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Experimental Investigation of Heat Transfer Properties and Viscosity of CNT Based Nanofluid in Low Temperature Conditions

Siddhant Kailash Kolase[1], Vaibhav N. Deshmukh[2], S Radhakrishnan[3]

[1]siddhant.kolase@gmail.com
[2]vaibhav.deshmukh@mitpune.edu.in
[3]radhakrishnan.s@mitpune.edu.in

Mechanical Engineering Department, Maharashtra Institute of Technology, Pune-411038, INDIA

ABSTRACT

Solid metallic and non-metallic materials such as copper, silver, iron, alumina, copper oxide, Silicon carbide and carbon nanotubes have much higher thermal conductivities than fluids. It is thus an innovative idea trying to improve the thermal conductivity by adding solid particles into fluids. The heat transfer enhancement of many industrial coolant by adding solid nanoparticles to liquids has attracted much attention in last few years. This project focuses on the satisfactory enhancement in heat transfer of industrial coolant by adding nanoparticles. Many reports are available on studies of nanofluid at high temperature but practically none at lower temperature (below Room Temp.). In addition this project takes into account the change in flow properties of nanofluid due to temperature variation. A great number of theoretical and numerical models have been proposed to predict the thermal conductivity and viscosity of nanofluids. Several models fails to predict thermal conductivity and viscosity of CNT based nanofluid have been discussed. The heat transfer benefits of nanofluids in laminar flow conditions have been explained in this study.

Keywords— Nanofluid, Carbon Nanotube, Ethylene glycol-water mixture, thermal conductivity, viscosity.

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I. INTRODUCTION

The heat exchangers are used on large extent in industries, power plants, refrigeration systems, air conditioning systems, radiators, etc. We require good heat transfer properties of coolant for high efficiency of heat exchangers. Solid metallic and non-metallic materials such as copper, silver, iron, alumina, copper oxide, Silicon carbide and carbon nanotubes have much higher thermal conductivities than fluids. It is thus an innovative idea trying to improve the thermal conductivity by adding solid particles into fluids. The conventional coolant used has several problems such as low thermal conductivity, low heat carrying capacity. Improving the thermal conductivity is the key idea to improve the heat transfer characteristics of conventional fluids. Addition of suitable fine particles into the base fluid is expected to improve the thermal conductivity of the resulting suspension.

Nanofluids are a new class of fluids engineered by dispersing nanometer-sized materials (nanoparticle, nanofibers, nanotubes, nanowires, nanorods, nanosheet, or droplets) in base fluids. In other words, nanofluids are nanoscale colloidal suspensions containing condensed nanomaterial. They are two-phase systems with one phase (solid phase) in another (liquid phase). Nanofluids have been found to possess enhanced thermo physical properties such as thermal conductivity, thermal diffusivity, viscosity, and convective heat transfer coefficients compared to those of base fluids like oil or water. It has great potential applications in many fields as demonstrated by several authors.

II. PREVIOUS RESEARCH

Nanofluids are solid liquid composite materials consisting of solid nanoparticles or nanofibers with sizes typically of 4-100 nm suspended in liquid. Even a small amount (<1% volume fraction) of Cu particles or Carbon nanotubes dispersed in ethylene glycol or oil is reported to increase the inherently poor thermal conductivity of the liquid by 40% and 150%, respectively. Conventional particle –liquid suspension required high concentration (>10%) of particle to achieve such enhancement.

Ganesh et al. [31] explained effect of different parameters such as particle volume fraction, particle material, particle size, particle shape, acidity and Brownian motion on thermal conductivity of nanofluid. Prasher, Song, Wang, et al. [23] found that the viscosity of nanofluids is extremely dependent on nanoparticle volume fraction, but is independent of the shear rate, nanoparticle diameter, and temperature. In paper published by Prasher, Song, Wang, et al. [23] solely on the experimental results of the viscosity of alumina particles in propylene glycol, they have shown the dependency on particle diameter, nanoparticle volume fraction, and temperature. The fact that the nanofluid viscosity is independent of shear rate and nanoparticle diameter indicated that the nanofluid obeys Newtonian flow behaviour. From their data, it can be assumed that it is possible for the increase in viscosity to get larger than the increase in thermal conductivity.

III. EXPERIMENTAL WORK

A. Preparation of Nanofluid

In the present study nanoparticles (Carbon Nanotubes) are procured from sigma Aldrich, USA. The nanotubes have an average diameter ranging from 10-200nm and length10µm-40µm. For the preparation of nanofluids ethylene glycol base commercial coolant (Purogaurd) is used. This coolant is having 20% solution of ethylene glycol in distilled water. Four different composition of nanofluid have been made by using 0.2%, 0.4%, 0.6% and 0.8% volume fraction of Carbon Nanotubes. Sodium lauryl sulphate is used as dispersing agent. The nanoparticle are mixed in EG-water slowly. 0.1% Sodium lauryl sulphate is used as a dispersing agent in a solution of ethylene glycol. Initially 200ml nanofluid is made and kept in an ultrasonicator for 40 min for obtaining a uniform homogenous solution of nanoparticle with base fluid. It is advised to keep the solution for more than 40 minutes if solution is nonhomogeneous. The nanofluids prepared by this method are found to be stable for over three months, with no visible sedimentations. The measurement of thermophysical properties of the nanofluids such as density, specific heat, and viscosity is carried out using the standard volumetric flask, mathematically and Brookfield viscometer respectively.

B. Viscosity Measurement

The viscosity of Nanofluid is measured with Brookfield DVII+pro Viscometer, which is first calibrated with ethylene glycol based fluid. It gives uncertainty of ±3%. It consist of rotating spindle immersed in fluid of which viscosity is to be measured. The principle of operation of the DVII+pro is to rotate a spindle (which is immersed in the test fluid) through a calibrated spring. The viscous drag of the fluid against the spindle is measured by the spring deflection. Spring deflection is measured with a rotary transducer which provides a torque signal. The measurement range of a DVII+pro (in centipoise or milliPascal seconds) is determined by the rotational speed of the spindle, the size and shape of the spindle, the container in which the spindle is rotating, and the full scale torque of the calibrated spring.

For the measurement of viscosity with Brookfield DV-II+ pro Viscometer first step is to AUTO ZERO the instrument with no spindle attached and the speed set as designated in the product specification. Immerse the spindle (S61 for this measurement) designated in the product specification into the sample to the groove on the spindle shaft. Do not allow air bubbles to be formed. Attach the spindle to the viscometer. The spindle should not touch the bottom or sides of the container and should be centered. Reading can be note down from display.

C. Heat Transfer Coefficient and thermal conductivity of Nanofluid

The measurement of thermal conductivity is done indirectly with the help of Dynamic Thermal conductivity measurement setups. The process flow diagrams of these setups are as shown in fig. 2 and fig.3. The heat transfer coefficient and thermal conductivity above and below room temperature is measured is measured on setup1 and setup2 respectively. In case of setup 1 the nanofluid initially heated above room temperature with the help of heater in hotbath and then cooled to room temperature as shown in the fig. 2 and temperatures at different locations T_1, T_2, T_3 and T_4 are noted. Heat loss by water and heat gain by nanofluid gives the heat transfer coefficient. After that Nusselt number is calculated with Seider Tate Correlation [4] and from that thermal conductivity can be obtained. Similar procedure is done for setup2. In this case initially nanofluid is cooled with the help of ice in coldbath and then it is heated to room temperature, heat transfer coefficient and thermal conductivity is obtained in similar way.

D. SYSTEM DESIGN

Fig. 1 and Fig.2 show the process flow diagram for dynamic thermal conductivity measurement setup above room and below temperature respectively. The whole system is heavily insulated to reduce heat losses. The U shape heat exchanger is placed in hot and cold bath. The fluid from storage tank first passes through the Rotameter. The Rotameter is provided to measure the flow of liquid. The volume flow rate of the fluid can be varied with changing the position of bypass valve. The fluid then enters the heat exchanger first, placed in hot bath. Temperature sensor 1 fitted at the inlet of heat exchanger passing through hot bath measures the temperature T_1. Temperature sensor 2 fitted at the outlet of heat exchanger coming out from hot bath measures the exit temperature, T_2 of

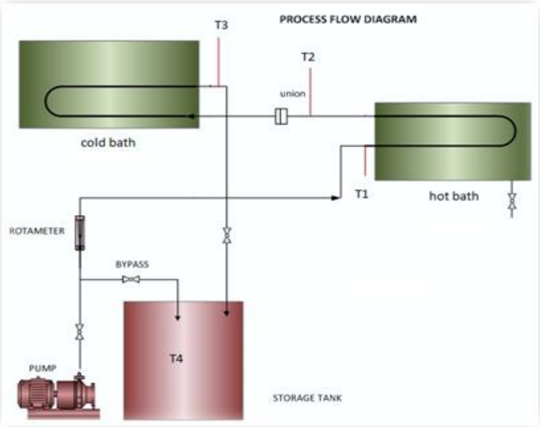

Figure 1: Dynamic thermal conductivity measurement setup with heating first

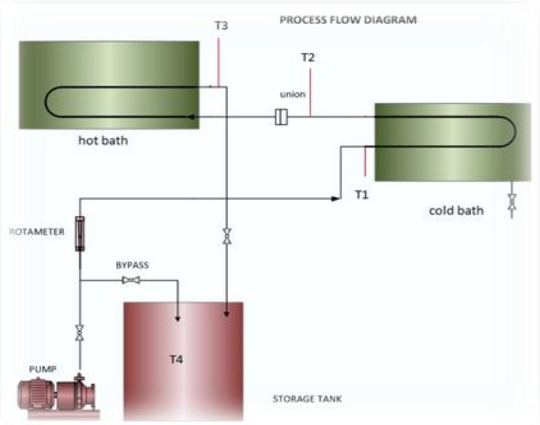

Figure 2: Dynamic thermal conductivity measurement setup with cooling first

fluid. Then fluid with increased temperature flows into the heat exchanger passing through cold bath. Temperature sensor 2 is common to the outlet of hot bath and inlet of cold bath. The exit temperature of fluid is measured by temperature sensor 3 which is fitted at the outlet of heat exchanger coming out from cold bath as temp T_3. Temperature sensor 4 is kept in storage tank to measure fluid temperature in storage. The effective thermal conductivity is calculated by taking the difference in temperature. All the temperature sensors are connected to the digital temperature indicators. The procedure is as follows:

i. The setup is initially run to ensure complete removal of air/water bubbles in the heat exchanger tubes as well as in the pump.
ii. The fluid to be tested is filled in the storage tank up to a certain required level.
iii. For study above room temperature the hot and cold bath tanks are filled with normal tap water, for below room temperature the coldbath filled with ice water and hot tank filled with normal tap water.
iv. The system is started by switching on the pump and the heater. The heater is set to a definite temperature, say 45o C. It takes 5-10 min to increase the temperature to the operating range and remove interior bubbles.
v. Similarly for study below room temperature the system is started by switching on the pump. The coldbath is set to a definite temperature, say 0^oC with the help of ice water.
vi. After the reaching the set temperatures, readings are taken for 5, 10, 15, 20 and 25 LPH of volume flow rate.
vii. Then again by changing the temperatures same procedure is repeated for taking readings.
viii. The system usually reaches at thermal steady state within 30 min.
ix. Each measurement is repeated at least twice.

IV. EXPERIMENTAL VALIDATION

Initially the experiments are performed with 20% ethylene glycol solution for the measuring of the viscosity, to ensure the accuracy and reliability of the Brookfield viscometer. Figure 3 shows the experimental viscosity and the actual values reported for 20% ethylene glycol solution. And the experimental setup tested with distilled water to ensure the accuracy and reliability. The experimental thermal conductivity and the actual values reported for water are compared. The Rotameter is calibrated using a distilled water. It is observed the results are in good agreement in both turbulent flow conditions and laminar flow condition.

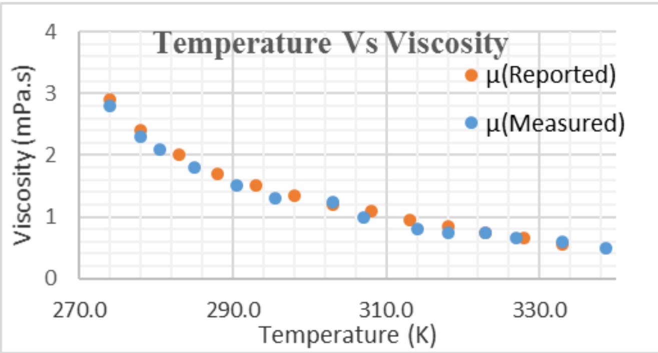

Figure 3: Experimental Validation of Viscometer

V. RESULT AND DISCUSSION

The heat transfer coefficient (HTC) was determined from the experimental values of (ΔT) at different concentrations, temperature as well as fluid flow rate. Figures 4 to 6 show the data obtained from the present experiments on nano graphite fibers dispersed in radiator coolant equivalent to 20:80 ethylene glycol water mixture.

It can be seen from the graphs on HTC with respect to Reynolds number as well as composition and temperature that the transfer of heat to and from nanofluid is dominated by conduction processes.

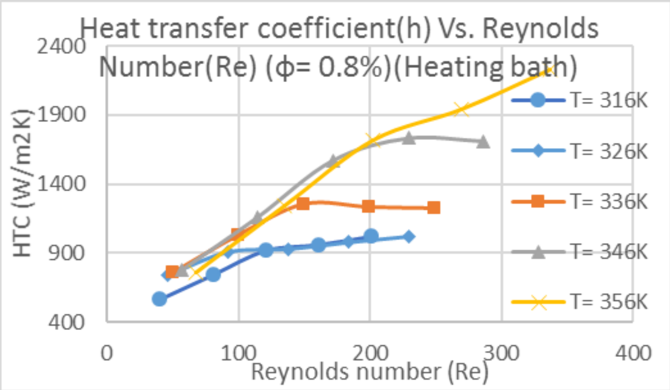

Figure 4: Heat transfer coefficient Vs. Reynolds Number

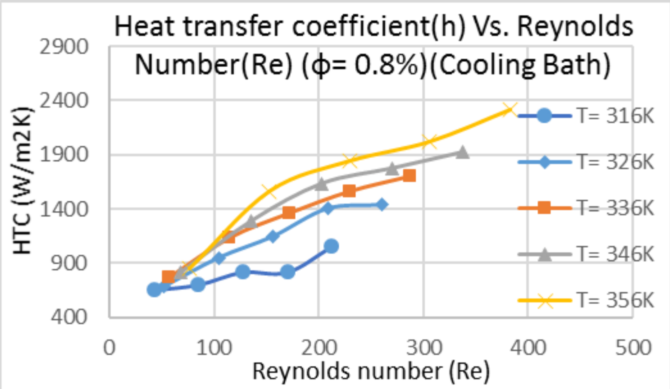

Figure 5: Heat transfer coefficient Vs. Reynolds Number

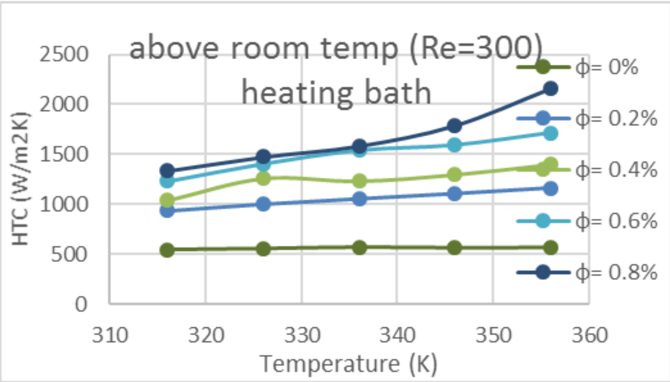

Figure 6: Heat transfer Coefficient Vs Temperatur

The measurements below room temperature which have been carried out for the first time in such nanofluids are of interest for secondary refrigeration systems as well as in automotives where the fluid can also act as anti-freezing

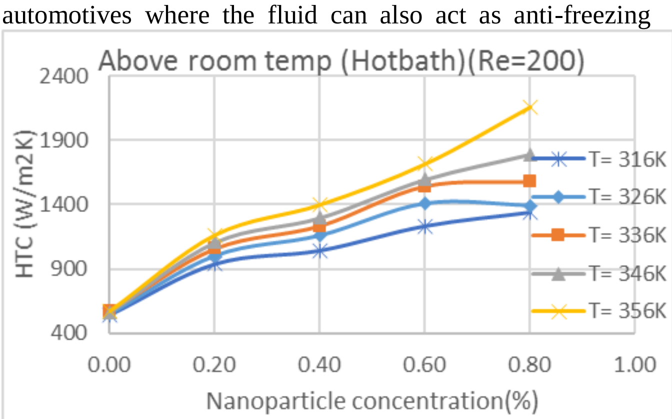

Figure 7: HTC Vs Nanoparticle weight %

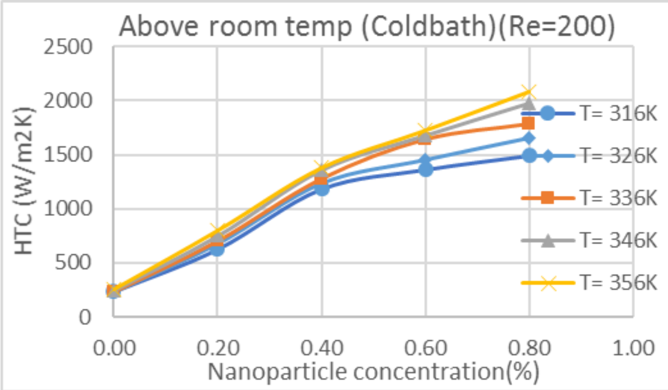

Figure 8: HTC Vs Nanoparticle Weight %

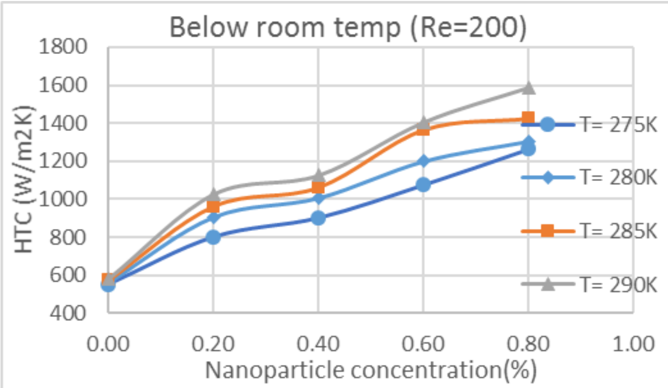

Figure 9: HTC. Vs Nanoparticle weight % (below room temp)

additive. Figures 7 to 9 indicate the results of these experiments below room temperature. It is interesting to note that the temperature and concentration dependence of HTC, thermal conductivity in this range is not as strong as that noted above room temperature. Typically, the HTC increased from 500 to 1200 W/m^2K in the low temperature region while from 500 to 2200 in the higher temperature region. In order to bring out this aspect, the thermal conductivity was estimated at single low Re value for different concentrations of the additive. Such a plot is depicted in Figures 10 and 11. It is seen that the nanofluid has 2 to 4 time's thermal conductivity than the base fluid and it increases tremendously with the concentration of the additive. It may also be noted that the thermal conductivity of the nanofluid is temperature dependent while it hardly varies for the base fluid with the increase of temperature.

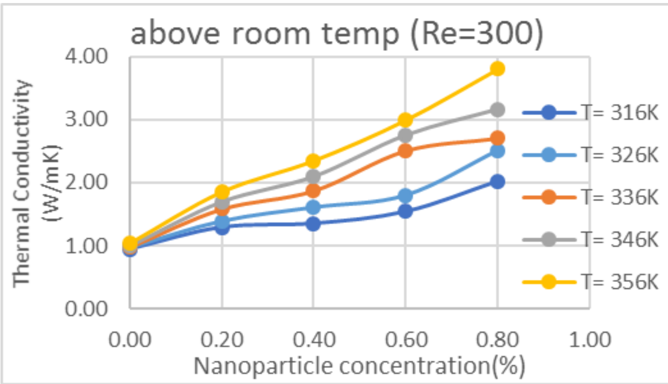

Figure 10: Thermal Conductivity Vs Nanoparticle weight %

The most important parameters of interest for nanofluids are thermal conductivity (k) and viscosity (η) since these control the efficiency of heat transfer for any application. The viscosity becomes of prime importance especially below room temperature. Hence these parameters are discussed in

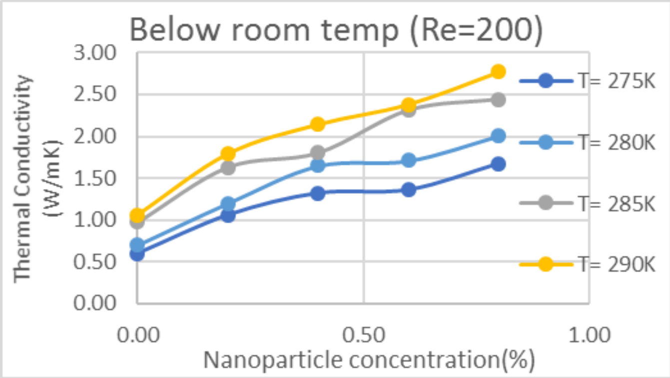

Figure 11: Thermal Conductivity Vs Nanoparticle weight %

details here. Figures 10 and 11 show the variation of thermal conductivity with respect to concentration of nano-additive at different temperature and data recorded for constant low Reynolds number (200). It is evident that there is considerable improvement in the thermal conductivity both at temperatures above and below room temperature. There are a number of theoretical models suggested for improvement of thermal conductivity due to addition of nano particles to fluids (in this case auto coolant liquid) [03].

One of the simplest equation is suggested by Prasher, Song and Wang (ref) which tries to eliminate the temperature dependence of the base fluid. The effective/ reduced thermal conductivity (k_r) is given by

$$k_r = (k_{nf} / k_{bf}) = 1 + C_k \Phi$$

Where subscripts nf and bf indicate nanofluid and base fluid, Φ is the volume fraction of the nanoparticle additive and C_k is a constant which depends on temperature. When the measurements are carried out at single temperature, C_k is constant. This suggests that k_r varies linearly with concentration of the nano-additive. In order to check the validity of the above equation for our present data, the graph as shown in Figure 12 was plotted. Each curve is isothermal for that particular temperature. The bold lines are attempted linear fit for the given temperature. It is quite clear from this figure that the simple empirical relation is not valid in the present case of nanofluid containing graphitic nano fibers.

Other models for the enhancement of thermal conductivity in nanofluids were also used in order to analyse the present data. However, most of these did not give good correlation with the experimental findings. The comparison of these with the experimental values is indicated in Figure 12 and 13. The large differences could be due to the nature of the nano particles (in fibrous form) as well as the base liquid which is a mixture of several components such as ethylene glycol, water, colorant, stabilizer, dispersing agent etc.

The other important parameter viz. viscosity was determined accurately with Brookfield viscometer at different steady temperatures ranging from 275 K to 356 K. Figure 14 shows the change in viscosity with temperature for different concentrations of the added particles. The increase in viscosity at lower temperature and with increasing concentration of nanoparticles is quite evident. In this case also, a number of models have been suggested by several authors to explain the change in viscosity in nanofluids with temperature and additive. Figure 15 gives the comparison of the present data with those expected from different model. It is seen that model predicts much lower or higher values than those observed in the present case.

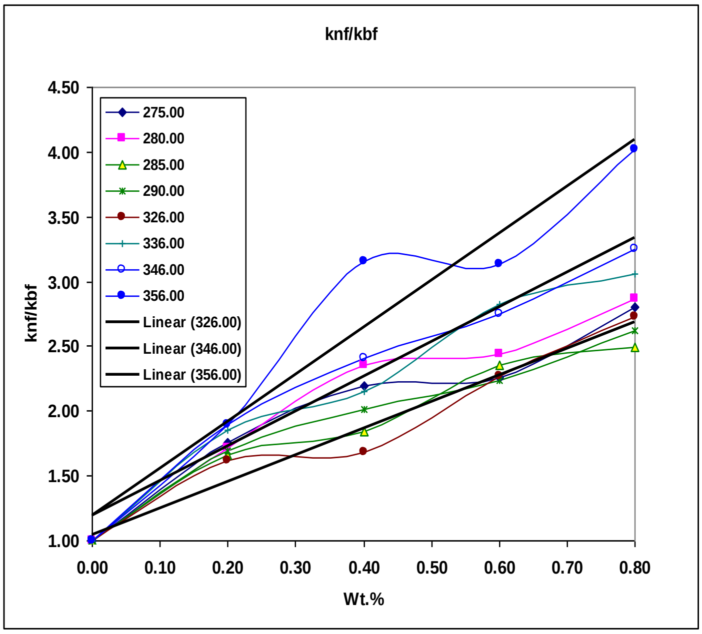

Figure 12: Other models for the enhancement of thermal conductivity in nanofluids were also used in order to analyze the present data. However, most of these did not give good correlation with the experimental findings. The comparison of these with the experiment

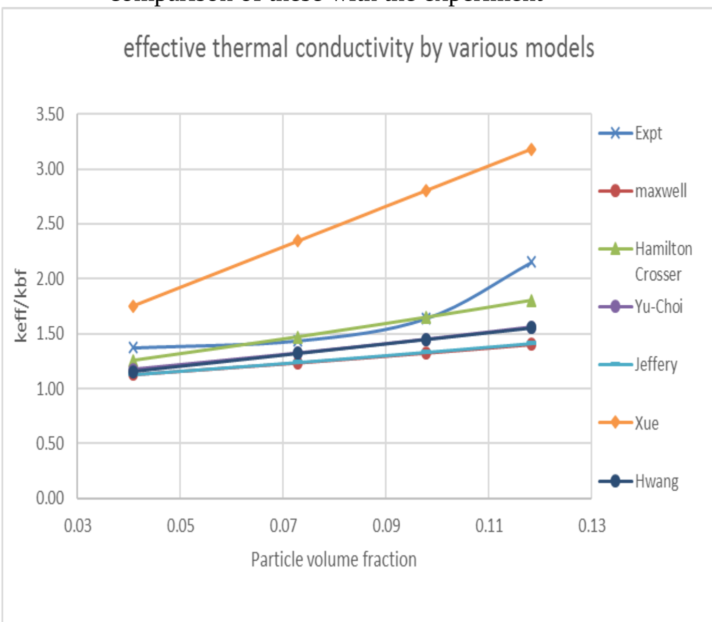

Figure 13: Thermal conductivity Vs. Particle volume concentration

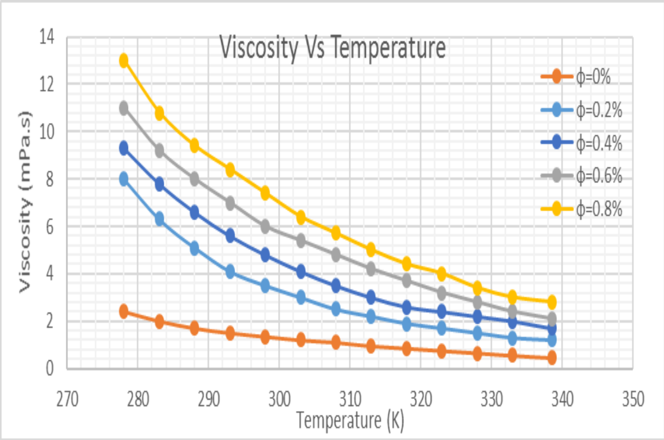

Figure 14: Viscosity (mPa.S) Vs. Temperature (K)

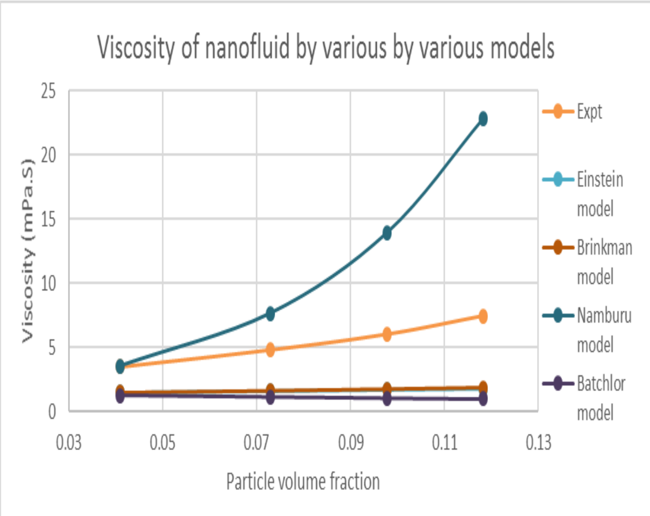

Figure 15: Viscosity (mPa.S) Vs. Particle volume concentration

Prasher et al. [34] as well as Timofeeva, Routbort and Singh [35] have suggested that in the variation of viscosity with the concentration of nanoparticles may follow a simple relationship viz.

□$_r$ = □ □ □$_{nf}$ / □ □$_{bf}$ = 1 + C$_□$ Φ

where □$_r$ is the reduced viscosity, nf and bf represent nanofluid and base fluid, C$_□$ is the viscosity enhancement factor independent of temperature and Φ is the volume fraction of the nanoparticles. This equation predicts a linear dependence of the viscosity with additive concentration. Figure 16 shows the plot of reduced viscosity with concentration in the present case. Although, there appears to be more or less linear dependence at higher temperatures, there is large deviation observed at low temperatures. Further, the temperature dependence of the "slope" is quite evident. Hence, the above equation does not explain our present results fully.

It is known that the viscosity for most of the liquids and polymer solution follows the Arrhenius law with temperature viz.

□ □ □ □ □ □$_o$ e$^{E/KT}$

where E is the activation energy for molecular motion/repetition and K is the Boltzman constant. This relation suggests that the graph of log □ vs 1/T should be straight line which gives the activation energy as the slope. Figure 17 shows such as plot for base fluid as well as the nanofluid in the present case and it is evident that there is a good correlation with the above. This graphs also indicates that the activation energy is only slightly affected but the pre-exponential factor changes considerably with the nanoparticle additive.

These data suggest that the heat transfer at low Reynolds number or under quasi-static conditions is mainly governed by the thermal conductivity of the nanofluid. Further, the thermal conductivity of the nano-fluid being temperature and concentration dependent, the internal Brownian motion may be affecting the same. In order to confirm this hypothesis, one has to consider the root mean square velocity under Brownian motion which is given as $< r^2 > = \frac{2kT}{3\pi\eta a} t$

where □ is the viscosity, t is the time and a the particle size. If the thermal conduction is considered to be proportional to the mean average velocity, the product of thermal conductivity and viscosity of the nano-fluid will be simply constant at any given temperature. Figure 18 shows the plot of the product of thermal conductivity and viscosity of the nanofluid studied in the present case. It is evident that this product (knf).(□$_{nf}$) varies linearly with concentration of the nanoparticles for all temperature and any variation / deviation is very small as compared to earlier suggested models. Thus, one may certainly consider the Brownian motion as the predominant process by which the thermal conductivity as well as the viscosity of nanofluid is controlled.

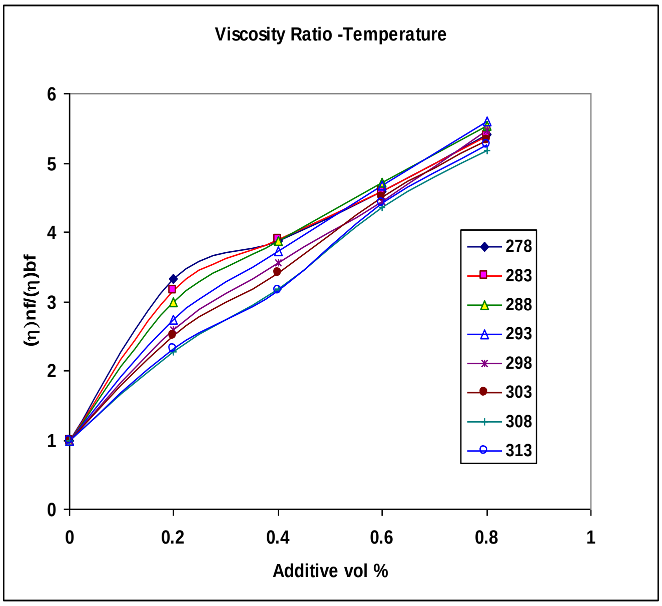

Figure 16: Reduced viscosity with respect to additive concentration at different steady temperatures

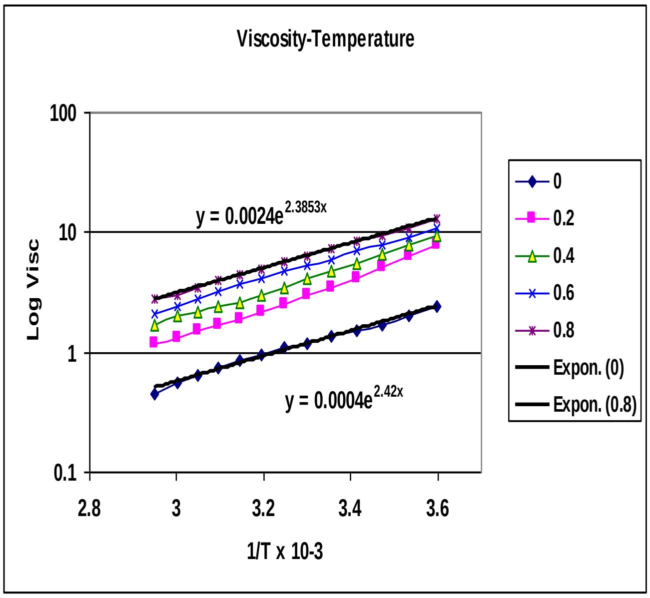

Figure 17: Arrhenius plot of log Viscosity Vs 1/T

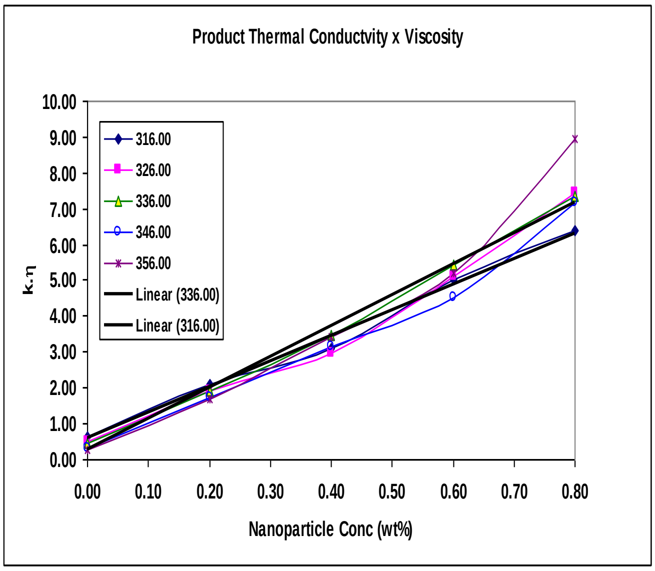

Figure 18: Product (thermal conductivity X Viscosity) Vs particle volume fraction

VII. CONCLUSIONS

The detailed experiments on the heat transfer co-efficient, thermal conductivity and viscosity of nanofluids have been carried out. The nanofluid was made using automotive coolant with addition of graphite nanoparticles in the range of 0.2 to 0.8 wt%. The temperature was changed from 275 K to 356 K. HTC was determined at different flow rates with Reynolds number varying from 50 to 400. The viscosity was determined using Brookfield viscometer at different temperatures and concentrations. The data was analysed according to various theoretical models as well as some empirical equations. However, there were large deviations seen in these which could be due to nature of the fluid as well as fibrous morphology of the particles used in the present case. None of these models consider Brownian motion as the main factor in the thermal conduction or viscosity. We have taken this into account and obtained a good explanation for the variation of thermal conductivity and viscosity with composition for the whole range of temperatures (both below and above room temperature) studied. Thus, one may certainly consider the Brownian motion as the predominant process by which the thermal conductivity as well as the viscosity of nanofluid is controlled.

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