Performance Evaluation of Shell and Tube Heat Exchanger by Using Fe_3O_4/water Nanofluid

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Abstract. This paper studies the forced convection heat transfer and flow characteristics of nanofluids composed of water and different volume concentrations of Fe_3O_4/water nanofluids (0.35%, 0.2%) under laminar flow conditions that move in counter current in a vertical shell-and-tube heat exchanger. Fe_3O_4 nanoparticles having a diameter of about 30 nm were used in this work. Various of Reynolds number were used during practical experiments on the device is (200,600,1000,1400). The results show that for the same mass flow and inlet temperature, the convective heat transfer coefficient of the nanofluid is slightly larger than that of the base fluid where the improvement ratio is up to 14%, 22% for 0.2%, 0.35%, respectively. Where it was concluded through the results that the total coefficient of heat transfer of the nanofluid has increased compared to the basic fluid, the maximum improvement at (0.2%, 0.35%) was about 34% and 61%, respectively. When the concentration of nanofluids increases sharply, the Nusselt number also increases sharply compared with the base fluid up to 10%, 19%. As the results showed that the friction factor increases when the concentration of nanofluid increase because the density and viscosity is higher than of base fluid, while decrease when the Reynolds number increase, where the ratios reached 25%, 47%. It was found that the effectiveness of nanofluids is higher than that of base fluids is up to 56%, 62%.

Keywords: *shell and tube, forced convection, Nusselt number, friction, effectiveness.*

1.Introduction

A heat exchanger is a mechanical device that transfers heat between two fluids that are at different temperatures. In industries, there are many different types of heat exchangers, but shell and tube heat exchangers are the most common. It is primarily utilized in oil refineries, food processing factories, thermal power plants, and chemical plants, among other places. This is commonly used because of the huge heat transfer area to volume weight ratio, easy cleaning technique, and replaceable portion, among other factors [1]. Choi created the word nanofluid while working on a research project at Argonne National Laboratory in 1995, and it was the first time it was defined [2]. Nanofluid consist of nanoparticles and base fluid. Because nanoparticles have a high thermal conductivity when combined with a base fluid, the base fluid's thermal conductivity will be increased [3]. As a result, nanofluids aid in the effective transfer of heat from a high-temperature fluid to a low-temperature fluid. Nanofluid is now widely utilized in heat transfer devices [4].

Modern material science enables us to create nanometer-sized particles with mechanical and thermal characteristics distinct from the parent materials. The use of nanoparticles to alter the heat transfer performance of solutions has recently piqued interest. Nanofluids are heat transfer fluids in which nanometer-sized particles (smaller than 100 nm in at least one dimension) are suspended in a stable suspension [5]. Nanofluids are suited for engineering applications and have numerous benefits over conventional suspensions, including improved stability, substantially increased thermal conductivity, and no additional pressure drop [6]. Many variables, such as particle volume fraction, particle material, particle size, particle shape, and temperature, have been found to impact the thermal conductivity of nanofluids in experiments [7].

There are some analytical and few experimental studies obtainable about nanofluids flow through a shell and tube heat exchanger. Shahrul et al. [8] Considering the various oxide-based nanofluids at different mass flow rates, the analysis and research were carried out using a shell and tube heat exchanger. They analyzed ZnO, CuO, Fe_3O_4, TiO_2 and Al_2O_3 nanoparticles with a volume fraction of 0.01-0.04 in water. It was found that the energy efficiency of the nanofluids listed above was increased by approximately 23-52%. In their research, ZnO-W nanofluid has the highest energy efficiency, while SiO_2/water nanofluid has the lowest energy efficiency.

Karemi et al. [9] He presented a research paper on the performance of the shell and tube heat exchanger using Fe_3O_4/water nanofluid experimentally and using concentrations (0.25%, 0.5%, 0.75% and 1%). Through what was concluded from the results, it was noted that there is a noticeable increase in the rate of heat transfer and at the same time there is an increase in the pressure drop as a result of the increase in the volumetric concentration of the nanomaterial. Where the increase in the heat transfer rate was about 19.8% due to the addition of nanoparticles

Said et al. [10] prepared a stable aqueous nanofluid from CuO and studied its use in the shell and tube heat exchanger in quantities (0.05%, 0.1% and 0.3%). The results indicated that for the same fluid inlet temperature and mass flow rate, the total heat transfer coefficient increased by 7% and the convective heat transfer coefficient increased by 11.39%. An area reduction of 6.81% was achieved.

Dhiaa et al. [11] studied the convective heat transfer of titanium oxide/water in the shell and tube heat exchanger when used at 0.1% concentration, the Nusselt number and heat transfer coefficient increased by about 17% and 37%, respectively, at 0.192 m/sec.

Rajput et al. [12] conducted a study to compare between the shell, tube and twin tube heat exchangers in the heat transfer efficiency using nanomaterials at a concentration of 0.1% to 0.3% of carbon nanotubes (CNT). The results showed that in the case of the shell and tube heat exchanger the heat transfer efficiency is about 24% higher than the double-tube exchanger and it showed that the number of Nusselt is 95% for the shell-and-tube exchanger, while it is 78% in the case of the double-tube.

Hussein et al.[13] they studied three dissimilar kind of nanoparticles (Al_2O_3, TiO_2, SiO_2) that has been dissolved in water. They measured the thermal property of nanofluids using practical methods. It was Noticed through the results that nanoparticle concentrations were augmented through about 20% in comparison to purified water that lead to increase thermal conductivity and viscosity.

Minsta et al. [14] experimented with two separate sizes of Al_2O_3 nanoparticles, 36 and 47 nm. According to the results obtained the thermal conductivity for nanofluids with smaller nanoparticles was increased more than nanofluids with larger nanoparticles.

Akhgar et al.[15] the researcher conducted a test to measure the thermal conductivity of the of MWCNT - TiO_2/Ethylene Glycol nanofluids, it was also observed that growing the concentrations of nanofluids leads to raise the hybrid nanofluids thermal conductivity. The concentrations considered in this study was 0.05 to 1%, and it was discovered that at a volumetric concentration of 1% the highest improvement in thermal conductivity reached to 40.1%.

2. Experimental

2.1 Preparation of Fe_3O_4/water Nanofluids

The initial step in using nanoparticles to modify the heat transfer performance of conventional fluids is to prepare nanofluids. Nanoparticles were added to distilled water at a concentration of 0.35 % in a two-step procedure to create the nanofluid. Then, after the addition, the nanomaterial is dispersed in water using a mechanical mixer as shown in Figure (1) and after mixing for a full hour, an ultrasonic device is used for a period of 40 minutes as shown in Figure (2) in order to obtain a stable nanofluid. Advanced equipment was used to test the thermophysical characteristics of the nanofluid and nanoparticles. The needed weight of nanoparticles was estimated using the equation below based on the desired size:

$$m_p = \frac{\varphi \times \rho_p \times \left(\frac{m_f}{\rho_f}\right)}{(1-\varphi)} \tag{1}$$

Figure 1. Mechanical mixer.

Figure 2. Nanofluid tank.

Figure 3. Ultrasonic device.

2.2 Experimental Setup and Instrumentation

The test portion is a shell and tube heat exchanger that operates in the laminar zone under a counter flow situation. The system mainly contains two flow loops (nano-liquid and water flow loops). The device consists of a shell made of glass and tubes made of stainless from (Elettronica Veneta) company mod. UTCA-2/EV, a boiler for heating water (200L), a nanofluid tank (27L), two pumps to provide the required flow rates with a capacity of (0.37, 0.55) kw, 2 thermocouples, 2 flowmeters, 2transmitters, signal transducer, control unit. As for the test section, it is a shell and tube heat exchanger with a length of 981 mm, where the nanofluid passes through 5 tubes with an outer diameter of 10 mm Its thickness is 2 mm and its length are 900 mm as shown in figure (3). The water passes inside the shell with an inner diameter of 50mm. Heat exchanger and pipelines are thermally insulated to reduce heat loss to surroundings. The flow rates are controlled by two valves one on the cold side flow loop and the other on the hot side. Four thermocouples (type K) were inserted for the shell and tube side heat exchanger. Thermocouples 1 and 2 measure the temperatures of the hot water at the entry and exit of the shell and the other thermocouples 3 and 4 measure the temperatures of the nanofluid at the entry and exit of the heat exchanger tubes.

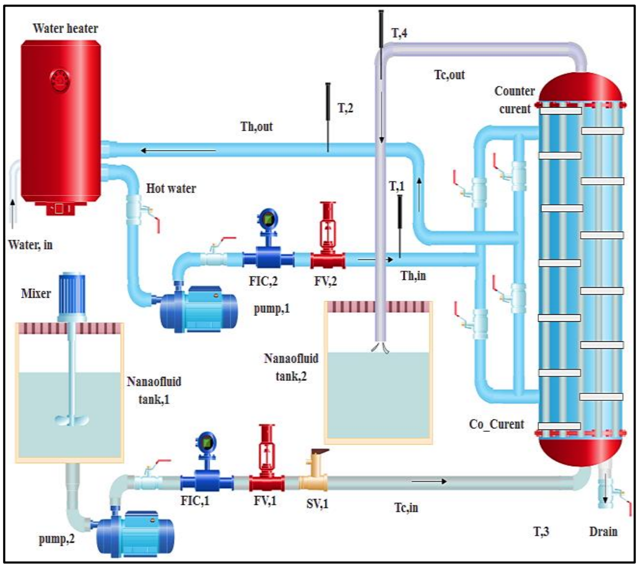

Figure 4. Experimental Schema.

Table 1. Physical properties of water, Nanoparticle and heat exchanger wall.

Material	ρ (g/Cm³)	k (W/m.K)	Cp (J/kg.K)	μ Pa.sec
Water	0.9982	0.6	4182	**0.001003**
Fe_3O_4	5.18	80.4	670	--
steel	8.05	16.27	502.4	--

2.3 Experimental calculation

The heat transfer rate of the nanofluid (cold) and the base fluid (hot) is calculated by the following equations [16]:

$$Q_c = \dot{m}c * c_{p,c}(T_{c,0} - T_{c,i}) \quad (2)$$

$$Q_h = \dot{m}_h c_{p,h}(T_{h,i} - T_{h,o}) \quad (3)$$

$$C_h = \dot{m}_h c_{ph} \quad (4)$$

$$C_c = \dot{m}_c c_{p,c} \quad (5)$$

The total heat transfer coefficient of the heat exchanger can be calculated by the following equation [16]:

$$U = \frac{Qavg}{As*F*(\Delta T)_{\text{LMTD}}} \quad (6)$$

Where As is surface area and F is correction factor and Q_{avg} is average heat transfer rate (Q_c + Q_h/2), F is the correction factor, ΔT_{LMTD} is the logarithmic mean temperature difference.

$$\Delta T_{\text{LMTD}} = \frac{\Delta T_2 - \Delta T_1}{\ln(\Delta T_2/\Delta T_1)} \quad (7)$$

$$As = \pi * L * do * N_t \quad (8)$$

$$\Delta T_1 = T_{h,i} - T_{c,o};\ \ \Delta T_2 = T_{h,o} - T_{c,i} \quad (9)$$

$$F = \frac{\sqrt{R^2+1}\ln\frac{(1-P)}{(1-PR)}}{(R-1)\ln\left[\frac{2-P\left(R+1-\sqrt{R^2+1}\right)}{2-P\left(R+1+\sqrt{R^2+1}\right)}\right]} \quad (10)$$

$T_{h,i}$, $T_{h,o}$, $T_{c,i}$, $T_{c,o}$ It represents the entry and exit temperature of the hot fluid and the entry and exit temperature of the cold fluid, respectively, for counter flow.

The Reynolds Number for cold fluid and hot fluid can be calculated from the following equations [17].

$$Re_c = \frac{\rho_c * u_c * \text{d}}{\mu_c} \quad (11)$$

$$Re_{,h} = \frac{\rho_{,h} * u_{,h} * d}{\mu_{,h}} \quad (12)$$

The Nusselt number and coefficient of thermal convection of the base fluid and nanofluid can be determined using the formulas below .[18]

$$Nu = \frac{hD}{k} \quad (13)$$

$$h = \frac{Q}{\text{A}(T_w - T_{,f})} \quad (14)$$

$$\text{where } \text{T}_\text{f} = \frac{T_{\text{in}} + \text{Tout}}{2} \quad (15)$$

Q is the heat transfer rate, A is the heat transfer area, T_f is the flim temperature.

According to the nanofluid and the base fluid used, the percentages of the nanofluid performance evaluation coefficient (PEC) are calculated from the equation below for laminar flow [19].

$$PEC = \left(\frac{Nu_{nf}}{Nu_f}\right) / \left(\frac{f_{nf}}{f_f}\right)^{\frac{1}{3}} \quad (16)$$

the effectiveness of the heat exchanger can be calculated from the below equation.

$$\boldsymbol{\varepsilon} = \frac{Q_{\text{actual}}}{Q_{\text{max}}} = \frac{Cc\ \Delta T_c}{Cmin\ (\Delta T)_{\text{max}}} \quad (17)$$

The friction factor is determined by using the blow equation.

$$f = \frac{64}{\text{Re}} \quad (18)$$

3. Results and discussion

3.1 Rate of heat transfer:

Figure (5) shows the variation in the heat transfer rate with respect to different parts of the volumetric concentrations of the nanofluid with different Reynolds number for the tube side (200, 600, 1000, 1400) and the Reynolds number for the shell side was fixed to (1000) as shown in Figure that the heat exchanged between the two fluids increases with the increase in the concentration of nanoparticles in the water, as well as with the increase in the volumetric flow rate. The reason for this increase is attributed to the thermophysical properties of the nanofluid, which are higher compared to the distilled water, as well as the increase in the surface area of heat exchange. The maximum heat transfer rates were obtained when using volumetric concentrations (0.2%, 0.35%), which are 15%, 25%, respectively. The results showed a good agreement with the researcher Ahmed. K [20].

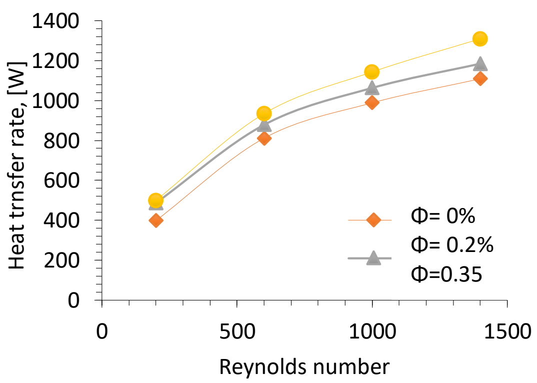

Figure 5. Heat transfer rate for different Reynolds number.

3.2 Total heat transfer coefficient

Figure (6) shows the variation in the total heat transfer coefficient of different Reynolds number for the side of the tube at the volume ratios of the nanofluid (Fe3O4/water (0.2%, 0.35%). The total heat transfer coefficient was examined for different experiments in the case of countercurrent flow In a vertical shell-and-tube heat exchanger, it can be seen from the figure that the total heat transfer coefficient increases with the increase in the Reynolds number and the concentration of nanoparticles in the base fluid. The reason for this is due to the enhanced thermophysical properties such as thermal conductivity, where the maximum improvement in the total heat transfer coefficient is reached. For the nanofluid at (0.2%, 0.35%) about 34%, 61%, respectively, this was in agreement with the researcher Ahmed. K [20] and Barzegarian [19].

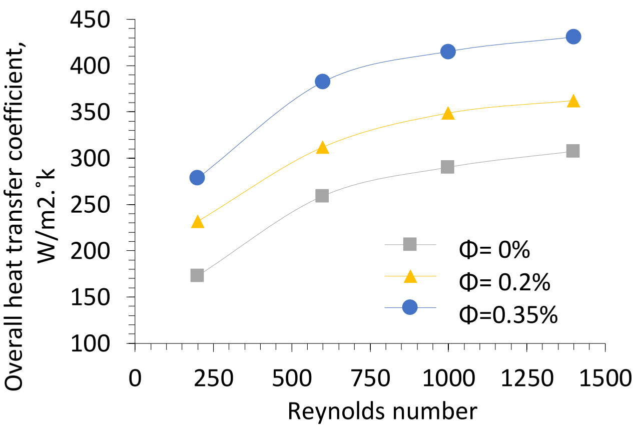

Figure 6. Total heat transfer coefficient at various Reynolds Number.

3.3 Friction factor

Figure (7) shows the variation in the coefficient of friction with different Reynolds number and at the volume ratios (0.2%, 0.35%) for the nanofluid. As shown in the figure, the friction coefficient decreases with the increase in the Reynolds number, while it increases with the increase in the concentration of nanoparticles in the base fluid, and this is consistent with most of what the researchers have found. This decrease in the friction coefficient is attributed to the increase in the density and viscosity of the nanofluid when adding particles, the nanoparticles were transferred to the main fluid (distilled water), where the increase in the friction coefficient at the volumetric ratios was 0.2%, 0.35%, 25% and 47%, respectively. What was concluded from the previous results is consistent with what the researchers concluded Barzegarian [19] , Hussein [21].

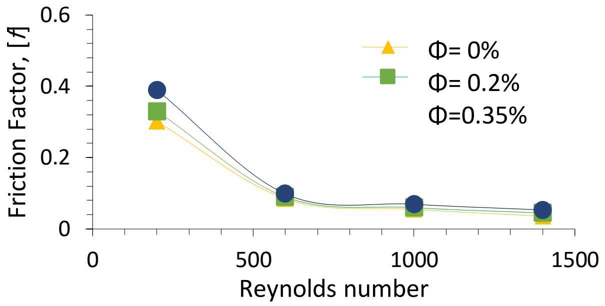

Figure 7. Friction factor for different Reynolds number.

3.4 Effectiveness of heat exchanger

Figure (8) shows the variation in the efficiency of the heat exchanger with Reynolds number (200, 600, 1000, 1400) for the tube side and (1000) for the shell side with volume ratios (0.2%, 0.35) for the nanofluid (Fe3O4/water). We note from the figure that the efficiency decreases with the increase of the Reynolds number and the reason for this is due to the increase in the flow velocity to the side of the tube and then reducing the residence time that takes a certain amount of fluid inside the heat exchanger and thus reducing the temperature change of both fluids. We also notice from the figure that a reverse increase occurs when using (Re = 1400) for the side of the pipe and the reason for this is that the side of the crust remains at (Re = 1000), and thus the flow rate of the side of the pipe is higher than it is in the crust, as well as a change in the value of the heat capacity (Heat capacity). The increase in efficiency with increasing concentration of nanoparticles is due to an increase in the thermal conductivity of the nanofluids. Where the results were consistent in terms of the behavior of the change in the efficiency of the heat exchanger with the researcher Ahmed. K [20].

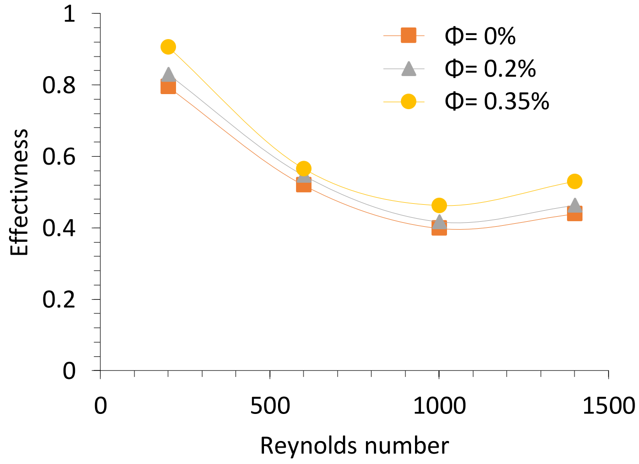

Figure 8. Variation in heat exchanger effectiveness with different Reynolds number.

3.5 Nusselt Number

Figure (9) shows the relationship between Nusselt number with different Reynolds number (200, 600, 1000, 1400) for the side of the tube and with different volume ratios of nanofluid (Fe_3O_4/water (0.2%, 0.35%). Based on the obtained results we note that The Nusselt number of the nanofluid was increased compared to the distilled water with the increase of the Reynolds number. It was also observed that there was an increase in the Nusselt number with the increase in the concentration of nanoparticles, so the maximum increase in the Nusselt number of the nanofluid was obtained at 0.2% and 0.35% by about 10%, 19 % respectively. This change in behavior is attributed to an increase in the thermal conductivity of the base fluid through the addition of nanoparticles, as well as a reduction in the thickness of the boundary layer and the random and irregular movement of the fluid. The results were consistent with what the researchers concluded Ramirez-Tijerina et al [22] , Hazbehian [23].

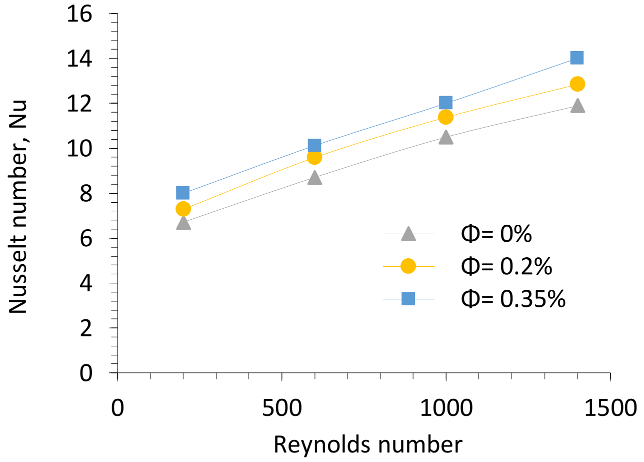

Figure 9. Relation between Nusselt Number and Reynolds number.

3.6 Performance evaluation coefficient of nanofluid

Figure (10) shows the performance coefficient of the nanofluid for different Reynolds number, and according to the results obtained, we note that the coefficient of thermal performance is always greater than one. It is clear that nanofluids perform better than water by greatly improving heat transfer performance although higher viscosity increases pressure drop. Therefore, we note that the performance coefficient increases with the increase of the nanofluid concentration and flow rate. This increase may be due to an increase in the flow rate, which leads to severe turbulence and therefore more particle collisions, leading to an increase in heat transfer. It can be inferred from this result that the largest concentrations of nanoparticles are in the base fluid. The use of Fe_3O_4/water in concentrations of 0.2% and 0.35% is critical as the enhancement of heat transfer increases with higher concentration of nanofluids as shown in the figure. According to researcher Darzi [24], as the nanoparticle concentration increases and the Reynolds number increases, the overall thermal efficiency increases. And that the results of the current study took the same behavior in increasing the improvement factor of the researcher Hazbehian [23].

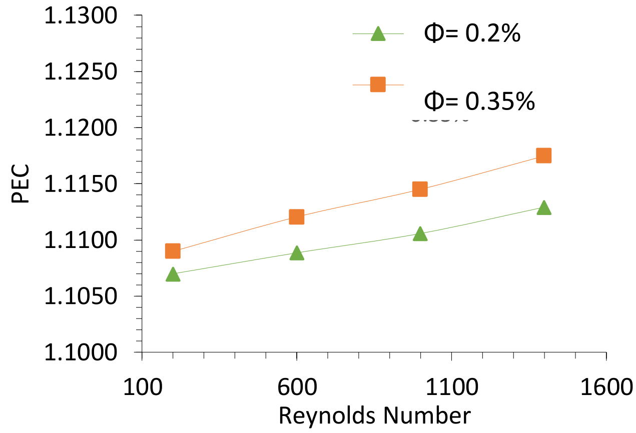

Figure 10. Performance factor of the nanofluid at different Reynolds number.

4. Conclusion

Before evaluating the heat transfer properties of different volume concentrations of Fe_3O_4/water, the experimental system was tested using purified water to ensure measurement accuracy. The temperatures of the hot water inlet and exit, as well as the nanofluids inlet and outlet, and the varied concentrations of nanofluids at different mass flow rates, have all been measured using the experimental setup. The tests were carried out on heat transfer, friction coefficient, Nusselt number, efficiency and performance evaluation coefficient of nanofluid in the shell and tube heat exchanger using nanofluid (Fe_3O_4/water). Particles of (Fe_3O_4) were taken as base metal and water as base fluid with particle concentrations (0.2%, 0.35%). The most important conclusions can be summarized as follows:

1-Increasing the dispersion of nanoparticles in distilled water increases the thermal conductivity and viscosity of the nanofluid.

2- The addition of nanoparticles increases the heat transfer area of the fluid and increases heat transfer by convective forced convection of the nanofluid. The reason for this is that the nanoparticles are located near the surface of the inner wall of the heat exchanger and thus rapid heat exchange occurs.

3- The Nusselt number was increased by increasing the Reynolds number due to the high velocity of the nanofluids and the increase in the Brownian motion of the nanoparticles. The Nusselt number of (Fe_3O_4) particles was increased with concentrations of (0.2%, 0.35%, (10, 19%), respectively.

4- The coefficient of friction increases with the increase in the particle concentration due to the increase in the viscosity of the nanofluid. While the coefficient of friction decreases as the Reynolds number increases, the coefficient of friction for the nanofluid was obtained at (0.2%, 0.35%) by (25%, 47%), respectively.

5- The convective heat transfer increases with the addition of nanoparticles to the base fluid, because the thermal conductivity of nanoparticles is more than that of the base fluid, so it creates a thermal bridge between nanoparticles and fluid. Thus, more heat transfer occurs for the nanofluid, where the convective heat transfer coefficient was obtained at (0.2%, 0.35%) (14%, 22%), respectively.

6- the addition of nanoparticle upsurge the total heat transfer coefficient and it was obtained at (0.2%, 0.35%) are 34% and 61%, respectively.

7- The results showed that the effectiveness of the heat exchanger decreases with the increase in the Reynolds number and that the reason for this is the increase in the flow velocity and the short stay of the fluid inside the heat exchanger. While the effectiveness increases with increasing concentration of nanoparticles.

Acknowledgments

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Nomenclature

Nu	Nusselt number
Cp	Specific heat, J/kg.K
K	Thermal conductivity, W/m.K
h	Convective heat transfer coefficient, W/m^2. K
Q	Rate of heat transfer, W
T	Temperature, K
D	Diameter, m
L	Length, m
A	Area of heat transfer, m^2
U	Overall heat transfer coefficient, W/m^2.K
PEC	Performance evaluation coefficient
T_f	fluid temperature, K
Re	Reynold number
Pr	Prandtl number
T_{in}	Inlet temperature, K
T_{out}	outlet temperature, K
D_h	Hydraulic diameter, m
$m^{\cdot}$	mass flowrate, kg/sec
V	Velocity, m/sec
ρ	Density, kg/m^3
T_w	Wall temperature, K
F	correction factor
f	friction factor
C_c	heat capacity of cold fluid
C_h	heat capacity of hot fluid
min	minimum
max	maximum

Uncertainty analysis

The data is analyzed by calculating the error of measurements of devices such as density meter, viscosity meter, flow rate meter, temperature scale. All measurement errors are summarized in Table 2.

Table 2. Uncertainty analysis

No.	Dimensionless	Uncertainty
1-	ρ (Kg/m^3)	± 0.05
2-	µ (Pa.sec)	± 0.00025
3-	$V^{\cdot}$ (m^3/sec)	± 0.001
4-	T (C^0)	± 0.49

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