Experimental Analysis of Heat Transfer Enhancement and Flow with Cu, TiO₂ Ethylene Glycol Distilled Water Nanofluid in Spiral Coil Heat

A B S T R A C T

This experimental investigation was performed to improve heat transfer in the heat exchanger (tube of shell and helically coiled) using nanoparticles for turbulent parallel flow and counter flow of distilled water (Dw) and ethylene glycol (EG) fluids. Six types of nanofluids have been used namely: copper – distilled water, copper – distilled water and ethylene glycol, copper – ethylene glycol, titanium oxide – distilled water, titanium oxide – distilled water and ethylene glycol, titanium oxide – ethylene glycol with 0.5%,1%,2%,3% and 5% volume concentration as well as the range of Reynolds number are 4000 – 15000. The experimental results reveal that an increase in coefficient of heat transfer of 50.2% to Cu – Dw, 41.5% to Cu – (EG + Dw), 32.12% for Cu – EG , 36.5% for TiO₂ – Dw, 30.2% to TiO₂– (EG + Dw) and 25.5%, to TiO₂ – EG . The strong nanoconvection currents and good mixing caused by the presence of Cu and TiO₂ nanoparticles. The metal nanofluids give more improvement than oxide nanofluids. The shear stress of nanofluids increases with concentration of nanoparticles in the case of parallel and counter flow. The effect of flow direction is insignificant on coefficient of overall heat transfer and the nanofluids behave as the Newtonian fluid for 0.5%,1%,2%,3% and 5%. Good assent between the practical data and analytical prediction to nanofluids friction factor which means the nanofluid endure pump power with no penalty. This study reveals that the thermal performance from nanofluid Cu – Dw is higher than Cu – (EG + Dw) and Cu – EG due to higher thermal conductivity for copper and distilled water compared with ethylene glycol.

Keywords: Nanofluid ethylene glycol enhancement metallic nano metallic

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كلاءة الفيصل

استمرار تحسين انتقال الحرارة والجريان للموائع النانوية باستخدام النحاس، وأوكسيد التيتانيوم مع أثيلين كلايكلو.

تقيق علمي لتغليق انتقال الحرارة والجريان بواسطة استعمال جزيئات نانوية مثل النحاس، وأوكسيد التيتانيوم من خلال مياج حراري حلزوني مع ماء مقطّع واثيلين كلايكول.

المجرين مصطبغ مثليز وتعاكس واثناء أنواع من المواد النانوية استعملت في هذه الدراسة، ماء مقطّع، نحاس، ماء مقطّع وأثيلين كلايكول، نحاس، ماء مقطّع، أوكسيد التيتانيوم، نحاس، ماء مقطّع وأثيلين كلايكول، أوكسيد التيتانيوم، نحاس، ماء مقطّع وأثيلين كلايكول، 0.5%, 2%, 3%, 5%.

في النتائج العملية ان الزائدة مهام انتقال الحرارة كانت كالكلي. النتائج العملية على ضعف للانقباضية على الضغط على انتقال الحرارة الكلي وقع مع انتقال الحرارة النانوية وذو انتقال حراري مثليز وتعاكس. لا تذكر لتجانس انقباضية على مهام انتقال حرارة الكلي ونظام هذه المواد النانوية مثليز وتعاكس انتقال حراري كلي. هذه الدالة يبين ان هناك فاقد بين النتائج التجريبية والتحليلية مع انتقال الحرارة الكلي للموائع النانوية. كما ووضح هذه الدراسة أن المواد النانوية لاستخدم جزء ضئيل من انتقال الحرارة النانوية مع انتقال الحرارة النانوية مع انتقال الحرارة الكلي.

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1. INTRODUCTION

Heat exchangers are used in various applications e.g. heating of thermal oil, generation of steam, plants of thermal processing, processing of food and dairy air conditioning, refrigeration and processes of heat recovery. The advantageous causes of helical coil tubes are high coefficient of heat transfer and small size compared with straight tubes. The cost and efficiency of the heat exchangers are very important factors in industry process; there must be an exact equation to determine the heat transfer. All engineering applications include heat transfer through a fluid medium such as refrigeration, automobiles, power plants and heat exchangers. Heat transfer in fluids, essentially, is convection. However, heat transfer coefficients depend on thermal conductivity of the fluid. To improve its a suspension of solid particles and in general solids thermal conductivity is greater than that of fluids. But the mill and micro sized nanoparticles are liable to plug and deposition in micro channels. On the other hand, nanofluid is on stable suspension at a low concentration of nanoparticles. The improvement of the fluid thermal conductivity is due to disperse in fluid of the conventional heat transfer and occurs without problems as plug and deposition and sedimentation and clogging. Pak and Cho [1], investigated experimentally the turbulent friction and heat transfer behaviors of dispersed fluids (Al$_2$O$_3$ and TiO$_2$ particles suspended in water) in a circular pipe. Lee et al. [2], observed enhancement of thermal conductivity of nanofluids using CuO and Al$_2$O$_3$ nanoparticles with water and ethylene glycol compared to base fluids. The thermal conductivities of nanofluids with CuO and Al$_2$O$_3$ nanoparticles have been determined experimentally using steady – state parallel – plate technique by Wang et al. [3], for different base fluids such as water, ethylene glycol and engine oil. The thermal conductivity of these nanofluids is increased with increasing volume fraction of the nanoparticles.

Xuan and Li [4], studied the augmentation of thermal conductivity of Cu–water nanofluid for different volume fractions of Cu nanoparticles. Xuan and Roetzel [5], concluded from their findings that the heat transfer enhancement is due to the increase of thermal conductivity and to thermal dispersion which is caused by random motion of the particles that coupled with enhanced thermal conductivity.

Das et al. [6], investigated the variation of the thermal conductivity of a nanofluids (Al$_2$O$_3$ – water and CuO–water) with temperature using temperature oscillation technique. They observed that an increase in the thermal conductivity with temperature. Yang et al. [7], measured, experimentally, the convective heat transfer coefficients of several nanoparticles – in – liquid dispersions under a laminar flow in a horizontal tube heat exchanger. Koo and Kleinstreuer [8], showed that the Brownian motion has more impact on the thermal properties of the nanofluid than thermo – phoresis. Herish et al. [9] have conducted an experiment to determine the thermal conductivity of Al$_2$O$_3$ – water nanofluid during forced convection in a laminar flow through a circular tube with a constant wall temperature. Recently, Zhang et al. [10], measured the thermal conductivity and thermal diffusivity of Au – toluene, Al$_2$O$_3$ – water, TiO$_2$ – water, CuO water and carbon nanotubes – water nanofluids using the transient short – hot – wire technique. Heat transfers of laminar and turbulent flows in coiled tubes were calculated by Seban and McLaughlin [11]. Regers and Mayhew [12] has been calculated pressure drop and heat transfer that heated helically using a coiled tubes by using steam heat.

This study indicates that failing to in the gain in the wall temperature uniformly because the large core region of the remaining work flow. The objective of this study is to analyze the characteristics of heat transfer and fluid flow in a heat exchanger of spiral tube for both, parallel flow and counter flow configurations using base fluid and nanoparticles. The effects of the nanoparticles concentration and different based fluids such as ethylene glycol, distilled water and ethylene glycol distilled water are investigated.

2. NANOFLUID PREPARATION

The two – steps method was used to prepare nanofluids from base fluid and copper (Cu) or titanium oxide (TiO$_2$) nanoparticles. Nanoparticles dispersion is in three types of base fluid which are namely: distilled water, ethylene glycol and the mixture of ethylene glycol and distilled water with volume ratio of 60:40. After prepare of the nanofluids and packed in an ultrasonic blender for half an hour to aggregate and disperse of a nanoparticle. The acidic pH is much less than the isoelectric point of these particles, thus ensuring positive surface charges on the particles. The surface enhanced repulsion between the particles producing uniform dispersions through the
experiments. An image of a nanofluids containing Cu (50nm) and TiO$_2$ (50nm) are displayed in Fig. 1.

A: Copper–Ethylene glycol
B: Titanium oxide – Ethylene glycol
C: Ethylene glycol

Fig.1. Nanofluids for two types and ethylene glycol.

2.1. Analysis of Geometric Shape for Heat Exchanger

Fig. 2 reveals geometric shape for heat exchanger (spiral coiled and shell heat exchange type). The curvature ratio of the coil is as follows:

$$\delta = \frac{d}{2\pi Rc}$$  \hspace{1cm} (1)

The non-dimensional pitch is as follows:

$$\gamma = \frac{b}{2\pi Rc}$$  \hspace{1cm} (2)

Dimensionless factors for heat exchanger in this study are as follows:

$$Re_i = \frac{\rho V_id_i}{\mu}, \quad Nu_i = \frac{h_d}{k}$$

$$De = Re_i \left( \frac{d_i}{2Rc} \right)^{0.5}, \quad He = \frac{De}{(1+\gamma^2)^{0.5}}$$  \hspace{1cm} (3)

Mori and Nakayama [13] investigated experimentally a curved pipe with UHF within large De. These articles indicate that the two regions of the flow are: BL near the wall and steam condensation on the surface of coil.

Shell – side Reynolds number ($Re_o$) and Nusselt number ($Nu_o$) are defined as follows:

$$Re_o = \frac{\rho V_o D_h}{\mu}, \quad Nu_o = \frac{h_o D_h}{k}$$ \hspace{1cm} (4)

where: $V_o$, $h_o$, and $D_h$ are the average velocity, convective heat transfer coefficient and the hydraulic diameter of the shell side respectively.

2.2. Experimental Facility and Procedure

An experimental apparatus and a schematic diagram are used in this work which are shown in Figs. 3 and 4. And a test section is shown in Fig. 5. The heat exchanger is made of Pyrex (soft glass) and the test section is a helical coiled tube of $d_i = 10 \text{ mm}$ and $d_o = 12 \text{ mm}$. This helical tube has 34 turns and the coil length is 750 mm. The Pyrex (soft glass) shell has $70 \text{ mm}$ inner diameter and $80 \text{ mm}$ outer diameter and $1000 \text{ mm}$ length. The set-up has helical coiled tube side loop and another side of shell loop. Six types of nanofluids flow in helically coiled tube and this type used copper – distilled water, copper – distilled water and ethylene glycol, copper – ethylene glycol, titanium oxide – distilled water, titanium oxide – distilled water and ethylene glycol, titanium oxide – ethylene glycol. Shell side loop handles hot water.

Fig. 2. Geometric shape of heat exchanger.

Fig. 3. The experimental system of the convective heat transfers and flow characteristics for the nanofluid.

The studied volume fractions of the nanofluids are ($\Phi = 0.5\%, 1\%, 2\%, 3\% \text{ and } 5\%$). Shell side loop consists of a storage vessel of 20 liter capacity with a heater of 3.25 kW, control valve, water pump and a temperature thermostat. The test section consists of a heat exchanger (type shell and spiral tube), pump, needle valve, flow meter of (0.01–3.5) lpm range, cooling unit and a storage vessel of 10 liter capacity. The temperature hot water of the inside the storage vessel (shell side) is maintained via thermostat. The inlet and outlet temperatures of the shell and tube are measured using four T – type thermocouples of 0.15 °C accuracy.

Fig . 4. Schematic diagram of the apparatus.
The wall temperatures of the coiled are measured by eight T-type thermocouples. The pressure drop is measured by a pressure gauges that are fixed via the helical tube. The shell is insulated using an Acrylic resin coating the fiberglass sleeve in order to minimize the heat loss from the shell to the atmospheric. The distilled water is tested prior to the nanofluid. And after finishing of construction and calibration of the flow loop then, testing of the loop's functionality for measuring Nusselt number and viscous constants analyzer (6.1) and specific heat apparatus (ESD) respectively. Density is gained by weighing sample and fluids nanoparticles [17] model dynamic viscosity with that obtained from the comparison between the practical measurement of field digital viscometer model DV-E, 1956 model [14], Brinkman, 1952 model [15], Wang et al. model [16] and Batchel model [17]. Figs. 8 and 9 represent viscosities of the two types of nanoparticles Cu and TiO₂ with three types of the base fluids DW, EG, EG+DW. The following equipment are used to measure the thermal properties (\( \rho, \mu, K, C_p \)) respectively. Density is gained by weighing sample and volume, viscometer model (DV – E), Hot Disk thermal constants analyzer (6.1) and specific heat apparatus (ESD – 201). However, the measure density is in a good agreement with the calculated values of that based on [18] theory as shown in Figs. 10 and 11. Figs. 12 and 13 reveal density for the six types of nanofluids. Figs. 14 and 15 indicated the experimental measurements of the thermal conductivity that compared with the thermal conductivity models of many researchers such as Wasp model [19], Hamilton and Crosser [20], Maxwell model [21] and Timo Feeva et al. model [22]. These results showed a good agreement between the Wasp model. Figs. 16 and 17 show the thermal conductivity ratio of the two types of nanoparticles Cu and TiO₂ with three types of the base fluids DW, EG, EG + DW. As well as the measure values for \( C_p \) compared with the two models of \( C_p \) [23, 24] which are shown in Figs. 18 and 19. The second model showed a good agreement with the measured values. Figs. 20 and 21 depicted the specific heat for the six types of nanofluids. The increase in the \( (\mu, \rho, k \text{ and } C_p) \) ratios are as follows 10.25%, 5.33%, 16% and 7.2% respectively. This is for the first type of nanoparticle while in the second type of nanoparticles ratios are 8.12%, 3.62%, 11.9% and 2.95% at 5 vol% and 25°C as compared with that of the distilled water.

**Fig. 5.** Test section (Pyrex spiral annulus).

The dynamic viscosity (\( \mu \)) is measured using brook field digital viscometer model DV–E. Figs. 6 and 7 show a comparison between the practical measurement of dynamic viscosity with that obtained from the empirical relation of Einstein, 1956 model [14], Brinkman, 1952 model [15], Wang et al. model [16] and Batchel model [17]. Figs. 8 and 9 represent viscosities of the two types of nanoparticles Cu and TiO₂ with three types of the base fluids DW, EG, EG+DW. The following equipment are used to measure the thermal properties \((\rho, \mu, K, C_p)\) respectively. Density is gained by weighing sample and volume, viscometer model (DV – E), Hot Disk thermal constants analyzer (6.1) and specific heat apparatus (ESD – 201). However, the measure density is in a good agreement with the calculated values of that based on [18] theory as shown in Figs. 10 and 11. Figs. 12 and 13 reveal density for the six types of nanofluids. Figs. 14 and 15 indicated the experimental measurements of the thermal conductivity that compared with the thermal conductivity models of many researchers such as Wasp model [19], Hamilton and Crosser [20], Maxwell model [21] and Timo Feeva et al. model [22]. These results showed a good agreement between the Wasp model. Figs. 16 and 17 show the thermal conductivity ratio of the two types of nanoparticles Cu and TiO₂ with three types of the base fluids DW, EG, EG + DW. As well as the measure values for \( C_p \) compared with the two models of \( C_p \) [23, 24] which are shown in Figs. 18 and 19. The second model showed a good agreement with the measured values. Figs. 20 and 21 depicted the specific heat for the six types of nanofluids. The increase in the \( (\mu, \rho, k \text{ and } C_p) \) ratios are as follows 10.25%, 5.33%, 16% and 7.2% respectively. This is for the first type of nanoparticle while in the second type of nanoparticles ratios are 8.12%, 3.62%, 11.9% and 2.95% at 5 vol% and 25°C as compared with that of the distilled water.

**Fig. 6.** Viscosity ratio for Cu - (EG+DW).

**Fig. 7.** Viscosity ratio for TiO₂ - (EG+DW).

### 2.3. Measurement of the Nanofluid Thermal Properties

The heat transfer for the distilled water, ethylene glycol and ethylene glycol. Distilled water are estimated using Eq. (5) and for nanofluid using Eq. (6). Fouling factor is not taken into account.

\[
Q_w = m_w c_p_w (T_{in} - T_{out})_w \tag{5}
\]

\[
Q_{nf} = m_{nf} c_p_{nf} (T_{in} - T_{out})_{nf} \tag{6}
\]

### 3. DATA ANALYSIS AND VALIDATION

The heat transfer for the distilled water, ethylene glycol and ethylene glycol. Distilled water are estimated using Eq. (5) and for nanofluid using Eq. (6). Fouling factor is not taken into account.
\[ q = \frac{Q_W Q_{nf}}{2} \]  

(7)

The temperature data and the heat transfer rate were used to calculate the overall heat transfer coefficient, \( U_o \), as following [25]:

\[ U_o = \frac{q}{A_o \text{LMTD}} \]  

(8)

where: \( A_o \) - surface area; \( q \) is the rate of heat transfer; and LMTD is the log of the mean temperature difference.

\[ \text{LMTD} = \frac{\Delta T_2 - \Delta T_1}{\ln \left( \frac{\Delta T_2}{\Delta T_1} \right)} \]  

(9)

Also

\[ Q = h_i A_i (T_W - T_b) \]  

(10)

\[ Nu_i = \frac{h_i d_i}{k_{nf}} \]  

(11)

where: \( T_W \) is the wall temperature, \( T_b \) is the bulk temperature, \( A_i \) is the inside area and \( h_i \) is the inner heat transfer coefficient. \( U_o \) and \( h_i \) are calculated using Eqs. (8) and (10). \( Nu_i \) is calculated using Eq. (11). The coefficient of overall heat transfer is often associated with the inner and the outer heat transfer coefficients using the subsequent equation [25]:

\[ \frac{1}{U_o} = \frac{A_o}{A_o h_i} + \frac{A_o \ln \left( \frac{D_i}{D} \right)}{2\pi kL} + \frac{1}{h_i} \]  

(12)

The Nusslet number in the shell side of the heat exchanger is calculate as follows.

\[ Nu_o = \frac{h_o D_h}{k_{nf}} \]  

(13)

where: \( D_h \) is the shell hydraulic diameter that calculate as following:

\[ D_h = \frac{4(V_{\text{shell}} - V_{\text{tub}})}{\pi(D + d)(L_{\text{shell}} + L_{\text{tub}})} \]  

(14)
Fig. 13. Three types of density ratio for TiO$_2$.

Fig. 14. Thermal conductivity ratio for Cu –(EG+DW).

Fig. 15. Thermal conductivity ratio for TiO$_2$ – (EG+DW).

Fig. 16. Three types of thermal conductivity ratio for Cu.

Fig. 17. Three types of thermal conductivity ratio for TiO$_2$.

Fig. 18. The specific heat ratio for Cu –(EG+DW).

Fig. 19. The specific heat ratio for TiO$_2$ – (EG+DW).

Fig. 20. The three types of the specific heat ratio for Cu.
Similarly, the coefficient of heat transfer, the nanofluids flowing friction factor via the heat exchanger are calculated as follows:

\[ f_{nf} = \frac{2D\Delta P_{nf}}{L\rho_{nf}u_{nf}^2} \]  

(15)

where: \( f_{nf} \) is the nanofluid friction factor, \( \Delta P_{nf} \) is the nanofluid measured pressure drop, \( L \) is the tube length, \( \rho_{nf} \) is the nanofluid density, and \( u_{nf} \) is the nanofluid mean velocity. The empirical relations between the nanofluids properties were compared with experimental results viscosity, density, thermal conductivity and specific heat.

A. Nanofluid viscosity models

<table>
<thead>
<tr>
<th>Equation</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \mu_{nf} = (1 + 2.5\phi)\mu_{bf} )</td>
<td>[14]</td>
</tr>
<tr>
<td>( \mu_{bf} = (1 - \phi)^{-1.5}\mu_{bf} )</td>
<td>[15]</td>
</tr>
<tr>
<td>( \mu_{nf} = (1 + 7.3\phi + 123\phi^2)\mu_{bf} )</td>
<td>[16]</td>
</tr>
<tr>
<td>( \mu_{nf} = (1 + 2.5\phi + 6.2\phi^2)\mu_{bf} )</td>
<td>[17]</td>
</tr>
</tbody>
</table>

A. Nanofluid density model.

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>( \rho_{nf} = (1 - \phi)\rho_{bf} + \phi\rho_{bf} )</td>
<td>[18]</td>
</tr>
</tbody>
</table>

B. Nanofluid thermal conductivity models [19–22].

\[
\begin{align*}
    k_{nf} &= \frac{k_b + (n - 1)k_b - (n - 1)(k_b - k_p)\phi}{k_b - (n - 1)k_b + (k_b - k_p)\phi} \\
    k_{nf} &= \frac{k_b + 2k_b + 2(k_b - k_p)\phi}{k_b - 2k_b - (k_b - k_p)\phi} \\
    k_{nf} &= (1 + 3\phi)k_p
\end{align*}
\]

C. Nanofluid specific heat models.

<table>
<thead>
<tr>
<th>Equation</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>( c_{nf} = (1 - \phi)c_{bf} + \phi c_p )</td>
<td>[23]</td>
</tr>
<tr>
<td>( c_{nf} = (1 - \phi)(\rho c)_bf + \phi(\rho c)_p )</td>
<td>[24]</td>
</tr>
</tbody>
</table>

\[ N_u = 0.112De^{0.51}Y^{-0.37}Pr^{0.72} \]  

(16)

\[ N_u = 5.48Re^{0.511}Y^{0.546}Pr^{0.226} \]  

(17)

The friction factor for a turbulent flow in a helical coiled tube, \( f \), is determined as [28].

\[ f_c = \frac{7.0144}{Re} \sqrt{De} \]  

(18)

Figs. 22 and 23 show a good agreement between the experimental results and the calculated one for using Dw. Figs 24 - 26 show the \( U_o \) of the counter flow versus the \( Uo \) of parallel flow for three types of nanofluids (Cu – DW, Cu – EG and Cu – (EG + DW)). These figures showed a good agreement between data. \( Uo \) of the counter flow is 6% – 12% greater than that for the parallel flow at 0.5 vol % for three types of nanofluids (Cu – DW, Cu – EG and Cu – (EG + DW)). \( Uo \) of the counter flow is 25% – 52% greater than that for the parallel flow at 5 vol % for the same three types of nanofluids. This means that there insignificant effect of change the heat transfer flow.

Fig. 21. Three types of the specific heat ratio for TiO₂.

4. RESULTS AND DISCUSSION

In this article the experimental data for the friction factors and coefficient of heat transfer are compared with Shokouhm and Salimpour [26], Salimpour [27] data for a flow in a helical coiled heat exchanger which are defined as follows:

\[ N_u_i = 0.112De^{0.51}Y^{-0.37}Pr^{0.72} \]  

(16)

\[ N_u_o = 5.48Re^{0.511}Y^{0.546}Pr^{0.226} \]  

(17)
The reason behind that is: the primary and secondary flow in the tube is perpendicular on the direction of the shell wall. The changing flow direction does not affect $U_o$. The results from the counter flow Configuration is similar to the that of parallel flow. Heat transfer rates, however, are much higher in the counter flow configuration, due to the increase of the log of the mean temperature difference.

Figs 27 - 38 show the change of $Nu_t$ with $De$ for both, parallel and counter flow. These figures show an insignificant effect on the $Nu_t$ for using nanofluids (Cu – DW,Cu – EG,Cu – ( EG +DW), TiO$_2$ – DW, TiO$_2$ – EG and TiO$_2$ – ( EG +DW)). This is the reason for the flow configuration and $h_t$. Also the centrifugal force and the secondary flow have an adverse negative effect. And also $Nu_t$ increases with $\phi$ increase.

In general, the thermal conductivity is proportional to the convective heat transfer. The experimentally determined coefficients of nanofluids friction are shown in Figs. 39 - 44. The experimental friction coefficient results of TiO$_2$ at 0.5%, 1%, 2%, 3% and 5% particle volume concentration are shown in these figures. Solid line indicates that the experimental results of distilled water and the symbols indicate the nanofluids for turbulent flow. The friction factor of nanofluids (TiO$_2$ – DW, TiO$_2$– EG and TiO$_2$ – (EG +DW)) are proportional to the friction factor of the distilled water at low volume fraction concentration of a spiral coil heat exchanger. These figures show that the coefficient of friction of TiO$_2$...

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**Fig. 25.** Overall heat transfer coefficient for two types of flow configuration (counter and parallel) of Cu – EG nanofluid.

**Fig. 26.** Overall heat transfer coefficient for two types of flow configurations (counter and parallel) of Cu – (EG+DW) nanofluid.

**Fig. 27.** Variation of $Nu_t$ to nanofluid (Cu-DW) and counter flow.

**Fig. 28.** Variation of $Nu_t$ to nanofluid (Cu-DW) and parallel flow.

**Fig. 29.** Variation of $Nu_t$ to nanofluid (Cu–EG) of parallel flow.

**Fig. 30.** Variation of $Nu_t$ to a nanofluid (Cu–EG) of counter flow.
is slightly increased compared with that of the distilled water at high volume fraction concentration due to nanoparticles suspension in Dw. Most of TiO$_2$ data are located above the line of the distilled water. The friction factor in the spiral coil heat exchanger had an insignificant effect with changing the concentrations of the nanoparticles.

In this case, there is no need for pumping power. An excess in pressure was noticed when using a nanofluid due to small nanoparticles suspension in Dw which did not change the nanofluid flow behavior. The pressure drop of the base fluid, ethylene glycol is smaller than the base fluid of the distilled water.

Figs. 45 - 50 show the shear stress versus the shear rate for the nanofluids (Cu–DW,Cu–EG and CU–(EG+DW) at 0.5%, 1%, 2%, 3% and 5% particle volume concentration. These figures indicated that the
nanoparticles and distilled water are a Newtonian fluid. As well as these figures indicated the shear stress increases with the increase of the shear rate of the nanofluids Cu–DW, Cu–EG and Cu–(EG+DW). These figures indicated the flow curve of the nanofluids which is measured using a spiral coil heat exchanger. The shear stress is increased with the volume fraction of parallel and counter flow nanofluids. The use of the nanofluid gives significant higher Nusselt number than the distilled water and ethylene glycol as a based fluid. Also the results indicated that an increase in \( h \) of 50.2\% to Cu–DW, 41.5\% to Cu–(EG+DW), 32.12\% to Cu–EG and 36.5\%, to TiO\(_2\) – DW, 30.2 \% for TiO\(_2\) – (EG + DW), 25.5\%, for TiO\(_2\) – EG.

Fig. 38. Variation of \( \text{Nu}_i \) with nanofluid TiO\(_2\) – (EG + Dw) of counter flow.

Fig. 39. The friction factor with nanofluid (TiO\(_2\) –DW) of parallel flow.

Fig. 40. The friction factor with nanofluid (TiO\(_2\) –DW) of counter flow.

Fig. 41. The friction factor with nanofluid (TiO\(_2\) – EG) of parallel flow.

Fig. 42. The friction factor with nanofluid (TiO\(_2\) – EG) of counter flow.

Fig. 43. Variation of friction factor for nanofluid TiO\(_2\) of (EG +DW) for parallel flow.

Fig. 44. Variation of friction factor for nanofluid TiO\(_2\) with (EG +DW) for counter flow.
The presence of the nanoparticles (Cu and TiO$_2$) produces a strong nano convection current and good mixing. The enhancements in the metal nanofluids are better than the oxide metal nanofluids. The coefficient of overall heat transfer is insignificant effect on the flow direction change and the nanofluids behave as the Newtonian fluid for 0.5%, 1%, 2%, 3% and 5%. The experimental results of the frication coefficient of the nanofluid show that there is a good agreement with data of the Colebrook formula. This means that it does not need pumping power and a high value for the pressure purpose drop when using a nanofluid which makes it appropriate for experimental. This study proved that the thermal of the nanofluid Cu–DW is higher than that of Cu–(EG+DW) and Cu–EG nonofluid due to a higher thermal conductivity for the silver and distilled water compared with ethylene glycol.

5. CONCLUSIONS

The main conclusions of the present experimental article are:
1. The type of nanoparticles and base fluid played an important role in the improvement of the heat transfer by the nanofluids.
2. The presence of Cu and TiO$_2$ nanoparticles attributes to the generation a good mixing.
3. The coefficient of overall heat transfer had insignificant effect on the of the flow direction of the nanofluid (Cu–
The improvement due to the metal nanofluid is better than that of the oxide metal of nanofluids.

5. The improvement of the nanofluid does not increase the thermal conductivity only but it affects other parameters i.e., viscosity of nanofluid, base fluid.

6. The shear stress of the nanofluids increases with the increasing volume fraction of the nanoparticles of parallel and counter flow.

7. The nanofluid with Dw is nearly the same for the pressure drop and friction coefficient while nanofluid with ethylene glycol is smaller than EG. This means that there is no need for pumping power and pressure drop.

REFERENCES


