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Investigation of Heat Transfer in Concentric Tube Heat Exchanger Equipped with Helical Coiled Insert Using CuO-H_2O Based Nanofluid

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Abstract **- Enhancement of heat transfer using CuO/water nanofluid in copper tube equipped with helical coiled insert is presented. The three different CuO concentrations (0.01%, 0.015%, and 0.02% by volume) and three different p/d ratio of helical coiled insert (0, 2, 4) are used in the present investigation. In this the working fluid is nano fluid. Nano fluid is made by the suspending nano particles in the fluid like water, ethylene glycol and oil, hydrocarbons, fluorocarbons etc. An investigation of forced convection heat transfer has been carried out in a concentric tube heat exchanger using nanofluid equipped with helical coiled inserts. Tests has been conducted for plain copper tube with nanofluid and for tube with helical coiled inserts for the determination of heat transfer, friction factor and thermal performance factor in the Reynolds number range 3000 to 11000 and volume concentration from 0.01%, 0.015% and 0.02% of nano fluid at room temperature. The results achieved from the use of the CuO/water nano fluid and helical coiled inserts, are compared with plain tube, with and without inserts when working with base fluid. The experimental results reveal that at similar operating conditions, heat transfer, friction factor as well as thermal performance factor associated with the simultaneous application of CuO/water nano fluid and helical coiled insert are higher than those associated with the individual techniques. Evidently, heat transfer rate increases with increasing CuO/water nano fluid volume concentration and decreasing pitch by diameter(p/d) ratio. In addition, the copper oxide based nano fluid coupled with helical coiled insert in a copper tube in parallel arrangement offer higher heat transfer performances than plain tube. In this experimental study, the maximum thermal performance factor 1.15 is found with the use of CuO/water nano fluid at volume concentration of 0.02% in copper tube coupled with helical coiled inserts at pitch ratio (p/d=2) in parallel arrangement, for Reynolds number of 3713.93.**

Keywords— Hear Transfer, Nano Fluid, Concentric Tube Heat Exchanger

1. INTODUCTION

Enhancement techniques of heat transfer in heat exchangers are used to promote the performance and reduce the size. There are many techniques are used for augmenting the heat transfer. Among them the following methods are considered as the effective ones (1) using nanofluids. (2) inserting modified inserts. (3) changing the geometry of surface area of heat exchanger. Nanofluids are the fluids containing nano size solid particles are made of metals, oxides and carbides while the base fluids are water, ethylene glycol, oils etc. Generally fluids have higher specific heat as compare to solids and solids have higher thermal conductivity as compare to liquids so the addition of nano particles in liquid in a very small amount increase the thermal conductivity of fluid.

Nano fluid a suspension of nano sized solid particles in a liquid has been found higher thermal conductivity than their base fluid resulting to better convective heat transfer coefficient [1]. Choi was the first who investigate the mixing of solid particles in nanometric size into a base fluid enhance the thermal conductivity compared to its base fluid [2]. A lot of investigation have done to find out the heat transfer performance and flow characterstics of various types of nanofluids in both laminar and turbulent flow [3-23]. The results of the investigation show that the mixing of nanoparticles improves the thermal conductivity compared to the conventional fluid and the heat transfer rate increases with the increase in nanoparticle concentration.

Inserting fluid turbulators, inserts and by changing the geometry of surface area of heat exchanger are classified as surface method [24] in which the contact surface area between heat exchanger and fluid is promoted. The above two techniques are responsible for turbulant flow and chaotic fluid mixing which is directly responsible for heat

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transfer increment between a fluid and a wall surface. According the previous investigation [25-27]. The combination of inserting fluid turbulators and by changing the surface area of heat exchanger (using both at a time) at limited conditions, offers higher transfer rate than the results achieved from the individual techniques.

The aim of the current work is to apply CuO based nanofluid in the copper tube equipped with helical coiled insert. The three concentrations of nanofluids at 0.01, 0.015, and 0.02 by vol, Three ratio of helical coiled insert (p/d = 0, p/d = 4, p/d = 2) and reynols number from 3000 to 11000. The effect of insert and nanofluid relative to a copper tube has also been investigated.

EXPERIMENTAL

1. Preparation of nanofluid

Generally the studies on the flow and heat transfer of nanofluids, common solid partiles such as Al_2O_3, TiO_2, and CuO are used as the additives to the base fluids. In the present work distilled water and CuO (average size of 40 nm) were used to produce nano fluids and prepared by maulana azad national institute of technology Bhopal in nano technology lab.

In the present work CuO was added to distilled water to fabricate nanofluids based on a two step method. For a given volume of fraction of the nanofluid. A small amount of copper oxide is directly added to the distilled water. Then the mixture stirred well and placed in the ultrasonic bath for 2 to 2.5 hours at the temperature of 30^0C with the power of 400 Watt and frequency 24 KHz this breaks down the aggolomeration of particles and also avoids the sedimentation issue. After ultrasonic bath a magnetic stirrer is used to mix the particle and distilled water for 2 hours. The prepare sample are stable for a short time (at least 48 to 60 hours) and no sedimentation is seen with naked eyes.

2. Helical coiled inserts

the helical coiled inserts were made from steel with diameter of 0.6 mm, length 2000 mm and a copper wire which is helical coiled over it at a particular pitch through its length. The inserts were prepared at three different pitches(p) of 0 mm, 20 mm and 40 mm.which corresponds to p/d ratio = 0, 2, and 4 respectively. Where p is the pitch of coiled wire and d is the diameter of insert ($6mm + 2mm \times 2 = 10mm$). The geometrical details of tapes are demonstrated in fig. 1.

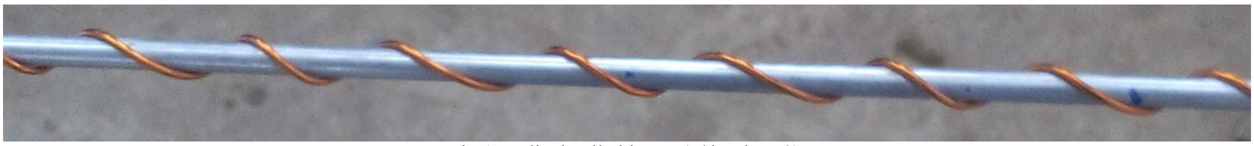

Fig.1. Helical coiled insert (p/d ratio = 2).

3. EXPERIMENTAL SET-UP AND PROCEDURE

The schematic representation of the experimental setup is depicted in Fig.1, along with its photograph in Fig.5, it consists of a test section, data logger, personal computer, flow meter, receiving tank, chiller, hot fluid tank, pump, bypass valve arrangement and u-tube manometer. The test section consists of a double pipe heat exchanger; The nano fluid was flowing in the inner tube or pipe (A straight copper tube with 2000mm length, 17 ± 0.02mm inner diameter, and 20 ± 0.05mm outer diameter was used as the test section) and the annulus tube is made of mild steel and its diameter is 0.05 m. The hot fluid is pumped through the annular region and the water/nanofluid flows through the inner tube by using a pump. The mass flow rates for both the hot fluid and the water/nanofluid are controlled with by-pass valve arrangements. Two flow meters (MAS Technologies Ltd., India) were used to measure the mass flow rate of cold fluid and hot fluid. Throughout the experiments the mass flow rate of hot fluid is kept constant and the mass flow rate of nano fluid is varied from 2 LPM to 6 LPM. The outside surface of the annulus tube is wounded with insulation rope and then a layer of POP insulation is done over the rope insulation to minimize the heat loss from the test section to atmosphere. In order to measure the temperatures of the fluids, a total of eight T-type thermocouples were used, Four T-type thermocouples were mounted on the test section at axial positions in mm of 40 (T3), 80 (T4), 120 (T5), and 160 (T6) from the inlet of the test section to measure the wall temperature distribution, and other two T type thermocouples were inserted into the flow at the inlet and exit of the test section to measure the bulk temperatures of nano fluids and hot water. Thermocouple ends are connected to the temperature indicator system and the thermocouple readings are recorded in the DTC for further processing. The thermocouples are calibrated (±0.1 ºC) before placement in the test section.The receiving tank and hot fluid tanks both have the capacity of 20 litres and they are made of stainless steel. The nanofluid, which runs in a closed loop, before entering the test section passes through a chiller to maintain the inlet temperature constant. The provision of chiller helps to achieve steady state condition faster. To confirm the steady state condition for each run, the time of arround 40-45 minutes depending upon Reynolds number and helical coiled inserts was taken prior to the data record. The pressure drop across the inner tube of the test section was measured by placing a U-tube manometer between both ends of the tube. To achieve this purpose, 4-mm holes drilled at both ends of the inner tube are connected using flexible tubing to the U-tube manometer; its fluid is mercury and the equivalent height is recorded as a function of the mass flow rate. Once the system reached to steady state, the readings of four T thermocouples were recorded and used for heat transfer calculations.

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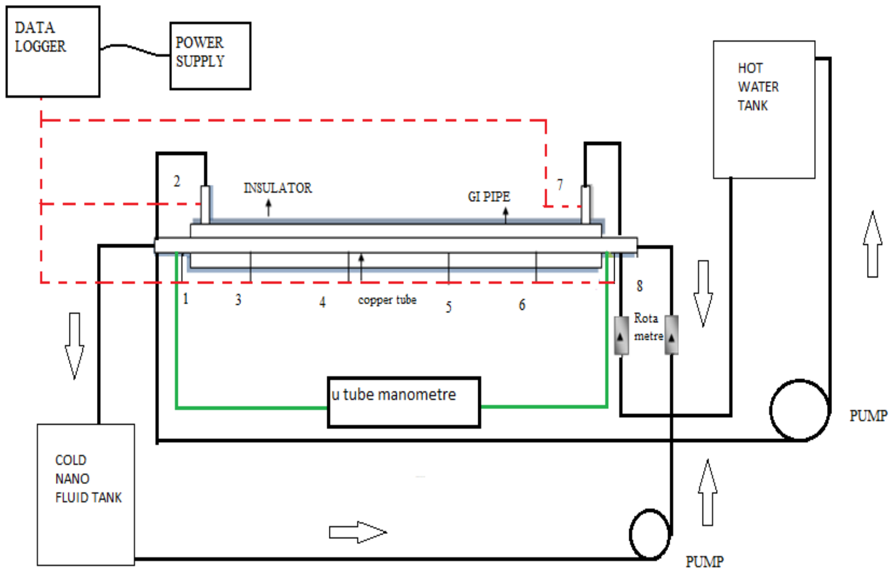

Fig. 2. Schematic diagram of experimental apparatus.

Fig. 3. Photograph of experimental apparatus.

4. THERMOPHYSICAL PROPERTIES OF NANOFLUID

The thermophysical properties like density, specific heat, viscosity, and thermal conductivity of the nanofluid were find out as a function of solid particle or nano particle volume concentration(φ) together with properties of base fluid and nano particles.

The density of nanofluid was evaluated using the general formula for the mixture:

$$\rho_{nf} = (1-\phi)\rho_w + \phi\rho_{np} \quad (1)$$

The specific heat of the nanofluid was evaluated from:

$$C_{pnf} = \frac{\phi\rho_{np}C_{pnp} + (1-\phi)\rho_w C_{pw}}{\rho_{nf}} \quad (2)$$

These equations have been found appropriate for nanofluids through experimental validation by Pak and Cho[28] and Xuan and Roetzel[29] .

The thermal conductivity was calculated from Maxwell model[30].

$$\frac{k_{nf}}{k_w} = \frac{k_{np} + 2k_w + 2\phi(k_{np} - k_w)}{k_p + 2k_w - \phi(k_{np} - k_w)} \quad (3)$$

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The effective viscosity of a nanofluid in volume concentrations less than 5% is given by Einstein equation[31]:

$$\mu_{nf} = \mu_f (1 + 2.5\phi) \quad (4)$$

5. DATA REDUCTION

In the present work, the CuO nanoparticles dispersed in distill water with concentrations of 0.01%, 0.015% and 0.02%. In this experiment nanofluid absorbed heat from hot water. The sensible heat gained by nanofluid was calculated from the following equation:

$$Q_{nf} = \dot{m}_{nf} C_{pnf} (T_o - T_i) \quad (5)$$

Where Q_{nf} is the heat transfer rate of the nano fluid and $\dot{m}_{nf}$ is the mass flow rate of the nanofluid. The convective heat transfer from the test section was calculated from the following equation:

$$Q_{conv} = hA(T_w - T_b) \quad (6)$$

The average value of experimental convective heat transfer coefficient (h) can be evaluated as:

$$Q_{nf} = Q_{conv}$$

$$\dot{m}_{nf} C_{pnf} (T_o - T_i) = hA(T_w - T_b) \quad (7)$$

Where T_w is the mean pipe wall/surface temperature

$$T_w = \frac{(T_{p4} + T_{p2} + T_{p3} + T_{p4})}{4} \quad (8)$$

T_{P1-4} = temperature of pipe surface at different locations.
And T_b is the mean bulk nano fluid temperature

$$T_b = \frac{T_i + T_o}{2} \quad (9)$$

Pressure drop across the pipe:

$$\Delta P_o = \rho_m \times g \times \Delta h \quad (10)$$

Where Δh is the difference of mercury level in u-tube manometer.

ρ_m is the density of mercury

Reynolds number is based on the inlet conditions of copper tube:

$$R_e = \frac{\rho V D}{\mu} \quad (11)$$

Nusselt number is also based on inner diameter of the copper tube:

$$Nu = \frac{hD}{k} \quad (12)$$

Friction factor can be calculated from the following equation:

$$f = \frac{\Delta P}{\left(\frac{L}{D}\right)\left(\frac{\rho V^2}{2}\right)} \quad (13)$$

The thermal performance factor is defined as the ratio of enhanced convective heat transfer coefficient(h_E) to the non-enhanced convective heat transfer coefficient(h_{NE})

$$TPF = \frac{h_E}{h_{NE}}$$

From the above defination, thermal performance factor can be written as:

$$TPF = \frac{\frac{Nu}{Nu_o}}{\left(\frac{f}{f_o}\right)^{\frac{1}{3}}} \quad (14)$$

RESULT AND DISCUSSION

1. Heat transfer

The present work were performed for a wide range of (3000–11000) reynolds number and for various concentrations of CuO nano particles (0.01, 0.015, and 0.02 vol.%) equipped with helical coiled inserts for different p/d ratio(0, 2, and 4). The variation of Nusselt number with nanoparticle volume concentration and Reynolds number for horizontal heat exchanger in parallel arrangement is shown in figs.4(a) and 4(b). Nusselt number increases with increase in Reynolds number and nanoparticle volume concentration. the Nusselt number of nanofluid is greater than that of the base fluid (distill water) and increases with nanoparticle concentration. Generally, the use of nanoparticles in fluid and the increase in nanoparticle concentration reponsible for the following points: (1) increment in the thermal conductivity and collision of nanoparticles which are favorable condition for heat transfer enhancement (2) increment in fluid viscosity which decreases the fluid movement and thus heat transfer rate. The above points says that for the given range, the effect of the increase in thermal conductivity and the collision of nanoparticles are more responsible than the increase of viscosity. At a particular Reynolds number 3713, the increase in Nusselt number for the nanofluid of 0.02% volume concentration is 18.84% when compared to water.

Nusselt number of the tube equipped with helical coiled insert is considerably improved when compared with that of the tube without insert. This is responsible by the formation of swirl generated by a insert. In addition, the heat transfer enhancement becomes more significant with decreasing p/d ratio of helical coiled insert, as swirl intensity increases. It can also be observed that the influence of helical coiled

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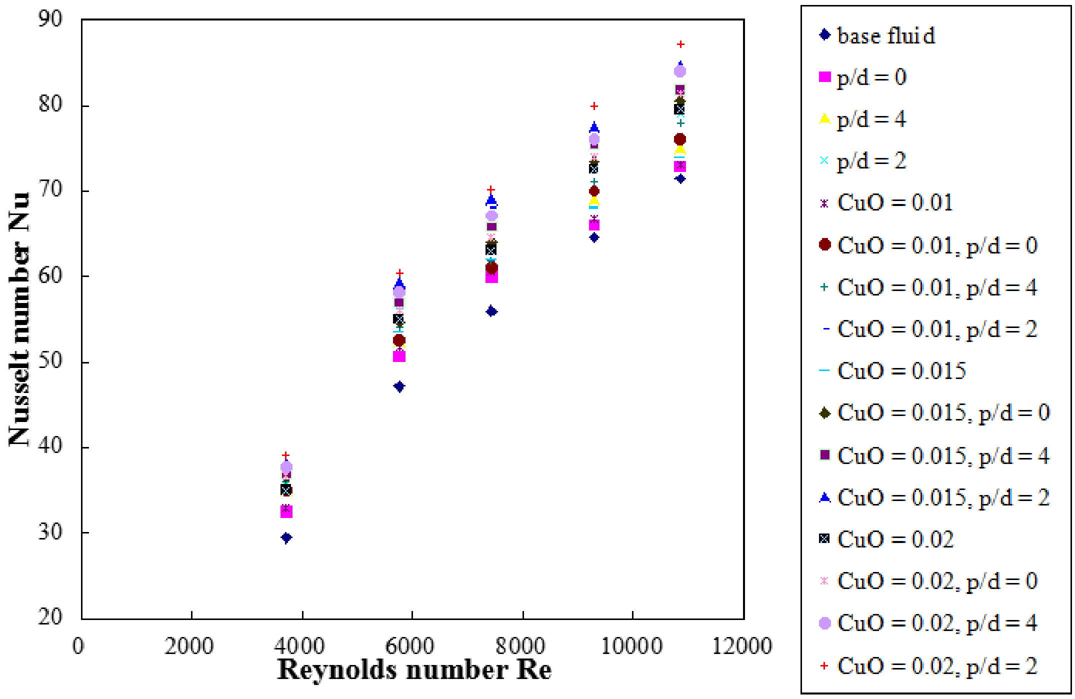
insert on heat transfer is more significant than nanoparticles in the fluid. Moreover, heat transfer enhancement associated by the applications of nanofluid and helical coiled insert is found to be more effective than those offered by the individual techniques. The presence of both nanofluid and helical coiled insert possibly promotes the dispersion and random movement of the particles, resulting in a better mixing between the core fluid and nanoparticles. The increase in Nusselt number when combination of both nanofluid(0.02% by volume) and helical coiled insert(p/d = 2) used at a particular value of Reynolds number(3713) is 32.42%.

(a)



(b)

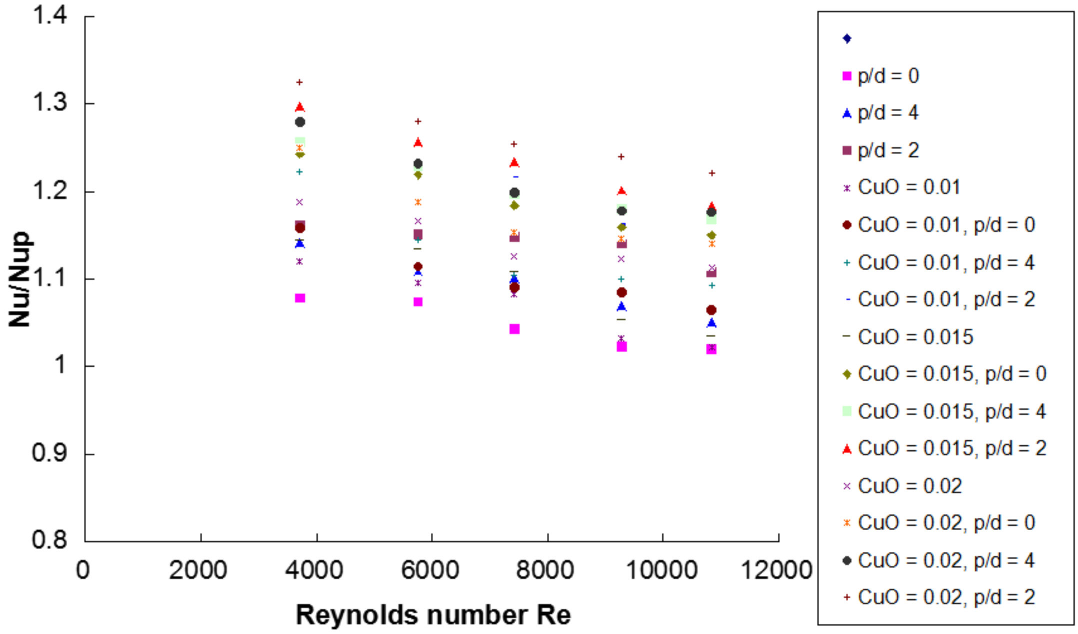


Fig. 4. Variation of p/d ratio/concentration of nanofluid on heat transfer enhancement, for the copper tube equipped with helical coiled insert in parallel arrangement: (a) Nu and (b) Nu/Nu_{p}.

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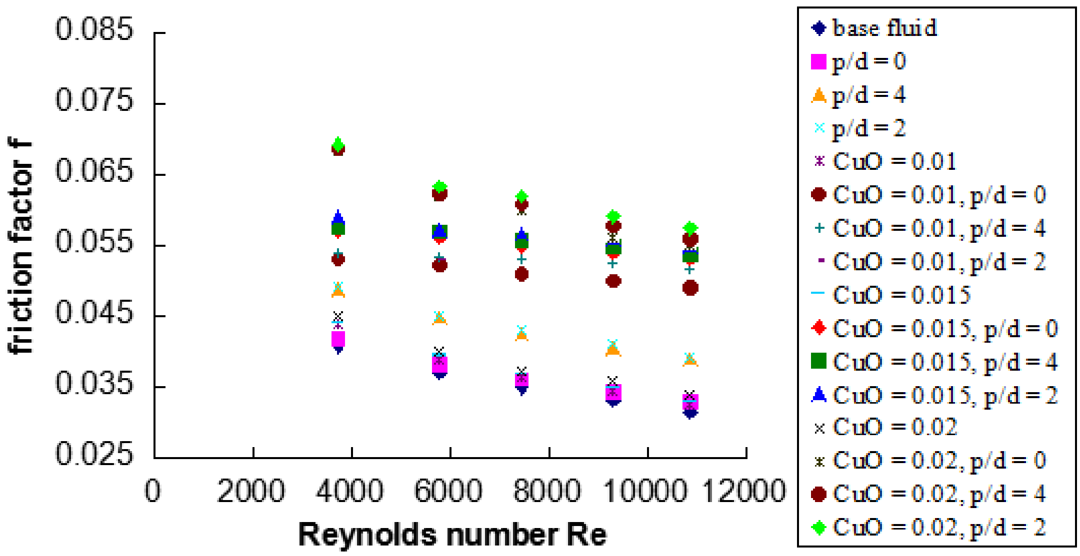
2. Friction factor

The results of friction factor are demonstrated in Figs. 5(a)and 5(b). For all cases, friction factors decreases with increasing Reynolds number. By using nanofluids for the range considered causes a little increment in friction factor as compared to the base fluid. This increase in friction factor shows a positive characteristic of utilizing nanofluid for heat transfer enhancement with an negligible penalty. However, with increase in concentration of CuO the value of friction factor of nanofluid increases. This can be due to the increase in shear force on the wall of tube acted by the nanoparticles. Apparently, the nanofluids with concentrations of 0.01%, 0.015% and 0.02% by volume provide average friction factors higher than the base fluid by around 2.1, 2.6 and 4.7%, respectively. The simultaneous uses of nanofluid and helical coiled insert result in higher friction loss as compared to those individual technique. With utilizations of the base fluid (distill water) together with helical coiled insert and nanofluid (all in a inner copper tube), friction factors increases from 4.7% to 35.1% , 5.4% to 41% and 7.8% to 66% respectively compared to those obtained by using base fluid in inner copper tube.

(a)



(b)

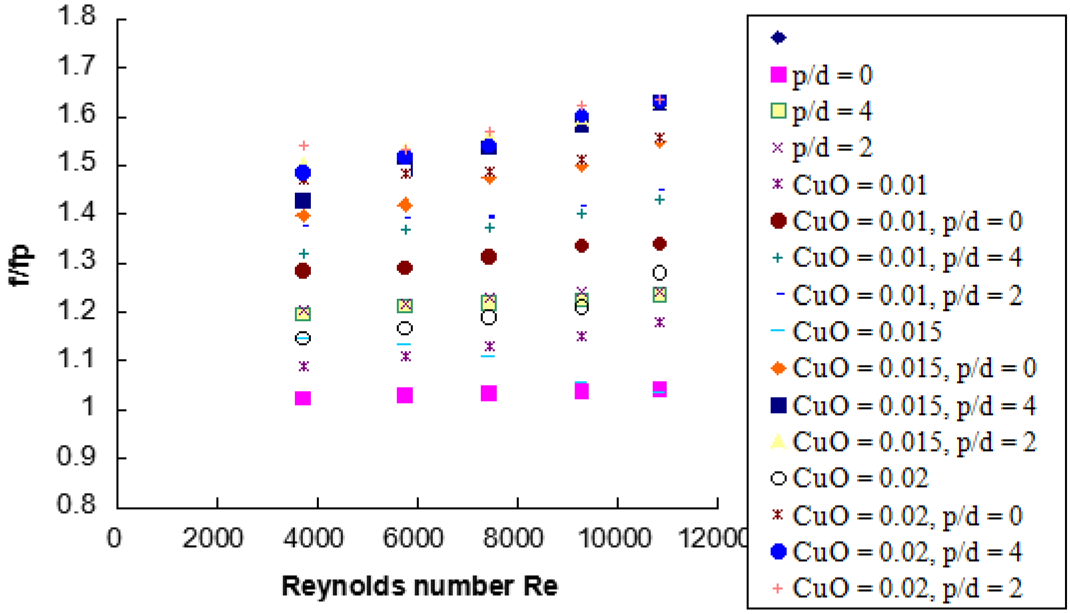


Fig. 5. Variation of p/d ratio/concentration of nanofluid on friction factor, for the copper tube equipped with helical coiled insert in parallel arrangement: (a) f and (b) f/f_p.

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3. Thermal performance factor

The variation of thermal performance factor versus Reynolds number are shown in fig.6. for a better heat transfer fluid, the increase in convective heat transfer given by the nanofluid should be greater than the increase in friction factor due to presence of nano scale solid particles in the base fluid. Thermal performance factor is determined using the Nusselt number ratio and the friction factor ratios that are calculated using the values obtained for nanofluid and water. nanofluids with higher concentration of CuO particles have higher thermal performance factors. Therefore, we can say that for the range investigated the increase of Nusselt number consider as a positive effect over that from the increase of friction loss as a negative effect. This result comes at low Reynolds number where pressure losses are negligible. The effects of the presence of helical coiled insert and their p/d ratio on thermal performance factor are also principally governed by the influence of heat transfer improvement. For the range investigated, the highest thermal performance factor of 1.15 is found with the use of nanofluid of 0.02% by volume in the copper tube equipped with helical coiled insert (in parallel pattern), at p/d ratio of 2 and Reynolds number of 3713.

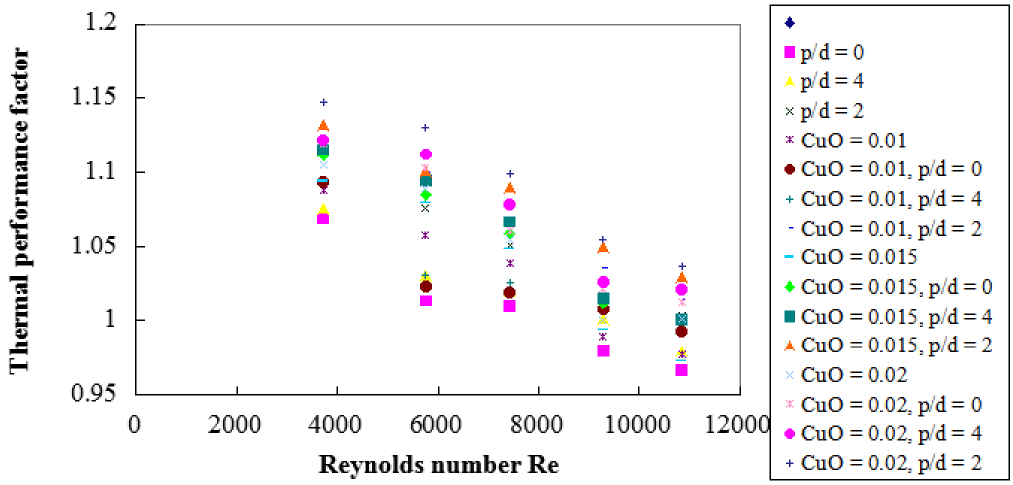

Fig. 6. Variation of p/d ratio/concentration of nanofluid on thermal performance factor, for the copper tube equipped with helical coiled insert in parallel arrangement.

CONCLUSION

In present work, an investigation were performed to find out the effect of CuO nano-particles in copper tube equipped with helical coiled insert lead to following conclusions.

1. Nusselt number, friction factor and thermal performance factor is increasing with increasing CuO concentrates hiion of nanofluid and decreasing pitch(p) of helical coiled insert.
2. Simultaneous application of CuO-water nanofluid and helical coiled insert gives higher values of nusselt number, friction factor and thermal performance factor than those associated with the individual techniques.
3. For the range considered, the maximum thermal performance factor of 1.15 is found with the use of nanofluid of 0.02% by volume in the copper tube equipped with helical coiled insert (in parallel arrangement) at p/d ratio of 2 and Reynolds number of 3713.

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