An Experimental Study of Counter flow Concentric Tube Heat Exchanger using CuO / Water Nanofluid

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Abstract

Nano fluid is a fluid having nano size particles, dispersed in the conventional base fluids such as water, engine oil, ethylene glycol, which tremendously enhances the heat transfer characteristics of original fluid. Because of this fluid containing suspensions of metallic nanoparticles and have higher thermal conductivity. In the present study, we have experimentally investigated effect of addition of 1 wt. % CuO nanoparicles in base cold fluid using counter flow concentric tube heat exchanger. The heat transfer coefficient and friction factor of the CuO –Water nanofluid flowing in a counter flow concentric tube heat exchanger under turbulent flow conditions are investigated. The results show that the convective heat transfer coefficient of nanofluid is higher than that of the base liquid by about 3.45 – 9.5%. The heat transfer coefficient of the nanofluid increases with an increase in the mass flow rate of the hot water and nanofluid.

" 1. Introduction "

Heat exchangers play an important part in the field of energy conservation, conversion and recovery. Several studies have focused on direct transfer type heat exchanger, where heat transfer between fluids occurs through a separating wall or into and out of a wall in a transient manner. There are two important phenomena happening in a heat exchanger: fluid flow in channels and heat transfer between fluids and channel walls.
Thus, improvements to heat exchangers can be achieved by improving the processes occurring during those phenomena. Firstly the rate of heat transfer depends on the surface area to volume ratio, which means the smaller channel dimensions provide the better heat transfer coefficient. Secondly, improving the properties of the heat transfer fluids (nanofluids) can yield higher heat transfer coefficient in a heat exchanger. In recent years, modem technologies have permitted the manufacturing of particles down to the nanometer scale, which have created a new class of fluids, called nanofluid.
The application of nanofluids or fluids containing suspensions of metallic nanoparticles to confront heat transfer problems in thermal management is one of the technological uses of nanoparticles that hold enormous promise today. Experiments have shown that nanofluids have improved thermal conductivities when compared to the base fluids and enhancement in the heat transfer coefficient.
In the present study, we have fabricated concentric tube heat exchanger to investigate the thermal performance of heat exchanger using nanofluid. We also have synthesized the CuO nanoparticles. We have experimentally investigated effect of addition of 1 wt. % CuO nanoparicles in base cold fluid using counter flow concentric tube heat exchanger.

" 2. Experimental methods "

" 2.1 Fabrication of Concentric tube Heat exchanger "

The experimental set-up for measuring the convective heat transfer coefficient is shown schematically in Fig 2.1. It mainly consist of a concentric tube heat exchanger , hot and cold water circulation pumps, storage water tanks, heater, digital temperature indicator and flowmeters. Cold water flows through inner tube in one direction only and hot water flows in an annulus. Direction of cold fluid flow can be changed from parallel or counter to hot water so that unit can be operated as parallel or counter flow heat exchanger. Flow rates of hot and cold water are measured using rotameters. A by-pass valve is used to reduce the load on the pump. A pump is used to circulate the hot water from a re-cycled type water tank, which is fitted with heater and thermostat.

The test section was a straight copper tube having a 9.35 mm inner diameter and while the outer tube is made from stainless steel and has a 33.5 mm inner diameter. The test section is thermally isolated from its upstream and downstream section by asbestos rope in order to reduce the heat loss along the axial direction. For measurement of the temperature of inlet and outlet condition , RTD/ PT -100 sensors are used.

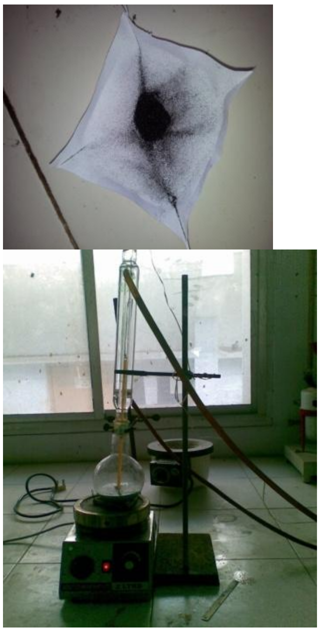
" Figure - 2.1 : The schematic of experimental set-up "

Measurements were carried out after 30 min when the system reached steady state at different mass flow rate of hot and cold fluid.

" 2.2 Synthesis of Nanoparticle "

In this method , CuO nanoparticle is synthesized with a wet chemical method. It has the advantages in terms of controlling the particle size, reducing agglomeration of the nanoparticles , and producing nanofluids in a large scale. This method is a promising technique for commercial synthesis of nanofluids as shown in Fig.2 .

In a typical procedure [19], 2.395 gms of copper acetate [$Cu(CH_3COO)_2$] is dissolved in 60 ml of water and make solution of Copper acetate ($Cu(CH3COO)_2 \cdot H_2O$) then add 0.6 ml of glacial acetic acid. heat the reaction mixture upto 15 min. then add 3ml NaOH solution (0.96 gm NaOH in 3ml Water). The color of the solution turned from blue to black immediately, and a black suspension formed simultaneously. The obtained mixture boil for 2 hours. [19]



" Figure 2.2. CuO nanoparticles using Wet chemical method "

Then mixture was cooled to room temperature . Then, a wet CuO precipitate was obtained. The wet precipitate was washed twice with distilled water to remove the impurity ions. filter it with filter paper and dry the particles. Finally obtained particle is as shown in figure.

" Table - 2.2. : Thermophysical properties of water and nanoparticles "

Property	Water	Cu	Al_2O_3	CuO	TiO_2
C (J / kg K)	4179	385	765	535.6	686.2
ρ (kg / m^3)	997.1	8933	3970	6310	4250
K (W / m K)	0.605	400	40	76.5	8.9538

Obtain particles are dispersed in base fluid with help of surfactant (SDS - Sodium Dodecyle Sulphate) to make colloidal mixture.

" 2.3 Effect on the Thermophysical properties of nanofluid "

The density is calculated from Pak and Cho using the following equation:

$$\rho_{nf} = \emptyset \rho_p + (1- \emptyset)\, \rho_w$$

where $\emptyset$ is the volume fraction of the nanoparticles, ρ_p is the density of the nanoparticles and ρ_w is the density of the base fluid.

Drew and Passman suggested the well-known Einstein equation for calculating the viscosity, which is applicable to spherical particles in volume fractions of less than 5.0 vol.% and is defined as follows:

$$\mu_{nf} = (1 + 2.5\varnothing)\,\mu_w$$

where μ_{nf} is the viscosity of the nanofluid and μ_w is the viscosity of the base fluid.

The specific heat is calculated from Xuan and Roetzel as follows:

$$(\rho Cp)_{nf} = \varnothing(\rho Cp)_p + (1-\varnothing)(\rho Cp)_w$$

where $(\rho Cp)_{nf}$ is the heat capacity of the nanofluid, $(\rho Cp)_p$ is the heat capacity of the nanoparticles and $(\rho Cp)_w$ is the heat capacity of the base fluid.

The thermal conductivity of the nanofluid is calculated from Yu and Choi using the following equation:

$$K_{nf} = \left[\frac{Kp + 2K_w + 2(K_p - K_w)(1+\beta)^3\varnothing}{Kp + 2K_w - (K_p - K_w)(1+\beta)^3\varnothing}\right] K_w$$

where k_{nf} is the thermal conductivity of the nanofluid, K_p is the thermal conductivity of the nanoparticles, K_w is the thermal conductivity of the base fluid and β is the ratio of the nanolayer thickness to the original particle radius.

Thermal conductivities of two kinds of nanofluids, copper oxide distilled water and also alumina-distilled water, in temperature range of 20 °C to 50°C were studied. Results show an increase in the thermal conductivity coefficient by increasing the temperature and also particle concentrations. Thermal conductivity of nanofluids was also increased by increasing the thermal conductivity of particles.

Some new correlations were also suggested to measure the thermal conductivity of the nanofluids. [20]

Nanofluid	Formula
Alumina-water 1%	knf=kf [1.6811-0.341(Tnf/Tw)]
Alumina-water 2%	knf=kf [1.792-0.381(Tnf/Tw)]
Alumina-water 3%	knf=kf [1.911-0.515(Tnf/Tw)]
Alumina-water 4%	knf=kf [2.108-0.616(Tnf/Tw)]
CuO-water 1%	knf=kf [1.631-0.209(Tnf/Tw)]
CuO-water 2%	knf=kf [2.181-0.599(Tnf/Tw)]
CuO-water 3%	knf=kf [2.358-0.712(Tnf/Tw)]
CuO-water 4%	knf=kf [2.497-0.793(Tnf/Tw)]

Before starting to determine the convective heat transfer coefficient and friction factor of the nanofluid, the reliability and accuracy of the experimental system are estimated by using water as the working fluid.

Moreover, the Pak and Cho and Xuan and Li correlations for predicting the Nusselt number for nanofluid are compared with the results which are defined as follows:

The Pak and Cho correlation is defined as:

$$Nu_{nf} = 0.021\, Re_{nf}^{0.8}\, Pr_{nf}^{0.5}$$

The Xuan and Li correlation is defined as:

$$Nu_{nf} = 0.0059\,(1.0 + 7.6286\,\phi^{0.6886}\, Pe_d^{0.001})\, Re_{nf}^{0.9238}\, Pr_{nf}^{0.4}$$

The Reynolds number of the nanofluid is defined as:

$$Re_{nf} = \frac{\rho_{nf} u_m D}{\mu_{nf}}$$

The Prandtl number of the nanofluid is defined as:

$$Pr_{nf} = \frac{\mu_{nf} Cp_{nf}}{K_{nf}}$$

The Peclet number of the nanofluid is defined as:

$$Pe_{nf} = \frac{u_m d_p}{\alpha_{nf}}$$

where d_p is the diameter of the nanoparticles.

In order to calculate the Peclet number, the thermal diffusivity of the nanofluid (α_{nf}) is defined as:

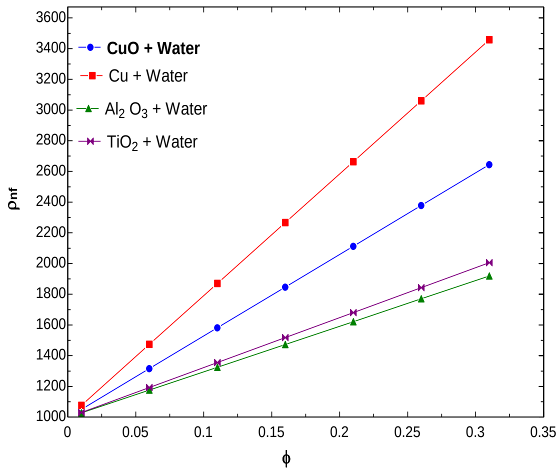
$$\alpha_{nf} = \frac{K_{nf}}{\rho_{nf} Cp_{nf}}$$

From the above equations we can find the thermophysical properties of nanofluids.

There is a effect of particle volume concentration on thermophysical properties of nanofluid .Using the correlation of this properties for nanofluid we can see the effect on it.

2.3.1. Effect on Density of nanofluid :

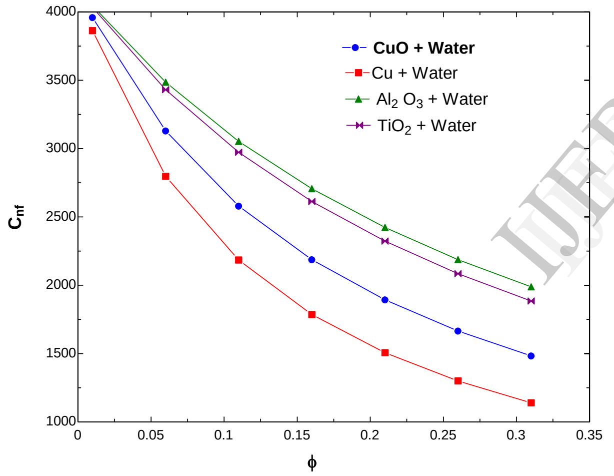
Using Pak and Cho relation in figure 4.1 , it is concluded that if we increase the volume concentration of nanoparticles then increase in density of nanofluid.



" Figure - 2.3.1 : Effect on density due to volume concentration "

2.3.2. Effect on Specific heat of nanofluid :

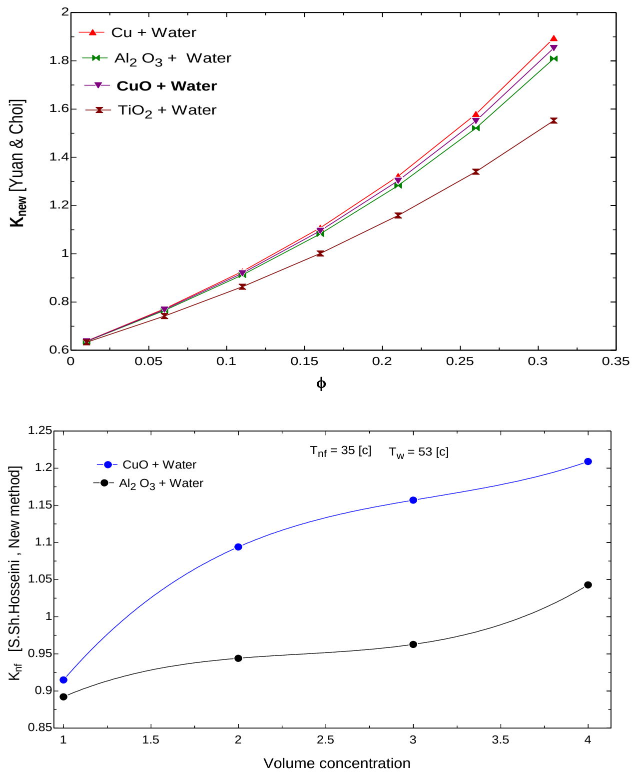
Using Xuan and Roetzel correlation in figure 4.2 , it can concluded that there is a decrease in specific heat with increase in the volume fraction.



" Figure - 2.3.2 : Effect on Specific heat due to volume fraction "

2.3.3. Effect on Thermal conductivity of nanofluid :

Most important property is thermal conductivity, Using Yuan and Choi relation we observe that there is a enhancement in thermal conductivity with increase in volume concentration of nanoparticle in base fluid. A temperature dependent thermal conductivity model by S.Sh. Hosseini shows a better enhancement in thermal conductivity. It is a easy and economic method to determine it.



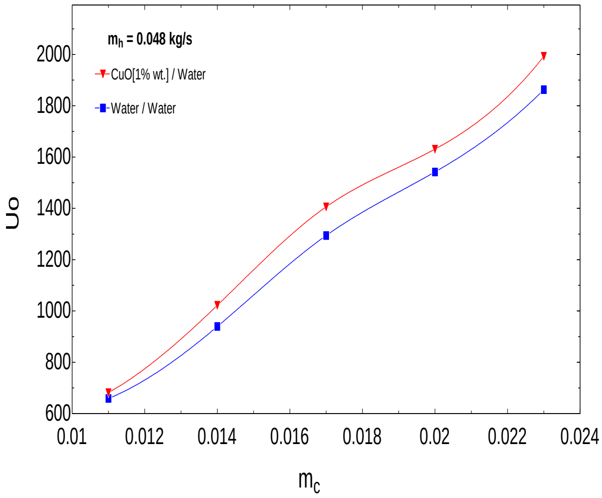
" Figure - 2.3.3 : Effect on Thermal conductivity due to volume fraction "

" 3 . Result and Discussion "

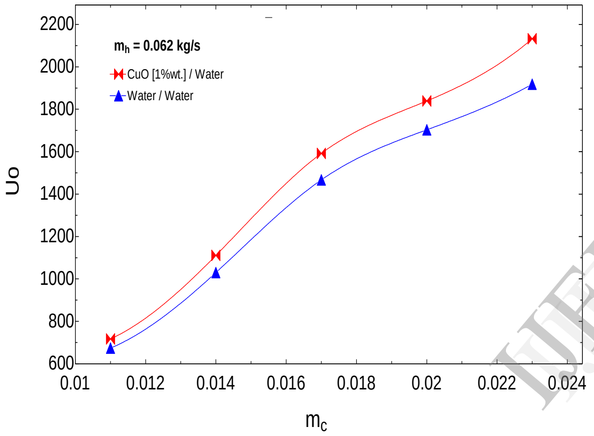
The experiments were carried out by varying the mass flow rate of hot and cold fluid to investigate the effect of nanofluid on heat transfer coefficent. First, the test is carried out with Water / Water, then adding nanoparticles in base cold fluid by 1% wt.

1) Effect of mass flow rate of cold fluid on overall heat transfer coefficient :

As shown in fig. 3.1, the heat transfer coefficient increases with increases with increase in mass flow rate of cold fluid keeping constant hot water mass flow rate at 0.048 kg/s . The inlet temperature of hot water is 53.1 °C and Cold fluid is 35.2 °C. At this mass flow rate it is observed that there is a enhancement in heat transfer coefficient by addition of 1 % wt of nanoparticle. The approximate increase in heat transfer coefficient is found to be in range of 3.5% to 8.6%.



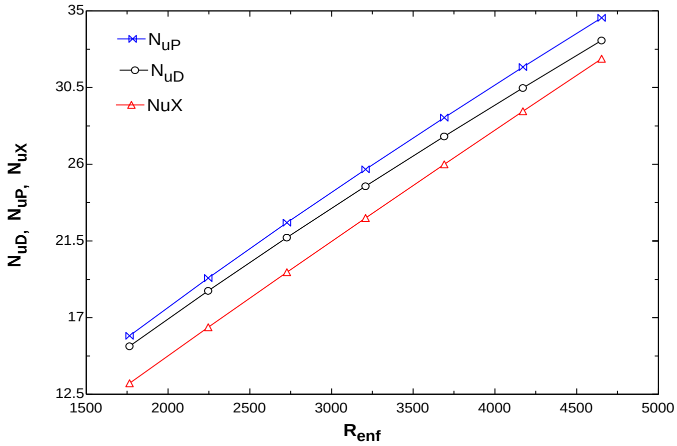
" Figure - 3.1 : Comparison of heat transfer coefficient obtained from water and that from the 1% wt. of CuO nanoparticles dispersed in water. "



" Figure - 3.2 : Comparison of heat transfer coefficient obtained from water and that from the 1% wt. of CuO nanoparticles dispersed in water. "

As the hot water mass flow rate is increased from 0.048 kg/s to 0.062 kg/s, it is observed that there is a enhancement in heat transfer coefficient in the range approximately 6.42 % - 10 % shown in fig. 3.2.

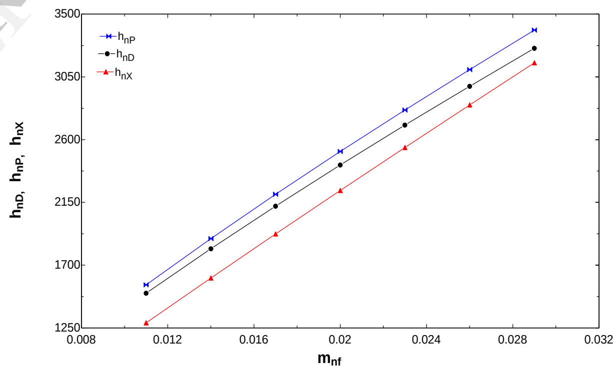
2) Effect of Reynolds number on Nusselt number of nanofluid using different correlation:



" Figure - 3.3 : Comparison of Nusselt number Vs Reynolds number using different correlation "

From the experiment it is found that the Nusselt number increases with Reynolds number . Fig. 3.3 shows that the calculated values of Nusselt number using Pak and Cho correlation gives better agreement to the behaviour of nanofluid than the Dittus-Bolter and Xuan and Li correlation.

3) Effect of mass flow rate of cold fluid on convective heat transfer coefficient using different correlation :

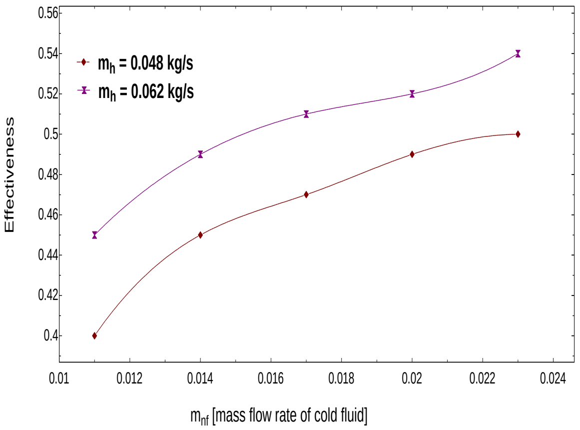


" Figure - 3.4 : Effect of mass flow rate of nanofluid on convective heat transfer coefficient based on different correlation "

As shown in Fig. 3.4, the convective heat transfer coefficient increases with increases in mass flow rate of nanofluid.

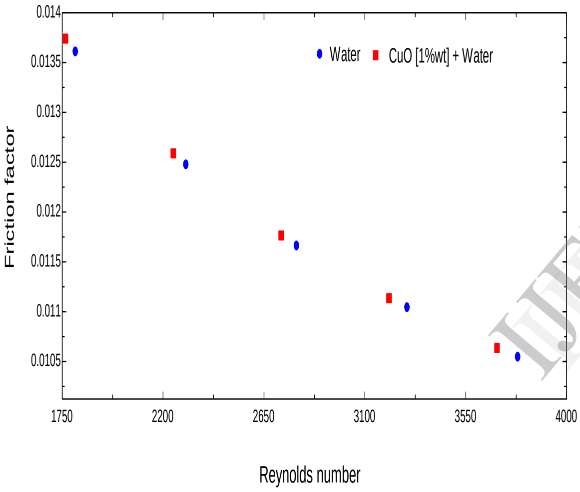
4) Effect of mass flow rate on effectiveness:

As shown in Fig. 3.5 , effectiveness is increases with increase in the mass flow rates of hot fluid and cold fluid.



" Figure - 3.5 : Effectiveness Vs mass flow rate of nanofluid "

5) Friction factor :



" Figure - 3.6 : Comparison of friction factor for water and CuO/Water nanofluid "

As shown in Fig. 3.6 , the friction factors of the nanofluid agree well with those of water data under the same Reynolds number at hot water flow rate is 0.048 kg/s. This may be because the small additional nanoparticles in the base liquid do not cause the change in the flow behaviour of the fluid. This means that the nanofluid will not cause a penalty drop in pressure and there is no need for additional pump power.

" 4. Conclusion "

The convective heat transfer performance and flow characteristic of a CuO – water nanofluid prepared by wet chemical method , flowing in a fabricated counter flow concentric tube heat exchanger is experimentally investigated.

Experiments are carried out to study the effects of the mass flow rate of the cold fluid as well as hot fluid on the heat transfer coefficient and flow characteristics.

The following conclusions have been obtained:

- The use of CuO – water nanofluid significantly gives higher heat transfer coefficients in the range approximately 3.45% - 9.5% than those of the pure base fluid. There is an enhancement in the heat transfer process because the suspended ultra-fine particles remarkably increase the thermal conductivity of the nanofluid.
- Pak and Cho correlation for predicting the heat transfer coefficient of a nanofluid agreed better with the results of this experiment than the Xuan and Li correlation.
- The convective heat transfer coefficient, overall heat transfer coefficient and effectiveness increases with an increasing Reynolds number and an increasing mass flow rate of the cold fluid and hot fluid.
- The friction factor of the nanofluid are approximately the same as those of water in the given conditions. This implies that the nanofluid incurs no penalty of pump power and may be suitable for practical application.

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