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HYDRODYNAMIC AND THERMAL CHARACTERISTICS OF NANODIAMOND-ENGINE OIL THROUGH CIRCULAR PIPES UNDER CONSTANT HEAT FLUX

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An experimental investigation has been carried out to study the pressure drop of a nanofluid through a horizontal copper tube. The tube is heated by an electrical heating coil wrapped around it. Also, the rheological properties of the used nanofluid have been studied. Nanodiamond particles which belong to carbon family have been chosen as dispersed particles. Because of high viscosity of the chosen base fluid (Engine oil - SAE 20 W 50), the Reynolds number is low and thus flow regime is laminar. Pressure drop of pure engine oil and also engine oil-nanodiamond nanofluids flowing inside the tube has been measured by a high precision differential pressure transmitter (PMD-75). Experimental results showed that the pressure drop of nanofluid substantially increases compare to pure engine oil. Furthermore, the pressure drop increases with the increase of nanodiamond concentration in the fluid.

Keywords: *Nanofluid, Engine oil, Laminar flow, heat transfer enhancement, pressure drop*

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Abstract —**An experimental investigation has been carried out to study the pressure drop of a nanofluid through a horizontal copper tube. The tube is heated by an electrical heating coil wrapped around it. Also, the rheological properties of the used nanofluid have been studied. Nanodiamond particles which belong to carbon family have been chosen as dispersed particles. Because of high viscosity of the chosen base fluid (Engine oil - SAE 20 W 50), the Reynolds number is low and thus flow regime is laminar. Pressure drop of pure engine oil and also engine oil-nanodiamond nanofluids flowing inside the tube has been measured by a high precision differential pressure transmitter (PMD-75). Experimental results showed that the pressure drop of nanofluid substantially increases compare to pure engine oil. Furthermore, the pressure drop increases with the increase of nanodiamond concentration in the fluid.**

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I. INTRODUCTION

Cooling is the main part of the processes which are used for keeping high efficiency and reliability of many products such as electronic systems, engines, lasers and high intensive X-rays. With increasing in produced heat fluxes from these devices, cooling is one of the abstruse problems in facing to high-tech industries such as microelectronic, transportation, production and military industries.

Recently, technologies with single-phase and two-phase cooling fluid have been emerged for chips or closed surfaces. However, intrinsic property of low heat conductivity of heat transfer fluids is the main limiting reason of developing effective heat transfer fluids which are needed for high efficiency systems. Many studies whether in past or present have been carried out to increase heat transfer rates in these devices; nanofluids are typical results of those recent studies [1-3]. After emerging Nano-Science in last decade, a new environment of heat transfer has been introduced by suspending nanoparticles (≤100 nm) of metals or metal oxides in prevalent heat transfer fluids (for enhancing heat transfer coefficient). Two outstanding characteristics of nanofluids (well dispersing of particles and enhanced heat conductivity coefficient) candidate them as a proper substitution for next generation of heat transfer fluids. Thus, more accurate investigation on these kinds of fluids for finding out their advantages (enhanced heat conductivity and heat transfer) and disadvantages (increasing pressure drop and abrasion) are inevitable. Although, a number of experimental investigations have been performed for detecting the advantages of this kind of heat transfer fluids [4-5]; the absence of experimental investigations in literature can be seen clearly for studying the probability defects.

Lee et al. [3] used four nanofluids with base fluids of water and ethylene glycol which contained particles of Al2O3 and CuO as nanoparticles. They observed enhancement of thermal conductivity about 20% in nanofluids with 4% volume fraction. In one of experimental investigations of Choi et al. [6], Multi-Wall Carbon Nano-Tubes (MWCNT) dispersed in oil with volume fraction about 1%, led to extraordinary enhancement of thermal conductivity. The reported enhancement was about 150% compare to the thermal conductivity of pure oil. He et al. [7] carried out an experimental study on the flow and heat transfer of aqueous TiO2 nanofluids flowing inside a straight vertical pipe under both laminar and turbulent flow conditions. They found that addition of nanoparticles to the base liquid enhances the thermal conductivity of the mixture. The enhancement increases with the increasing of particle concentration and decreasing particle (agglomerate) size. They reported that the pressure drop of nanofluids is very close to that of the base liquid at a given flow Reynolds number. The predictions of the pressure drop with conventional theory for the base liquid agree well with the measurements at relatively low Reynolds numbers. They mentioned that the deviation occurs at high Reynolds numbers possibly is due to the entrance effect. In general, the majority of reported studies have not investigated the effects of nanoparticles on the pressure drop. One exception is [7], where as mentioned above, they did not observe significant changes in pressure drop for nanofluids. Therefore, further investigation should be performed on this aspect.

In the present study, the effect of using nanodiamond particles with different volume fractions on pressure drop during heating of engine oil flowing through a pipe under constant heat flux has been investigated experimentally. Because of high viscosity of the chosen engine oil (SAE 20 W 50), the flow regime is laminar. The recorded values have been compared with the results returned by theoretical models. Also, the rheological properties of the used nanofluid have been studied.

II. EXPERIMENTAL SET-UP

Figure 1 shows the schematic diagram of experimental set-up. The flow loop consists of test section, cooler, receiver, gear pump, flow measuring apparatus, different thermocouples and flow controlling system. In order to control the fluid flow rate a reflux line with a valve was used. The test section was a copper tube of 1.2 m long and 8.92 mm inner diameter. The nanofluid flowing inside the tube was heated by an electrical heating coil wrapped around it. The test section (tube and heater) was completely insulated with glass wool pads. Two K-type thermocouples were used to measure the bulk temperatures of nanofluid flow at inlet and outlet of test section. Also, six K-type thermocouples were mounted on the external surface of the test tube. In order to measure the total pressure drop of flow across the test section, a high precision differential pressure transmitter (PMD-75) was employed. The fluid leaving the test section is entered to flow measuring apparatus, then cools partially in the reservoir and after that pumps through a heat exchanger (cooler) in which water is used as cooling fluid.

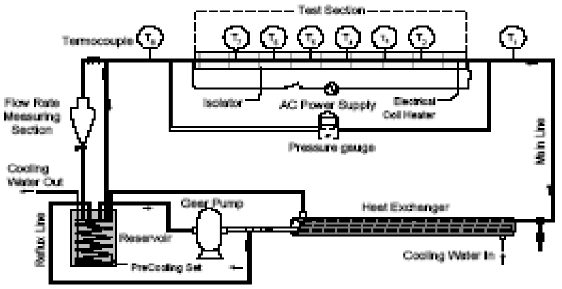

Figure 1: Schematic diagram of experimental set-up.

III. NANOFLUID PREPARATION

In this study, four different nanofluids by using nanodiamond as nanoparticles and engine oil (SAE 20W50) as base fluid were prepared and used. The black color nanodiamond has primary crystal size of 4-6 nm but its average uncrushable aggregates size was about 20-50 nm. The purity of the powder was estimated about 52 to 85 %. To achieve proper and stable suspensions, nanoparticles were mixed with pure engine oil in a flask and then kept under ultrasonic (Starsonic model 35, frequency from 28 to 34 kHz) vibration.

The suspensions of nanodiamond were prepared in four particle concentrations, respectively 0.2, 0.5, 1 and 2% of weight fraction which are equal to 0.054, 0.134, 0.268 and 0.537% volume fraction respectively[1].

IV. RESULTS AND DISCUSSION

A. Rheological measurements

The experiments were carried out under three constant heat fluxes varied from 3333 to 16666 ($Watt / m^2$) with different Reynolds numbers up to 100. The dynamic viscosity of nanofluids in different weight fractions and different temperatures were measured using BROOKFIELD LV DV-II + Pro dynamic viscometer and also the kinematic viscosity of nanofluids were measured using the ASTM D445 standard by Thomson kinematic viscometer.

The behavior of nanofluids shear stress against shear rate is shown in Figure 2. As can be seen in this figure, all the prepared nanofluids may be treated as Newtonian fluids at nanoparticles concentration up to 2%.

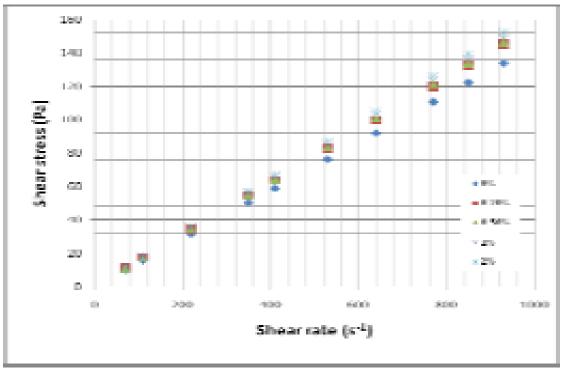

Figure 2: Shear stress of nanodiamond-engine oil nanofluid versus shear rate at different concentrations.

Figures 3 and 4 respectively display the dynamic viscosity of the nanofluid verses particle concentration at 40°C and 100°C. It can be seen that the dynamic viscosity increases with the increase of nanodiamond concentration. Also from Figures 3 and 4, it is noted that the increase rate of dynamic viscosity with nanodiamond concentration is higher for low particle concentrations (up to 0.2%) than for high particle concentrations. Comparing Figures 3 and 4, one can find that the jump in viscosity with increasing particle concentration is subsided in higher temperatures. Figures 3 and 4 also

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[1] Assuming nanodiamond true density about 3150 kg / m^3 and engine oil density about 845 kg / m^3.

include the predictions of Einstein relation (Eq. 1) for non-interacting dilute suspensions of particles;

$$\mu_{nf} = \mu_f (1+2.5\,\phi) \qquad (1)$$

Where μ_f and ϕ respectively are the base liquid viscosity and volume fraction.

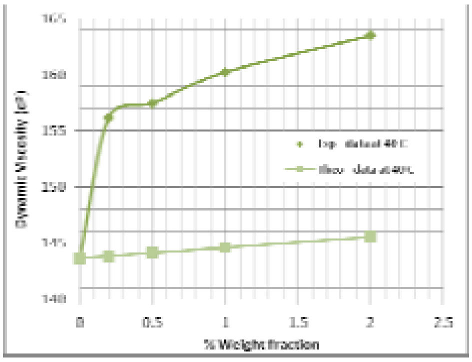

Figure 3: Dynamic viscosity of nanofluid at 40 °C versus particle concentration.

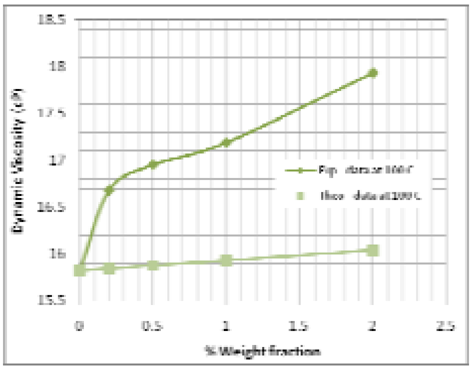

Figure 4: Dynamic viscosity of nanofluid at 100 °C versus particle concentration.

Two additional observations can be made from Figures 3-4. First, the measured viscosities of nanofluids are much higher than the predicted values by the Einstein model, indicating possible strong interactions between particles in the nanofluids. Second, the measured nanofluid viscosity relates to the particle volume concentration in a non-linear fashion. The exact reason for the non-linearity requires further investigations but different structures of nanofluids at different concentrations may be a possible reason.

A. Pressure drop

The pressure drop of flow across the whole length of the test section was measured using a high precision differential pressure transmitter (PMD-75) with an accuracy of ±0.075%. Because of high dependency of engine oil viscosity to temperature variation (Figures 3 and 4) and the existence of considerable temperature difference between the inlet and outlet of the test section, the viscosity of tested nanofluids abated significantly through the test section. Therefore, the calculation of pressure drop and Reynolds number using equations (2) and (3) are highly dependent upon the point of test section which was chosen.

$$\Delta P = (128\mu_{nf} L Q) / (\pi D^4) \qquad (2)$$

$$Re = (\rho_{nf}\, V_D) / \mu_{nf} \qquad (3)$$

The variation of measured (experimental) and calculated pressure drops with Reynolds number for nanofluid of 1% particle concentration is shown in Fig. 5. For better investigation of measured data, three calculated pressure drop curves are plotted by employing the viscosity at inlet, outlet and average viscosity of inlet-outlet of test section. As expected, from this figure, it is noted that, the pressure drop increases with the increase of Reynolds number. Also, it is observed that the experimental curve under imposed constant heat flux is between and to some extent close to the theoretical calculation with average viscosity.

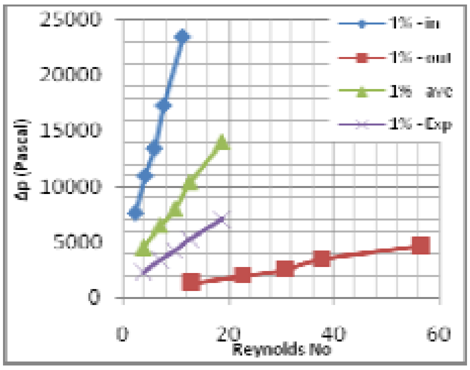

Figure 5: Pressure drop of nanofluid 1% Wt versus Reynolds number under 9000 ($Watt / m^2$) heat flux.

Figures 6 to 8 show the effect of nanodiamond concentration on pressure drop of engine oil under three different heat fluxes. From these figures it is concluded that pressure drop increases with the increase of particle concentration at a given Reynolds number. On the contrary of some experimental researches [7] that showed no significant changes in pressure drop due to addition of nanoparticles, an increase in pressure drop of engine oil nanofluids is observed in the present work for all the imposed heat fluxes.

Carefully investigation of Figures 6-8 lead to this conception that at a fixed Reynolds number and a particle concentration, the increase in heat flux causes less increment of pressure drop as a consequence of existing nanoparticles and it is justifiable because the increment of viscosity for engine oil in higher particle concentration subsided in higher temperatures. Another tenor that one can get noting to the figures 6-8 is, at the same particle concentration in all imposed heat fluxes, with increasing Reynolds number the experimental curves diverge in comparison with base fluid through the tube. With an increase in Reynolds number, consequently, flow rate increases and whereas it multiple to the viscosity in Eq. (2), causes to emboss the increase of viscosity due to particle concentration.

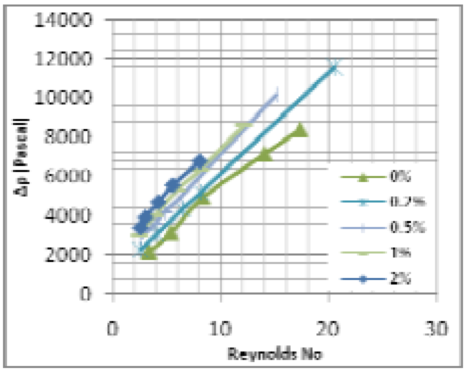

Figure 6: Variation of pressure drop with Reynolds number for constant heat flux of 3333 ($Watt / m^2$)

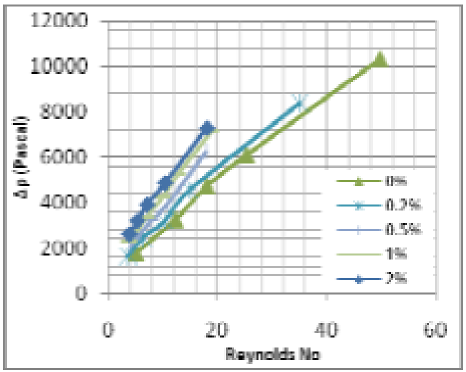

Figure 7: Variation of pressure drop with Reynolds number for constant heat flux of 9000 ($Watt / m^2$)

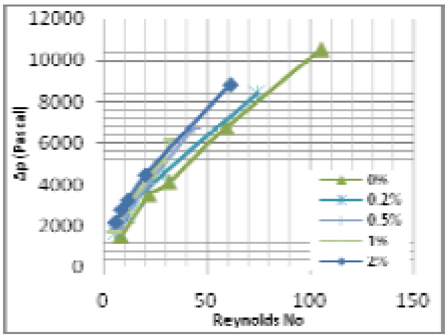

Figure 8: Variation of pressure drop with Reynolds number for constant heat flux of 16666 (Watt / m2)

V. CONCLUSION

The following conclusions were obtained from the present research work:

- Addition of nanoparticles into base fluid increases the viscosity and this increment grows with increasing of nanodiamond concentration. Also the prepared nanofluids treated as Newtonian fluid at concentrations up to 2% Wt.
- The measured pressure drop under all 3 imposed constant heat fluxes, is located between the calculated pressure drop curves based on inlet, outlet or average test section temperatures. It is to some extent close to the theoretical calculation with mean viscosity.
- The pressure drop at a given Reynolds number increases with the increase of particle concentration. Also, at a given Reynolds number and particle concentration, the increase in heat flux causes less increment of pressure drop as a consequence of existing nanoparticles.
- At the same particle concentration in all imposed heat fluxes, with the increase of Reynolds number, the experimental pressure drop curves are diverging through the tube in comparison with base fluid.

V. ACKNOWLEDGEMENTS

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