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Heat Transfer Enhancement of CuO–Water Nanofluid in a Double Tube Heat Exchanger

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Abstract

In this study, heat transfer , Overall heat transfer coefficient and Nusselt number of a fluid containing nanoparticles of Cu oxide with the water volume fraction (0.1-0.5%)(V/V) percent has been reported. Heat transfer of the fluid containing nano water Cu oxide with a diameter of about 40 nm in a horizontal double pipe counter flow heat exchanger under turbulent and laminar flow conditions was studied. Based on the results of the present investigation, for, heat transfer , Overall heat transfer coefficient and Nusselt number of nanofluids are higher than those of distilled water. The enhancement increases with increasing nanoparticle concentration. The results showed that the heat transfer , Overall heat transfer coefficient and Nusselt number of nanofluid in comparison with the heat transfer of fluid is slightly higher than (20 percent).

Introduction

Double pipe heat exchangers is the apparatus providing heat transfer between two or more fluids, and they can be classified according to the mode of flow of fluid or their construction methods. Heat exchangers with the convective heat transfer of fluid inside the tubes are frequently used in many engineering application. Enhancement of heat transfer intensity in all types of thermo technical apparatus is of great significance for industry. Beside the savings of primary energy, it also leads to a reduction in size and weight.Application of nano-technology in classical thermal designs lead to Nano-Fluid (NF) as a new class of heat transfer fluids. Since conventional heat transfer fluids including water, oil, Ethylene Glycol (EG) show relatively poor heat transfer characteristics, NF has been introduced. By dispersing solid particles, fibers or tubes of 1 to 50 nm length in conventional heat transfer fluids, NFs are formed. There are remarkable characteristics associated with NFs such as: high heat transfer rate, low fluculation ability through passages, thermal homogeneity. In this view, NFs found extensive demand in electronics and automotive industries to name but a few. Consequently, further study of heat transfer of NF suspensions seemed necessary. Ever since Choi et.al. [1] published their first findings in NFs studies, there have been several other works addressed to the improvement of heat transfer up to 20% by using densely distribution of nano-particles in NFs [2-5]. Aghayari et al.[6] reported experimental results which illustrated the heat transfer and Overall heat transfer coefficient of AL_2O_3 nanoparticles dispersed in liquid for Turbolent flow in a Double pipe heat exchanger. Effects of the Reynolds number, volume fraction, temperature, nanoparticle source on the Overall heat transfer coefficient have been investigated. The experimental results showed that the heat transfer coefficient increased with the Reynolds number and the particle concentration. For example at 0.2 (v/v) % the Overall heat transfer coefficient of the nanofluids were 5.2% higher than the base fluid(water) at 35°C fluid temperature and 10.52% higher at 40°C(Re=16000). For the sake of argument, at Reynolds number equals 26000 for water at the Overall heat transfer coefficient valuesare 2300 and 2500, respectively. Nano-particles of Cu with less than 100 nm diameter were employed. The results show that nano-suspended particles substantially improved the performance of conventional base fluid heat transfer. The volume fraction of base fluid in NF fits well with that of water. Furthermore, new convectional heat transfer relations were established to foresee heat transfer coefficients in both laminar and turbulent flows Recently, Khanafer et. Al. [7] discussed on the similar results obtained from a fundamental simulation work. In spite of remarkable potentials in NFs, few steps have been made so far. Further research works on the effect of nano-particles on fluid heat transfer are inevitable. Accordingly, it is necessary to obtain experimental data from fluids containing variety of nano-sized particles. O.S. Prajapati et al. [8] investigated on nanofluids indicate that the suspended nanoparticles markedly change the heat transfer characteristics of the suspension. In this study, heat transfer characteristics of ZnO-water nanofluids were investigated. Experiments were conducted with ZnO-water nanofluids at particle volume concentrations up to 0.1 volume %, constant subcooling of 20°C, pressure 2 bar, mass flux 400 kg/m^2s and heat fluxes up to 500 kW/m^2 with variable. Effect of heat flux and nanofluid concentration on heat transfer coefficient of ZnO-water nanofluids was investigated. Study reveals that heat transfer coefficient increases with ZnO-water nanofluids.K.B. Rana et al.[9] reports an experimental study on the

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pressure drop characteristics of ZnO-water nanofluids through the horizontal annulus. Experiments were performed in single phase and boiling flow of nanofluids under turbulent flow with different low particle concentrations($\leq$0.01 vol. %). Experiments were conducted at flow rates from 0.1 to 0.175 lps, heat fluxes from 0 to 550 kW/m^2 and 1 bar constant inlet pressure. The results show that the pressure drop of the nanofluids is very close to that of the base liquid flows for given flow rates. The pressure drop of the water and nanofluids increases with an increase in the flow rate and remains almost constant with increase in the heat flux.Aghayari et al.[10] reports experimentally the convection heat transfer coefficient and Nusselt number of the Fe_3O_4-water nanofluids flowing in a double pipe heat exchanger under turbulent flow ($14000 \leq Re \leq 34600$)conditions. Fe_3O_4 nanoparticles with diameters of 15-20 nm dispersed in water with volume concentrations of $0.08 \leq \varphi \leq 0.1$ vol. % are used as the test fluid. The results show that the convection heat transfer coefficient and Nusselt number of nanofluid was approximately 12 -26% greater than that of pure fluid. In addition, the heat transfer coefficients and Nusselt number increases with increase in flow rate, nanoparticle concentration and nanofluid temperature. Comparison of experimental results with valid theoretical data based on semi-empirical equations shows an acceptable agreement .

Experimental

Experimental setup

The experimental investigation of heat transfer characteristic of nanofluid was carried out using the experimental apparatus as shown in Figure 1. It mainly consists of a test section, receiving tanks in which working fluids are stored, heating and cooling system, thermometer, flow meter, Rota-meter, pressure measurement system and data acquisition system. The working fluids were circulated through the loop by using variable speed pumps of suitable capacity. The test section is of 1.2 m length with counter flow path within horizontal double pipe heat exchanger in which hot nanofluid was applied inside the tube while cooling water was directed through the annulus. The inside pipe is made of a soft copper tube with the inner diameter of 0.006m, outer diameter of 0.008m and thickness of 0.002 m while the outside pipe is of steel tube with the inner diameter of 0.014m,outer diameter of 0.016 m and thickness of 0.002m. To measure the inlet and outlet temperature of the nanofluid and cold water at the inlet and outlet of the test section, 4 J-type thermocouples with precision 0.1ºC were used. All of the thermocouples were calibrated before fixing them. All four evaluated temperature probes were connected to the data logger sets. A 6kw electronic heater and a thermostat installed on it were used to maintain the temperature of the nanofluid. During the test, the mass flow rate and the inlet and outlet temperatures of the nanofluid and cold water were measured. The temperature of inlet water was maintained around 20 ºC and the flow rate of the water was kept constant at 500 lit/hr .To measure the pressure drop across the test section, differential pressure transmitter was mounted at the pressure tab located at the inlet and outlet of the section. The nanofluid flow rate was measured by a magnetic flow meter which was placed at the entrance of the test section. Water flow meter and nanofluidics using the weight of water and nanofluids have been collected during the calibration means For each test run, it was essential to record the data of the temperature, volumetric flow rates and pressure drop across the section at steady state conditions. Two storage tanks made of stainless steel at capacity of 45 lit were used to collect the fluids leaving the test section. Hot nanofluid was pumped from the fluid tank through the inner tube included twisted tapes at different Reynolds number between 1700 to 15000. To ensure the steady state condition for each run, the period of around 15-20 minutes depending on Reynolds number and twisted tapes was taken prior to the data record.

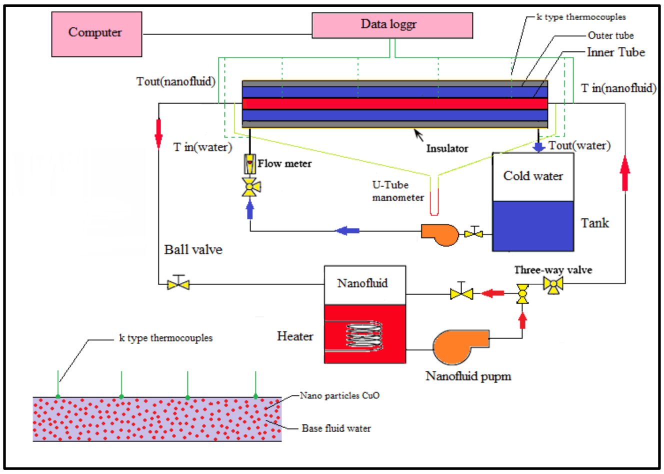


Figure 1: Schematic diagram of the experimental setup.

Thermal Properties of Nanofluid

The nanofluid used in the experiment was +99% pure CuO oxide pre-dispersed in Water, with an average particle size of 40 nm. The nanofluid was mixed with de-ionized water to prepare experimental concentrations. Figure 2 is the TEM photograph of CuO nanoparticles with particle size about 40 nm. (Table.2)

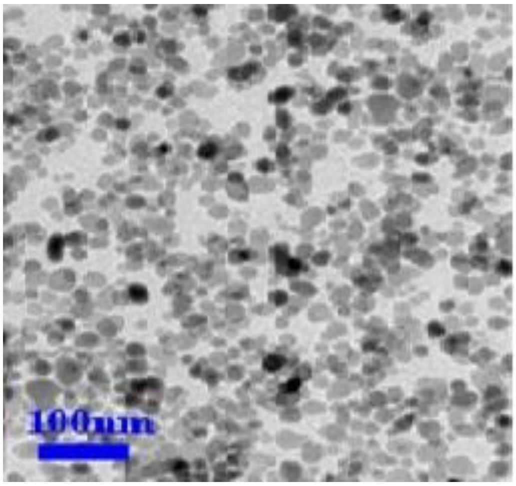


Figure 2: TEM photograph of CuO nanoparticles.

Table.2. Physical properties of the nanoparticles

Nano-particles	sized particles	Special surface	purity	Appea -rance	Bulk Density	True Density	Morpholo-gy
CuO	40 nm	20m^2/g	99%	black	0.79g/cm^3	6.4g/m^3	spherical

Data processing

The experimental data were used to calculate overall heat transfer coefficient, convective Overall heat transfer coefficient of nanofluids with various particle volume concentrations. The thermophysical properties were calculated based on average temperature of nanofluids. The heat transfer rate of the nanofluid is:

$$Q_{nf} = m^{\circ} C_{pnf} \left(T_{out} - T_{in} \right) \qquad (1)$$

Where Q_{nf} is the heat transfer rate of the nanofluid and m° is the mass flow rate of the nanofluid, and T_{out} and T_{in} are the outlet and inlet temperatures of the nanofluid, respectively.The effective density of nanofluid is:

$$\rho_{nf} = (1 - \varphi_V)\rho_f + \varphi_v \rho_p \qquad (2)$$

Subscripts f, p, and nf refer to the base fluid, the nanoparticles, and the nanofluid, respectively. φ_V is the nonoparticle volume concentration. Cp_{nf} is the effective specific heat of the nanofluid which can be calculated from equation (3):

$$(\rho C_p)_{nf} = (1 - \varphi_v)(\rho C_p)_f + \varphi_v (\rho C)_p \qquad (3)$$

The average heat transfer rate is defined as follows:

$$Q_{(average\ )} = \frac{(Q_{nano\ fluid} + Q_{cold\ fluid})}{2} \qquad (4)$$

Where is the average heat transfer rate between the hot water and the nanofluid.

$$Q_{(average\ )} = U\, A\, \Delta T_{(log\ main\ temperature\ difference\ )} \qquad (5)$$

$$U = \frac{Q_{(average\ )}}{A \Delta T_{(log\ main\ temperature\ difference\ )}} \qquad (6)$$

Nusselt number of nanofluids is defined as:

The convection heat transfer from the test section can be written by:

$$Q_{(convection\ )} = h_i A_i ((T_{\tilde{W}} - T_b) \qquad (7)$$

$$T_b = \frac{T_{out\,(nano\ fluid\ (hot\ fluid\ ))} + T_{in\,(nano\ fluid\ (hot\ fluid\ ))}}{2} \qquad (8)$$

$$\left(T_{\tilde{W}} = \sum \frac{T_W}{4}\right) \qquad (9)$$

T_w is the local surface temperature at the outer wall of the inner tube .The average surface temperature $T_{\tilde{W}}$ is calculated from 4 points of T_w lined between the inlet and the exit of the test tube. The heat transfer coefficient hi and the Nusselt number, Nu are estimated as follows:

$$h_i = \overset{\circ}{m}_{(nano\ fluid\ (hot\ fluid\ ))} C_{p\,(nano\ fluid\ (hot\ fluid\ ))} (T_{out} - T_{in}) \;/A_i((T_{\tilde{W}} - T_b) \qquad (10)$$

$$Nu_{nf} = \frac{h_i d_i}{k_{nf}} \qquad (11)$$

Where the effective thermal conductivity (k_{nf}) of the nanofluids can be evaluated by Maxwell's model that is given as following [11]:

$$k_{nf} = k_f \frac{k_P + 2k_f - 2\varphi_V (k_f - k_p)}{k_p + 2k_f + \varphi_V (k_f - k_p)} \qquad (12)$$

Maxwell's formula shows that the effective thermal conductivity of nanofluids (k_{nf}) relies on the thermal conductivity of spherical particles (k_P), the thermal conductivity of base fluid (k_f) and volume concentration of the solid particles (φ_V).

Results and Discussion

Experimental Results

Preliminary experiments with water were performed to gain experience in operating the set-up. The experiments were performed varying the nanofluid flow rate at a given concentration.

Base line experiment using water/water

Using nanoflouid as the heating fluid in the tube side, and water cold as the cooling medium on the outside tube, temperature measurements were taken at fluid inlet and exit positions after steady state has been reached. Steady state was determined when the temperatures remained constant with time for a 30 mine period. The Reynolds number of the fluid flowing inside the tube, and heat transfer rate (W) were plotted and the result shown in Figure 3(a,b).

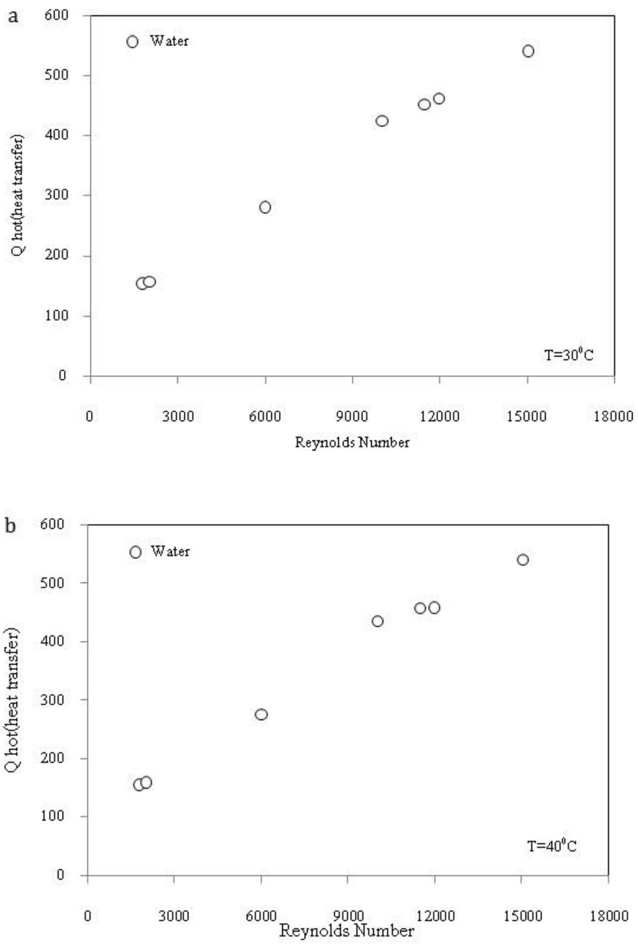


Figure 3:Heat transfer rate - water/water exchange

Heat transfer between water/nanofluid with concentration of 0.1% and 0.5% volumes:

A very low nanofluid concentration was used as the first nano heat transfer experiment. An increase in heat transfer rate was observed at any given flow rate. The plot of Reynolds number rate vs.heat transfer rate is shown in Figure 4(a,b). There is an improvement in heat flow rate due to the addition of nanoparticles even at very low concentrations.

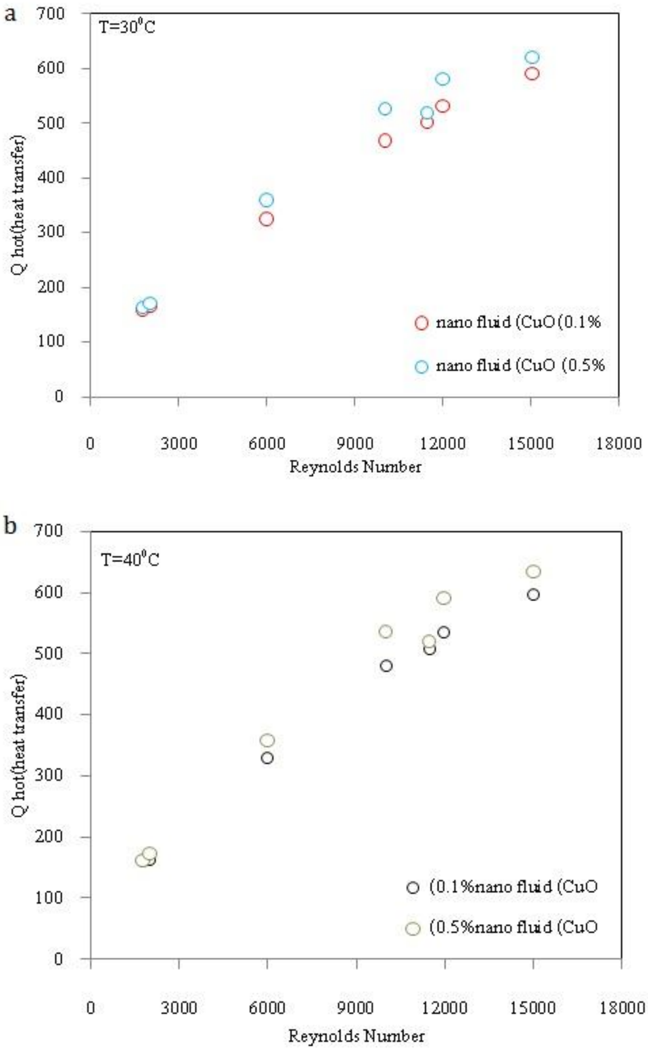
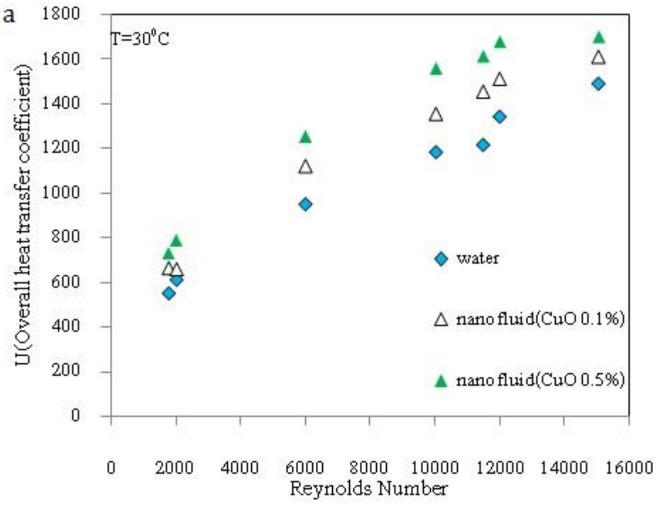


Figure 4: Heat transfer rate water/nano concentration, 0.1% and 0.5% by volume.(T= 30°,T=40°C).

Overall heat transfer coefficient and Reynolds number

The relationship between Overall heat transfer coefficient and Reynolds number for the water/water exchange and water/nanofluid concentration of 0.1 and0.5% are shown in Figure 5(a,b).



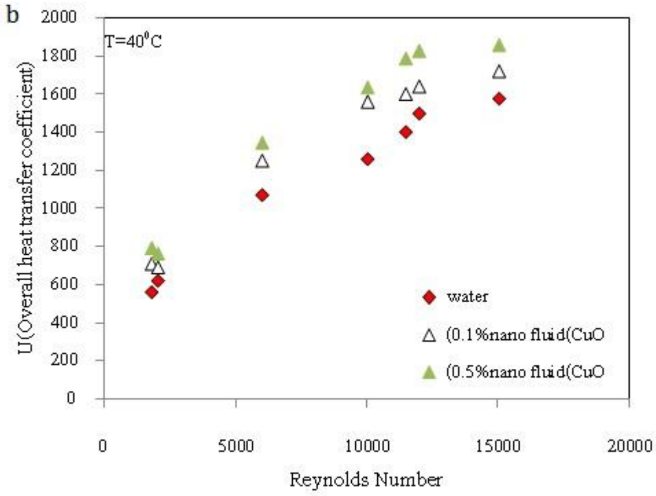


Figure 5: Overall heat transfer coefficient of CuO/water nanofluid versus Reynolds Number for various volume concentration(0.1%,0.5% v/v)

Nusselt number and Reynolds number

The relationship between Nusselt number and Reynolds number for the water/water exchange and water/nanofluid concentration of 0.1 and0.5% are shown in Figure 6(a,b).

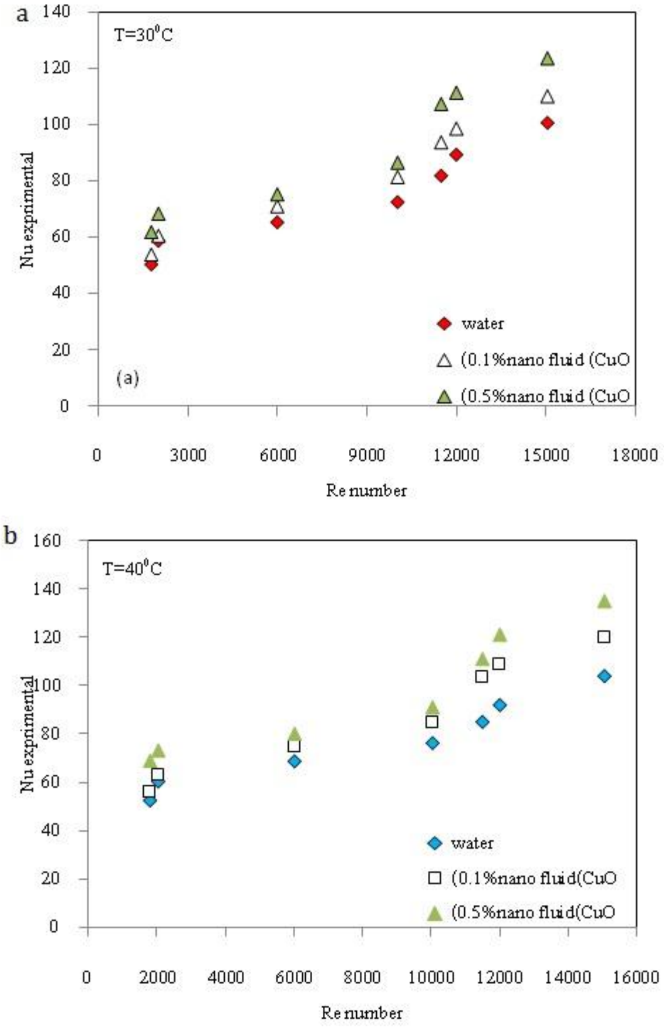


Figure 6: Nusselt number of CuO/water nanofluid versus Reynolds Number for various volume concentration(0.1%,0.5% v/v)

In the present study, CuO nanoparticles mixed with the water by (0.1-0.5) vol. % were used to investigate the effect of the Reynolds number and temperature of the flowing nanofluid and mass flow rate water on the heat transfer characteristics of the nanofluid. Figures 5 and 6(a,b) shows the overall heat transfer coefficient and Nusselt number of CuO nanofluid and water in terms of the Reynolds number at different volume concentrations show. The results show the increase of the overall heat transfer coefficient and Nusselt number with the Reynolds number and temperature of the nanofluid. Compared to the base fluid, the heat transfer coefficient of CuO nanofluid increases with the increase of concentration in a fixed Reynolds number. The overall heat transfer coefficient and Nusselt number is found to be highest for CuO nanofluid at the concentration of 0.5%(v/v) and a Reynolds number of about 15050, increasing up to (15 and 23) % at the temperatures of 30 and 40°C compared to the base fluid. For water, this value is (4.6 and 6.82) percent for the temperatures of 30 to 40°C (Reynolds number of 15050). This increase can be attributed to the immigration of the particles, non-uniform distribution of the thermal conductivity and viscosity of the fluid which decreases the boundary layer thickness, resulting in the delay in the development of the thermal boundary layer. Another reason is the contact of the suspended particles in the nanofluid which increases with the temperature and mass flow rate of the fluid, resulting in the increase of the contacts with the exchanger wall. Friction is also determined on the basis of the nano fluid type and properties of the heat exchanger wall. These factors have also effects on the performance and efficiency of the heat exchanger. The heat transfer enhancement due to nanofluids may be because of several factors such as improved effective thermal conductivity of the nanofluid as compared to base fluid, Brownian motion of nanoparticles, particle migration, reducing the thickness of the boundary layer and inducing turbulence motion. Heat transfer coefficient of nanofluid can be considered as a function of nanoparticle properties, concentration and size together with fluid flow rate. Collision and random motion of nano-particles and particles movement from high to low concentration region is an important contributing factor in heat transfer enhancement of nanofluids which, in turn, contributes to flatten the temperature profile. As a result, the temperature gradient at the wall becomes steeper and the heat transfer rate at the wall increases.

Conclusions

This research is related to the measurement of Overall heat transfer coefficient and Nusselt number performance of CuO nanofluids. The experiments were conducted in Double pipe heat exchanger boundary condition under turbulent and laminar flow regime. The experimental results reveal findings as below:

CuO nanofluids have better heat transfer performance than the base fluid.

For nanofluid CuO the relative enhancements of Overall heat transfer coefficient and the Nusselt number increase by increasing the concentrations of nanoparticles and Reynolds number. This can be explained by increasing thermal conductivity of nanofluid in comparison to the base fluid.

In general add nano particles by using three mechanisms will increase heat transfer:

a) Nano particles have higher heat guide and the higher density of particles more increase in transfer of heat as a result.
b) Nano particles with fluid molecule based on the wall and turned into heat and the cause of increase in energy.

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