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Experimental Study of Force Convective Heat Transfer for CuO–water Nano-Fluid Flow in a Tubular Heat Exchanger

N. Aeini, Ms. Student, Energy Division, Materials and Energy Research Centre, Karaj
A. H. Zamzamian, Ass. Prof., Energy Division, Materials and Energy Research Centre, Karaj
K. Abbaspoursani, Ass. Prof., Dept. of Energy Conversion, the faculty of Mech. Eng., TIAU

E-mail: narges.aeini1@gmail.com

Abstract: Nano-fluids are suspensions of metallic or nonmetallic nanopowders in based liquid which show modified heat transfer treatment in various applications. In the present paper, we investigate the effect of a nano-fluid on the heat transfer coefficient in a tubular heat exchanger. Samples of copper oxide and water suspension nano-fluid are prepared in low concentrations about 1%, 2%, 4%wt and experiments are carried out for prediction of the heat transfer coefficient in a novel design tubular heat exchanger with using these samples as a hot fluid. As a result, using of CuO-Water nano-fluid cause an increase in the heat transfer coefficient more than 30% compared with the result obtained from distilled water. Also, the effect of inlet temperature of nano-fluid on the performance of the heat exchanger in the laminar flow has been studied. A careful examination of results reveals that by increasing inlet temperature, the Nusselt number is decreasing. Therefore, in lower temperatures nano-fluids are more efficient than high temperature.

Keywords: Cuo-water Nano-fluid, tubular heat exchanger, Forced convection, Heat transfer coefficient

بررسی تجربی انتقال حرارت جابجایی اجباری در جریان نانوسیال آب- اکسیدمس در داخل مبدل حرارتی لوله‌ای

نرگس آئینی- دانشجوی کارشناسی ارشد مهندسی انرژی‌های تجدیدپذیر پژوهشکده انرژی، پژوهشگاه مواد و انرژی کرج
امیرحسین زمزمیان- استادیار پژوهشی پژوهشکده انرژی، پژوهشگاه مواد و انرژی کرج
کمال عباسپورثانی- استادیار گروه تبدیل انرژی، دانشکده مهندسی مکانیک، دانشگاه آزاد اسلامی واحد تاکستان

چکیده: نانوسیال‌ها عبارتند از محلول نانوپودرهای فلزی و یا غیر فلزی در سیال پایه که انتقال حرارت بیشتری در کاربردهای مختلف نشان می‌دهند. در تحقیق حاضر، تأثیر استفاده از نانوسیال آب و اکسید مس درون یک مبدل حرارتی دولوله‌ای بطور تجربی بررسی شده‌است. نمونه‌های نانوسیال اکسیدمس و آب در غلظت‌های پایین وزنی ۱، ۲ و ۴ درصد تهیه شده و به منظور تخمین ضرایب انتقال‌حرارت جابجایی اجباری درون یک مبدل حرارتی دولوله‌ای طراحی شده به‌کار گرفته شده‌اند. نانوسیال به عنوان سیال گرم درون لوله داخلی مبدل جریان یافته و در طی مسیر گرمای خود را به سیال سرد درون پوسته منتقل می‌کند. این آزمایش برای غلظت‌های مختلف محلول در دبی های متفاوت و دماهای متفاوت نانوسیال ورودی انجام شده و داده های مورد نیاز برای تخمین ضریب انتقال حرارت جابجایی ثبت شده‌اند. بررسی دقیق نتایج نشان می‌دهد که ضریب انتقال حرارت جابجایی برای نانوسیال آب و اکسیدمس نشانگر افزایشی بیش از ۳۰٪ نسبت به آب خالص می‌باشد.

واژه‌های کلیدی: نانوسیال آب و اکسید مس، مبدل حرارتی دولوله‌ای ، جابجایی اجباری و ضریب انتقال حرارت.

1. Introduction

Usually an increase in heat flux leads to the enhancement of efficiency in the interest heat exchanging systems. Recently, some researchers have proposed some new materials, so-called nano-fluids which are suspension of metal or metal oxide or carbon nano-tube (CNT) in thermal fluids such as water, ethylene glycol, and oil. Literatures show that using these nano-particles in heating of fluids lead to increase the efficiency compared with the obtained results from the same basic fluids. These fluids could have important role in many processes, including heating and cooling process, transportation, microelectronics and chemical process. A Nobel Prize approach to choi, [1] in 1995, who was the first to apply nano-fluids with better heat transfer properties, at Argonne National Laboratory of USA.

Many studies have investigated the prediction of thermal conductivity of nano-fluids [2, 3, 4, 5] and also they studied the effect of some operating conditions such as; temperature, particle size, and concentration on the effective thermal conductivity of nano-fluids. Some of obtained results from literature show that these fluids have high thermal conductivity more than the base fluids and it increases with enhancement of concentration and temperature.

Eastman et al, [2], reported an increase of 29% and 60% in thermal conductivity for a 5%vol Al_2O_3 and CuO in water, respectively. Wang et al, [3] reported a significant enhancement in the thermal conductivity, nearly 17% for low concentration of 0.4%vol of CuO in water.

Choi et al, [4] measured the thermal conductivity of oil suspensions containing multi-walled carbon nano-tubes (MWCNT) at 1%vol concentration and show an increase of 160% in thermal conductivity. The thermal conductivity for various nano-fluids concluding suspension of different nano-powders in oil, ethylene glycol and water were studied experimentally by

Hwang et al, [5]. Their results show an enhancement in thermal conductivity about 850% for 5%vol of MWCNT in mineral oil.

In the past decade, the force convective heat transfer phenomena of nano-fluids were studied both experimentally and numerically. Eastman et al, [2] studied thermal performance of 0.9%vol CuO-Water nano-fluid in turbulence flow and reported the convective heat transfer is 15% more than water.

Heris et al, [6] investigated convective heat transfer in laminar flow of a nano-fluid containing nano-particles of CuO in water through circular tube under constant wall temperature boundary condition. They found an enhancement of less than 40% for Al_2O_3-Water nano-fluid. Also they compared the experimental results with the results obtained from single phase correlations model and reported that homogeneous model is not able to predict heat transfer mechanism in turbulent flow of a diluted CuO-Water nanof-fluid and reported an increase of 20% in heat transfer coefficient.

Pantzali et al, [7] investigated the efficacy of typical nano-fluids, namely 4%vol CuO suspension in water as a coolant in plate heat exchangers in turbulence flow. Practically, industrial heat exchangers need high volume of nano-fluids and often turbulent flow is usually developed, the suspension of conventional fluids by nano-fluids seems inauspicious.

The performance of CuO, Al_2O_3, and

SiO_2nanofluids, with ethylene glycol and water mixture have been analyzed experimentally by Kulkarni et al, [8] and show replacing conventional fluids with nano-fluids as heat transfer fluids one can reduce the volumetric flow rate, mass flow rate and the pumping power for the same heat transfer rate.

The heat transfer coefficient of TiO_2 in water nano-fluid in force convective heat transfer is investigated by Duanghongsuk et al, [9] in tubular heat exchanger as cold fluid and 6-11% enhancement in heat transfer coefficient is reported.

In this paper we have studied the convective heat transfer of the copper oxide nano-fluid as the hot fluid in a tubular heat exchanger in laminar flow.

2. Nano-fluid Preparation

Nano-fluid is prepared usually by dispersion the commercial nano-particles at base fluid such as water, ethylene glycol and, oil with change the surface properties of nano-particles and suppress the formation of clustering particles is common. One of the general methods to approach a stable suspension is use of an ultrasonic vibration device which throws the liquid media in wave formation and led to broking the clustering particle from each other. Also add surface activators or surfactants improve the surface properties in order to avoid sedimentation. In this study an additional surfactant were used to disperse the CuO nano-particle with an average diameter of 30 nm in to the distillated water. SDBS surfactant dispersed in to the water in low concentration (1% wt nano-particles) well before addition the nano-particles. Then 1%wt CuO nano-particles were added in mixing suspension in different time stages. Finally the suspension was stabilized by ultrasonic for five hours. The stability of samples strongly depends on volume fraction, the size and the type of nano-particles. Usually, CuO nano-particles have high density compared with other usual nano-particles that result in fast sedimentation. So to approach to a stable suspension should employ effective methods.

3. Experimental Set-up

The experimental set-up consisted of a tubular heat exchanger, a pump, a control valve, a receiver tank, a hot water tank, an electrical heater, five thermocouples and a programmable data logger with a user interface. The schematic of the experimental apparatus is shown in Figure. 1. The tubular heat exchanger have an inner copper tube with 8.3 mm inner diameter and 9.5 mm out diameter and outer tube is a steel tube with 25.2 mm inner diameter and 33.5 mm out diameter. Municipal tab water is used as a cold fluid in shell side with an average temperature of 20 °C. Nano-fluid flows through the inner tube as the hot fluid after became warm in receiver tank. Nano-fluid after circulation is collected in a receiver tank and is maintained warmer in it. Receiver tank is located inside of a hot water tank that is heated by an internal electric. The outer tube of the heat exchanger and all the circuit tubes and hot water tank walls are insulated well to avoid heat loss to soundings.

The temperature distribution through the tubular heat exchangers is variable that mean the thermal boundary layer in inner tube is not constant. Hence measurement the bulk liquid temperature in inlet and outlet of tube and shell is enough according to calculate the overall convective heat transfer coefficient. Four PT100 type thermocouples were installed at the both end of the tube and shell in order to measurement the inlet and outlet mean temperature of flows. Also, one

PT100 thermocouple is in receiver tank in order to control the receiver nano-fluid temperature by PLC programmable controller. All of the thermocouples were calibrated and have maximum 0.1 °C error. Flow rate was measured by weighting the fluid in specific volume of it.

4. Thermo-physical Properties

According to literatures Nano-fluids show signification change in thermo-physical properties such as; thermal conductivity, viscosity, heat capacity and density. Usually they depend on volume concentration, type, size of Nano-powder and temperature. In this study some of these properties have been measured experimentally and the other have been predicted by using theoretical models in literature.

The density of suspensions is predicted by Pak and Cho's model as mentioned in [10] as below:

$$\rho_{nf} = \varphi\rho_p + (1-\varphi)\rho_w \quad (1)$$

Where ρ_w is water density which was assumed about 996 kg/s, ρ_p is particle density that is equal to 6310 kg/s for CuO nanoparticles and φ is volumetric concentration. Volume concentration (φ) were calculated by equation (2) [17]:

$$\varphi = \frac{\rho_w \varphi_m}{\rho_w \varphi_m + \rho_s (1-\varphi_m)} \quad (2)$$

φ_m is mass fraction.

Addition the particles to the base fluid usually results in its viscosity increasing which has negative effects on fluid heat transfer coefficient

Brinkman [12] predicts the viscosity of a nano-fluid in terms of as follows:

$$\mu_{nf} = \frac{\mu_w}{(1-\phi)^{2.5}} \quad (3)$$

Where, μ_w is the absolute viscosity of water.

The heat capacity of a nano-fluid can be expressed by Eq. (4) [10]:

$$C_{P,nf} = \phi.C_{P,np} + (1-\phi).C_{P,w} \quad (4)$$

$C_{P,,w}$ and $C_{P,\ np}$ are the heat capacities of water and nano-particles, respectively. Usually nano-fluids show lower heat capacity compared with the based fluids.

The main nanofluid property which is effect in the enhancement of the fluid heat transfer behavior is its thermal conductivity k_{nf}. In this study, the transient hot-wire (THW) method is applied to measure this property. For this purpose, KD2-Pro thermal property meter instrument with an accuracy of 5% is used. Nano-fluids samples were held in cylindrical glass containers which were located in a water bath to ensure all the measurements at a constant temperature. To achieve a better result with lowest error, the measurement of thermal conductivity was repeated in each sample 5 times.

5. Convective Heat Transfer

In this study, the prediction of convective heat transfer coefficient of nano-fluids in tubular heat exchangers was investigated. For this purpose, water and copper oxide suspension at several volume fractions as a hot fluid is applied for this heat exchanger. The results are compared with the similar results obtained from the experiments of distilled water. The physical properties needed for calculations are measured experimentally or predicted by theoretical models as described in proceeding sections.

Dilute CuO-water nano-fluids with different concentrations of 1%, %2, and 4% wt were used. The experiments were performed in wide range of laminar flow with Reynolds numbers of 600-2100 and in different nano-fluid temperatures for each nano-fluids samples.

For evaluating the reliability and accuracy of the experimental setup, experiments were conducted by distilled water as the working fluid and results were compared with the Seider-Tate [13] correlation for laminar flow. Figure (2) shows a good agreement between experimental data and results of Seider-Tate Eq. (5):

$$Nu = 1.86\left(Re\,.\,Pr\,.\,\frac{D}{L}\right)^{\frac{1}{3}}\left(\frac{\mu}{\mu_w}\right)^{0.14} \tag{5}$$

The heat transfer rate removed from nano-fluid, Q_{nf} as a hot fluid, and the heat absorbed by the water as a coolant fluid, Q_w are calculated using Eqs. (6) and (7) by applying the mass flow rate and temperature data recorded. The heat capacity C_{Pnf} are calculated using Pak and Cho's equation based on nano-fluid volume fractions:

$$Q_{nf} = \dot{m}_{nf}\,.(C_P)_{nf}\,(T_{in} - T_{out})_{nf} \tag{6}$$

$$Q_{nw} = \dot{m}_w\,.(C_P)_w\,(T_{out} - T_{in})_w \tag{7}$$

Usually, the measured heat transfer rates are not exactly equal due to loss heat but it is negligible. Therefore, to accurate the calculation it is better to use the mean value of these heat transfer rates:

$$Q_{ave} = \frac{Q_w + Q_{nf}}{2} \tag{8}$$

For different CuO volume fraction, the result of calculation heat transfer rate is depicted as a function of Reynolds number in Fig. (3). The Reynolds number of nano-fluid is calculated using Eq. (9):

$$Re = \left(\frac{\rho.u}{\mu}\right)_{nf}.D_i = \frac{1}{\pi D_i}\left(\frac{\dot{m}}{\mu}\right)_{nf} \tag{9}$$

Where, $\dot{m}_{nf}$ is the measuring mass flow rate, μ_{nf} is the nano-fluid viscosity is predicted by Eq. (3) and D_i is inside tube diameter. As shown in Fig. (3), it is very interesting to observe, that the inclusion of nano-particles into water as a heating fluid in the heat exchanger has greatly enhanced the heat transfer rate of the water. The possible reason for this enhancement arises from this fact that of a large energy amount exchange process resulting from the brawny movement of nano-particles is done inside the tube. As discussed above, nano-particles have significant higher thermal conductivity compared with the base fluid. Therefore, particles near the wall absorb the heat from the wall more rapidly and exchange it to the base fluid substance by their movement. Further, by examination of Fig. (3), it reveals that an increase in the heat transfer rate is achieved by increasing the Reynolds number and particles concentration , clearly so that high concentration resulting higher effective thermal conductivity than low concentration. For example it is more than 40% in case of 4%wt (or 0.65% volume fraction).Previously conducted studies (Pantzali et al, [11], Heris et al,[6], Nguyen et al, [14]) reported lower than this amount. Pantzali et al, [11] reported an enhancement of 10% for 4%vol CuO-water nanofluid in a miniature plate heat exchanger and Nguyen et al, [14] who reported 18% enhancement for Al_2O_3 in PHE. This different Maybe is because of differences in the fluid regime.

Pantzali et al, [11] experiments were conducted in turbulent flow regime where effect of thermal conductivity on heat transfer enhancement is low. It has been shown for laminar flow the heat transfer coefficient is proportional to the fluid thermal conductivity, while for turbulent flow it depends mainly on the ratio of heat capacity over viscosity and in a smaller degree on the thermal conductivity of the fluid.

The overall heat transfer coefficient in the tubular heat exchanger, U, is calculated using LMTD procedure based on the measured data. The result for different nano-fluid concentrations over a range of Reynolds are illustrated in Fig. (4). As shown in Fig. (4), by increasing of the nano-fluid concentration and Reynolds number it increases the overall heat transfer coefficient compared with distilled water. But it should be noted that the effect of nano-powder addition to the water in lower velocities is more sensitive than higher velocities. For example, for the case of 4% wt nano-fluid at Re = 673, it increases the overall heat transfer coefficient more than 37%, whereas this is half in the case of Re = 1280 which is in agreement with the reported results in literatures [11, 15]. As reported by Chein and Chuang [15], this can be attributed to the fact that at high flow rates, where convection is the main heat transport mechanism, the contribution of the nano-particles to the overall heat transfer rate turns out to be negligible.

The internal convective heat transfer coefficient, h_i, is another heat transfer index which is investigated by many researchers. This coefficient for water-CuO nano-fluids calculated using Eq. (10):

$$\frac{1}{u} = \frac{A_\circ}{h_i A_i} + \frac{D_\circ \ln\left(D_\circ / D_i \right)}{2k_s} + \frac{1}{h_\circ} \qquad (10)$$

Where, A_i and A_o are the inside and the outside surface areas, respectively and k_s is the copper tube thermal conductivity of inner tube. Given h_o is convective heat transfer coefficient of water in shell side and can be calculated using Gnielinski [16] Eq. (11) for turbulent regime:

$$Nu_\circ = 0.012\left(Re^{0.87} - 280\right)Pr^{0.4} \qquad (11)$$

Prandtl and Reynolds are determined by evaluating water thermo-physical properties at mean operation temperature.

By using Eqs. (11) and (12) and based on measured data, the convective heat transfer coefficient of nano-fluid, h_i, is calculated and results are depicted in Fig. (5), in the various nano-fluid concentrations for a range of Re.

A careful examination of Fig. (5), it reveals that the effects of nano-fluid concentration and Reynolds number on the convective heat transfer are similar to that ones for the overall heat transfer coefficient as described above. For example in the case of Re = 673 byfor1%, 2% and4%wt nano-fluid concentrations, Fig. (5), shows an enhancement of 10.6%, 23.2%, and 35%, respectively compared with distilled water whereas , they are 9.5%, 21%, and 33% , respectively for Re = 1650. The main reason is the fact that the effect of thermal conductivity in laminar flow with low velocity is significant, while in the high velocity the rapid flow movement of water's molecules is the key parameter which transfers the heat from the wall and thermal conductivity has smaller effect on heat transfer. As reported by Chein and Chuang [15], at the low flow rate the nano-particles absorb heat more than water, while at higher flow rate nano-particles and water absorb heat from the wall together. The other reason may be because of clustering the particles together which due to reduce the efficiency of nano-fluid.

Figure (6) shows the variation of Nusselt number with Reynolds number under laminar flow condition. The Nusselt number is calculated from deducted values of nano-fluid heat transfer coefficient h_i by following equation:

$$Nu_{nf} = \left(\frac{h_i}{k}\right)_{nf} .D_i \qquad (12)$$

The obtained results confirm that the suspended nano-particles in water increase the Nusselt number even for low concentration .As shown in Figure 6., for 1%, 2%, and 4% wt in concentration an increase of 6%, 10% and 18%, respectively are achieved for copper oxide water suspension in compared with distilled water. The result is very closed to that of reported by Heris et al, [6] for CuO nano-fluid in laminar flow and similar geometry.

Another effective parameter which was investigated in this study is the nano-fluid temperature and its effects on the heat transfer parameters. Figures (7), (8) and (9) show the variations of the heat transfer rate, convective heat transfer coefficient and Nusselt number in terms of nanpo-fluid temperature. As shown in Figures 8. and 9,the convective heat transfer coefficient and Nusselt number of nano-fluid show a reduction by increasing the inlet nano-fluid temperature, respectively. The main reason may be due to higher value of the nano-fluid thermal conductivity which cause a reduction in Prandtl Nu, and finally in the convective heat transfer coefficient. On the other hand, as shown in Fig. (7), the heat transfer rate shows an enhancement by increasing of the nano-fluid inlet temperature. Because the *heat duty* increase while the inlet temperature increases which result in heat transfer rate enhancement based on Eq. (5). In conclusions, in a tubular heat exchanger nano-fluid as the heating medium show more efficient in lower temperatures as reported by Duangthongsug [9].

6. Conclusion

In this paper aims is efficiency improvement of a one-phase closed system using Cuo–water nano-fluid flow in a tubular heat exchanger as the working fluid. Different mass fraction of nano-particles (1-4%) in suspension within closed system were experimentally examined and results were compared with pure water, and the following remarks are concluded from the results of one-phase performance study:

- Using of nano-fluids as heat transfer medium in double-tube heat exchanger show efficient enhancement. Suspension of nano-particle in base fluid, increase the heat transfer rate.

- Nano-fluids in all mass fraction studied showed better thermal performance than pure fluid. For example, for the case of 4% wt nano-fluid at a Re of 673, it increases the overall heat transfer coefficient U_{nf} more than 37% compare whit distilled water.

- The Reynolds distributions (laminar flow) on the nano-fluid were upper level using nano-fluid compared to pure water. But it should be noted that the effect of nano-powder addition to the water in lower velocities is more sensitive than higher velocities.

- The obtained results confirm that the suspended nano-particles in water increase the Nusselt number even for low fractions. For 1%, 2%, and 4% wt in mass fraction an increase of 6%, 10%, and 18%, respectively are achieved for copper oxide water suspensions in compared with distilled water.

- The heat transfer rate, convective heat transfer coefficient and Nusselt number show a reduction by increasing the inlet nano-fluid temperature.

7. Nomenclature

A Plate heat exchanger area, (m^2)
D Inside diameter of the tube, (m)
C_P Heat capacity, (J/kg K)
F LMTD correction factor
k Thermal conductivity, (W/m K)
L Characteristic length, (m)
LMTD Logarithmic mean temperature difference, (K)
m Mass-flow rate, (kg/s)
Q Heat flow rate, (W)
Re Reynolds number
Nu Nusselt number
Pr Prandtl number
h Convective heat transfer coefficient, ($W/m^2.K$)
T Temperature, (K)
U Total heat transfer coefficient ($W/m^2.K$)

Greek letters

μ Dynamic viscosity of the fluid, (po)
φ Particle volume fraction
ρ Density of the fluid, (kg/m^3)

Subscripts

c Cold fluid
h Hot fluid
o Outlet
p nano-particles
i Inlet
w Water

8. References

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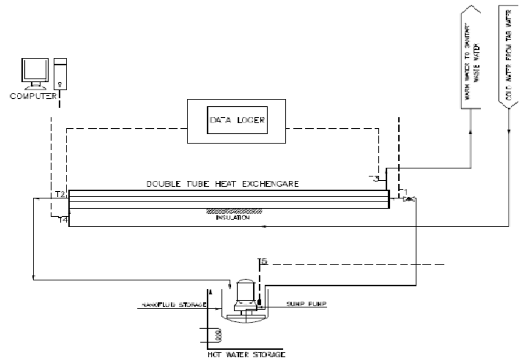

Fig. (1): Schematic representation of the experimental set-up

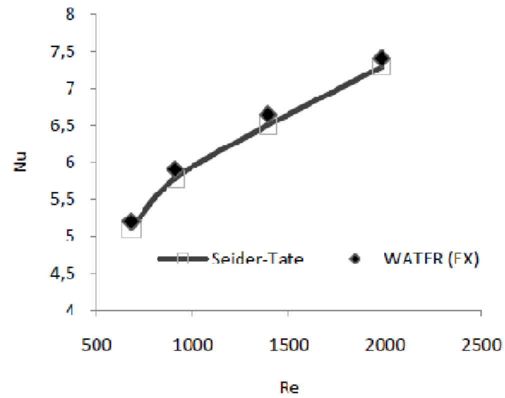

Fig. (2): Variation of Nu vs. Re in laminar flow for distilled water and Comparison the experimental results with correlation of Saider-Tate [13].

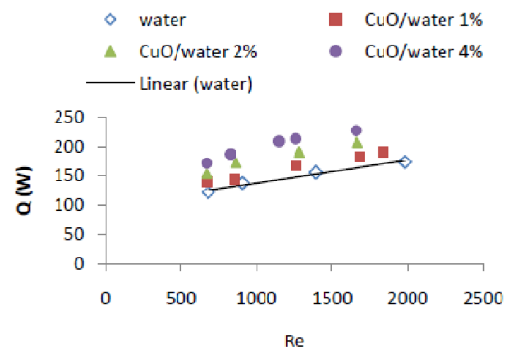

Fig. (3): The variations of the heat transfer rate vs. Re at different nano-fluid mass fraction.

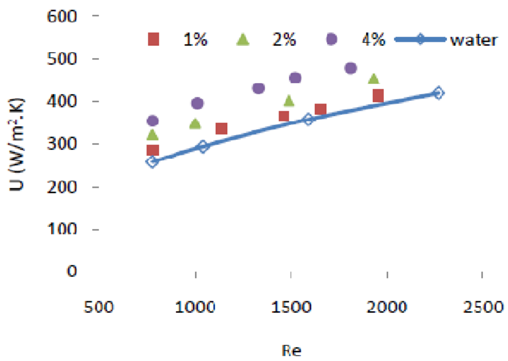

Fig. (4): The variations of the overall heat transfer coefficient vs. Re at different nano-fluid mass fraction.

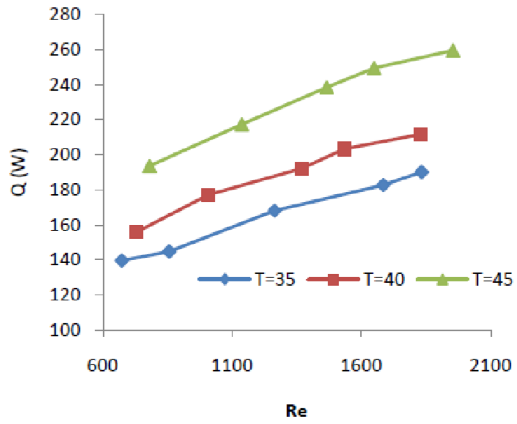

Fig.(7): The effect of nano-fluid inlet temperature on the variations of the heat transfer rate in laminar flow

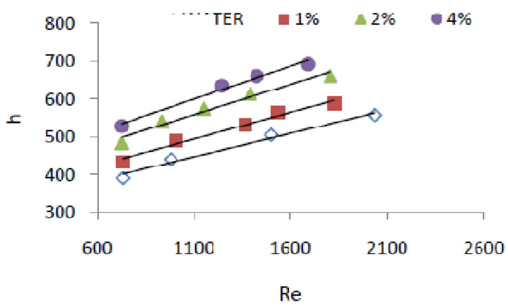

Fig.(5): The variations of the convective heat transfer coefficient vs. Re at different nano-fluid mass fraction

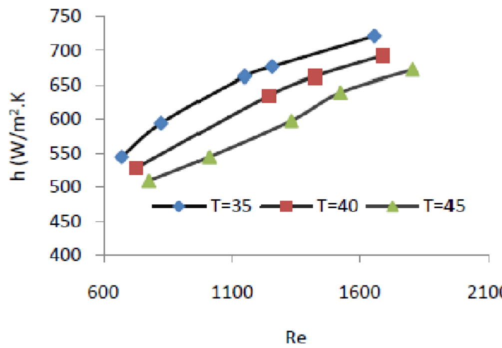

Fig.(8): The effect of nano-fluid inlet temperature on the variations of the convective heat transfer coefficient in laminar flow

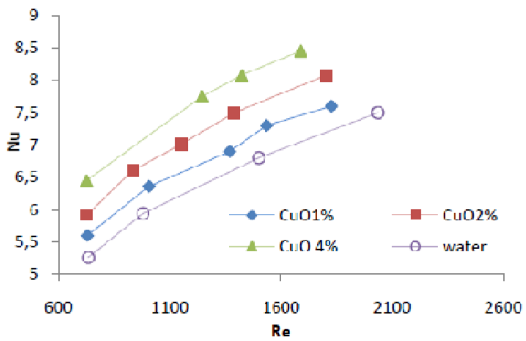

Fig.(6): The variations of Nusselt number vs. Re at different nano-fluid mass fraction

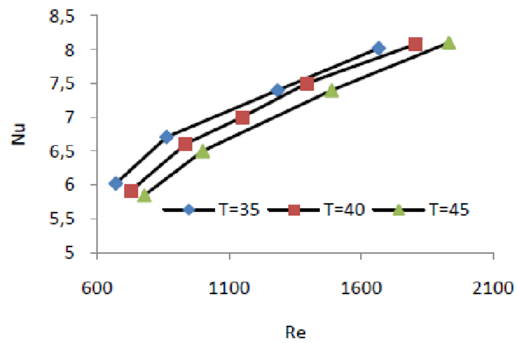

Fig.(9): The effect of nano-fluid inlet temperature on the variations of Nusselt number in laminar flow