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Research Paper

CONVECTIVE HEAT TRANSFER CHARACTERISTICS OF GRAPHENE DISPERSED NANO FLUIDS

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Nano fluids are having wide area of applications in heat transfer equipments. In the present work graphene nanoparticles, Dispersed in De-ionized water (DI), Ethylene Glycol (EG) based nano fluids were developed. Thermal conductivity and convective heat transfer properties of these nanofluids were systematically investigated. In the present investigation thermal convection of glycol based nanofluids with different volumetric concentrations and fractions is experimentally determined in the temperature range of 30 °C to 80 °C graphene nano particles with average particle size of 11 nm-15 nm is used for the preparation of glycol based nano fluids. Basefluid used in the present investigation is 70% water and 30% ethylene glycol by weight. Thermal convection of graphene nano fluids is measured for different volume concentrations in the range of 0.2%-1.0% of nano particles. Based on the experimental results It is concluded that thermal convection of graphene nanofluids considered in the present investigation increases with increase in percentage of volume concentrations of graphene particles at different temperatures. These results provide insights in the increase of convective heat transfer in the base fluid temperatures.

Keywords: Thermal convection, Ethylene glycol + water, Graphene nano particles, Graphene nano fluid, Base fluid

INTRODUCTION

Many of the industries using conventional fluids such as water, engine oil, De-ionized water (DI), Ethylene Glycol (EG),Transformer oil etc are generally used as heat transfer fluids. The duration period and life time of the equipment is based upon the performance and efficiency of the heat transfer fluids. The low heat transfer performance of these conventional fluids reduces the performance and enhancement due to this the size of the heat exchanger may be increases and the experiments proved that the conventional fluids have low thermal conductivity compared to solid parts, so in

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substitute of the conventional fluids. Solid particles with high thermal conductivity are generally added as an additive to the conventional fluids to increase their thermal conductivity. How ever the addition of the macro and micro sized particles can create problems like clogging, sedimentation and agglomeration etc.To avoid these problems Choi *et al.* (2001) and Eastman *et al.* (2001) introduced a new type of fluid called nano fluid. A nano fluid is prepared by dispersing- solid nano particles in a base fluid. It can also be described as colloids since a colloid is a substance made up of a system of particles that is insoluble yet remains in the solution and dispersed in another fluid medium. The concept of increasing the thermal conductivity and convective heat transfer of fluids by suspending solid particles in the base fluid could be traced to the theoretical work by Max (1881), and the continuum of studies on suspension of solid particles in base fluid for heat transfer applications has been reported, Lee *et al.* (1999) properties of copper oxide and almuninum oxide nano fluids and measured their thermal conductivity using the transient hot wire method. Many research groups have worked on the thermal conductivity and heat transfer mechanism of different nano materials with dispersed nano fluids, several groups have shown increase in thermal conductivity with Al_2O_3,TiO_2 and Cuo nano particles dispersed water and EG based nano fluids (Wang *et al.*, 1999; and Das *et al.*, 2003). But in our investigation we are going to find out the convective heat transfer characteristics of graphene dispersed nano fluids. The enhancement in thermal conductivity depends on several parameters like size, shape, PH of base fluid,Temp of the working fluid, presence of surfactants, additivies,and concentration of nano materials and formation of colloids, and type of flow (laminar and turbulent) shape of the pipe in the heat exchanger, etc. Since the graphene is a derivative of carbon it works as good heat absorbent. So by using this nano fluids we can reduce the size of the entire unit and there by increasing the efficiency of the unit, Hence it is necessary to determine the heat transfer performance of graphene nano fluid flow under steady state thermal conductivity measurements the heat transfer measurements have been carried out, Yang *et al.* (2005) studied the heat transfer performance of several nano fluids under laminar conditions in a horizontal tube heat exchanger, Heris *et al.* (2006) found heat transfer enhancement as high as 40% with Al_2O_3 particles theoretical studies of thermal conductivity on graphene suggests that it is having un usual thermal conductivity (Mingo and Broido, 2005; and Ding *et al.*, 2006).

PREPARATION OF NANO FLUIDS

Various methods have been came into existence for to the preparation of different kinds of nano particles and nano suspensions with different shapes and different sizes (nm) there are mainly two techniques used to produce nano fluids the single-step and the two step method, the single step is based on the physical, chemical and laser-based methods Inert-Gas Condensation (IGC) method can produce 2-200 nm sized particles are available for the production of the nano particles required for nano fluids. The major problem with this method is its tendency to form aggloments and its un stability to produce pure metallic nano powders, DEC method (Direct Evaporation Condensation). It provides excellent control over particle size and produces particles for stable nano fluids without surfactants, laser vapour deposition technique, chemical vapour deposition, sol-gel technique, ball milling technique are available.

The two step method is extensively used in the synthesis of nano fluids considering the available commercial nano powders supplied by several companies. In this method nano particles was first produced and then dispersed in the base fluids for to avoid the co-agulation and agglomeration ultra sonic equipment is used to intensively disperse the particles and reduce the agglomeration of the particles except for the use of ultra sonic equipment some other techniques such as control of PH or addition of surface active agents are also used to attain stability of the suspensionof the nano fluids against sedimentation. These methods change the surface properties of the suspended particles and then suppress the tendency to form particle clusters. It should be noted that selection of surfactants should depend mainly on the properties of the base fluid and particle for the preparing the graphene nano fluid 70% water (DI) and 30% ethylene glycol by weight with 2 gm of Sodium Dodecyl Sulfate (SDS) acts as an surfactant. The surfactant does not change the properties of the nano fluid and the graphene nano particles with an average particle size of 15 nm are purchased from sky spring nano materials Inc USA and these are dispersed in mixture of water and ethylene glycol with dodecyl sulfate (SDS) mixture for preparation of the nano fluids. The quality of the graphene nano particles required for different volume concentrations can be calculated by using the standard formula of method of mixtures

Percentage of volume concentration

$$= \frac{Volume\ of\ graphene\ nano\ particles}{Volume\ (graphene\ nano\ particles + base\ fluid)} \quad ...(1)$$

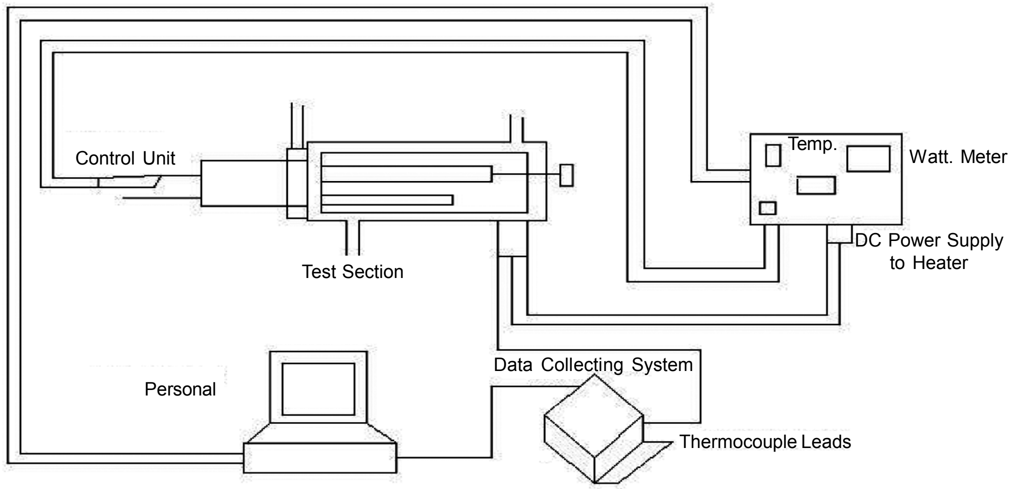
$$\frac{w_p/\rho_p}{w_p/\rho_p + w_f/\rho_f} \quad ...(2)$$

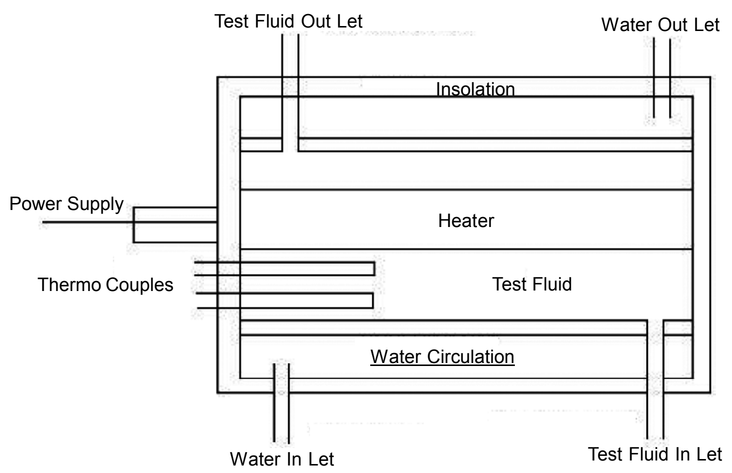
The density of graphene (ρ_p) is 2.09-2.23 g/cm^3. The density of 70% water and 30% ethylene glycol mixture is 1.1132 gm/m^2 at room temperature. Substuting the (ρ_p) and (ρ_f) values in the Equation (2) and the weight of the water + ethylene glycol in the ratio of (70:30) (w_f) 100 g is considered the nano fluid thus prepared are kept in an ultrasonic mixer system(model par sonic 3600 s) for (12-16 hrs) in order to avoid any sedimentation using the same procedure five different samples with 0.2%, 0.4%, 0.6%, 0.8%, 1.0% nanoparticles concentration are prepared and these samples are used for the measurement of thermal conductivity.

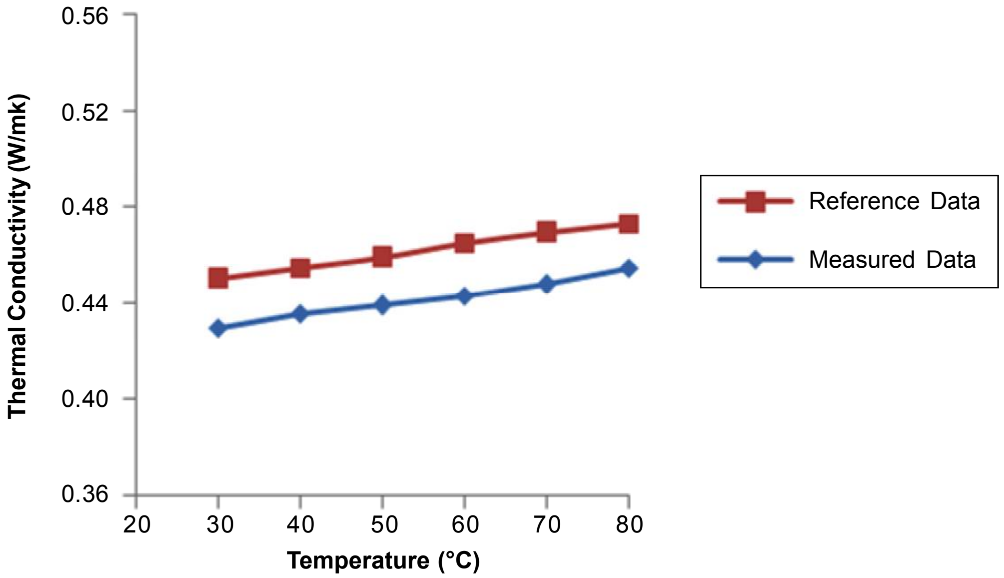
EXPERIMENTAL SET UP

Graphene (99.99% and 15 nm) surface area 50-80 m^2/g was purchased from Sky Springs Inc. Ltd., USA. The thermal conductivity of the working fluid is measured by using the thermal conductivity apparatus supplied by Hilton, UK as shown in Figure 1a. The schematic diagram of the test set up shows the test section, DC power supply, data acquisition system, thermo couple sensors, personal computer, control unit with on-off switch, temperature indicator, watt meter, dimmer stat, etc. The test section

Figure 1: Comparision of the Measured Thermal Conductivity with Reference Data







is totally insulated to control the heat input and thermal conductivity of liquids and gas samples of nanofluids is passed in the same radial clearance shown in Figure 1b between a heated plug and water cooled jacket. The clearance is small enough to prevent natural convention in the fluid and the fluid is presented as a lamina of face area $\Pi d_x L$ and thickness Δ_r transferring heat from the heater to the jacket. The heater plug is made up of aluminium and contains a cylindrical heating element. A thermo couple is inserted into the heater plug close to its external surface and also the plug has ports which works as an inlet and out let for the working fluid and the jacket is constructed with brass and has a water inlet and out let connections. A thermocouple is carefully fitted to the inner sleeve. Due to the arrangement of the thermo couples and the high thermal conductivities of the materials involved the temperatures that are measured by thermocouple is definitely cold and hot surfaces of the fluid lamina for to control the heat input of the heater an analog voltmeter is arranged and a digital temperature indicators with sensitivity of 0.1 °C temperatures of the heater plug and jacket surfaces for to finding out the standardization of the unit. Take the working fluid as air at atmospheric temp and 1 bar is entrapped into the test section once calibrated the data is used as reference data in the determination of the thermal conductivity of the other fluids cooling water is passed through the jacket ensuring one dimensional heat transfer in test section and the heater input is varied to maintain a small temperature difference across the air lamina under the steady state conditions the voltage applied to the heater and the temperatures are noted then the rate of heat transfer "Q" through the air lamina is calculated by using the formula:

$$Q = \frac{K_{air} \pi d_m L \Delta t}{\Delta r} \quad ...(3)$$

The variation of the electrical power in put $Q_{ELEC} = v^2/R$. That can be calculated by using Equation (3) The same procedure is repeated for other plug and jacket temperature and the calibration curve showing incidental heat transfer against plug or jacket temp difference is drawn for reference for every time the test section is cleaned with DI water for every break up and a new working fluid is introduced into the test section, when it reaches to steady state condition. The rate of heat transfer along with plug and jacket temperatures are noted. The difference between the heat supplied and the incremental heat transfer is the energy passing through the fluid lamina the thermal conductivity of the fluid lamina can be calculated from Equation (3) by substituting the values of Kfluid instead of Kair. The effective thermal conductivity of a two phase mixture can be theoretically estimated by [HC nodel[3]].

$$K_{nf} = k_f \left[\frac{k_p + (n-1)\,k_f - \Phi(n-1)\left(k_f - k_p\right)}{k_p + (n-1)k_f + \Phi\left(k_f - k_p\right)} \right] \quad ...(4)$$

Where k_p = Thermal conductivity of particle

k_f = Thermal conductivity of fluid

$n = 3/\Psi$ where n is the empirical shape factor and Ψ is the sphere city

$$\frac{\textit{Surface area of a sphere}}{\textit{Surface area of the particle}}$$

It is 1 for spherical and 0.5 for cylindrical (Wang *et al.*, 1999) modified the bruggeman model and developed the following expression for thermal conductivity of nano fluids

$$K_{nf} = 1/4\left[(3\Phi - 1)k_p + (2 - 3\Phi)k_f\right] + k_f / 4\sqrt{\Delta} \quad ...(5)$$

where,

$$\Delta = \left[(3\Phi - 1)^2\left(\frac{k_p}{k_f}\right)^2 + (2 - 3\Phi)^2 + 2\left(2 + 9\Phi - 9\Phi^2\right)\left(\frac{k_p}{k_f}\right)\right]$$

(Mingo and Broido, 2005) derived an equation for calculating the thermal conductivity of nano fluids

$$K_{nf} = k_f\left[\frac{k_p + 2k_f - 2\Phi(k_f - k_p)}{k_p + 2k_f + \Phi(k_f - k_p)}\right] \quad ...(6)$$

For spherical particles the result given by the WASP model concur with those of the H-C model.

An alternative expression for calculating the effective thermal conductivity of solid-liquid mixtures was introduced by Yu and Choi (2003) the solids particles like nano layer acts as a thermal bridge between a solid nano particle and a bulk liquid.

$$K_{nf} = k_f\left[\frac{k_p + 2k_f + 2(k_p - k_f)(1+\beta)^2\Phi}{k_p + 2k_f - (k_p - k_f)(1+\beta)^2\Phi}\right] \quad ...(7)$$

$$\beta = \frac{Nano\ layer\ thickness}{Original\ particle\ radius}$$

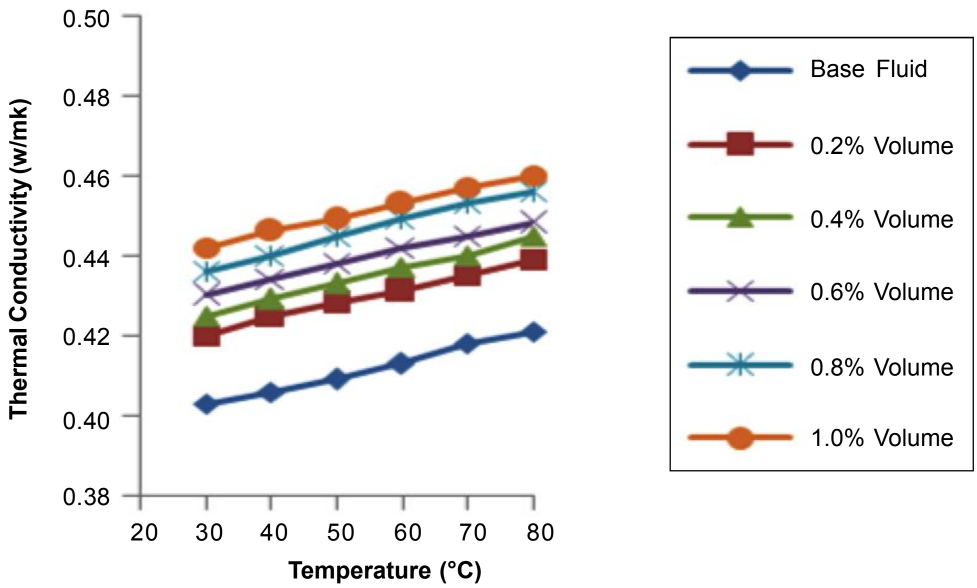
Normally β = 0.1 is used to calculate the thermal conductivity of nano fluid.

Heris *et al.* (2006) suggested the effective medium theory to calculate thermal conductivity of nano fluids which is expressed as follows:

$$K_{nf} = k_f[1 + 3\Phi] \quad ...(8)$$

Thermal conductivity of 70% of water and 30% ethylene glycol mixture (base fluid) at room temperature (30 °C) and at different temperatures is calculated by using the thermal conductivity measurement instrument of Hilton UK and the results are shown in Figure 2. From the figure it is observed that the results are in very good proceed with the Ashrae hand book values. From the calibrated results the deviation of the measured value

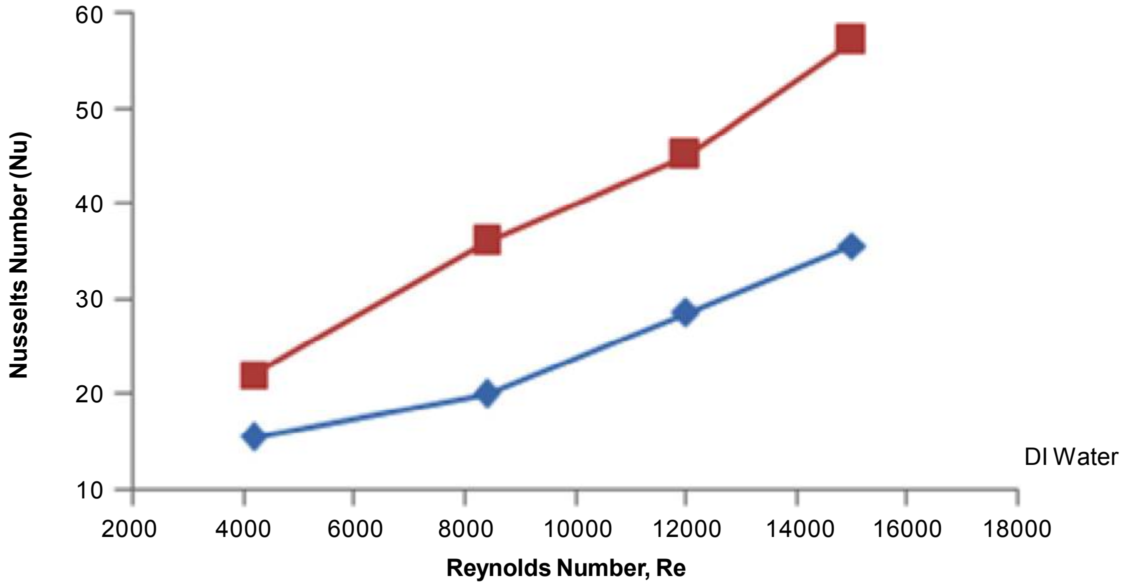
Figure 2: Thermal Conductivity of Ethylene Glycol Water Based Nano Fluid as a Function Temperature and Volume Concentration



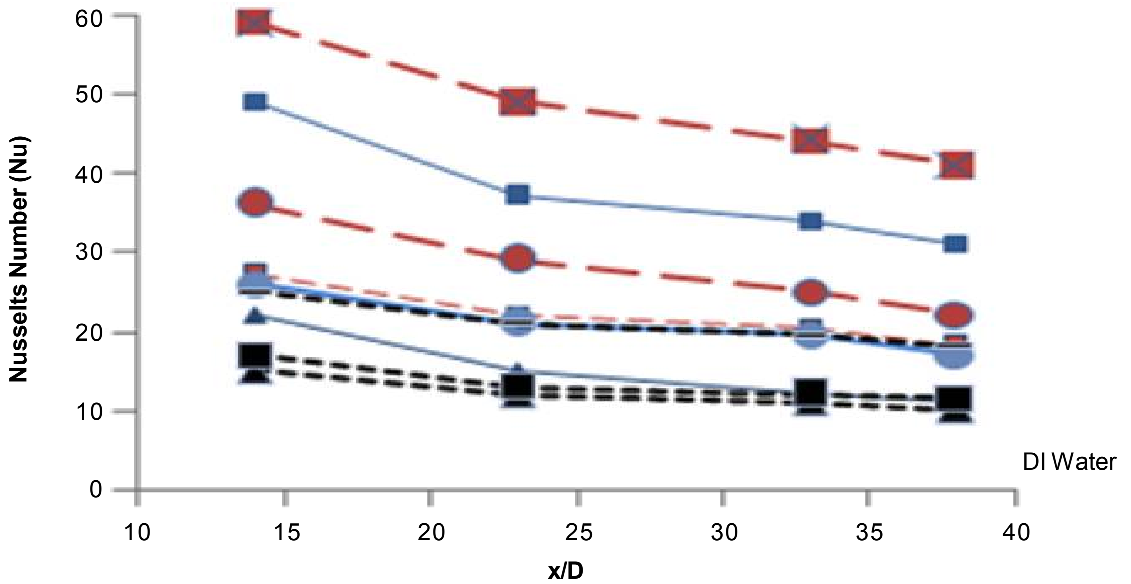
from the reference value is less than 1.5% which shows that the experimental set up is well calibrated different volume concentrations of graphene nano fluid is passed into the test section for the estimation of thermal conductivity. The experimental values of thermal conductivity for different volume concentrations of graphene nano fluid is shown in Figure 3 along with different thermal conductivity models from the graph shows that

Figure 3: Convective Heat Transfer Study

(a) Heat transfer measurement of graphene dispersed DI water based nanofluids. Black dotted lines, blue solid lines, and red dashed lines are for DI water alone, 0.010% of Graphene and 0.02% of Graphene, respectively. Symbols represents Re = 4500 (square), Re = 8700 (circle), and Re = 15,500 (triangle)



(b) Measurement of nusselts number with respect to different reynolds numbers for DI water based nanofluids, containing 0.02% volume fraction of graphene



the thermal conductivity obtained from the various theoretical models increases with increase % of volume concentrations and a Graph 4 shows the relation of temperature and thermal conductivity of a graphene nano fluids, from all these graphs it is evident that thermal conductivity is a function of temperature and particle volume concentration so a regression equation has been developed in the following form based on the present investigation.

$$\frac{k_{nano\ fluid}}{k_{base\ fluid}} = a + b\Phi \qquad ...(9)$$

Where *a* and *b* are constants which are listed in Table 1, Equation (9) is derived through the use of the data on ethylene-glycol water based graphene nano fluids which is applicable for:

- Temp range between 30 °C to 70 °C.
- Particle volume concentration range between 0.2% to 1.0%.

Table 1: Regression Constants 'a' and 'b' at Various Temperatures

Temp (°c)	a	b
30	1.0215	0.0276
40	1.0240	0.0280
50	1.0350	0.0310
60	1.0480	0.0330
70	1.0560	0.0345

Table 2: Sample Data of Graphene

Volume Fraction %	Weight of Graphene
0.2	1.6110
0.4	2.2551
0.6	3.4364
0.8	4.6210
1.0	5.2210

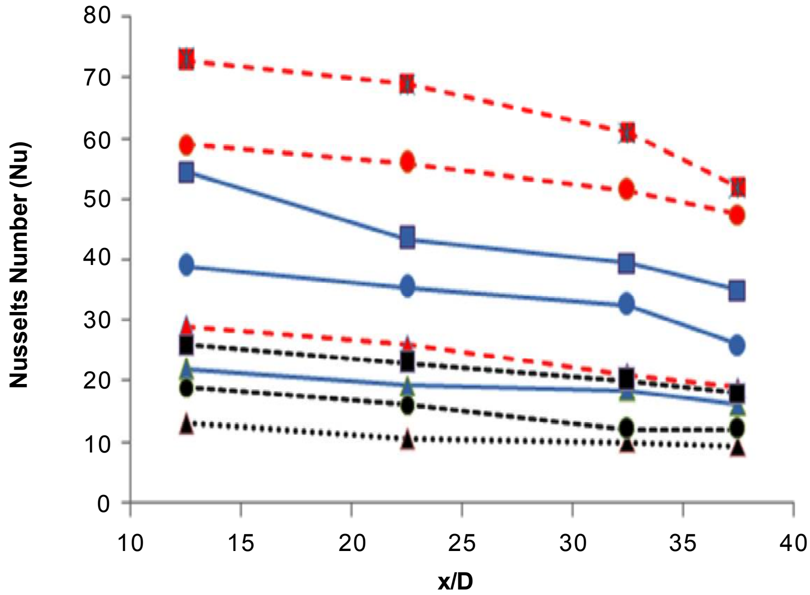
The thermal conductivity of 70:30% of water and ethylene glycol mixture was experimentally determined and the results found to be in nearer with the thermal conductivity values specified in Ashrae hand book .The effective thermal conductivity of graphene water nano fluids with particle volume concentrations of 0.2, 0.4, 0.6, 0.8, 1.0 vol% were investigated experimentally and the temp erature region between 30 °C to 70 °C from the thermal conductivity measurement.

CONVECTIVE HEAT TRANSFER OF GRAPHENE NANOFLUIDS

Having established confidence in the experimental system, systematic experiments were performed at different flow conditions (Reynolds numbers) for different Graphene volume fractions under a constant heat flow. From the experiment heat transfer coefficient was calculated and then converts it into corresponding Nusselts number. The Reynolds number is calculated based on the viscosity of the nano fluid. Since the calculated Reynolds numbers were greater than 4000, for DI water based nanofluids, the flow was considered to be turbulent. Figure 3a shows the heat transfer measurement of DI water, 0.010 and 0.02% volume fractions Graphene dispersed DI water for different Reynolds numbers. X-axis shows the ratio of axial distance to diameter of the tube (x/D) and Y-axis the corresponding Nusselts number. Black dotted lines, blue solid lines, and red dashed lines are for DI water alone, 0.010% of Graphene respectively. Symbols represents Re = 4500 (▲), Re = 8700 (●), and Re = 15500 (■). For better understanding the change in Nusselts number for different

Reynolds number is shown in Figure 3b. Similar measurements on Graphene based nanofluid for different volume fractions and varying Reynolds number are shown in Figure 4. Black dotted lines, blue solid lines, and red dashed lines are for Graphene alone, 0.010% of Graphene and 0.02% of Graphene, respectively. Symbols represents Re = 250 (▲), Re = 550 (●), and Re = 1000 (■). Since the calculated Reynolds numbers were less than 2800, for Graphene based nanofluids, the flow rates used were laminar.

Figure 4: Heat Transfer Measurement of Graphene Dispersed EG Based Nanofluids



Black dotted lines, blue solid lines, and red dashed lines are for EG alone, 0.010% of Graphene and 0.02% of Graphene, respectively. Symbols represents Re = 250 (triangle), Re = 550 (circle), and Re = 1000 (square).

Both the DI water and EG based nanofluids results suggests that the presence of nonmaterial's dispersed nanofluids increases the Nusselts number significantly, and the increase is considerably more at high volume fractions and high Reynolds numbers. From Figure 3 it is clear that for a given Graphene volume fraction, the Nusselts number decreases with axial distance. This is as expected for heat transfer in the entrance region. The percentage enhancement in heat transfer is calculated using the relation $[h_n(x) - h_f(x)] \times 100/h_f(x)$, where $h_f(x)$ and $h_n(x)$ are the heat transfer coefficient for the base fluid and nanofluid at distance x, respectively. The enhancement in heat transfer for Re = 4500 at the tube entrance is about 64 and 76% for 0.010 and 0.02% volume fractions, respectively. At the outlet, the value decreases to about 21 and 57%, respectively, for 0.010 and 0.02%. When the Reynolds number increases (Re = 15,500) the enhancement also increases and it is about 108 for 0.010% and 171 for 0.02% at the entrance. At the end, the values change to about 92 for 0.010% and 141 for 0.02%, respectively.

Similar trend is observed in the case of EG based nanofluid also. Figure 4 shows the variation of Nusselts number for 0.010 and 0.02% Graphene dispersed EG based nanofluids. From graph it is clear that heat transfer increases with volume fraction. The enhancement in heat transfer for Re = 250 at the tube entrance is about 100 and 172% for 0.010 and 0.02%, respectively. At the exit, the value decreases to about 59 and 140%, respectively, for 0.010 and 0.02%. Like water based nanofluids, here also the Nusselts number increases with increase in Reynolds number and it is around 150 and 239% for 0.010 and 0.02% volume fractions, respectively, at the entrance for Re = 1000. At the tube exit, the values change to about 79% for 0.010% and 198% for 0.02%. The enhancement in Nusselts number for EG based nanofluids are higher than that of DI water based nanofluids. Figure 3b shows the effect of the Reynolds number on heat transfer. Figure clearly shows that the Nusselts number increases with increasing Reynolds number. There is a large difference in the Nusselts number at Re = 4500 and that at Re = 15,500 for DI water based nanofluids. Similar will be the case for EG based nanofluids also . This suggests that Reynolds number has a significant effect on the heat transfer mechanism. The enhancement in heat transfer is very drastic compared to the enhancement in thermal conductivity. Another important observation is that even though enhancement in thermal conductivity is very low, enhancement in heat transfer is high for EG based nanofluid. The reason for decrease in heat transfer from entrance to exit of the tube is due to the variation of thermal boundary layer. In a simple way heat transfer can be written as k/δ with δ the thickness of thermal boundary layer. At the entrance ($x = 0$), the theoretical boundary layer thickness is zero, hence the heat transfer coefficient approaches infinity. The boundary layer increases with axial distance until fully developed after which the boundary layer thickness and hence the convective heat transfer coefficient is constant. Since there is not much enhancement in thermal conductivity, the effect of thickness of thermal boundary may be the reason for this huge enhancement in heat transfer.

CONCLUSION

We clearly present that the nano-particles suspended in DI Water + Ethylene glycol enhance the convective heat transfer co-efficient in the thermally fully developed regime despite low volume fraction between 0.2% and 1.0 vol% especially the heat transfer co efficient of base fluid is increased by 40% at 0.8 vol% under the fixed Reynolds number compared with that of pure water and the enhancement of the heat transfer co efficient is larger than that of the effective thermal conductivity at the same volume concentration. Also the convective heat transfer co efficient of DI Water + Ethylene glycol based graphene nano fluid is increased with volume fractions of graphene nano particles. The nano particle concentration of base fluid and particle size appears to be the most influencial parameters for improving the heat transfer efficiency of nano fluids. Besides the generally observed trends in nano fluids, discussed here, nano materials with unique properties should considered to create a dramatically beneficial nano fluid for heat transfer or other application. The effective thermal conductivity increased in linear fashion with respect to the graphene nano particles classical methods failed to predict the experimental results, by using the nano particles on the base fluid the ratio of the nusselt number of nano fluids to the base fluid is increased, how ever it has been clearly shown by the available results that the heat transfer behavior of nano fluids is very complex and many other important factors influence on the heat transfer performance of the nano fluids in natural convective heat transfer. The graphene nano particles enhance heat transfer rate by increasing the thermal conductivity of the nano fluid and incurring thermal dispersion in the flow which is an innovative way of augmenting heat transfer process.

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