

Heat Transfer Enhancement of Multi-Walled Carbon Nanotubes and Al_2O_3 Nanofluids in a Smooth Tube

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Abstract - Experimental investigation outcomes for the MWCNT nanofluids and its comparison with the test results of Al_2O_3 nanofluids are presented in this paper. Since multi-walled carbon nanotubes are having thermal conductivities which are thousands of times more than that of basic fluids for heat transfer, it has a great potential for enhancing the heat transfer. The volumetric concentration of mineral water-based MWCNT nanoparticle was varied from 0.05% to 0.2% whereas for Al_2O_3 it ranges from 0.2 to 1%. Tests were conducted under uniform heat flux conditions in the complete flow regime from laminar to turbulent with the maximum Reynolds number of around 20,000. The uniform temperature at the test inlet section was ensured by providing an adequate cooling system at the outlet section of the experimental setup. Maximum enhancement in heat transfer of around 38% was observed with 0.2% volumetric concentration of MWCNT nanofluid at the flow rate of 9 LPM having Reynolds number of 18,072. On the other hand, maximum enhancement at the same volumetric concentration of 0.2% for Al_2O_3 nanofluid was 33% at the Reynolds number of 14,464. For Al_2O_3 nanofluid maximum enhancement of 47.75% was observed at the volumetric concentration of 1% having Reynolds number of 14,488.

Key Words: Heat Transfer Coefficient, Reynolds Number, Nanofluids, Nusselt Number, Volumetric Concentration

1. INTRODUCTION

The introduction of nanofluids was given in the year 1995 by Steve Choi and Jeff Easterman belonging to Argonne's Division of Energy Technology [1]. Most of the researchers have reported that the coefficient of heat transfer obtained by means of using nanofluids is observed to be much higher as compared to that of commonly used base fluids with, in some cases little and in few cases no penalty in pressure drop [2]. The basic reason behind this enhancement is that solid particles have thermal conductivities values which are several times more than that of commonly used base fluids for heat transfer applications. As a result, we can observe the higher thermal conductivities for nanofluids as compared to that of base fluid due to the presence of these highly conductive solid nanoparticles.

Metals, in particular, pure metals, exhibit a large value of thermal conductivity than base fluids but it has been observed that they undergo oxidation which is non-avoidable when they are manufactured. Hence it is more convenient to use oxide forms of nanoparticles rather than its pure form for preparation of nanofluids owing to economic considerations and easiness in manufacturing. Amongst the various available forms of metal oxides, Al_2O_3 , TiO_2 , and CuO are mostly preferred in practical applications. The practical usage of Al_2O_3 nanoparticles is very common amongst the researchers due to their additional feature of easiness of availability having purity in the range of 94 to 99.8%. The property of having a lower density of Al_2O_3 nanoparticles had been highly demanded since it results in an improvement in the dispersion stability of these nanoparticles in the base fluid. In general, it can be commented that the lower cost, easiness in manufacturing, higher thermal conductivities and improved suspension stabilities are the major key considerations behind the most often usage of these nanoparticles in practical as well as an experimental applications by varied range of researchers [3].

The highest enhancement in terms of thermal conductivity can be observed with the carbon nanotubes suspensions (CNT), which are having a very high aspect ratio of nearly 2000. There exist two categories of carbon nanotubes namely single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs). Amongst these two, SWCNTs are having thermal conductivity of the order of 6000 W/m.K and MWCNTs are having thermal conductivity of around 3000 W/m.K., which gives a clear indication that the carbon nanotubes have the potential for improvising the thermal conductivity of the basic heat transfer fluids which generally includes water, mineral oil, and ethylene glycol etc. [4].

Experimental investigations to compare thermal performance analysis for Al_2O_3 and MWCNT nanofluids have been presented in this paper. The flow rate was varied from 0.5 LPM to 9 LPM resulting in Reynolds number range from 900 to 20,000. Thus entire flow regime from laminar to turbulent has been covered and tests were conducted under uniform heat flux conditions.

2. LITERATURE SURVEY

S. Suresh et al had compared the performance of water-based Al_2O_3 and CuO nanofluids with respect to enhancement in heat transfer [5]. An average enhancement of 10.22% and 18.19% in Nusselt numbers were reported for water-based Al_2O_3 and CuO nanofluids respectively. Investigations for a performance of cooling for microchannel heat sink were conducted by C. J. Ho. et al by using Al_2O_3 nanofluid [6]. At Reynolds number of 1641 with 1% of the volumetric concentration of nanofluid, maximum enhancement of 53% in heat transfer was reported. Heris et al [7], Almohammadi et al [8] and Sajadi & Dizaji [9] have studied the thermal behavior of Al_2O_3 nanofluids and reported an increase in heat transfer rate by using nanofluids in place of the base fluid. An experimental study of heat transfer enhancement for Al_2O_3 nanofluid in the turbulent flow regime was carried out by and M. H. Kayhani et al [10]. Kalbasi and Saeedi [11] have conducted a numerical analysis of the thermal behavior of water-based CuO nanofluids. 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 [12]. Hamid et al [13] 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 studied by Aghayari et al [14]. Most of the researches have reported an increase in heat transfer enhancement with the use of nanofluids as compared to that of the base fluid.

The performance of Al_2O_3 nanofluid equipped with twisted tape inserts was evaluated by L. Shyam Sunder [15]. Around 50% increment in heat transfer was observed for in the tested laminar regime at the maximum Reynolds number of 2200. S. N. Ramteke et al [16] have performed experimentation using Al_2O_3 nanofluid having the volumetric concentration of 0.1, 0.3 and 0.5% using distilled water as the base fluid. They had reported maximum enhancement with respect to heat transfer at the concentration of 0.3%. Experimental analysis of Al_2O_3 nanofluid with transformer oil was performed by Anuj Khullar [17] et al having a maximum volumetric concentration of 0.5%. The maximum enhancement of 246% with reference to the heat transfer coefficient was reported with 0.5% volumetric concentration and at the flow rate of 30 LPH.

Ahmad Azari et al [18] performed experiments on Al_2O_3 nanofluid with butterfly tube insert. The maximum enhancement in Nusselt number was reported as high as 345%. Experimental evaluation of SiO_2 and TiO_2 nanofluids with water as base fluid was conducted by W. H. Azmi [19] et al. P. C. Mukesh Kumar et al have carried out tests on water-based Al_2O_3 nanofluid. At 0.8% concentration by volume of the nanofluid, it was reported that the overall coefficient of heat transfer and inner coefficient of heat transfer & Nusselt numbers are 24%, 25% & 28% higher respectively as differentiated with water [20]. The contribution of different researchers in analyzing the thermal behavior of nanofluids had been summarized by various researchers such as Kakac and Pramuanjaroenkij [21], Motevasel et al [22], Balla et al [23], Kamel [24], and Wang et al [25]. The mechanism behind heat transfer enhancement with nanofluids had been discussed in detail by Keblinski et al [26] and Ranakoti [27] et al.

Experimental investigations for heat transfer enhancement of Al_2O_3 nanofluids were performed by H. Almohammadi et al [28]. They had reported a maximum enhancement in terms of average coefficient of heat transfer of 27% at the volumetric concentration of 1%. D. Mala et al [29] have conducted an experimental study of Al_2O_3 nanofluids having a volumetric concentration of 0.1%. They have concluded that twisted tape having holes at regular intervals gives better results in terms of heat transfer enhancement as compared to that of twisted tape having knurling impressions on it. Experimental investigations of heat transfer enhancement for Al_2O_3 nanofluids were performed by Heydar Maddah et al [30]. They have reported a maximum enhancement in heat transfer of 52% when RGPR twists were employed with Al_2O_3 nanofluids as compared to simple twisted tape inserts without nanofluids. M. Pourrajabi et al have numerically investigated the heat transfer characteristics for Al_2O_3 nanofluids [31]. They concluded that the coefficient of heat transfer increased with the increase in the volumetric concentration of the nanofluid and the diameter of nanoparticles with little penalty in terms of friction factor.

Wan et al have experimentally investigated the effective enhancement of thermal conductivity for multi-walled carbon nanotubes [32]. They reported an abrupt enhancement in thermal conductivity at the volumetric concentration of 0.03% at lower temperatures. Gupta et al had reviewed the enhancement reported by different researchers for the experimental studies conducted on varied nanofluids under the uniform heat flux conditions [33]. Experimental analysis of CNT nanofluids was performed by Fallahiyekta et al [34] with a horizontal tube that was equipped with wired coil inserts. The maximum enhancement of 102% in the coefficient of heat transfer was observed at the Reynolds number of 5700. Enhancement in heat transfer associated with a considerable increase in pressure drop was observed by Chougule and Sahu [35] for the tests conducted in the laminar flow region on water-based Al_2O_3 and CNT nanofluids.

Behabadi et al have conducted experimentation on water-based MWCNT nanofluids equipped with coiled wire inserts [36]. An average increase of 85% in coefficient of heat transfer along with a pressure drop of 47.5% was reported for the largest Reynolds number with the largest wire diameter of wired coil insert. Variations of density and other thermo-physical properties like specific heat, thermal conductivity and viscosity for MWCNT with base fluid as a mixture of water and ethylene glycol were studied by Kumar et al [37]. Fakoor-Pakdaman et al experimentally investigated pressure drop behavior for MWCNT nanofluids in the laminar flow regime [38]. Fallahiyekta et al have conducted experiments on CNT nanofluids with water as base fluid and reported maximum enhancement of 25% in the thermal conductivity [39].

Experimental investigations of the dependence of thermo-physical properties of MWCNT nanofluids on the ultrasonication duration, temperature range and type of surfactant used is done by Rad Sadri et al [4]. M. Piratheepan and T. N. Anderson [40] have conducted an experimental study on MWCNT nanofluids. 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. Improvements in the convective heat transfer coefficient for MWCNT nanofluids had been experimentally investigated by F. Rashidi and N. Mosavari Nezamabad [41]. They reported that this enhancement is dependent on the axial distance measured from the inlet and tends to decrease from inlet to outlet.

In the current experimentation, the effect of MWCNT and Al_2O_3 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. Constant heat flux criterion is used while performing the experimentation and the entire flow regime is covered from laminar to turbulent flow.

3. EXPERIMENTAL SET-UP AND TEST PROCEDURE

Experimental set up as shown in fig. 3.1 comprises of Reservoir, Pump, Rotameter, Test Section, U-Tube Manometer, Cooling unit, Thermocouples, and Display units. The test section comprises a horizontal copper tube having 1000 mm length, with 16 mm Outer diameter and 14 mm inside diameter. Electrically insulated heating wire made up of Nichrome, was uniformly wound along the 800 mm of the test section leaving equal distance at both the ends of the test section. The complete test section and thermocouples were wound with thick glasswool insulation to eliminate the heat losses to the surrounding. Rotameter is used to record the flow rate of fluid in LPM. Thermocouples are attached at different locations to record the temperature which is displayed on display unit.

Experimentation is carried out under constant heat flux conditions with heater input of 588 Watts which is kept constant throughout the experimentation process. Tests were conducted with plain water without nanofluid and flow rates were varied from 0.5 LPM to 9 LPM for which Reynolds number ranges from 900 to 20,000. All the temperatures displayed were recorded at each flow interval after achieving steady-state conditions. Water leaving the test section is first passed through the riser section and then sufficiently cooled in the cooling unit so as to bring its temperature back to inlet temperature so as to ensure a constant temperature at the inlet section throughout the investigations. MWCNT and Al_2O_3 nanofluid samples were prepared and tested one by one by repeating the same procedure. Volumetric concentrations of nanoparticles used in nanofluids for experimentation were 0.05% to 0.2% for MWCNT nanofluids and from 0.2% to 1% for Al_2O_3 nanofluids.



Fig. 3.1: Pictorial view of Experimental Set-up

4. RESULTS AND DISCUSSION

Experimentation was conducted with MWCNT nanofluids for varied volumetric concentration. Fig. 4.1 shows the changes in the Nusselt Number as the Reynolds Number was varied for the MWCNT nanofluids having a volumetric concentration of 0.05%, 0.1%, 0.15%, and 0.2% with that of plain 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 an increase in Reynolds number.

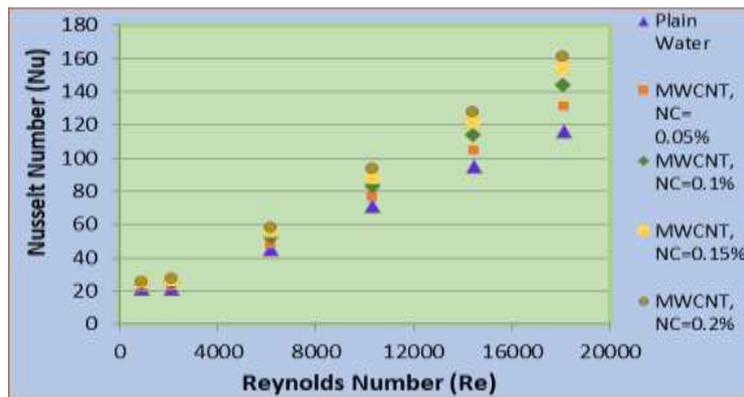


Fig. 4.1: Nusselt number variation with Reynolds number for MWCNT Nanofluids

The same experimental process is repeated for Al_2O_3 nanofluid at each volumetric concentration. Fig. 4.2 shows the changes in the Nusselt Number as the Reynolds Number was varied for the Al_2O_3 nanofluids having a volumetric concentration of 0.2%, 0.4%, 0.6%, 0.8%, and 1% with that of plain water. Heat transfer enhancement obtained using Al_2O_3 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 an increase in Reynolds number.

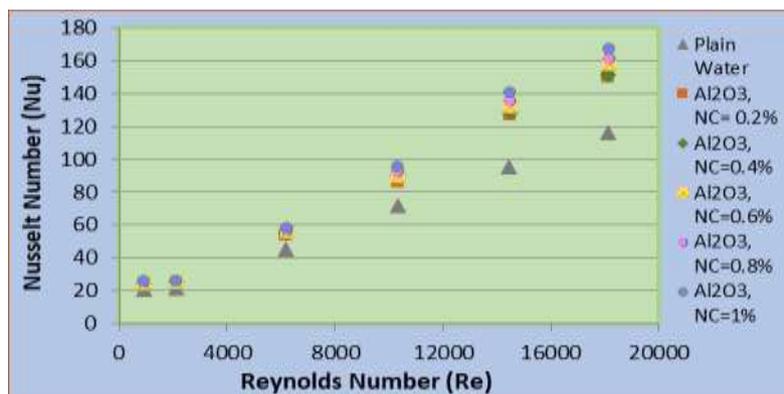


Fig. 4.2: Nusselt number variations with Reynolds number for Al_2O_3 nanofluids

When the thermal performance of Al_2O_3 nanofluid was compared with MWCNT nanofluids for the same volumetric concentration of 0.2%, it has been observed that MWCNT has much higher enhancements in heat transfer than that of Al_2O_3 nanofluids as can be observed from Fig. 4.3. The enhancement for Al_2O_3 nanofluid ranges from 14.71% to 29% when the nanofluid flow rate was varied from 0.5 LPM to 9 LPM. On the other hand for the same set of input variables, the enhancement recorded was 20.58% to 38.31%. For MWCNT nanofluids. At the Reynolds number of 2138, the enhancement obtained by MWCNT nanofluid is nearly twice (85.3%) than that of enhancement obtained by Al_2O_3 nanofluid under the same operating parameters of 0.2% volumetric concentration.

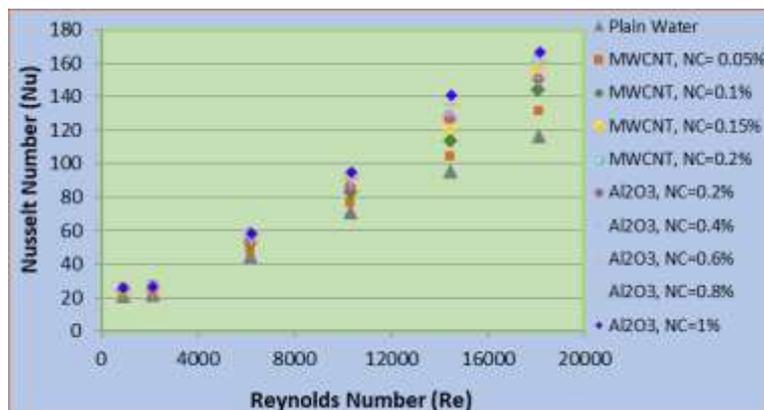


Fig. 4.3: Nusselt number variations with Reynolds number for Plain water, Al_2O_3 nanofluid and MWCNT nanofluid at varied volumetric concentrations

For MWCNT nanofluid, in Turbulent flow region, gradual increase in heat transfer enhancement can be observed, whereas; in case of Al_2O_3 nanofluids it has been observed that when the Reynolds number changes from 6,000 to 10,000 enhancement in terms of increase in Nusselt number was found to be very much lower and as the Reynolds numbers changes from 10,000 to 15,000, a sudden rise in heat transfer enhancement was observed. Maximum heat transfer enhancement of 47.75% was reported for Al_2O_3 nanofluid at the Reynolds number of 14,488 with a volumetric concentration of 1%.

5. CONCLUSIONS:

The following points can be concluded from the research work carried out with water-based MWCNT and Al_2O_3 nanofluids.

- 1) In the laminar region, the heat transfer enhancements due to both MWCNT and Al_2O_3 nanofluids were found to be less, whereas; in turbulent regions much higher enhancements of heat transfer were recorded.
- 2) Heat transfer coefficient and hence the Nusselt number was found to be increasing with the increase in Reynolds number except for few cases in laminar flow regimes.
- 3) 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 27.7% was observed at the volumetric concentration of 0.2% at the Reynolds Number of 18,072.
- 4) Maximum heat transfer enhancement in the case of Al_2O_3 nanofluids was observed between Reynolds number of 10,000 to 15,000 having a volumetric flow rate of 5 to 7 LPM for all the combinations of volumetric concentration and flow rates under study.
- 5) With Al_2O_3 nanofluid, maximum enhancement in terms of increase in Nusselt number of the order of 47.75% has been observed with the nanoparticle volumetric concentration of 1% at the volumetric flow rate of 7 LPM having the Reynolds number of 14,488.

6. NOMENCLATURES

CNT = Carbon nanotubes

MWCNT = Multi walled carbon nanotubes

C_p = Specific heat

NC = Nanoparticle Volumetric Concentration

d = Inside diameter of test section tube

Nu = Nusselt Number

f = Friction factor

Pr = Prandtl number

h = Heat Transfer Coefficient

Re = Reynolds Number

k = Thermal Conductivity

SWCNT = Single walled carbon nanotubes

L = Length of test section tube

ULP = Ultrasonic Probe Sonicator

LPM = Litres per minute

μ = Dynamic viscosity

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