Eng. &Tech.Journal, Vol. 33 , No.9, 2015

Augmentation of Heat Transfer for Spiral Coil Heat Exchanger in Solar Energy Systems By Using Nano fluids

The 5th International Scientific Conference for Nanotechnology and Advanced Materials and Their Applications ICNAMA 2015 (3-4) Nov.2015

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ABSTRACT

This article presents an experimental study on pressure drop and enhancement of heat transfer of nanofluids flow in coil heat exchanger of solar energy system. In this study the method using to enhancement of heat transfer and pressure drop, by used the spiral coiled tube heat exchange in solar energy system and the nanofluids instead of the distilled water. The weight concentrations of nanoparticles used are ranging from (15 – 35 wt %). Two types of nanoparticles used in this article cupper (Cu (30nm)) and titanium Oxide (TiO_2 (50nm)) as well as the distilled water. The effects of different parameters such as nanofluid temperature, concentration, type of nanoparticle and flow Reynolds number, on pressure drop and heat transfer coefficient of the flow are studied. The results indicated that an increase in heat transfer coefficient of 55.45 % for Cu + Dw and 40.2 % for TiO_2 + Dw at concentration of 35 wt % compared with base fluid. The pressure drop and heat transfer coefficient is increased by using nanofluids (Cu, TiO_2 – Dw) instead of the distilled water. As well as the results indicated that by using heat exchanger with helically coiled tube and shell, the heat transfer performance is improved moreover the pressure drop enhancement due to the curvature of the coil tube. The maximum increase of 44.32% (Cu + Dw) and 34.42% (TiO_2+ Dw) in Nusselt number ratio for a range of Reynolds numbers between 200 – 800. This article decided that the nanofluid behaviors are close to typical Newtonian fluids through the relationship between shear rate and viscosity. Furthermore to performance index are used to present the corresponding heat transfer technique and flow. The size and type nanoparticles play an important role in enhancement of heat transfer rate.

Keywords: Nanofluids, Solar energy system, coil tube heat exchange, performance index

زيادة انتقال الحرارة لمبادل حراري ذو ملف حلزوني في نظم طاقة شمسية باستخدام الموائع النانوية

الخلاصة

يقدّمُ هذ البحث دراسةَ تجريبيةَ على تعزيز انتقالِ الحرارةِ وهبوطِ الضغطِ للموائع الفائقة الدقة حيث في هذه الدراسةِ الطريقة المستخدمة عَلى تحسينَ نقلِ الحرارةِ وهبوطِ الضغطِ، هي بواسطة استعمالِ مبادل حراري ذو انبوب حلزوني نانوية بدلا من ماء مقطر في منظومة تسخين شمسي .إنّ

https://doi.org/10.30684/etj.2015.117370
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تراكيز الموائع النانوية المستعملة تَتراوحُ مِنْ (35wt% – 15). المبادل الحراري يتألف من انبوب داخلي بشكل حلزوني بينما الأنبوب الخارجي يكون معزولة . أثنان مِنْ أنواعِ الجزئيات النانوية استعملت في هذه الدراسة وهي النحاس ((Cu (30nm) وأوكسيد التيتانيوم ((TiO_2 (50nm) بالإضافة إلى مائع الأساس (ماء مقطر). أنّ تأثيرَ العوامل المختلفةِ مثل عدد رينولدز للتدفقِ ، درجة حرارة المائع النانوية ونوع وتركيز الجزئيات النانوية على معاملِ نقلِ الحرارةِ وهبوطِ ضغطِ التدفقِ من خلال منظومة تسخين شمسي قد درست. أوضحت الدراسة ان الزيادةً في معاملِ انتقال الحرارةِ كانت كالتالي (Cu + Dw) 5.4%، (TiO_2 + Dw) 40.25% عند تركيزِ 35 wt % بمقَارنَة مع مائع الأساس (ماء مقطر). إنّ معاملَ انتقال الحرارةَ وهبوطَ الضغطِ يزدادُ باستعمال الموائع النانوية ((Cu, TiO_2– Dw) بدلاً مِنْ سائلِ الأساس (ماء مقطر). علاوة على ذلك اشارت النتائج ان استعمالِ مبادل حراري على شكل غلاف وانبوب بشكل حلزوني هي طريقة أكثر فعّالية لتَحسين معاملِ انتقال الحرارةِ بالإضافة الى تحسين انحدار الضغط بسب التقوس بالأنبوب الحلزوني . كما بينت الدراسة ان اقصى زيادة كانت الى 44.32% (Cu + Dw) ، 34.42 % (TiO_2+ Dw) في عدد نسلت ولمدى عدد رينولدز (800 – 200) لمبادل حراري على شكل غلاف وانبوب بشكل حلزوني . كما قرّرتْ هذه الدراسة بأنّ سلوك الموائع النانوية هي موائع نيوتونيةِ من خلال العلاقةِ بين معدل القصَّ واللزوجةَ للموائع النانوية علاوة على ذلك ان معامل الأداءِ يُستَعملُ لإظهار الجريان وتقنيةَ انتقال الحرارة. ان نوع وحجم الجزئيات النانوية يلعب دورا هاما في تحسين انتقال الحرارة.

INTRODUCTION

The elimination of thermal load is a great concern in many industries such as transportation and electronics, power plants, production and chemical processes. In order to meet the growing need for cooling surfaces of the high heat flux, different methods for Enhanced heat transfers have been proposed. these methods most are based on vibration of heated surface, structure variation, suction of fluid and applying magnetic fields which are the literature review was good [1,2]. Nevertheless, applying these methods of enhanced heat transfer is no longer feasible requirement of cooling in future generation systems microelectronic, where it is would result in undesirable cooling system low efficiency and size of heat exchangers. To avoid this problem, enhanced thermo – fluidic properties with nanofluids it has been suggested since the last decade. Nanofluid is a uniform dispersion of nanometer sized particles inside base fluid which was first devised by Choi [3]. The nanofluid have excellent properties such as long time stability, enhanced thermal conductivity, and a few penalty in pressure drop increasing and tube wall erosion have motivated many researchers to study on flow behavior and thermal of nanofluids. The mainly focused in these studies on phase change behavior, tribological properties, effective thermal conductivity, flow and convective heat transfer of nanofluids. The experimental and theoretical studies have wide range done on effective thermal conductivity of nanofluids within last decade. The effect of different parameters in many studies,such as particle concentration, particle size, mixture temperature and Brownian motion on thermal conductivity of nanofluids was investigated. The results indicated that thermal conductivity of nanofluid increasing with the nanoparticles concentration and mixture temperature [4 –7]. As well it was shown that enhancement of larger in thermal conductivity is attributed to the finer particle size [6–8]. Most of recent studies are focused on convective heat transfer behavior of nanofluids in turbulent and laminar flows due to the enhanced thermal properties of nanofluids. Roughly all of these works report the enhancement of nanofluid convective heat transfer. The Many numerical and experimental studies have considered nanofluid convective heat transfer in turbulent flow [9–12], while other studies have investigated the convective heat transfer of nanofluids in laminar flow. [13 – 16] investigated of convective heat transfer of nanofluids in laminar inside a straight tube with a constant heat flux at the wall, horizontal tube with and without wire coil inserts at constant heat flux.Results indicated that nanofluids give substantial enhancement of heat transfer rate compared to base fluid. Also they noticed claimed that the friction factor for the nanofluids at low volume fraction did not produce extra penalty in pumping power. Heat transfer characteristics of single – phase in the helical tubes have been widely studied by researchers both theoretically and experimentally.[17 – 19] investigated enhancement in the heat transfer rates between a helically coiled heat exchanger and a straight tube heat exchanger. The results indicated that the nanofluids for three types indicated a small enhancement in the heat transfer coefficient at a Reynolds number range of 100 to 500, the transition from laminar to turbulent flow covers a wide Reynolds number range and the geometry of the temperature and the heat exchanger of the water bath surrounding the heat exchanger affected the heat transfer coefficient. The aim of this study is to investigate experimentally the heat transfer characteristics and flow of spiral tube heat exchanger for both parallel flow and counter flow configurations by using nanofluids through solar heating system. As well as to study the effect of nanoparticles concentration, size of nanoparticles, Reynolds number and nanofluid temperature.

Experimental work

Material: cupper (Cu (30 nm)) and Titanium oxide (TiO_2 (50 nm)) nanoparticles

Nanofluid preparation

The preparation of nanofluid samples are prepared by dispersing pre – weighed quantities of dry particles of cupper (Cu (30 nm)) and Titanium oxide (TiO_2 (50 nm)) in base fluid (distilled water). In a typical procedure, the acidity (pH) of each concentration of nanofluid a mixture was measured (pH = 4.5 – 5). The mixtures were then subjected to ultrasonic mixing [100 kHz, 300 W at 25 – 30 C^0, and Toshiba, England] for two hour to break up any particle aggregates. The nanofluid of this study was included distilled water and nanoparticles from (US Research Nanomaterials, Inc). Their properties are shown in table 1, and 2 respectively. The picture of preparation of nanofluids containing cupper (Cu (30 nm)) and Titanium oxide (TiO_2 (50 nm)) is display in Fig .1. Nanofluids prepared with different weight percent (Φ = 15, 20, 25, and 35 wt %).

Table (1)The properties of nanoparticle Cu [20]

Cupper Nano powder Cu, 99%, 30 nm	
Purity	> 99%
crystal phases	Monoclinic
APS	30 nm
SSA	20– 40 m^2/g
Color	read
Morphology	Nearly spherical
True density	8.933 g/cm^3

Table (2) The properties of nano partical TiO2[20]

Titanium oxide Nano powder TiO_2, 99%, 50 nm	
Purity	>99%
crystal phases	Monoclinic
APS	50 nm
SSA	20 – 40 m^2/g
Color	white
Morphology	spherical
True density	4.250 g /cm^3

Figure(1) Show nanofluids for Cu + Dw , TiO_2 + Dw and Dw

Experimental setup

The experimental set up consists of the fifteen evacuated tube solar collector, helically coiled tube heat exchanger, pump, flow meter, two pressure gauges. This study concentrated on heat exchanger in solar energy system. The experimental of apparatus used for this study is shown in Fig.(2) and flow diagram of the system as shown in Fig.(3). The heat exchanger is made of cupper and test section has the helically coiled tube internal diameter of 13 mm, the external diameter of 16 mm and shell internal diameter of 370 mm and external diameter 385mm and 1000mm length test section as shown in Fig.(4). The set – up has helically coiled tube side loop and shell side loop. The helically coiled tube side loop handles two types of nanofluids used copper – distilled water, titanium oxide – distilled water. Shell side loop handles hot water. Shell side loop consist of storage vessel of 60 L capacity with heater of 4.5 Kw, control valve, pump and thermostat. The helically coiled tube side loop consists of test section containing shell and spiral tube, pump [Bosch 1046 – AE], needle valve , flow meter (Dwyer series MMA mini – master flow meter) having a range of (5 – 20 LPM). Four T – type thermocouples of 0.15 ^{0}C accuracy are used to measure inlet and outlet temperatures of shell and tube side. Eight T– type thermocouple were placed at equal interval on the outer surface of coiled tube to measure the wall temperatures. The thermocouples are placed and glued with epoxy to avoid leakage. The pressure gauges are placed across the helical tube to measure the pressure drop. The shell is insulated with Acrylic resin coated fiberglass sleeving to minimize the heat loss from shell to the ambient. The numbers of the total tests were 200. The nanofluids (Cu +DW, TiO_2 +DW, at 15%, 20%, 25%, 30%, 35 %, weight concentration was circulated through the tube side. Shell side pump is switched on when distilled water reaching to a prescribed temperature. This done by thermostat attached in distilled water storage system. The flow configuration was made parallel flow condition. The corresponding temperatures were recorded after attaining the steady state. The same procedure was done for nanofluid at 15 % weight concentration. The flow configuration is changed from parallel to counter flow. The same procedure is followed and the temperatures are recorded. Flow rate on shell side (5 L/min) and coiled tube pitch are maintained constant throughout the test. The flow rate on coiled tube side is varied. The flow in coiled tube side is in the range of 5 – 20 /min.

Figure (2) Set up of the heat exchanger in solar energy system

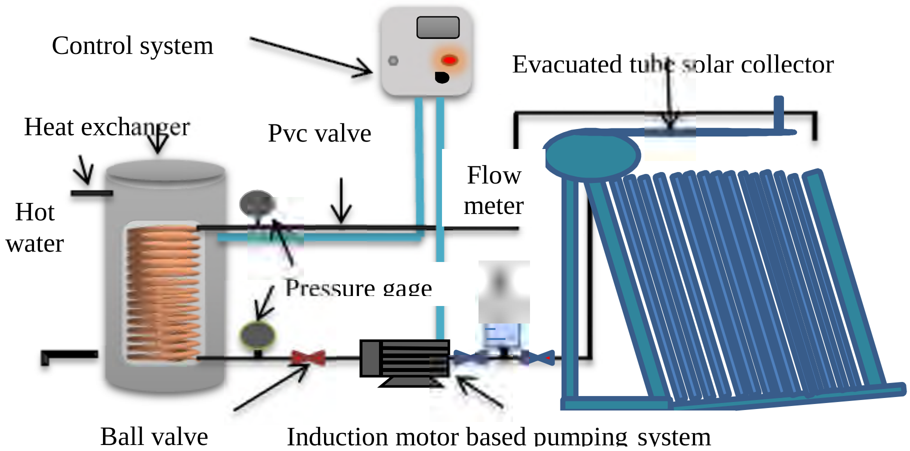

Figure (3) Flow diagram of solar energy system

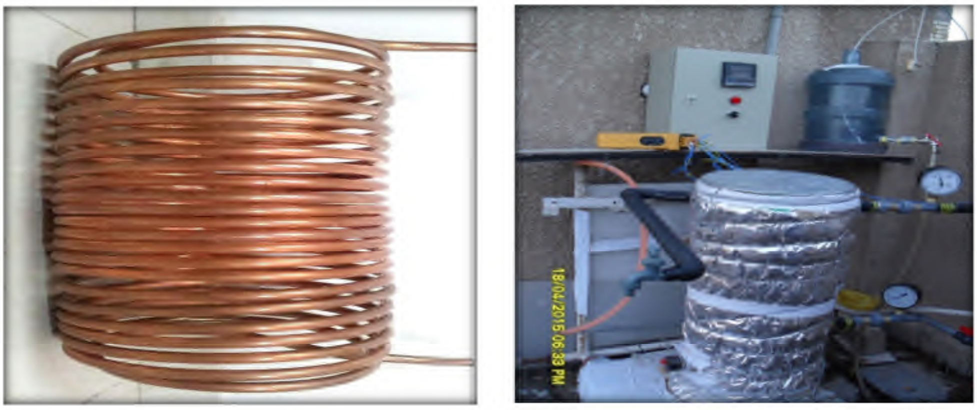

Figure (4) Test section for heat exchanger

Measurement of Thermal Properties Nanofluid

The properties of the nanofluids (Cu+ Dw) and TiO_2 +Dw) needed to calculate the convective heat transfer and the pressure drop are measured. The dynamic viscosity (μ) is measured using brook field digital viscometer model DV – E. The thermal conductivity, specific heat and density are measured by Hot Disk Thermal Constants Analyzer (6.1), specific heat apparatus (ESD – 201) as well as the measurement of density was carried out by weighing a sample and volume. The nanofluids thermal properties dynamic viscosity (μ) , thermal conductivity, specific heat and density are measured with different weight concentrations at (Φ= 15, 20, 25,30 and 35 wt %). The empirical relation used in this study to comparison with the practical measurements for nanofluid properties. The thermo properties of nanofluid were calculated at the average bulk temperature of the nanofluid by the following equations. The volume fraction (Φ) of the nanoparticles is defined by.

$$\varphi = \frac{v_p}{v_p + v_f} = m\frac{\pi}{6}d_p^{-3} \qquad \dots (1)$$

Density [21].

$$\rho_{nf} = \Phi\,\rho_s + (1-\Phi)\,\rho_{Dw} \qquad \dots (2)$$

Viscosity [21].

$$\mu_{nf} = (1 + 2.5\Phi)\mu_{Dw} \qquad \dots (3)$$

Specific heat [21].

$$Cp_{nf}\,\rho_{nf} = \Phi(\rho_s\,Cp_s) + (1-\Phi)(\rho_{Dw}Cp_{Dw}) \qquad \dots (4)$$

Recently Chandrasekar et al.[22] presented an effective thermal conductivity model (Eq.5)

$$\frac{k_{nf}}{k_{Dw}} = \left[\frac{Cp_{nf}}{Cp_{Dw}}\right]^{-0.023}\left[\frac{\rho_{nf}}{\rho_{Dw}}\right]^{1.358}\left[\frac{\mu_{Dw}}{\mu_{nf}}\right]^{0.126} \qquad \dots (5)$$

Figures (5 – 8) indicated that density, viscosity, specific heat, and thermal conductivity for the two types of nanofluid (Cu + Dw) and (TiO_2 + Dw).

Data processing and validation

The heat transfer for water and nanofluid are estimated from Eqs.(6) and (7). The average heat transfer is taken for this analysis. Fouling factor was not taken into account.

$$Q_{Dw} = m_{Dw}\,Cp_{Dw}\,(T_{in} - T_{out})_{Dw} \qquad \dots (6)$$

$$Q_{nf} = m_{nf}\,Cp_{nf}\,h_{nf}\,(T_{in} - T_{out})_{nf} \qquad \dots (7)$$

$$q = \frac{Q_{Dw} + Q_{nf}}{2} \qquad \dots (8)$$

The overall heat transfer coefficient, Uo, was calculated from the temperature data and the heat transfer rate using the following equation [23]:

$$U_o = \frac{q}{A_o LMTD} \qquad \dots (9)$$

Where:

A_o is the surface area; q is the heat transfer rate; and LMTD is the log mean temperature difference based on the inlet temperature difference, ΔT1, and the outlet temperature difference, ΔT2.

$$LMTD = \frac{\left(\Delta T_2 - \Delta T_1\right)}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)} \qquad \dots (10)$$

$$Q = h_i A_i \left(T_w - T_b\right) \qquad \dots (11)$$

$$Nu_i = \frac{h_i d_i}{k_{nf}} \qquad \dots (12)$$

The inner heat transfer coefficient and overall heat transfer coefficient of coiled tube are calculated from Eqs.(9) and (11). The Nusselt number is calculated from Eq.(12). It measures the convective heat transfer in the helical tube. The overall heat transfer coefficient can be related to the inner and outer heat transfer coefficients by the following equation [23]:

$$\frac{1}{U_o} = \frac{A_o}{A_i h_i} + \frac{A_o \ln\left(\frac{D_i}{d}\right)}{2\pi K L} + \frac{1}{h_o} \qquad \dots (13)$$

Where:

Di is the inner diameter of the shell; d is the diameter of the inner spiral tube; K is the thermal conductivity of the Pyrex wall; and L is the length of the heat exchanger. The Nusslet number in shell side is determined by the following definition.

$$Nu_o = \frac{h_o D_h}{k_{nf}} \qquad \dots (14)$$

Where:

D_h is the hydraulic diameter of shell which is calculated from the following formula:

$$D_h = \frac{4\left(V_{shell} - V_{tube}\right)}{\pi\left(D + d\right)\left(L_{sheel} + L_{tube}\right)} \qquad \dots (15)$$

Similarly to the heat transfer coefficient, The friction factor for laminar flow inside helical coiled tube can for range of Dean number (De) of (11.6 < De <2000) is correlated as: [24].

$$\frac{f}{f_s} = \left[1 - \left[1 - \left(\frac{11.6}{De}\right)^{0.45}\right]^{2.22}\right]^{-1} \qquad \dots (16)$$

Where:

$$De = Re\sqrt{\left(\frac{d}{De}\right)}$$

The friction factor for helical coiled tube, f, is determined as [24].

$$f_e = \frac{7.0144}{Re}\sqrt{De} \qquad \dots (17)$$

The pressure drop of nanofluid in coil tubes is evaluated as

$$\Delta p = f\,\frac{L}{D}\frac{\rho\,V^{2}}{2} \qquad \ldots(18)$$

Results and Discussion

The accuracy and the reliability of the experimental system, the heat transfer coefficients are experimentally measured using distilled water as the working fluid before the nanofluids of distilled water based Cupper and titanium oxide nanofluids**.** The results of the experimental pressure drop and heat transfer coefficient are compared with results from the Shokouhmand , Salimpour [25] , Salimpour [26], Seban and Metauchlin [24]. The flow in spiral coiled heat exchangers which are defined as follows.

$$Nui = 0.112\ De^{0.51}\gamma^{-0.37}\,Pr^{0.72} \qquad \ldots(19)$$

$$Nuo = 5.48\,Re_{o}^{0.511}\gamma^{0.546}\,Pr^{0.226} \qquad \ldots(20)$$

The change of experimental values with theoretical values for heat transfer coefficient as shown in Figure. (9), therefor good agreement between these values in this figure. Figure. (10) Indicated the change of the theoretical values for pressure drop along the test section versus measured pressure drop. The experiments are done at the same condition explained in the heat transfer validation. The deviation of the experimental data from the theoretical one is within −2.2 % and +3.5 % as a shown in Fig. (10). Having established confidence in the experimental system, the characteristics of nanofluids flowing inside the helical tube is investigate experimentally for laminar flow conditions. As well as the following results, heat transfer and pressure drop data for each two specific cases are not achieved under exactly the same Reynolds numbers. This is because the viscosity of distilled water based nanofluid is so dependent on volume concentration and nanofluid temperature. The parallel flow versus the counter flow overall heat transfer coefficients are plotted in Figures. (11 and 12) for two types of nanofluids (Cu + Dw), and (TiO_2 + Dw). There is a reasonable agreement between the two values. These figures indicated that a reasonable agreement between the two values. The overall heat transfer coefficient for counter flow was 30 – 57 % more than that of parallel flow for two types of nanofluids (Cu + Dw), and (TiO_2 + Dw) with 35 wt % weight concentration. The overall heat Transfer coefficient for counter flow was 8 – 15 % more than that of parallel flow at 15 wt % for two types of nanofluids.

The change of flow direction does not affect overall heat transfer. Therefore, the reason is that the tube side primary flow and generation of secondary flow are always perpendicular to the shell side flow. There is no significant effect of heat transfer on changing flow condition. The results for the parallel flow configuration were similar to the counter flow. Heat transfer rates, however, are much higher in the counter flow configuration, due the increased log mean temperature difference. The changing of inner Nusselt number versus Dean number for the flow of base oil and the nanofluids (Cu + Dw and, TiO_2 + Dw) with different nanoparticle weight concentrations as shown Figures. (13 – 16). On comparing the counter flow and parallel flow configuration, it is found that there is no significant impact on inner Nusselt number when Cupper and titanium oxide with based distilled water nanofluids are circulated. This is because whatever be the flow configuration between coiled tube and shell, the inner heat transfer coefficient is the same. This means that the generation of secondary flow and centrifugal force did not get negative impact. It is also observed that the inner Nusselt number increases with particle concentration. This is due to higher thermal conductivity and inner heat transfer coefficient. In general, higher the convective heats transfer and higher the thermal conductivity. The addition nanoparticle of titanium oxide and cupper to the base distilled water has led to an increase in Nusselt number for flow inside helical tube. In general the addition of nanoparticles enhances the thermal conductivity of the distilled water. The enhancement of thermal conductivity would increase the convective heat transfer coefficient. The chaotic movement of the nanoparticles in flow will disturb the thermal boundary layer formation on the tube wall surface. The development of the thermal boundary layer is delayed. Since, higher Nusselt number of nanofluid flow in a coil tube are obtained at the thermal entrance region, the delay in thermal boundary layer formation resulted by adding nanoparticles will increase the Nusselt number. The higher weight concentrations of the nanoparticles for both the thermal conductivity of the mixtures (Cu, TiO_2 – base distilled water) and the disturbance effect of the nanoparticles will increase. Therefore, as it is expected, nanofluids with higher Nusselt number have generally higher weight concentrations. The ratios of Nusselt number of nanofluids with 35 wt % to that of base distilled water as a function of Reynolds number for helical tube as shown in Figures. (17 – 18). The nanofluids (Cu + Dw and, TiO_2 + Dw) have better heat transfer performance when they flow inside helical tube. The results indicated that at nearly the same range of Reynolds numbers, the highest Nusselt number ratios are obtained for the helical tube. The maximum increase of 44.32% (Cu + Dw) and 34.42% (TiO_2+ Dw) in Nusselt number ratio for a range of Reynolds numbers between 200 – 800 is obtained for the coil tube. This case could be due to the intensified chaotic motion of the nanoparticles inside coil tube. Since, the shear rate near the wall of the coil tube is high, the non – uniformity of the shear rate across the cross section will increase and therefore, the nanoparticles are more motivated by the changing of the shear rate. The measured pressure drop for the flow of distilled water and Cu, TiO_2 + distilled water nanofluids with different weight concentration as a function of Reynolds number along the coil tube is show in Figures. (19 – 22), respectively. The results indicated that there is a noticeable increase in pressure drop of nanofluid with 15 wt % nanoparticle concentration compared with the distilled water value. This enhancement tends to continue for the nanofluids with higher weight concentration. This is because of the fact that suspending solid nanoparticles in a base fluid generally increases dynamic viscosity relative to the distilled water. Since, the viscosity is in direct relation with pressure drop, the higher value of pressure drop leads to increased amount viscosity. As well as another reason which can be responsible for pressure drop increasing of nanofluids may be attributed to the migration and chaotic motion of nanoparticles in the base fluid. This reason indicated why at higher flow rates, the rate of increase in pressure drop has gone up while at very low Reynolds numbers, the pressure drops of base fluid and nanofluids are almost the same. However, the rate of pressure drop increasing achieved for nanofluids with concentration ranges from 15 wt% - 35 wt % is less than that obtained when nanofluid with 15 wt% is used instead of base fluid. One reason for this behavior may be due to the anti – friction properties of Cupper, titanium nanoparticles. Cupper and titanium nanoparticles are basically spherical. The spherical shape of nanoparticles may result in rolling effect between the rubbing

surfaces and the situation of friction is changed from sliding to rolling, thus the lubricant with nanoparticles achieves a good friction reduction performance.
The nanoparticles rolling effect was also reported by Battez et al. [27] and Wu et al. [28]. However, for the coill tube, the maximum pressure drop enhancement of 25.42 % (Cu + Dw) and 15.32 % (TiO_2 + Dw) are achieved when nanofluid with 15 wt % concentration is used instead of distilled water.

When applying the heat exchanger with coiled tube and shell using nanofluid flow inside the test sections instead of the base fluid flow, the convective heat transfer coefficient of enhanced. However, these enhanced heat transfer techniques were both accompanied with increase in pressure drop which can limit the use of them in practical applications. Therefore, in order to find the optimum work conditions, a further study on the overall performance of these techniques should be carried out to consider pressure drop enhancement besides heat transfer augmentation, simultaneously. To do so, a new parameter called performance index, ζ, is defined as follows:

$$\zeta = \frac{\left(\frac{Nu_{nf}}{Nu_{ht,\ bf}}\right)}{\left(\frac{\Delta p_{nf}}{\Delta p_{ht,\ bf}}\right)} \qquad \ldots(10)$$

Where, Nu and ΔP represent Nusselt number and pressure drop of the flow resulted by applying enhanced heat transfer techniques, respectively. In addition, $Nu_{ht,\ bf}$ and $\Delta P_{ht,\ bf}$ are the Nusselt number and pressure drop of the distilled water flow inside the coil tube, respectively. Apparently, when the performance index is greater than 1, it implies that the heat transfer technique is more in the favor of heat transfer enhancement rather than in the favor of pressure drop increasing. Therefore, the heat transfer methods with performance indexes greater than 1 would be feasible choices in practical applications. The performance index is greater than 1 just for nanofluids with 15, 20, 25, and 35 wt % concentrations as show in Figures (22– 25). The maximum performance index of 1.5 and 1.32 are obtained for the nanofluids (Cupper + distilled water) and (titanium oxide + distilled water) with 35 wt % concentration at Reynolds number of 790. The all concentration for the coil tube has performance indexes greater than 1 as show in these figures. It means that for distilled water flow along the coil tube, the rate of increasing in pressure drop is lower than increasing in heat transfer coefficient.

Figures. (23, – 26) indicated when applying coil tube is a more effective way to enhance the convective heat transfer compared to using nanofluids instead of the distilled water. The high performance index suggests that applying both of the heat transfer enhancement techniques studied in this article is a good choice in practical application. The shear stress is plotted against shear rate for Cu, and TiO_2 + Dw nanofluids at (Φ= 15, 20, 25, and 35 wt %) nanoparticle weight concentration as show in Figures.(27 – 30). The plot data for these types of nanofluid are not parallel, indicating that the materials are a Newtonian fluid over this range of shear stress. Therefor these figure indicated the shear stress increases with shear rate, for Cupper, and titanium oxide base distilled water nanofluids. These figures reveal the flow curve of the Cu, and TiO_2 + distilled water nanofluids measured using coil heat exchanger. The shear stress of nanofluids increases with concentration of nanoparticles for both flow counter and parallel flow.

CONCLUSIONS

The main conclusions of the present study are:

- The type and size nanoparticles for cupper and titanium oxide play an important role in enhancement of heat transfer rate.
- The shear stress of nanofluids increases with concentration of nanoparticles for both counter flow and parallel flow.
- Nanofluids that contain metal nanoparticles such as Cupper, indicate more enhancements compared to oxide nanofluids TiO_2 + distilled water and compared with base fluid flow as well as the use of nanofluid significant gives higher Nusselt number than base fluid.
- No much effect of changing flow direction on overall heat transfer coefficient and the nanofluids (Cupper, and titanium oxide – distilled water) behaves as the Newtonian fluid for (Φ = 15, 20, 25, and 35 wt %).
- The heat transfer characteristic in coil tube is better than distilled water by using Nano fluids.
- The performance index of the nanofluid flow inside the coil tube is greater than the performance index of the base fluid. The high performance index suggests that applying both of the heat transfer enhancement techniques studied in this investigation is a good choice in practical application.
- The pressure drop of distilled water flow is lower than the pressure drop of nanofluids in coil tube.

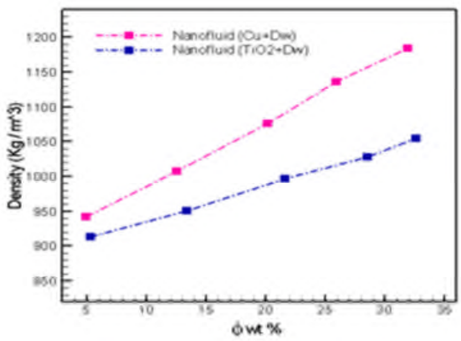

Fig 5. Density of nanofluids for (Cu + Dw) and (TiO_2+Dw) at different weight fraction

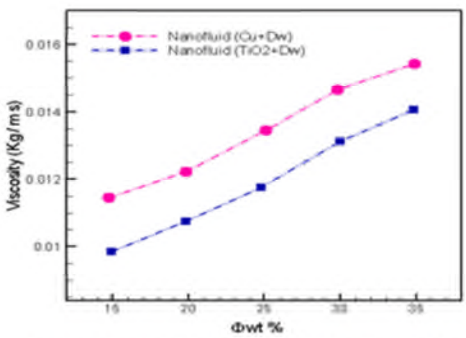

Fig 6. Viscosity of nano fluids for (Cu + Dw) and (TiO_2+ Dw) at different weight fraction

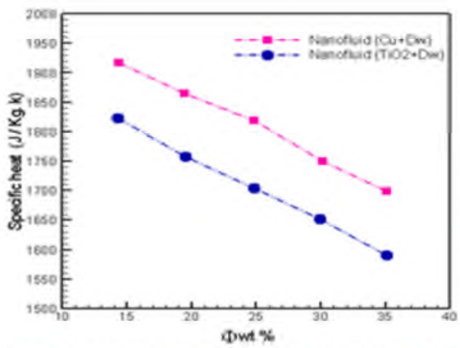

Fig 7. Specific heat of nanofluids for (Cu + Dw) and (TiO_2+ Dw) at different weight fraction

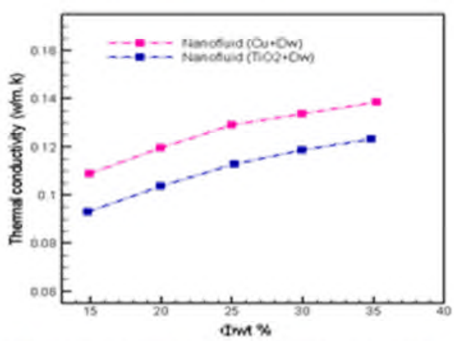

Fig 8. Thermal conductivity of nanofluids for (Cu + Dw) and (TiO_2+ Dw) at different weight fraction

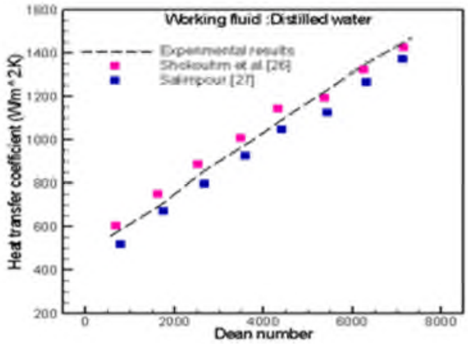

Figure (9) Comparison between measured heat Transfer coefficient and that calculated from [27, 28]

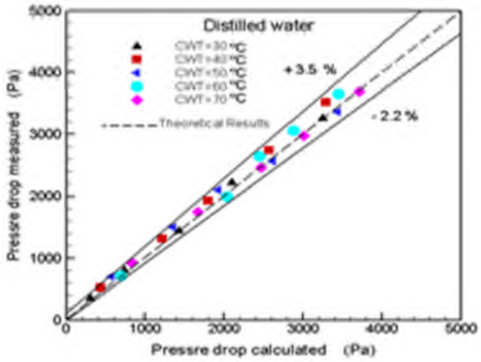

Figure (10) Comparison between theoretical and experimental pressure drop of Distilled water

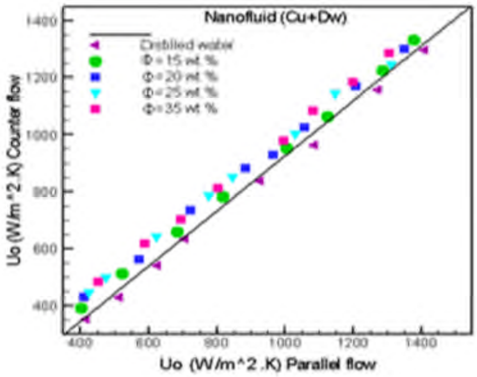

Figure (11) Comparison of overall heat transfer Coefficient of counter and parallel flow Configuration for (Cu +Dw) nanofluid

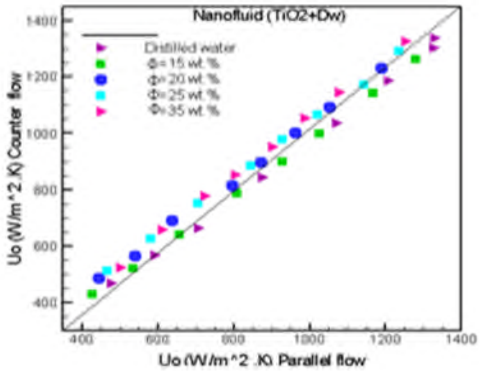

Figure (12) Comparison of overall heat transfer Coefficient of counter and parallel flow configuration for (TiO_2+ Dw) nanofluid

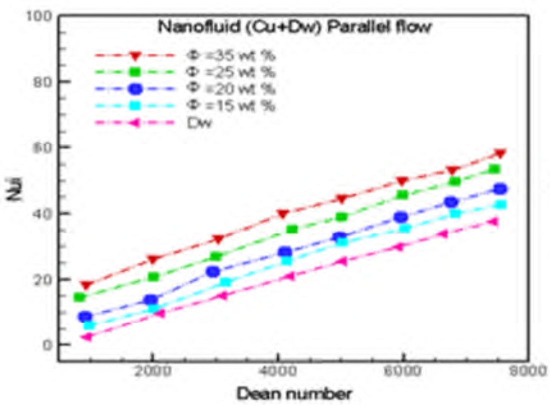

Figure (13) Variation of inner Nusselt number for nanofluid (Cu +Dw) with parallel flow

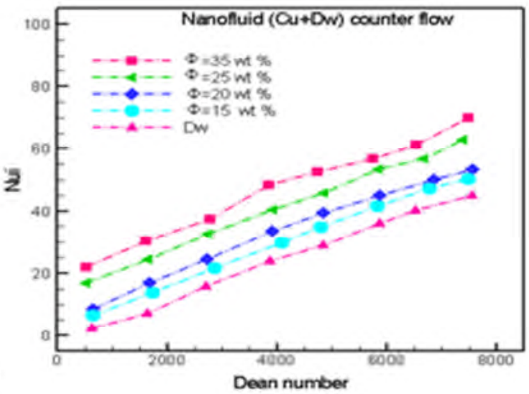

Figure (14) Variation of inner Nusselt number for nanofluid (Cu +Dw) with counter flow

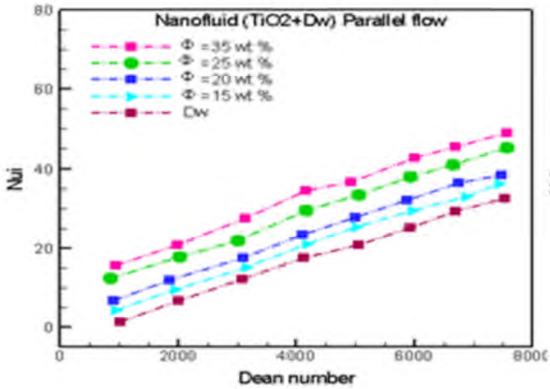

Figure (15) Variation of inner Nusselt number for nanofluid (TiO2 +Dw) with parallel flow

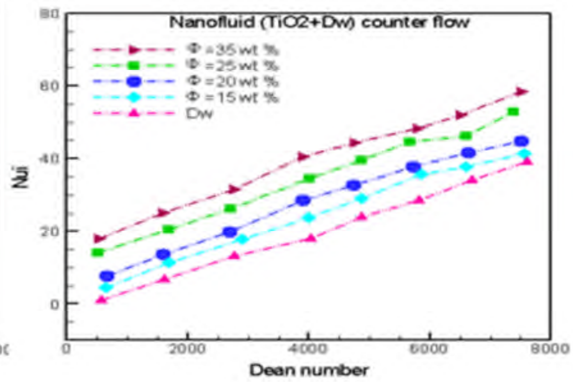

Figure (16) Variation of inner Nusselt number for nanofluid (TiO2 +Dw) with counter flow

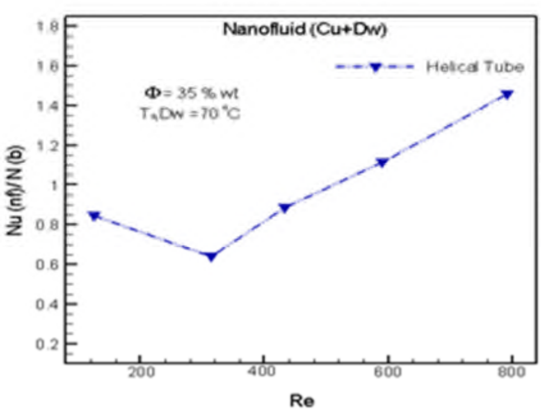

Figure (17) The Nu ratio versus Re to nanofluid (Cu+ Dw) in helical tube at Φ=35 wt %

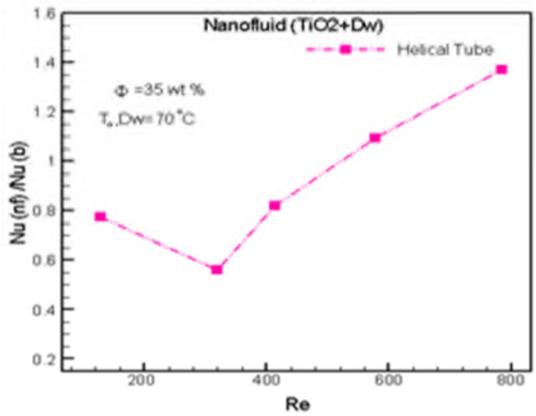

Figure (18) The Nu ratio versus Re to nanofluid (TiO_2 + Dw) in helical tube at Φ=35 wt %

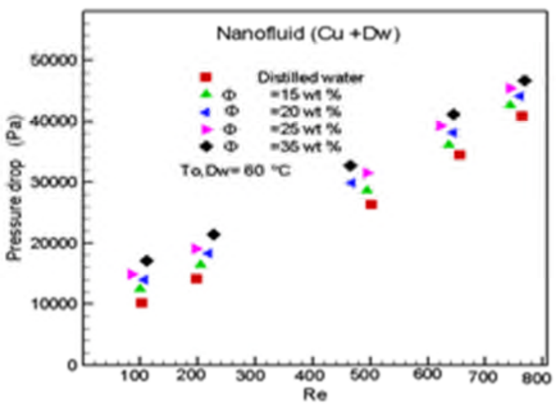

Figure (19) Pressure drop versus Re to Nano fluid (Cu + Dw) with parallel flow at different Φ

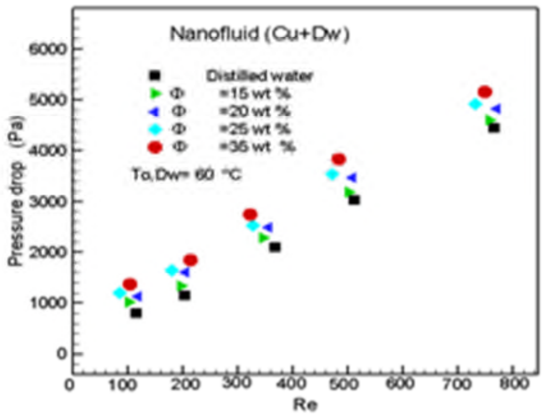

Figure (20) Pressure drop versus Re to Nano fluid (Cu + Dw) with counter flow at different Φ

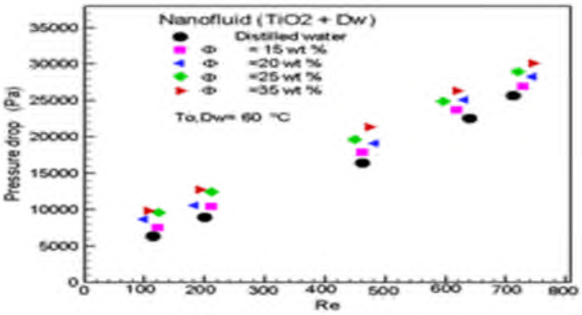

Figure (21) Pressure drop versus Re to Nano fluid (TiO_2 + Dw) with parallel flow at different Φ

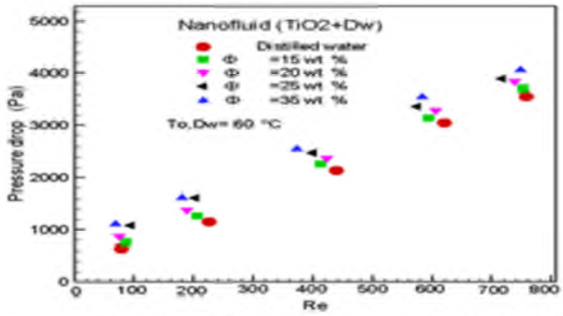

Figure (22) Pressure drop versus Re to Nano fluid (TiO_2 + Dw) with counter flow at different Φ

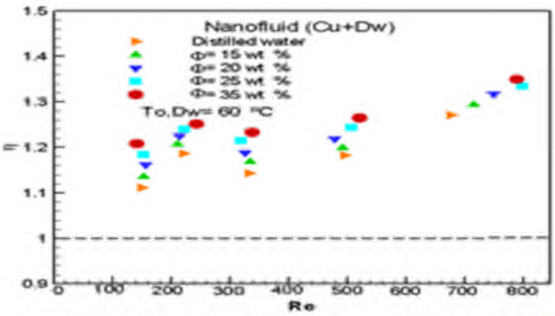

Figure (23) The performance index versus Re to Nano fluid (Cu + Dw) with parallel flow at different Φ

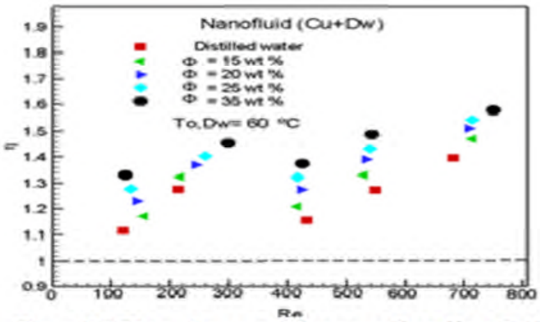

Figure (24) The performance index versus Re to Nano fluid (Cu + Dw) with counter flow at different Φ

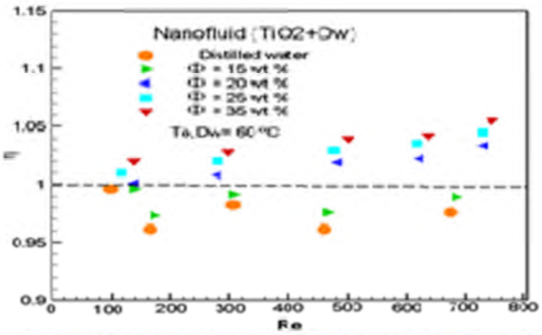

Figure (25) The performance index versus Re to Nano fluid (TiO_2 + Dw) with parallel flow at different Φ

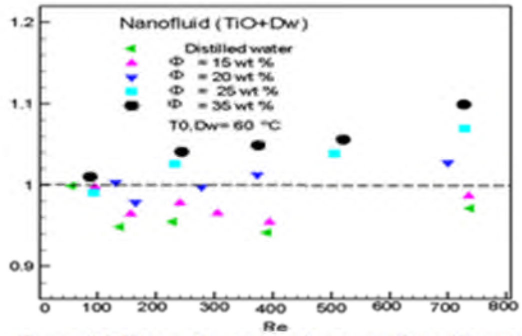

Figure (26) The performance index versus Re to Nano fluid (TiO_2 + Dw) with counter flow at different Φ

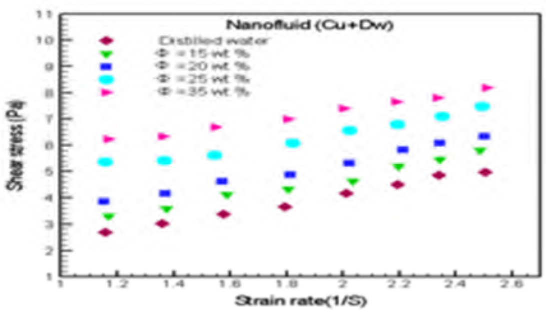

Figure (27) Shear stress versus shear rate for Nano fluid (Cu +Dw) with parallel flow

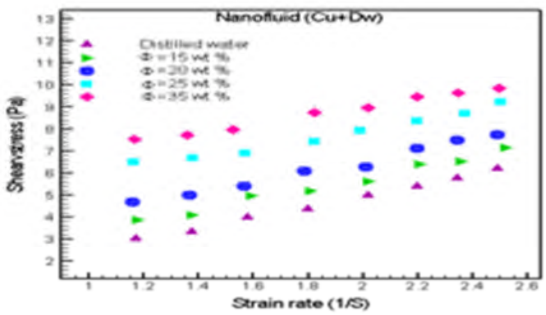

Figure (28) Shear stress versus shear rate for Nano fluid (Cu+Dw) with counter flow

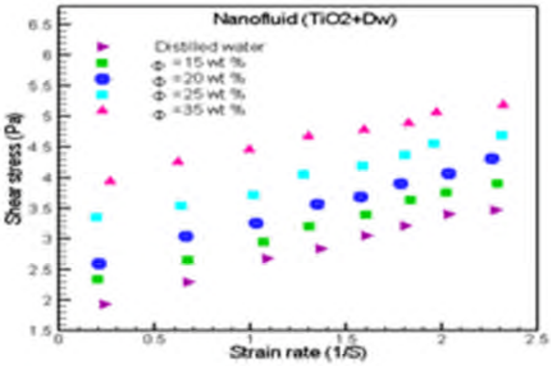

Figure (29) Shear stress versus shear rate for Nano fluid (TiO_2 +Dw) with parallel flow

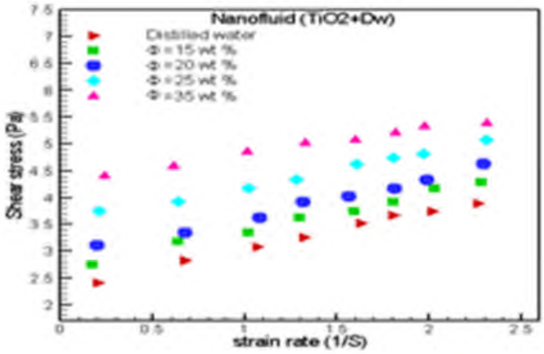

Figure (30) Shear stress versus shear rate for Nano fluid (TiO_2+Dw) with counter flow

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