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Effect Of Cuo-Distilled Water Based Nanofluids On Heat Transfer Characteristics And Pressure Drop Characteristics.

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Abstract:
In this paper, the heat transfer and pressure drop characteristics of the distilled water and the copper oxide-distilled water based nanofluid flowing in a horizontal circular pipe under constant heat flux condition are studied. Copper oxide nanoparticles of 40nm size are dispersed in distilled water using sodium dodecyl sulphate as surfactant and sonicated the nanofluid for three hour. Both surfactant and sonication increases the stability of the nanofluid. The nanofluids are made in three different concentration i.e. 0.1 Vol. %, 0.25 Vol. % and 0.50 Vol. %. The thermal conductivity is measured by KD2 PRO, density with pycnometer, viscosity with Brookfield LVDV-III rheometer. The results show that the thermal conductivity increases with both temperature and concentration. The viscosity and density increases with concentration but decreases with temperature. The specific heat is calculated by model and it decreases with concentration. The experimental local Nusselt number of distilled water is compared with local Nusselt number obtained by the well known shah equation for laminar flow under constant heat flux condition for validation of the experimental set up. The relative error is 4.48 % for the Reynolds number 750.9. The heat transfer coefficient increases with increase in both flow rate and concentration. It increases from 14.33 % to 46.1 % when the concentration is increased from 0.1 Vol. % to 0.5 Vol. % at 20 LPH flow rate. Friction factor decreases with increase in flow rate. It decreases 66.54 % when the flow rate increases from 10 LPH to 30 LPH for 0.1 Vol. %.
Keywords: CuO-distilled water nanofluids, heat transfer coefficient, pressure drop, laminar flow, concentration.

I. Introduction

Now a day's conventional heat transfer fluids such as air, water, helium, minerals oils, ethylene glycol and freon are inadequate for ultra-high cooling require in super computers, industries, automobile, integrated-electronic devices, fuel cell, high power microwaves tubes and superconducting magnets due to limited thermal conductivity. So, the research had been going on, to find the new method for enhancing the heat transfer from past few decades. One of the methods is incorporating the very small size particles such as metallic, non-metallic and polymeric in to base fluid to enhance the heat transfer.

Increase in thermal conductivity by suspending micrometer or millimeter size particles but these techniques had many drawback. The drawbacks are poor stability of the suspension, abrasion/erosion in pipe walls and clogging of the flow channel. In 1995, Stephen U. S. Choi at the Argonne National Laboratory of USA gave a concept of nanofluids. Nanofluids are a heat transfer fluids produced by dispersing particles (size less than 100 nm) into a conventional heat transfer fluids such as water, ethylene glycol, refrigerants and oils [1]. A lot of researches have been carried out on the heat transfer properties of nanofluids in the past decade. Some of these experimental studies are expressed as follows.

Anoop et al. [2] evaluated the effect of particle size on convective heat transfer in laminar developing region. Two particle sizes were used, one with average particle size off 45 nm and the other with 150 nm. It was observed that both nanofluids showed higher heat transfer characteristics than the base fluid and the nanofluid with 45 nm particles showed higher heat transfer coefficient than that with 150 nm particles. It was also observed that in the developing region, the heat transfer coefficients showed higher enhancement than in the developed region.

Shuichi et al. [3] had performed Experimental study to investigate heat transfer performance of aqueous suspensions of nanoparticles, that is, Al_2O_3, CuO, and diamond. They found that (1) by suspending nanoparticles in base fluid the heat transfer enhancement was caused and become more prominent with increase in particle volume fraction. (2) The presence of particles produces adverse effects on viscosity and pressure loss that also increased with the particle volume fraction. The enhancement of the above properties was due to particle aggregation.

Fotukian et al. [4] had conducted an experiment to find the turbulent convective heat transfer performance and pressure drop of very dilute (less than 0.24% volume) CuO/water nanofluid flowing through a circular tube. In average 25% increase in heat transfer coefficient was observed with 20% penalty in pressure drop. Also the ratio of convective heat transfer coefficient of nanofluid to that of pure water decreased with increasing Reynolds number. It was observed that the wall temperature of the test tube decreased considerably when the nanofluid flowed in the tube.

Chandrasekar et al. [5] had synthesized Al_2O_3 nanoparticles of 43nm size by chemical precipitation method and prepared a nanofluid with a volume concentration of 0.1% by dispersing a specified amount of Al_2O_3 nanoparticles in distilled water. Two wire coil inserts made of stainless steel with pitch ratios (defined as the ratio of pitch of the coil to diameter of tube) 2 and 3 were used The heat transfer performances of nanofluid was better with wire coil insert and was attributed to the effect of dispersion or back-mixing which flattens the temperature distribution and make the temperature gradient between the fluid and wall steeper. The measured pressure loss with the use of nanofluids was almost equal to that of the distilled water.

Syam et al. [6] had studied experimentally the turbulent convective heat transfer and friction factor behavior of Al_2O_3 nanofluid in a circular tube with different aspect ratios of longitudinal strip inserts. It was found that heat transfer coefficients increase with nanofluid volume concentration and decrease with aspect ratio.

Rashidi et al. [7] measured heat transfer coefficient of CNTs nanofluid in laminar flow regime. There was considerable enhancement in convective heat transfer coefficient of nanofluids. The increment was particularly significant in entrance length and it depended on the CNTs concentration and flow condition (Reynolds number). The enhancement in convective heat transfer was a function of axial distance from inlet and it had a decreasing trend.

Yanuar et al. [8] has investigated experimentally the flow and convective heat transfer characteristics of water-based nanofluids flowing through a spiral pipe. The heat transfer enhancement was more as compared with that of pure water. The Pressure drop was also significant. At a given Reynolds number and nanoparticles concentration the local heat transfer coefficient of nanofluids as well as base fluid decreased with increasing axial distance from the inlet of the test section.

Heyhat et al. [9] had done experiment to determine the heat transfer coefficient and friction factor of the nanofluids flowing in a horizontal tube on fully developed region under the constant wall temperature and laminar flow condition. The results showed that the heat transfer coefficient of nanofluid was higher than that of the base fluid and increased with increasing the Reynolds number and particle concentrations.

Naraki et al. [10] investigated experimentally the overall heat transfer coefficient of CuO/water nanofluids under laminar flow regime ($100 < Re < 1000$) in a car radiator. The experimental system is quite similar to cars' cooling system. The nanofluids in all the experiments had stabilized with variation of pH and use of suitable surfactant. The overall heat transfer coefficient increased with the enhancement in the nanofluid concentration from 0 to 0.4 vol. %. Increasing the flow rate enhanced the overall heat transfer coefficient. According to the analysis performed using Taguchi method, the best operating conditions included minimum temperature, maximum concentration of nanofluid, maximum flow rate of nanofluid and maximum flow rate of air.

Jianli et al. [11] had experimentally investigated the convective heat transfer and pressure drop of dilute nanofluids containing multi-walled carbon nanotubes (MWNT) in a horizontal circular tube. There was enhancement in heat transfer compared with that of DI water at $Re > 100$.The pressure drop was found to increase linearly with increasing Re, under the laminar flow condition. The corresponding friction factor for the dilute nanofluids was approximately the same as that of DI water.

Meyer et al. [12] had done experiment to determine the convective heat transfer of multi-walled carbon nanotubes flowing through a straight horizontal tube for a Reynolds number range of 1000–8000, which included the transitional flow regime. It was found that heat transfer was enhanced when comparing the data on a Reynolds–Nusselt graph but when comparing the data at the same velocity; it was shown that heat transfer was not enhanced. Pressure drop results indicated that as particle volume concentration increased, the pressure drop increased, which results from increase in viscosity.

Esmaeilzadeh et al. [13] had determined the hydrodynamics and heat transfer characteristics of □-Al_2O_3 nanoparticles inside a circular tube in laminar flow with constant heat flux. There was enhancement in convective heat transfer coefficient if the particle volume fraction was increased. The heat transfer coefficient increased if heat flux was increased at a constant volume fraction, there was no significant change of friction factor for nanofluids in comparison with base fluid.

Dongsheng et al. [14] had investigated the convective heat transfer of nanofluids at the entrance region under laminar flow conditions. The enhancement increased with Reynolds number, as well as with particle concentration. It was also shown that the classical Shah equation failed to predict the heat transfer behavior of nanofluids. The enhancement decreased with axial distance and it was

significant in the entrance region. The cause of enhancement was supposed to be particle migration.
The main purpose of this study is to determine the heat transfer and pressure drop characteristics of the CuO-distilled water based nanofluid. The effects of the concentration and flow rate on thermal properties, heat transfer coefficient and friction factor are studied. In additional the effects of concentration and flow rate on the Reynolds number are also studied.

II. Experimental procedure

2.1. *Preparation of nanofluids*

The copper oxide (CuO) nanoparticles of average size 40nm were purchased from Intelligent Materials Pvt. Ltd, Panchkula. TEM analysis of CuO nanoparticles is shown in Fig.1. The properties of CuO nanoparticles are given in table1.

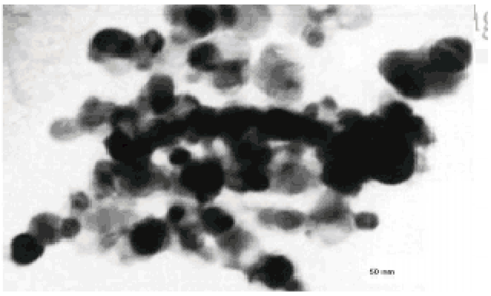


Fig. 1. TEM analysis of CuO nanoparticles.

Table 1 Properties of the copper oxide nanoparticles [15]

Chemical formula	Purity	d_P(mm)	ρ(kg/m^3)	C_P(J/kg.K)	k(W/m.K)
CuO	>99%	40nm	6400	535	69

The distilled water and sodium dodecyl sulphate surfactant was obtained from the chemical engineering Department of the Thapar University, patiala. The preparation of the nanofluid is the first step for this heat transfer experiment. The nanofluid was prepared by the two-step method in which the nanoparticles were dispersed in the base fluid. First of all calculation was made for the weight of CuO nanoparticles used for 50ml of the distilled water for different concentration. It was 0.32gm, 0.8gm and 1.6gm for 0.1 vol. %, 0.25 vol. % and 0.5 vol. %, respectively of the nanofluid. The mass of the SDS surfactant used, was 0.1gm for the 50ml distilled water and for all the three concentration. After the calculation of the mass of the CuO nanoparticles and the SDS surfactant, the required mass of the SDS was directly added to the distilled water and thoroughly stirred. Then required mass of the CuO was added to the surfactant dissolved distilled water and then stirred thoroughly [16]. To increase the dispersion stability the sonication was done by the ultra-sonicator water bath for three hours. After the sonication the prepared nanofluids were used to measure the thermo-physical. A fresh nanofluid was prepared every time when it was used in experimental set-up for taking the readings.

2.2. *Experimental set-up*

The experimental set-up for measuring the convective heat transfer coefficient and pressure drop is shown schematically in Fig. 2. It consisted of a flow loop, a heating unit, a cooling unit, and a measuring and control unit.The flows loop included pump, rotameter, flow control valves, by-pass line, collection tank and test section. The test section was a straight copper pipe outer diameter ½ inch (12.7 mm), inner diameter 0.0095m, length 1.5m, embedded with 8 RTD Pt 100 thermocouples, 6 on surface, 1 each at inlet & outlet with U-tube differential manometer for measuring pressure difference across test length. The test section is electrically heated by an adjustable AC power supply. A nickel-chrome wire heater of 250 watts is wrapped over the test piece with varied for controlled external heating of section. An AC power supply is used as a power source to the heater. There is a thick thermal isolating layer surrounding the heater along the test section. A double pipe type heat exchanger is employed to cool the nanofluids. The flow rates are measured by a stop watch and measuring cylinder. It is also measured by rotameter. Collection tank is made of stainless steel insulated with ceramic fibre wool. The pump used in this set-up is air cooler submersible pump (18W). Control panel consists of ammeter, voltmeter, digital temperature controller, digital temperature indicator with heater supply switch, pump supply switch, on/off switch etc.

III. Evaluation of heat transfer coefficient and pressure drop

For the calculation of the heat transfer coefficient and pressure drop, the thermo- physical properties of the CuO-distilled water required to be calculated. The conductivity was measured with the help of KD2 PRO thermal properties analyzer, viscosity was measured with Brookfield LVDV-III Rheometer and density with pycnometer or specific gravity bottle. Specific heat was calculated by the model or equation which assumes that the base fluid and the nanoparticles are in thermal equilibrium [17, 18]. The equation is:

$$C_{nf} = \frac{\left(\phi C_p + (1+\phi)\rho_{bf} C_{bf}\right)}{\rho_{nf}} \qquad (1)$$

where C_{nf} is the specific heat of the nanofluids, C_{bf} is the specific heat of the base fluid, ρ_{bf} is the density of the base fluid and ρ_{nf} is the density of the nanofluids.

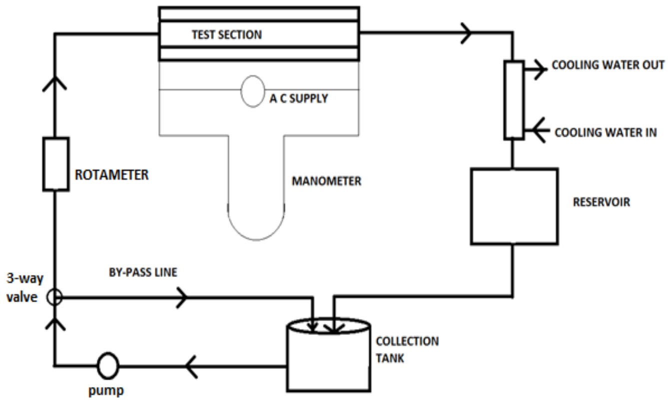


Fig. 2. Experimental Set-up.

As the test section is explained earlier, Q_1 heat supplied from the nichrome wire heater which is wrapped around the outer surface of the test section. The tube become heated which heat up the fluid flowing through it. So, Q_2 is the heat gained by the base fluid or CuO/water nanofluid which is less than the heat supplied i.e. Q_1. Some heat losses as the insulation losses. In equation form:

Q_1 (Heat supplied) = V x I (2)

Q_2 (Heat gained) = Q_1- Losses (3)

Which is further equals to:

$$Q_1 = mC_p \Delta T = mC_p (T_8 - T_1) \tag{4}$$

where Q_1 is the heat gained by the nanofluid, *m* is the mass flow rate of nanofluid, and T_8 and T_1 are the temperatures of the nanofluid at the outlet and inlet of the test section, respectively. The thermocouples are fixed at the outer section of the pipe. So reading of the temperature at the inner section is given by the conduction equation for hollow cylinder which is given below:

$$Q_1 = \frac{2\pi k L(T_{so} - T_{si})}{\ln \frac{r_o}{r_i}} \tag{5}$$

From above equation T_{si} can be calculated.

Where,

T_{so} = Outside Avg. surface temperature of test section

$$= \frac{(T_2 + T_3 + T_4 + T \ \ + T_6 + T_7)}{6} \tag{6}$$

T_{si} = Inside Avg. surface temperature of test section

The convective heat transfer coefficient (h) is defined as:

$$h(x) = \frac{q}{(T_w(x) - T_f(x))} \tag{7}$$

where, x is the axial distance from the inlet of the test section, q is the heat flux, T_w and T_f are the wall and fluid mean temperature, respectively.

And fluid mean temperature is given by the energy balance:

$$T_f = T_{in} + \frac{qPx}{(\rho A_C \bar{V} C_p)} \tag{8}$$

The Nusselt number is defined as:

$$Nu(x) = \frac{h(x) \bullet D}{k} \tag{9}$$

And Nusselt number is the function of the Reynolds number and Prandtl number

$$\mathrm{Re} = \frac{(\rho \bar{V} D)}{\mu} \tag{10}$$

$$\mathrm{Pr} = \frac{\nu}{\alpha} \tag{11}$$

Where ν is the kinematic viscosity, μ is the dynamic viscosity and α is the fluid thermal diffusivity.

The pressure drop was calculated by Hagen-Poiseuille equation.

$$\Delta p = \frac{32 \mu L \bar{V}}{D^2} \tag{12}$$

IV. Result and discussion

4.1. *Validation*

Before conducting the experiment on nanofluid in test section the reliability and accuracy of experimental setup has been tested by using distilled water as the working fluid at constant heat flux flowing through test section at different flow rates. The results were compared with the result obtained from the Shah equation [19] for laminar flow under constant heat flux.

Shah equation:

$$Nu = 1.953(\mathrm{Re}.\mathrm{Pr}.\frac{D}{x})^{1/3} \qquad (\mathrm{Re}.\mathrm{Pr}.\frac{D}{x}) \geq 33.3 \tag{13}$$

$$Nu = 4.364 + 0.0722 \mathrm{Re}\,\mathrm{Pr}\frac{D}{x} \qquad (\mathrm{Re}.\mathrm{Pr}.\frac{D}{x}) < 33.3 \tag{14}$$

From shah equation Nusselt number is calculated and was compared with experimental data for distilled water at Reynolds number 750.9 and 1340.3.

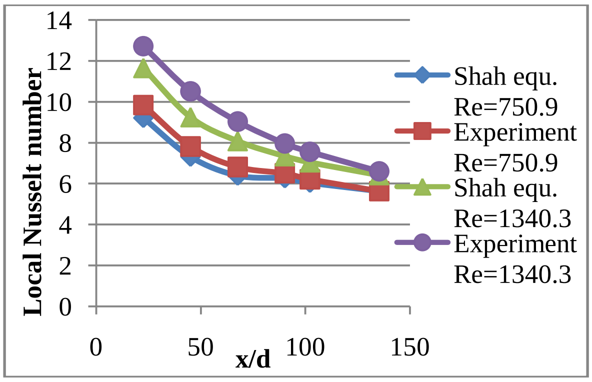


Fig. 3. Comparison between the experimental Nusselt number and shah equation versus axial distance.

Fig. 3 shows the comparison between the Shah equation and the measurements using distilled water at Re = 750.9 and 1340.3 and the relative error are 4.48 % & 8.84 %, respectively. Hence good conformity can be seen between the results predicted by shah equation and those by the experiments.

4.2. *The density of nanofluids*

The calculated value of density of distilled water, 0.1 %, 0.25 % and 0.5 % volume fraction of copper oxide distilled water based nanofluids for temperature range 30°C to 80°C are shown in Fig. 4. It can be seen that at 30°C, with the increase in the concentration of nanoparticles from 0.1 % to 0.50 %, density of copper oxide-distilled water based nanofluids increases from 0.93 % to 1.66 % (i.e. 0.93 % for 0.1 % concentration, 1.33 % for 0.25 % concentration, 1.66 % for 0.50 %) compared to base fluid i.e. distilled water.

And with the increase in temperature, density of distilled water and copper-oxide distilled water based nanofluids decreases. From 30°C to 80°C, density decreases by 2.24 % for distilled water, 1.77 % for 0.1 % concentration, 1.64 % for 0.25 % concentration, and 1.26 % for 0.50 % concentration.

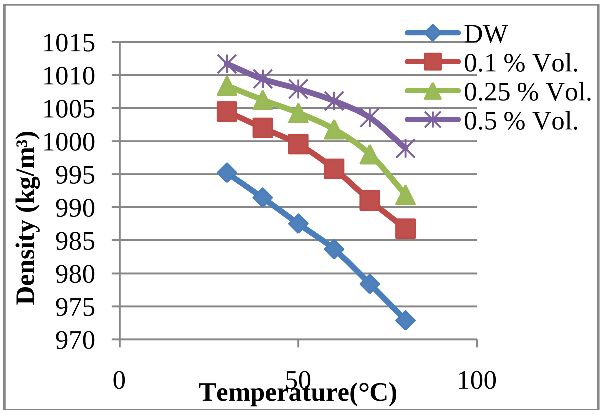


Fig. 4. Temperature-density graph.

4.3. *The viscosity of nanofluids*

Viscosity has measured for different concentrations (0.1%, 0.25% and 0.5%) of CuO-distilled water based nanofluids for temperature range between 20ºC and 80ºC. The variation of viscosity with temperature and concentrations are shown by Fig. 5. Viscosity of nanofluid increases as the concentration increases at same temperature but it decreases as temperature increases at same concentration.

It can be seen that at 20°C, with the increase in the concentration of nanoparticles from 0.1 % to 0.5 %, viscosity of copper oxide-distilled water based nanofluids increases from 10.50 % to 65.21 % (i.e. 10.50 % for 0.1 % concentration, 35.67 % for 0.25 % concentration, 65.21 % for 0.50 % concentration) compared to base fluid i.e. distilled water.

And with the increase in temperature, viscosity of copper oxide-distilled water based nanofluids decreases. From 20°C to 80°C, viscosity decreases by 67.72 % for distilled water, 65.34 % for 0.1 % concentration, 65.48 % for 0.25 % concentration and 67 % for 0.50 % concentration.

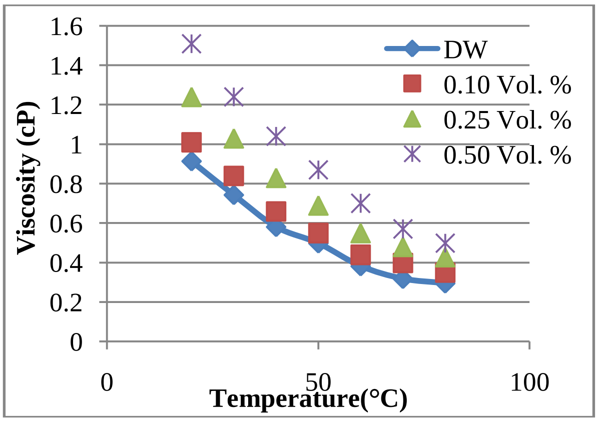


Fig. 5. Temperature-viscosity graph.

4.4. *The thermal conductivity of nanofluids*

Thermal conductivity of the samples has been measured from temperature range 20ºC to 80ºC. The variation of thermal conductivity with temperature and concentration are shown by Fig. 6.

It can be seen that at 20°C, with the increase in the concentration of nanoparticles from 0.1 % to 0.5 %, thermal conductivity of copper oxide-distilled water based nanofluids increases from 0.68 % to 2.0 % (i.e. 0.68 % for 0.1 % concentration, 1.36 % for 0.25 % concentration, 2.0 % for 0.50 % concentration) compared to base fluid i.e. distilled water.

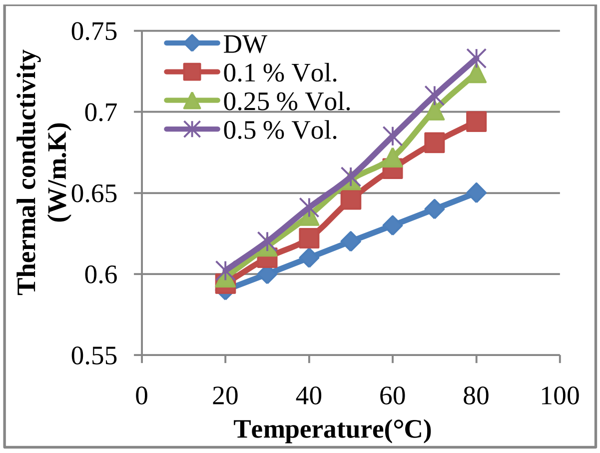
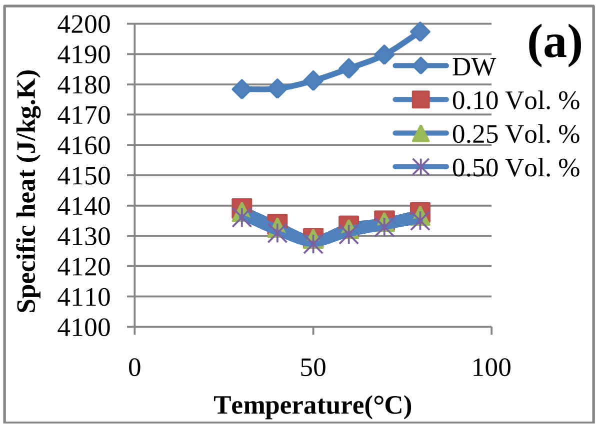


Fig. 6. Temperature-thermal conductivity graph.

And with the increase in temperature, thermal conductivity of copper oxide-distilled water based nanofluids increases. From 20°C to 80 °C, thermal conductivity increases by 10.57 % for distilled water, 16.84 % for 0.1 % concentration, 21.07 % for 0.25 % concentration, and 21.76 % for 0.50 % concentration.

4.5. *Specific heat calculation of nanofluids*

Specific heat for nanofluids has been calculating by using energy balance equation as discussed above. The variation of the specific heat with the concentration is shown in Fig. 7 specific heat decreases as the concentration of nanoparticles increases for example it can be seen from the graph that at 20°C, with the increase in the concentration of nanoparticles from 0.1 % to 0.5 %, specific heat of copper oxide-distilled water based nanofluids decreases from 0.94 % to 1.01 % (i.e. 0.94 % for 0.1 % concentration, 0.97 % for 0.25 % concentration, 1.01 % for 0.50 % concentration) compared to base fluid i.e. distilled water. But it decreases first and then increases with the increase in temperature.



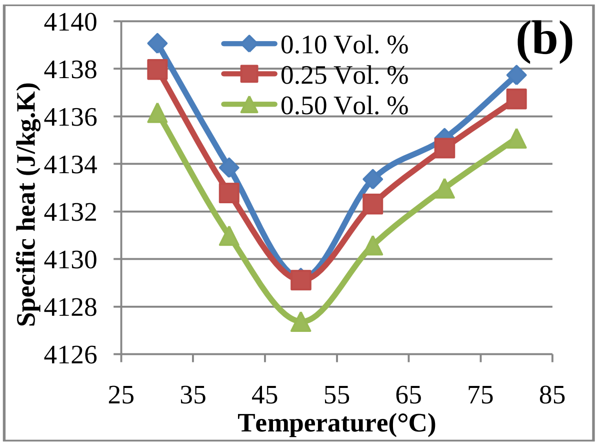


Fig. 7. Temperature-specific heat graph (a) shows DW, 0.10 Vol. %, 0.25 Vol. % and 0.50 Vol. % concentrations (b) shows 0.10 Vol. %, 0.25 Vol. % and 0.50 Vol. % concentrations.

4.6. *Reynolds number of nanofluids*

The experiments were performed on constant power input at different flow rate i.e. 10 LPH, 20 LPH, 25 LPH and 30 LPH with distilled water and three different concentrations (0.1 %, 0.25 % and 0.5 %) of copper oxide with distilled water as base fluids. The voltage was 214.46 V and current was 1.709 A. From the fluid inlet and outlet temperature for particular flow rate and concentration fluid mean temperature was calculated. At the calculated fluid mean temperature the various thermo-physical properties of the fluid were calculated. With the help of formulae already mention and using the values of these properties, the values of Reynolds number, heat transfer coefficient and Nusselt number are calculated.

Fig. 8 shows the calculated value of the Reynolds number at different flow rate and at different concentration. It is observed that the Reynolds number is increases with the flow rate. The reason is that it is directly proportional to the velocity and velocity always increases with increasing the flow rate.

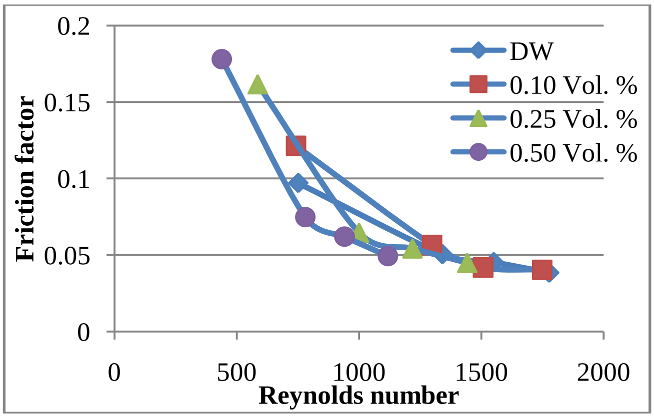


Fig. 8. Flow rate versus Reynolds number at various volume concentrations.

But it is not true for the concentration. It decreases with the increase in concentration. The reason is that it is inversely proportion to the viscosity and viscosity increases with the increase in concentration. But increase in concentration also increases the density which is directly proportional the Reynolds number. So, both density and viscosity increases with the increase in concentration. But the effect of viscosity is predominated or more than density hence Reynolds number decreases.

4.7. *Convective heat transfer coefficient of nanofluids*

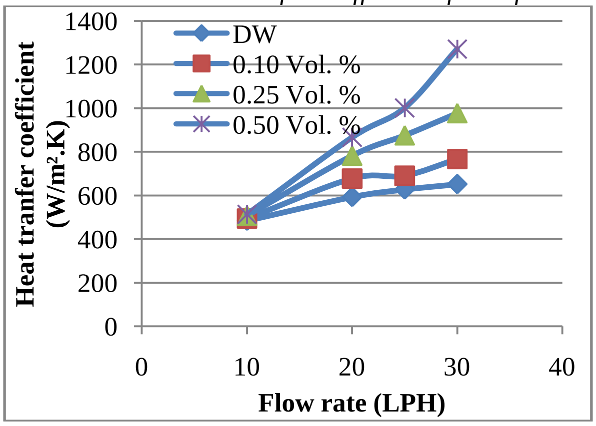


Fig. 9. Flow rate versus heat transfer coefficient at various volume concentrations.

Fig. 9 shows the variation of the average heat transfer coefficient with different flow rate at given concentration. The value of average heat transfer coefficient increases with increase in flow rate and also with the increase in the concentration. Here heat transfer coefficient means the average heat transfer coefficient.

At 10 LPH flows rate of nanofluid, there is an increment of 2.23 % in heat transfer coefficient at 0.1 vol. % concentration of CuO-distilled water based nanofluid, 5.0 % increment in heat transfer coefficient at 0.25 vol. % of CuO-distilled water based nanofluid and 6.04 % increment in heat transfer coefficient at 0.5 vol. % of CuO-distilled water based nanofluid as compared to distilled water heat transfer coefficient.

At 20 LPH flows rate of nanofluid, there is an increment of 14.33 % in heat transfer coefficient at 0.1 vol. % concentration of CuO-distilled water based nanofluid, 32.0 % increment in heat transfer coefficient at 0.25 vol. % of CuO-distilled water based nanofluid and 46.1 % increment in heat transfer coefficient at 0.5 vol. % of CuO-distilled water based nanofluid as compared to distilled water heat transfer coefficient.

At 25 LPH flows rate of nanofluid, there is an increment of 10.0 % in heat transfer coefficient at 0.1 vol. % concentration of CuO-distilled water based nanofluid, 39.57 % increment in heat transfer coefficient at 0.25 vol. % of CuO-distilled water based nanofluid and 59.55 % increment in heat transfer coefficient at 0.5 vol. % of CuO-distilled water based nanofluid as compared to distilled water heat transfer coefficient.

At 30 LPH flows rate of nanofluid, there is an increment of 17.61 % in heat transfer coefficient at 0.1 vol. % concentration of CuO-distilled water based nanofluid, 49.90 % increment in heat transfer coefficient at 0.25 vol. % of CuO-distilled water based nanofluid and 95.03 % increment in heat transfer coefficient at 0.5 vol. % of CuO-distilled water based nanofluid as compared to distilled water heat transfer coefficient.

4.6. *Nusselt number of nanofluids*

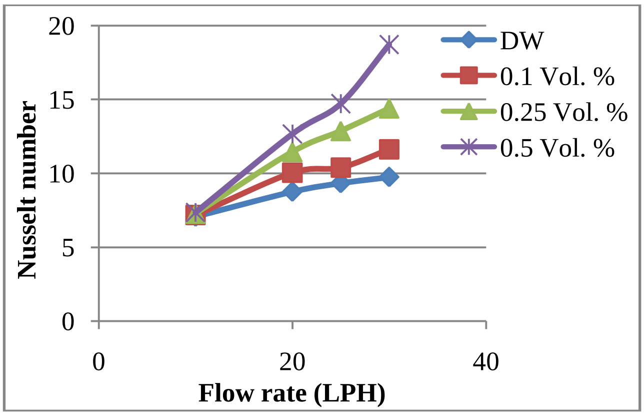


Fig. 10. Flow rate versus Nusselt number at various volume concentrations.

Fig. 10 shows the variation of Nusselt number with the flow rate. This figure reveals the same thing as by the Fig. 9. This is because the Nusselt number is directly proportional to the heat transfer coefficient. Fig. 11 shows the variation of the Nusselt number with the Reynolds number. The purpose of the Fig. 11 is to shows the additional effect of concentration on the Nusselt number. It is increases with the concentration.

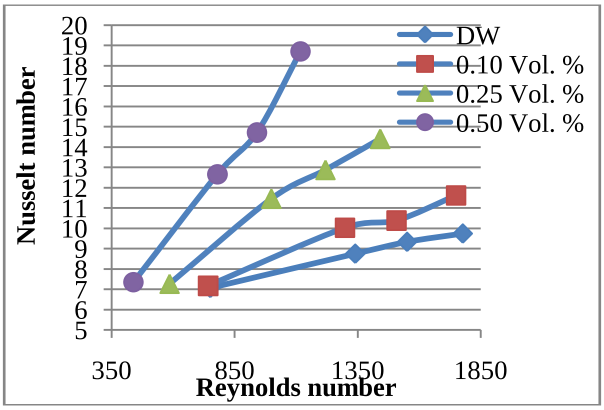


Fig. 11. Reynolds number versus Nusselt number at various volume concentrations.

4.10. *Pressure drop of nanofluids*

The pressure drop is measured for different flow rate (10 LPH, 20 LPH, 25 LPH and 30 LPH).

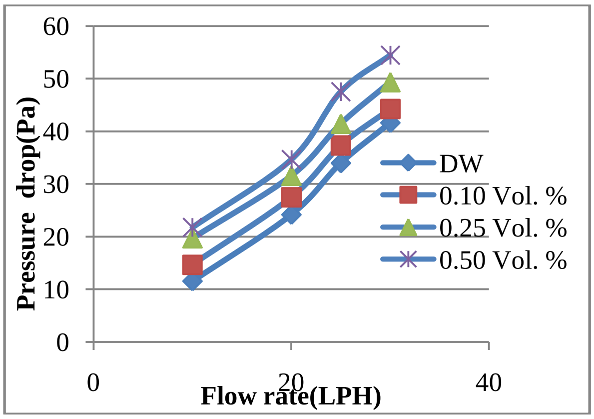


Fig. 12 Flow rate versus pressure drop at various volume concentrations

Fig. 12 shows the variation of the pressure drop with the flow rate and concentration. The value pressure drop increases with the increase in flow rate. The pressure drop increases with nanoparticles concentration. The pressure drops are high at higher volume fractions. For example at 30 LPH flow rate for 0.5 % is 30.7 % higher than distilled water and for the same flow rate but at 0.1 % it was 6.2 % higher than the distilled water. So using the nanofluids at higher concentration is also not good as it may create penalty in pressure drop.

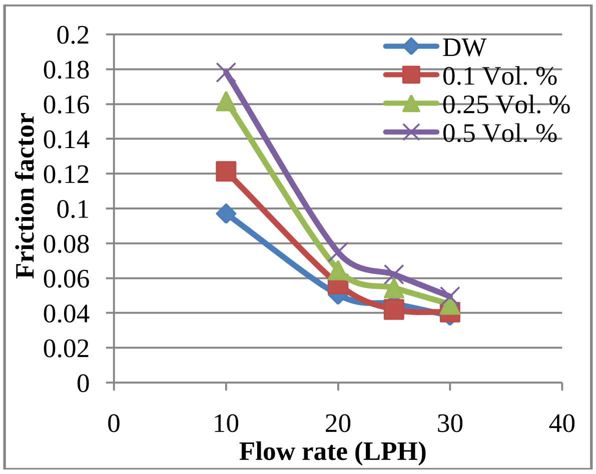


Fig. 13. Variation of the friction factor with flow rate and concentration.

Fig. 13 shows the variation of the friction factor with the flow rate at different concentration. Friction factor decreases continuously with the increase in flow rate. For nanofluids it increases with the increase in concentration except for 0.1 Vol. % at 25 LPH flow rate where it shows the decrement of 7.3 %, when compared with distilled water for the same flow rate.

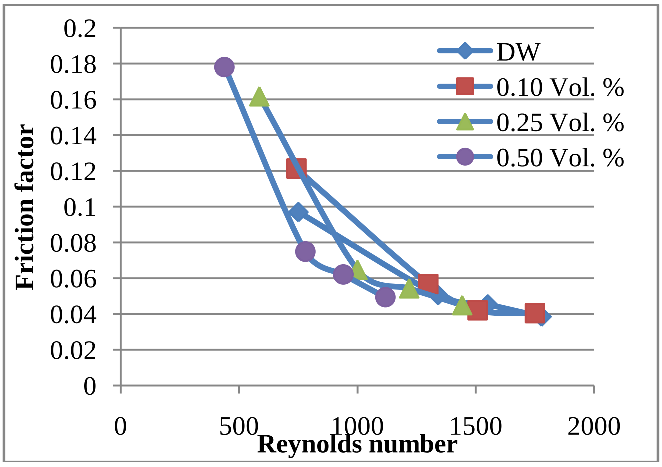


Fig. 14. Reynolds number versus friction factor at various volume concentrations.

Fig. 14 shows the variation of the friction factor with the Reynolds number. It decreases with the increase in Reynolds number but increases with the increase in concentration. It is because of the decrease in Reynolds number with the increase in concentration. Fig. 13 and Fig. 14 show the same thing i.e. the variation of the friction factor with the flow rate and with the Reynolds number. But Fig. 14 also shows the effect of the concentration. The friction factor increases with the increase in concentration.

V. Conclusion

The purpose of this study was to observe and measure the heat transfer and pressure drop characteristics of the distilled water and the copper oxide-distilled water based nanofluid flowing in a horizontal circular tube in a laminar flow under constant heat flux condition. The CuO-distilled water based nanofluids are prepared by dispersing the nanoparticles of 40nm size into distilled water and using sodium dodecyl sulphate as surfactant and the prepared nanofluids are sonicated with the help of ultra sonicator water bath. The nanofluids are made in three different concentrations i.e. 0.1 vol. %, 0.25 Vol. % and 0.5 Vol. %. Based on experimental results the following discussions are drawn:

- The addition of the nanoparticles in the base fluid increases the density. At 30°C, the density of copper oxide-distilled water based nanofluids increases from 0.93 % to 1.66 % with the increase in the concentration of nanoparticles from 0.1 % to 0.50 %. It decreases continuously with the increase in temperature.
- The viscosity increases with the increase in concentration. At 30°C, the viscosity of copper oxide-distilled water based nanofluids increases from 10.50 % to 65.21 % with the increase in the concentration of nanoparticles from 0.1 % to

0.50 %. It decreases continuously with the increase in temperature.

- The thermal conductivity is also increases with the addition of the nanoparticles. At 30°C, the viscosity of copper oxide-distilled water based nanofluids increases from 0.68 % to 2.0 % with the increase in the concentration of nanoparticles from 0.1 % to 0.50 %. It increases continuously with the increase in temperature.
- The specific heat was first decreases and then increases with temperature. But with the increase in concentration it decreases.
- The experimental local Nusselt number of distilled water is compared with Nusselt number obtained by the well known shah equation for laminar flow under constant heat flux condition for validation of the experimental set up. The relative errors are 4.48 % and 8.84 % for the Reynolds number 750.9 and 1340.3, respectively.
- Reynolds number increases with temperature but decreases with the increase in concentrations.
- Heat transfer coefficient increases with increase in both flow rate and concentration. for example At 20 LPH flows rate of nanofluid, there is an increment of 14.33 % in heat transfer coefficient at 0.1 vol. % concentration of CuO-distilled water based nanofluid, 32.0 % increment in heat transfer coefficient at 0.25 vol. % of CuO-distilled water based nanofluid and 46.1 % increment in heat transfer coefficient at 0.5 vol. % of CuO-distilled water based nanofluid as compared to distilled water heat transfer coefficient.
- And with the increase in flow rate, heat transfer coefficient of copper oxide-distilled water based nanofluids increases. From 10 LPH to 30 LPH, heat transfer coefficient increases by 34.69 % for distilled water, 54.94 % for 0.1 % concentration, 92.28 % for 0.25 % concentration and 147.72 % for 0.50 % concentration.
- Nusselt number increases with increase in both Reynolds number and concentrations.
- Pressure drop increases with increase in flow rate and concentrations.
- Friction factor decreases with increase in Reynolds number but increases with the increase in concentration.
- Friction factor decreases with increase in flow rate. For 0.5 Vol. %, the decrement in friction factor of copper oxide-distilled water based nanofluids is 72.22 % with the increase in the flow rate from 10 LPH to 30 LPH.

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