe_3O_4 nanofluid have been experimentally evaluated by Aghayari *et al* [10]. All these researches report a rise in heat transfer enhancement with the use of nanofluids as compared to that of base fluid.

Wan *et al* [11] have experimentally analyzed the effective enhancement of thermal conductivity for multi walled carbon nanotubes. They have conducted studies for lower volumetric concentrations of MWCNTs ranging from 0.01 % to 0.05 % using deionized water as a base fluid. They concluded that formation of CNT chains having much higher thermal conductivities in the medium were responsible for sudden enhancement in thermal conductivity at the 0.03% volumetric concentration at lower temperatures. They have reported an enhancement in terms of thermal conductivity as the temperature and volumetric concentration increases. Gupta *et al* [12] had reviewed the enhancement reported by different researchers for the experimental studies conducted on varied nanofluids under the uniform heat flux conditions. Majority of the researchers had reported an enhancement in heat transfer with increase in volumetric concentration of nanofluids and as well as with increase in the Reynolds number.

Contribution of different researchers in analyzing the thermophysical behavior of nanofluids had been summarized by various researchers such as Kakac and Pramuanjaroenkij [13], Motevasel *et al* [14], Balla *et al* [15], Kamel [16] and Wang *et al* [17]. Mechanism behind heat transfer enhancement with nanofluids had been discussed in detail by Keblinski *et al* [18] and Ranakoti *et al* [19]. Convective heat transfer for turbulent flow region and related drop in pressure for CNT nanofluids were experimentally investigated by Fallahiyekta *et al* [20]. Maximum concentration by volume of 0.1% was used with the highest Reynolds number of 20,000. Maximum enhancement of 102% in coefficient of heat transfer was observed at the Reynolds number of 5700 and decrease in performance was reported for further rise in Reynolds number. Enhancement in heat transfer associated with considerable increase in pressure drop was observed by Chougule and Sahu [21] for the tests conducted in laminar flow region. Water based Al_2O_3 and CNT nanofluids were used along with helical type screw tape inserts. Maximum heat transfer enhancement with CNT nanofluids was observed at the twist ratio of 1.5.

Behabadi *et al* [22] have conducted experimentation in the turbulent flow region for investigating the enhancement in heat transfer and associated pressure drop for water based MWCNT nanofluids equipped with coiled wire inserts. An average increase of 85% in coefficient of heat transfer along with pressure drop of 47.5% were reported for the largest Reynolds number with largest wire diameter of wired coil insert. Variations of density and other thermophysical properties like specific heat, thermal conductivity and viscosity for MWCNT with base fluid as a mixture of water and ethylene glycol was studied by Kumar *et al* [23]. Maximum of 11% enhancement in thermal conductivity was reported for the nanofluid having concentration of 0.9% by weight.

Fakoor-Pakdaman *et al* [24] experimentally investigated pressure drop behavior for MWCNT nanofluids that were flowing in a helically coiled vertical tube. Tests were conducted in laminar flow region. They observed that pressure drop increases with increase in Reynolds number and also quoted that pressure drop increase was observed with the increase in weight based nanoparticle concentration. Fallahiyekta *et al* [25] have conducted experiments at constant heat flux of 1500 Watts and reported maximum enhancement of 25% in the thermal conductivity for water based CNT nanofluids. Experimental investigations of dependence of thermophysical properties of MWCNT nanofluids on the ultrasonication duration, temperature range and type of surfactant used is done by Rad Sadri et.al. [2]. It was reported that as the sonication time was increased, the nanofluid thermal conductivity was found to be increased. Maximum thermal conductivity was reported to be observed at 45^0C temperature and 40 mins of sonication time.

M. Piratheepan and T. N. Anderson [26] have conducted experimental study on MWCNT nanofluids to investigate heat transfer characteristics in turbulent flow regime. They have reported that the overall coefficient of heat transfer using MWCNT decreases; on the other hand pumping power requirement increases for the turbulent flow regime. Thus they suggest that, use of MWCNT nanofluids is not suitable for enhancing the heat transfer in turbulent flow region. Improvements in convective heat transfer coefficient for MWCNT nanofluids had been experimentally investigated by F. Rashidi and N. Mosavari Nezamabad [27]. They reported that this enhancement is dependent on the axial distance measured from inlet and tends to decrease from inlet to outlet.

In the current experimentation, effect of MWCNT nanofluid concentration on heat transfer enhancement in the flow region ranging from laminar to turbulent were investigated and compared with pure water flow inside a horizontal circular tube.

3. EXPERIMENTATION

For nanofluid preparation, direct method is used i.e. required weight of nanoparticles which is to be added for preparing nanofluid samples with concentration of 0.05 %, 0.1 %, 0.15%, and 0.2% were firstly evaluated. After that, the emulsion of nanoparticles in water was kept in Ultrasonicator to carry out sonication for around 2 to 3 hours with alternate on/off cycle comprising of 18 Seconds on time and 2 Seconds off time.

Experimental set up comprises of Reservoir, Pump, By-pass valve, Rotameter, Test Section, Cooling unit, U-Tube Manometer, Thermocouples, and Display units as shown in Figure 1, which represents the pictorial view of experimental set up . Test section was comprising of smooth horizontal tube made up of copper having length of 1000 mm and outer diameter and inner diameter of 16 mm and 14 mm respectively. Electrically insulated heating wire of Nichrome material was uniformly wrapped along the test section for 800 mm length leaving uniform distance from both the ends of test section. Both ends of heating coil were then attached to the power supply which heats the test section uniformly and the heater input can be adjusted with the help of Dimmer-Stat. Complete test section and thermocouples were wounded with thick glasswool insulation to eliminate the heat losses to surrounding. Rotameter was used for recording the flow rate of working fluid in LPM. Thermocouples were attached at different points for recording the temperatures which are displayed on the display unit.

Figure 1: Pictorial view of Experimental Set-up

4. EXPERIMENTAL TEST PROCEDURE

Experimentation was conducted under the criteria of constant heat flux which was maintained as 588 Watts during the entire experimentation process. Firstly the tests were performed with mineral water as working fluid and the flow rates were changed from 0.5 LPM to 9 LPM for which Reynolds number ranges from 1240 to 18,120. All the displayed temperatures were noted down at every flow interval after ensuring steady state conditions. After that MWCNT nanofluids were prepared and experimented one by one by performing the same procedure. Volumetric concentrations of MWCNT nanoparticles used in the nanofluids during experimentation were 0.05%, 0.1%, 0.15% and 0.2%. With every sample, flow rates were varied and corresponding readings were charted.

5. RESULTS AND DISCUSSION

Graphical representations of the thermal enhancement obtained as a result of using the MWCNT nanofluids to that of mineral water has been shown in Figure 2 to Figure 5.

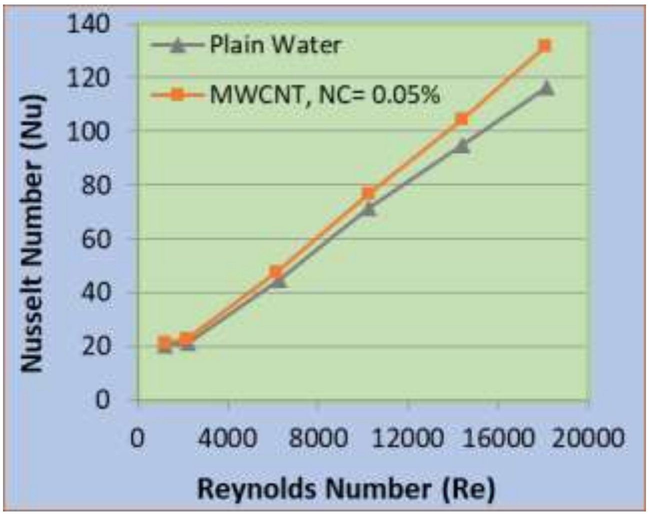

Figure 3: Nusselt Number Versus Reynolds Number at Volumetric Concentration of 0.05%

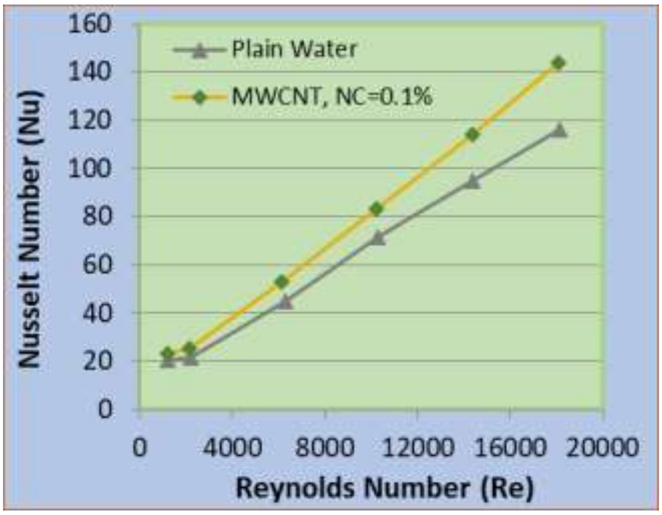

Figure 2: Nusselt Number Versus Reynolds Number at Volumetric Concentration of 0.1%

The variation in Nusselt number with the Reynolds number are shown in Figure 2 for MWCNT nanofluids and base fluid i.e. mineral water. The Reynolds number varies from 1237.19 to 18122.46 as the flow rate of water was varied from 0.5 LPM to 9 LPM respectively. For MWCNT nanofluid, the Reynolds number varies from 1236.33 to 18109.89 for the same flow rate variations. Maximum Nusselt number of 131.47 and 116.32 were observed for MWCNT and water respectively at the highest flow rate of 9 LPM under consideration for a volumetric concentration of 0.05%. Maximum and minimum enhancements in heat transfer reported were 5.79% and 8.82% respectively at 0.05% volumetric concentration of MWCNT nanofluids. At the volumetric concentration of 0.1%, Reynolds number was observed to vary from 1235.48 to 18097.35 for MWCNT nanofluid as shown in figure 3. The enhancement in heat transfer was observed to vary from 13.13% to 23.77% as the flow rate was varied from 0.5 LPM to 9 LPM as compared to that of distilled water for MWCNT nanofluids having volumetric concentration of 0.1%.

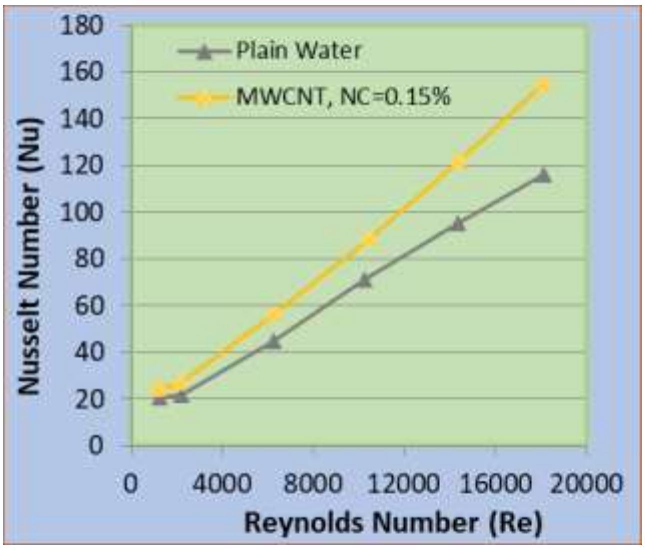

Figure 4: Nusselt Number Versus Reynolds Number at Volumetric Concentration of 0.15%

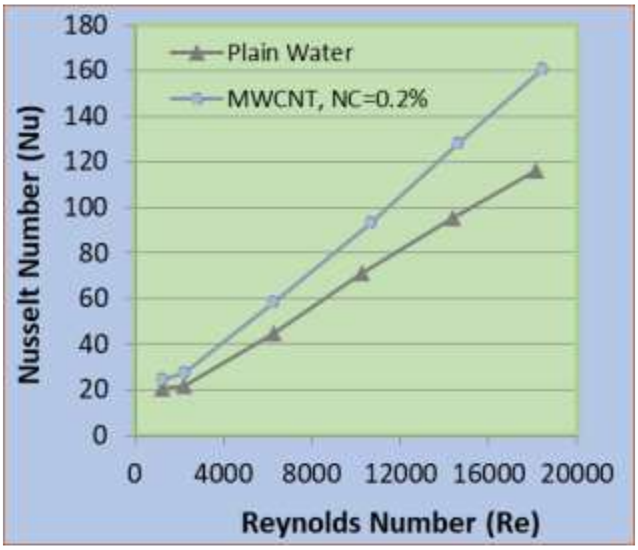

Figure 5: Nusselt Number Versus Reynolds Number at Volumetric Concentration of 0.2%

Nusselt number was observed to vary from 24.25 to 154.45 as the flow rate was varied from 0.5 LPM to 9 LPM with the corresponding Reynolds number varying from 1213.16 to 18084.85 at the volumetric concentration of 0.15% of MWCNT nanofluids as shown in Figure 4. A minimum and maximum enhancement in heat transfer of 20.85 and 32.78 were observed at this concentration. For the maximum volumetric concentration of 0.2% under considerations, a maximum of 37.92% rise in thermal performance in terms of increase in Nusselt number has been recorded for MWCNT nanofluids as compared to that of distilled water. Maximum Nusselt number of 160.43 has been recorded at the maximum Reynolds number of 18435.60 for 0.2% volumetric concentration of MWCNT nanofluids as can be observed from Figure 4.

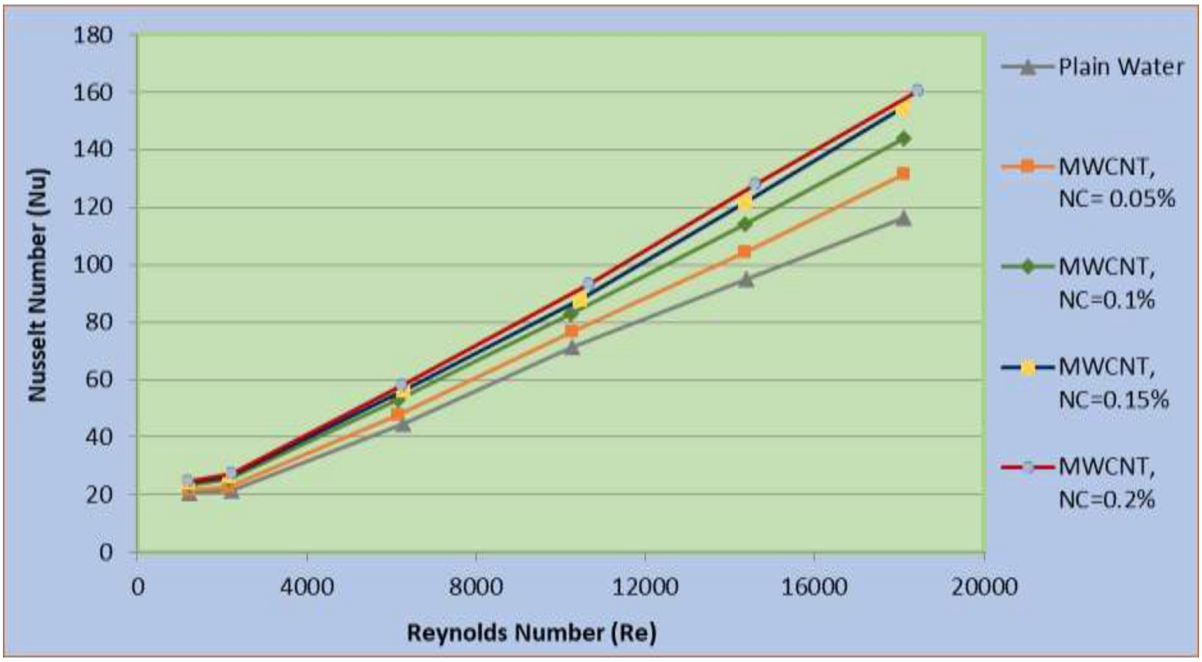

Figure 6: Nusselt number versus Reynolds number for water and MWCNT nanofluid at varied volumetric concentrations

Figure 5 shows the changes in the Nusselt Number as the Reynolds Number was varied for the MWCNT nanofluids having the volumetric concentration of 0.05%, 0.1%, 0.15% and 0.2% with that of mineral water. Heat transfer enhancement obtained using MWCNT nanofluids over that of the distilled water is found to be increasing as the volumetric concentration of the nanoparticles in the nanofluid increases. Also, heat transfer enhancement was found to be increased at a particular concentration with increase in Reynolds number obtained as a result of increasing the flow rate from 0.5 LPM to 9 LPM. The enhancement in heat transfer in terms of increase in Nusselt number was observed to vary from 4.88% to that of 37.92% during the tested range of MWCNT nanofluids.

6. CONCLUSIONS

The following points can be concluded from the research work carried out with mineral water based MWCNT nanofluids.

In the laminar region, the heat transfer enhancements due to MWCNT nanofluids were found to be less, whereas; in turbulent regions much higher enhancements of heat transfer were recorded.

Heat transfer coefficient and hence the Nusselt number was found to be increasing with the increase in Reynolds number except for few cases.

Heat transfer enhancement was found to be increasing with the increase in the volumetric concentration of MWCNT nanofluids and the maximum enhancement in Nusselt number of 37.92% was observed at the volumetric concentration of 0.2% having the Reynolds Number of 18,435.60 at the flow rate of 9 LPM.

Nomenclatures :

CNT = Carbon nanotubes
Cp = Specific heat
d = Inside diameter of test section tube
f = Friction factor
h = Heat Transfer Coefficient
k = Thermal Conductivity
L = Length of test section tube
LPM = Litres per minute

NC = Nanoparticle Volumetric Concentration
Nu = Nusselt Number
Pr = Prandtl number
Re = Reynolds Number
SWCNT = Single walled carbon nanotubes
ULP = Ultrasonic Probe Sonicator
μ = Dynamic viscosity

MWCNT = Multi walled carbon nanotubes

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