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# Improving Thermal Performance of Heat Exchangers Using Compatible Nanoparticles Fluids

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ABSTRACT

In the present work, the possibility of improvement of heat efficiency of double-tube counter-flow heat exchanger has been investigated experimentally. By using a sub-scale model of a shell - tube heat exchanger with two types of Nano-fluids; single Nano-fluids, hybrid Nano fluids [α-$Al_2O_3$ (20nm)/water Nano fluid, CuO (50nm)/water Nano fluid, and α-$Al_2O_3$-CuO/water hybrid Nano fluid and a mixing ratio (50:50)], as cooling fluids at two volumetric concentrations (0.1% and 0.5 %) for each working fluid. The Nano fluids and water flow inside the cold internal cycle with constant inlet temperature (29℃), flow rates (100, 150, 200, 250) l/h and transitional and turbulent flow conditions within a range Re (3207 to 8070), Hot water flows into the hot external cycle with an inlet temperature that constant (70℃) and at a steady volumetric flow rate (150 l/h) and within the range Re (2941 to 3094). The experimental results showed that the maximum enhancement in the heat transfer coefficient and thermal conductivity at $Al_2O_3$-CuO/water hybrid Nano fluid and concentration Ø=0.5% (1.1766 and 0.6391), respectively. And the maximum percent enhancement in heat transfer rate is (72.87%) at $Al_2O_3$-CuO/water hybrid Nano fluid and concentration (Ø=0.5%). The results obtained in this work indicated that the good effects of employing a hybrid Nano fluid were superior to using a single-type Nano fluid. It also showed that the rate of heat transfer increases with the increase in the concentration of nanoparticles. In the same context, the effect of the type of nanoparticles on the rate of heat transfer was observed it had a higher heat transfer rate α-$Al_2O_3$ (20nm)/water Nano fluid than a heat transfer rate CuO (50nm)/water Nano fluid. The highest effectiveness of the heat exchanger is (0.29188) when using $Al_2O_3$-CuO/water hybrid Nano fluid at (Ø=0.5%). The highest pressure drop in the inner tube is (ΔP=285.299 Pa) at CuO/water Nano fluid (Ø=0.5%) at a flow rate (250 l/h) and Re ($8\times10^3$).

KEYWORDS

Double tube heat exchanger, Heat transfer rate, Petroleum Refinery, Hybrid Nano fluids, Heat transfer coefficient.

## INTRODUCTION

Energy and material costs have grown in recent years, resulting in greater efforts to develop more efficient heat exchange equipment. For example, heat exchanger design requires a precise study of heat transfer rate and pressure drop. Heating and cooling systems must be compact and efficient to accomplish high heat transfer rates with minimum pumping power [1]. Heat transfer efficiency is a major consideration in energy conversion systems. which is usually achieved by utilizing heat exchangers [2,3]. In addition, instead of conventional heat transfer working fluids, using Nano fluids is more effective way to increase the thermal performance of heat exchangers.

Nano fluids is a new class of fluids with their amelioration properties over conventional fluids. Nano fluids suspensions containing condensed nanomaterials may be classified as Nano colloidal suspensions. Nano fluid is the term coined to characterize this new class of heat transfer fluids, based on nanotechnology that has thermal characteristics superior to those of host fluids or traditional suspension fluids [4]. Both the Nano fluid characteristics and the geometric parameters of heat exchanger utilized determine the efficiency of using Nano fluids in heat exchangers, It's important to note that Nano fluids thermal behavior depends on a variety of factors, including nanoparticle size and shape as well as the nanoparticle type, nanoparticle concentration, surfactant kind, and base fluid characteristics [5-7].

In other hand, improvement it is possible to improve the thermal efficiency of Nano fluids by dispersing two or more various nanoparticles or nanocomposites in the base working fluids, and the product is known as hybrid Nano fluids [8,9]. The hybrid Nano fluids exhibit high thermal conductivity compared to the single Nano fluids because of the synergistic effect [10]. Some studies have shown that hybrid Nano fluids have a superior thermal behavior to single Nano fluids [11,12]. Many studies performed an investigation to determine the thermal behavior of single and hybrid Nano fluids, and we will focus on this research when using Nano fluids in the heat exchanger.

[13] studied experimentally the effect of adding $\gamma$-$Al_2O_3$(10nm) nanoparticles were suspended in de-ionized water with volume concentrations of (0.25%, 0.5%, 0.75%, and 1%) and flowed at volume flow rates (150, 200, 250, and 300) L/h in the turbulent flow area inside a concentric counter flow heat exchanger to calculate the improvement of convective heat transfer The experimental results showed that the maximum enhancement obtained was at the particles volume fraction of 1% and the Reynolds number of 6026, the enhancement was 20% and 22.8% in the Nusselt number and the heat transfer coefficient, respectively.

[14] studied experimentally the effect of adding CuO/water Nano fluid on the performance of the shell and tube heat exchanger, the particle size of nanoparticles (30-50 nm), and volume concentrations (0.1%, 0.25%, 0.5%, 0.75%). The results showed the heat transfer coefficient of the Nano fluid is upmost than that of water by about 18.49%. (Aghayari et al., 2014) experimentally studied the effect of temperature and concentration of nanoparticles $Al_2O_3$ (20 nm) nanoparticles and a volume fraction within the range (0,001-0.002) on the heat transfer variation also the total coefficient of heat transfer in a double-tube heat exchanger under turbulent flow conditions. The experimental outcomes showed a significant increase in the mean heat transfer and the overall heat transfer coefficient by (8% to 10%). Accordingly, an increase in the overall heat transfer coefficient was observed with an increase in the processing temperature and/or particle concentration.

[15] the effect of adding $Al_2O_3$ and $TiO_2$ nanoparticles with particle sizes (28 nm, 25-45 nm), respectively, to deionized water as a base fluid on the heat transfer performance and flow characteristic of the double-tube heat exchanger under flow conditions was investigated experimentally. Horizontal counter turbulence. (Nano fluids) flows at various flow rates (2.5, 3, 3.5, 4, and 4.5) L/min with volumetric concentrations of Nano fluids (0.1, 0.2, and 0.3%) and a constant inlet temperature (30°C). The results demonstrated that by increasing the concentration of the nanoparticle size and also by increasing the flow rates of Nano fluids, the rates of heat transfer, heat transfer coefficient, overall heat transfer coefficient, and Nusselt number increased, and these properties strongly depend on the type of nanoparticles. Through the results, it was observed that $Al_2O_3$/water Nano fluid has better heat transfer coefficients, total heat transfer coefficient, and Nusselt number than those of $TiO_2$/water Nano fluid and pure water.

[16] the effect of using $Al_2O_3$–$SiO_2$/deionized water hybrid Nano fluid with different particle ratios on the effectiveness of parallel and opposite flow heat exchangers has been studied experimentally. To prepare the hybrid Nano fluids, $Al_2O_3$–$SiO_2$ nanoparticles were dispersed in water with concentrations of (0.5, 1, and 1.5% weight), and a surfactant was added to the Nano fluid to prevent sedimentation and to obtain better stability of the hybrid Nano fluids. The utmost improvement of the overall heat transfer coefficient was 25%, 60%, and 67% when using $Al_2O_3$–$SiO_2$/deionized water hybrid Nano fluid with 0.5%, 1%, and 1.5% of nanoparticles ratio, respectively. The largest increase in overall heat transfer coefficient for parallel flow tube-type heat exchanger and counter flow tube-type heat exchanger was recorded, respectively, at 67% and 20%. The 1.5% concentration of nanoparticles and it was shown the highest thermal performance compared to the other concentrations.

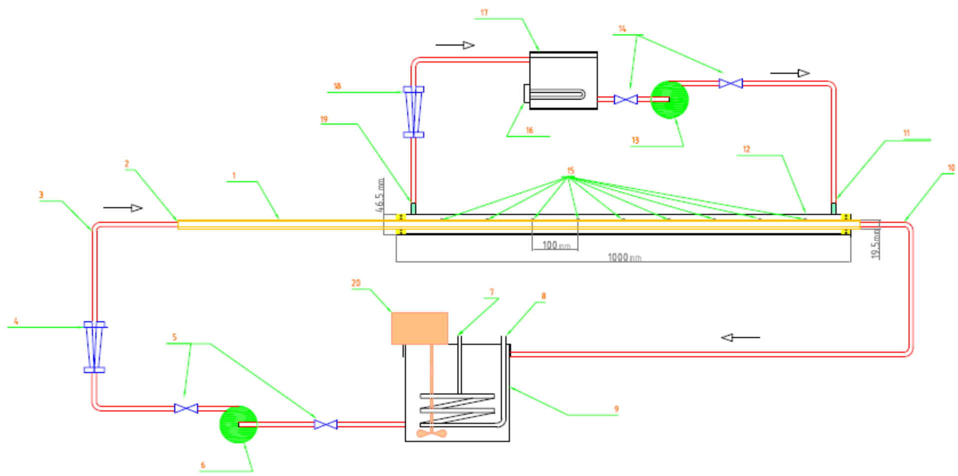
[17] An experimental and numerical investigation was conducted to study the effect of using a CuO-$Al_2O_3$/water hybrid Nano fluid in a U-type tubular heat exchanger. Hybrid Nano fluids were prepared at two concentrations (0.5% and 1%) as well as in comparison to CuO/water Nano fluids at similar concentrations in addition to water. The numerical results demonstrated that the heat exchanger's heat transfer rate can increase when adding hybrid Nano fluids and fins. The experimental results indicated that there is significant improvement in the thermal efficiency of the U-type tubular heat exchanger was when the CuO-$Al_2O_3$/water hybrid Nano fluid was added, and the total heat transfer coefficient was maximum when utilizing the CuO-$Al_2O_3$/water hybrid Nano fluid with concentrations (0.005 and 0.01) was (0.095 and 0.12), respectively. The study's outcomes also revealed that utilizing a hybrid Nano fluid was superior to using a single Nano fluid. The obtained results showed a successful use of CuO-$Al_2O_3$/water hybrid Nano fluids in the heat exchanger. The present work included experimental study

of the impact of using $Al_2O_3$-CuO/Water Nano fluid, $Al_2O_3$/Water Nano fluid, CuO/Water Nano fluid, water on heat transfer enhancement and flow through a double-tube heat exchanger counter flow.

## MATERIALS AND METHODS

The Experimental Test Rig: In figures (4-1a), (4-1b), and plate (4-1) the schematic diagram and plate of the experimental rig, the rig is consisted of the following main parts and measuring devices:

- Test section (double tube heat exchanger).
- The hot water outer cycle is composed of a heater, flow meter, pump, piping system, pump control valves, and hot water tank.
- The cold fluid inner cycle is composed of a cold fluid tank it contains (a mixer and a coil), control valves, flow meter, piping system, and pump.
- Thirteen thermocouples (K-type).
- Temperature recorder.
- Digital temperature controller thermostat.



| Cold water loop | |
|---|---|
| 1 | Brass pipe |
| 2 | Inlet thermocouple type K |
| 3 | Inlet cold water pipe |
| 4 | Cold loop flow meter |
| 5 | Valve |
| 6 | Water pump |
| 7 | Outlet cooling water |
| 8 | Inlet cooling water |
| 9 | Cold water tank (nano fluid tank) |
| 10 | Outlet thermocouple type K |

| Hot water loop | |
|---|---|
| 11 | Inlet thermocouple type K |
| 12 | Outer plastic pipe |
| 13 | Hot loop water pump |
| 14 | valve |
| 15 | Thermocouple type K |
| 16 | heater |
| 17 | Hot water tank |
| 18 | hot loop flow meter |
| 19 | Outlet thermocouple type K |
| 20 | Mixer |

**Figure 1.** The Schematic Diagram of The Experimental Rig.

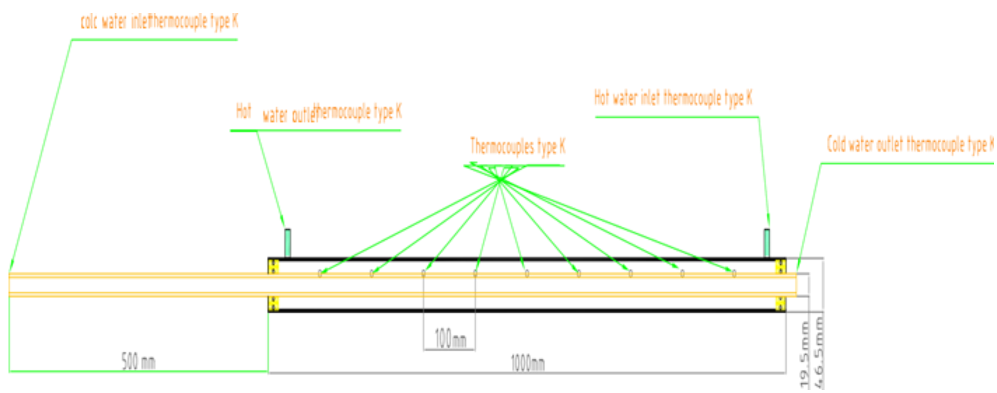



**Figure 2.** The Schematic Diagram of The Test Section.

**Figure 3.** Photo of The Experimental Rig.

The test section used in the present experimental work involves an Iraqi Midland Refineries Company shell-and-tube heat exchanger sub-scale concentric double-tube heat exchanger was designed and built to emulate the working conditions of the actual shell and tube heat exchanger. Where the brass alloy (B-111) substrate which is a square plate with dimensions (1.5 X 1.5) mm and thickness (2.5mm) was obtained after cutting the brass tube for the heat exchanger from the Iraqi Midland Refineries Company. a brass (B-111) metal tube the inner tube of heat exchanger (inner diameter: 14.5mm, outer diameter: 19.5mm, length of inner tube: 1.5m was (1m) inside the heat exchanger and (0.5m) Well-insulated inlet length outside heat exchanger to get a fully developed flow inside the heat exchanger, and thickness: 2.5mm). And the outer tube is a plastic tube with a well-insulated outer surface used as an outer tube for the heat exchanger (inner diameter: 40.5mm, outer diameter: 46.5mm, thickness: 3mm, and length: 1mm). Both ends of the tube have an inlet and outlet of hot water perpendicular to the tube. Both ends of the tube and the inner tube were sealed using an O-ring water-tight seal with a Teflon flange. The inlet of a tube is connected to the control valve and the outlet is connected to the flow meter. Water, single and hybrid Nano fluids were selected as inner fluid and cold fluid for the heat exchanger, with a constant inlet temperature (29°C). The volumetric flow rate of the interior flow (100, 150, 200, 250) l/h, and Re (3207 to 8070). While, water is selected as outer fluid and hot fluid for heat exchanger, the heater tank heats the water to the necessary input temperature., The temperature of 70°C was chosen as the inlet temperature, which is within the domain of temperatures of the water supplied- to the heat exchanger in the Petroleum Refinery, which was selected out to be a case study for this investigation. With the constant volumetric flow rate at (150 l/h), Reynold's number rang (2941 to 3094).

**Table 1.** The characteristic of the used devices in the test rig.

| Devices | Characteristic |
|---|---|
| Cold fluid tank | Dimensions (diameter16mm, height 17mm) |
| Electric mixer | 1500 rpm |
| Cold fluid pump | (120W, 220V) |
| External pump | (90W, 220W, 50Hz) |
| Hot water tank | Dimensions (24mm length, 10mm width, 16mm height) |
| Electric water heater | 2300W |
| Electric thermostat | 220V |
| Hot water pump | (90W,220V,50Hz,12l/min) |
| Thermocouple | K-type |
| Temperature recorder | 12 channels BTM-4208SD |
| Flowmeters | Two flowmeters |
| Drill machine | (350W, 220-240V, 50/60Hz, 0-3800 min$^{-1}$) |
| Electronic compact scale | SF-400C |

Preparation Procedure for the Nano fluid

In the experiments, two different types of Nano fluids were employed. The first one is α-Aluminum Oxide ($Al_2O_3$/water Nano fluid) and another one is Copper Oxide (CuO/water Nano fluid), in addition to using the ($Al_2O_3$-CuO/water hybrid Nano fluid).

**Table 2.** Thermophysical Properties of ($Al_2O_3$ Nanoparticles and CuO Nanoparticles).

| **Properties** | **$Al_2O_3$** | **CuO** |
|---|---|---|
| Purity % | 99.5 | 99.5 |
| Average particle size (nm) | 20 | 50 |
| Density ρ (kg/$m^3$) | 3970 | 6500 |
| Thermal conductivity K (W/m.K) | 40 | 20 |
| Specific heat $c_p$ (J/kg.K) | 765 | 535.6 |
| Color | White | Black |

The quantity of nanoparticles required for a specific volume concentration is calculated using the following relationship: [18].

$$\text{Ø}\% = \frac{V_p}{V_t} = \frac{\frac{m_p}{\rho_p}}{\frac{m_p}{\rho_p}+\frac{m_w}{\rho_w}} \quad (1)$$

Where (Ø: volume concentration of Nano fluid, $V_P$: volume of nanoparticles ($m^3$), $m_p$: mass of nanoparticles (kg), $\rho_p$: density of nanoparticles (kg/$m^3$), $V_t$: total volume ($m^3$), $m_w$: mass of water (kg), $\rho_w$: density of water (kg/$m^3$)).

Single and hybrid Nano fluids were prepared using the two-step method, the first step is to obtain the nanoparticles as a dry powder and the second step is to suspend the nanoparticles in the base fluid to obtain a stable suspension.

The following steps were used to prepare the single and hybrid Nano fluid:

- Nanoparticles are mixed directly with the base fluid.
- utilizing a high mechanical shear mixing technique to avoid agglomeration of nanoparticles. For this purpose, high mechanical shear mixing was created, consisting of a rod at the end of which is an eight-blade fan and an attachment to a drilling machine, The Nano fluid was mixed using this device for 30 min.

The final step of mixing includes the close circulation of the Nano fluid inside the test device where only the pump, the bypass line, and the Nano fluid tank were used, and the tank contains a mixer that continues to mix the Nano fluid during the experiment. The circulation time is 20 min.

Experiments

The heat exchanger cold side has had water testing done on it. Then the performance tests of prepared Al2O3/water Nano fluid, Cuo/ water Nano fluid, and Al2O3-CuO/water hybrid Nano fluid (50:50) with Ø= (0.1% and 0.5%), have been performed out and comparison with water. Performance a variety of flow rates were used in the experiments (100-250 l/h) to define the effect of utilizing these single and hybrid Nano fluids as well as to demonstrate the impact of particle concentration. The hot water flow rate remained constant. (150 l/h).

THEORETICAL EQUATIONS

The heat transfer rate between hot and cold fluid must be equal in accordance with the first law of thermodynamics [18,19].

$$Q_c^{\circ} = m_c^{\circ} \times Cp_c\left(T_{o,c} - T_{i,c}\right) \quad (2)$$

$$Q_h^{\circ} = m_h^{\circ} \times Cp_h(T_{i,h} - T_{o,h}) \quad (3)$$

$$Q_h^{\circ} = Q_c^{\circ} \quad (4)$$

$A_{c.i} = \frac{\pi}{4}\, d_{in}^2$ is the cross-section area of the inner tube. (5)

$A_{c.o} = \frac{\pi}{4}\,(D_i^2 - d_o^2)$ is the cross-section area of the annulus. (6)

To calculate the experimental heat transfer coefficient and Nusselt number, The following equation was used [20-22].

$$Q^{\circ} = hA\Delta T = h\, A_s(T_s - T_b) \tag{7}$$

Where: $A_{i,s} = \pi d_i L$ is the inner surface area of the inner tube. (8)

$A_{o.s} = \pi\, d_o\, L$ is the outer surface area of the inner tube (9)

$T_b = \frac{T_{in}+T_{out}}{2} = \frac{T_{c,i}+T_{c,o}}{2}$ is bulk temperature. (10)

$T_s = \frac{T_1+T_2+T_3+T_4+T_5+T_6+T_7+T_8+T_9}{9}$ , $T_s$: tube surface temperature. (11)

From the equations below, the convective heat transfer coefficient ($h_i$) and Nusselt number (Nu) of the fluid in the inner tube can be calculated.

$$h_i = \frac{Q^{\circ}}{A_{i.s}\times(T_s - T_b)} \tag{12}$$

$$Nu = \frac{h_i\, d_i}{k} \tag{13}$$

And the properties of hot water (outer flow) can be calculated at (Tb) as follow:

$Re = \frac{\rho_w\, V_h\, D_e}{\mu_w}$ , $Pr_w = \frac{\mu_w\, Cp_w}{k_w}$ , $D_e = \frac{D_i^2 - d_o^2}{D_i}$ is the equivalent shell diameter. (14)

For hot water and fully developed turbulent flow in smooth tubes with moderate temperature differences between wall and fluid conditions. the recommended by (Gnielinski, 1976a), the Nusselt number is calculated by [20,23]:

$Nu = 0.012(Re^{0.87} - 280)Pr^n$ for turbulent flow (15)

In this equation, the properties were assessed at the temperature of common liquids, and the exponent n had the following values:

n = (0.3, 0.4 for cooling and heating respectively) of the fluid, for 1.5 < Pr < 500 and 3000< Re <$10^6$.

Both the transitional and the fully developed turbulent regimes can be used a modified equation recommended by Gnielinski, in this study has been used this equation below for transitional flow [24,25].

$Nu = \frac{(f/8)\,(Re-1000)\,Pr}{1+12.7\,(f/8)^{1/2}\,(Pr^{2/3}-1)}$ , for $0.5 \le Pr \le 2000$ and $3000 \le Re \le 5\times10^6$

$$f = (0.790 \ln Re - 1.64)^{-2} \tag{16}$$

The heat transfer rate in a heat exchanger may also be represented by the equation below:

$$Q^{\circ} = U\, A_s\, \Delta T_{lm} \tag{17}$$

To assessment the appropriate mean temperature difference between the two fluids, The following relationship was used according to the counter flow: [20].

$$\Delta T_{lm} = \frac{(T_{i.h}-T_{o.c})-(T_{o.h}-T_{i.c})}{\ln\left[\frac{(T_{i.h}-T_{o.c})}{(T_{o.h}-T_{i.c})}\right]} \tag{18}$$

The overall heat transfer coefficient of the heat exchanger that computed [20].

$$Q^{\circ} = \frac{T_A - T_B}{\frac{1}{h_i\, A_i} + \frac{\ln(r_o/r_i)}{2\pi k l} + \frac{1}{h_o\, A_o}} \tag{19}$$

$$U_i = \frac{1}{\frac{1}{h_i} + \frac{A_i\, \ln(r_o/r_i)}{2\pi k l} + \frac{A_i}{A_o}\cdot\frac{1}{h_o}} \quad , U_o = \frac{1}{\frac{A_o}{A_i}\cdot\frac{1}{h_i} + \frac{A_i\, \ln(r_o/r_i)}{2\pi k l} + \frac{1}{h_o}} \tag{20}$$

To calculate the improvement in heat transfer utilizing various working fluids and the thermal conductivity enhancement:

$$h_{enhancement} = \left[\frac{h_{nf}-h_{bf}}{h_{bf}}\right] \; , \; k_{enhancement} = \left[\frac{k_{nf}-k_{bf}}{k_{bf}}\right] \tag{21}$$

The effectiveness can be calculated from the following equation [26].

$$\text{Eff} = \frac{Q^{\circ}}{Q^{\circ}_{max}} \tag{22}$$

$$Q^{\circ} = C_h(T_{h.i} - T_{h.o}) = C_c(T_{c.o} - T_{c.i}) \tag{23}$$

$$Q^{\circ}_{max} = C_{min}(T_{h.i} - T_{c.i}) \tag{24}$$

Where: $C_{min}$ is the smaller of $C_h$ and $C_c$

Note: $C_c = \dot{m}_c Cp_c$ , $C_h = \dot{m}_h Cp_h$ (25)

The friction factor and the pressure drop are calculated from the equations below: [20]

$$f = \frac{0.184}{Re^{0.2}} \quad \text{for turbulent flow} \tag{26}$$

$$f = (0.790 \ln Re - 1.64)^{-2} \quad \text{for transitional flow} \tag{27}$$

$$\Delta P = f \, \frac{L}{D} \left[\frac{\rho\, u^2}{2}\right] \tag{28}$$

Thermophysical Properties of Nano fluid

The physical thermal properties of Nano fluid and hybrid Nano fluid were calculated based on the bulk temperature.

The equation for calculating Nano fluid density is: [27, 28].

$$\rho_{nf} = (1 - \phi)\rho_{bf} + \phi\rho_{np} \tag{29}$$

Also, the following equation may be used to calculate the specific heat of Nano fluid (Engineering, 2004).

$$C_{p,nf} = \frac{(1-\phi)\rho_{bf}C_{p.bf} + \phi\rho_p C_{np}}{\rho_{nf}} \tag{30}$$

The general Einstein's formula is used to calculate the viscosity of Nano fluids [29,30].

$$\mu_{nf} = \mu_{bf}(1 + 2.5\, \emptyset\,) \tag{31}$$

It's possible to calculate the thermal conductivity of Nano fluids ($k_{nf}$) using Maxwell's model as follows: [31,32].

$$k_{nf} = k_{bf}\left[\frac{k_{np} + 2k_{bf} - 2\phi(k_{bf} - k_{np})}{k_{np} + 2k_{bf} + \phi(k_{bf} - k_{np})}\right] \tag{32}$$

Considering Nano fluid properties, Reynolds and Prandtl's numbers are computed as follows:

$$Re_{nf} = \frac{\rho_{nf}\, u_{nf}\, D_{h.nf}}{\mu_{nf}} \;\; , \;\; Pr_{nf} = \frac{C_{p_{nf}}\, \mu_{nf}}{K_{nf}} \tag{33}$$

The effective density ($\rho_{hnf}$), heat capacity ($Cp_{hnf}$), thermal conductivity $(k_{hnf})$ and viscosity $(\mu_{hnf})$ of the hybrid nanofluid were calculated from the equations below: [33,34].

$$\emptyset = \emptyset_{np1} + \emptyset_{np2} \tag{34}$$

$$\rho_{hnf} = \emptyset_{np1}\,\rho_{np1} + \emptyset_{np2}\,\rho_{np2} + (1 - \emptyset_{np1} - \emptyset_{np2})\,\rho_{bf} \tag{35}$$

$$(Cp)_{hnf} = \frac{\emptyset_{np1}(\rho Cp)_{np1} + \emptyset_{np2}(\rho Cp)_{np2} + (1 - \emptyset_{np1} - \emptyset_{np2})(\rho Cp)_{bf}}{\rho_{hnf}} \tag{36}$$

$$\mu_{hnf} = \frac{\mu_{bf}}{(1 - \emptyset_{np1} - \emptyset_{np2})^{2.5}} \tag{37}$$

$$k_{hnf} = \frac{\frac{\emptyset_{np1}k_{np1} + \emptyset_{np2}k_{np2}}{\emptyset_{np1} + \emptyset_{np2}} + 2k_{bf} + 2(\emptyset_{np1}k_{np1} + \emptyset_{np2}k_{np2}) - 2(\emptyset_{np1} + \emptyset_{np2})k_{bf}}{\frac{\emptyset_{np1}k_{np1} + \emptyset_{np2}k_{np2}}{\emptyset_{np1} + \emptyset_{np2}} + 2k_{bf} - (\emptyset_{np1}k_{np1} + \emptyset_{np2}k_{np2}) - (\emptyset_{np1} + \emptyset_{np2})k_{bf}} \tag{38}$$

Reynolds and Prandtl's numbers are computed for hybrid Nano fluid as follows:

$$Re_{hnf} = \frac{\rho_{hnf}\, u_{hnf}\, D_{h.hnf}}{\mu_{hnf}} \;\; , \;\; Pr_{hnf} = \frac{C_{p_{hnf}}\, \mu_{hnf}}{K_{hnf}} \tag{39}$$

Error Analysis

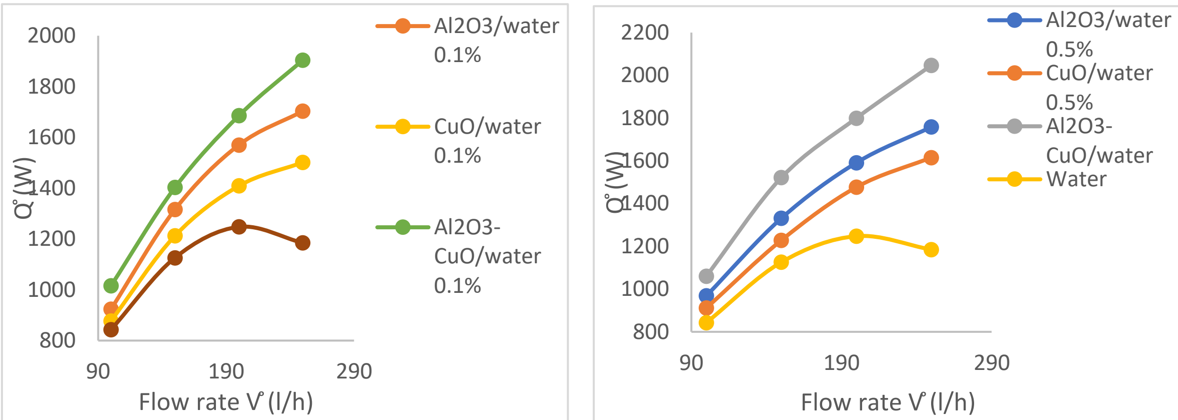
To calculate the error in the obtained results, the procedure as recommended by Kline and McClintock is used in this field [35,36].

$$S_f = \left[\sum_{i=1}^{n}\left\{\left(\frac{\partial f}{\partial x_i}\right) S_{x_i}\right\}^2\right]^{0.5} \quad (40)$$

Where: $Sx_i$ = Distinct uncertainties related to variables, $S_f$ = Total uncertainty related to function.

RESULTS AND DISCUSSIONS

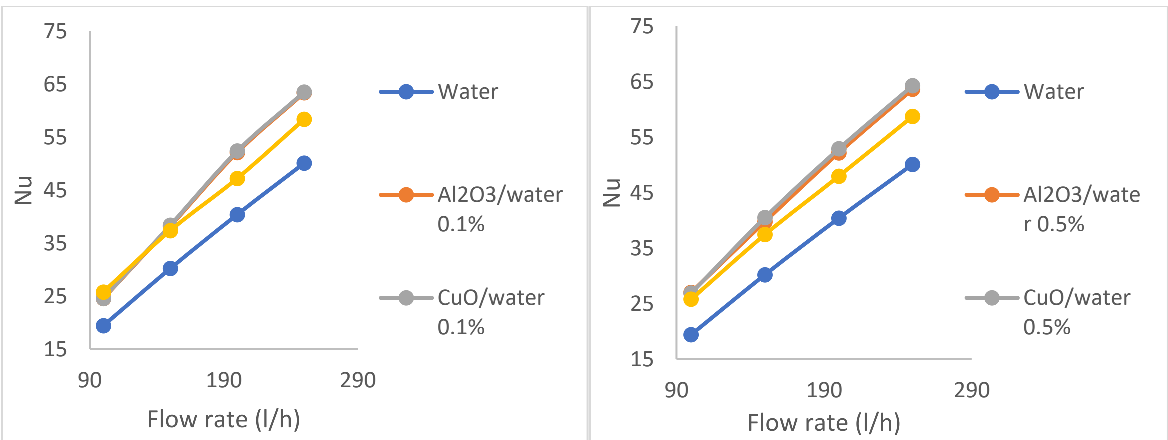
In this part, the results of experiments with single and hybrid Nano fluids with various flow rates in counter flow double-tube heat exchanger are described.




(a) (b)

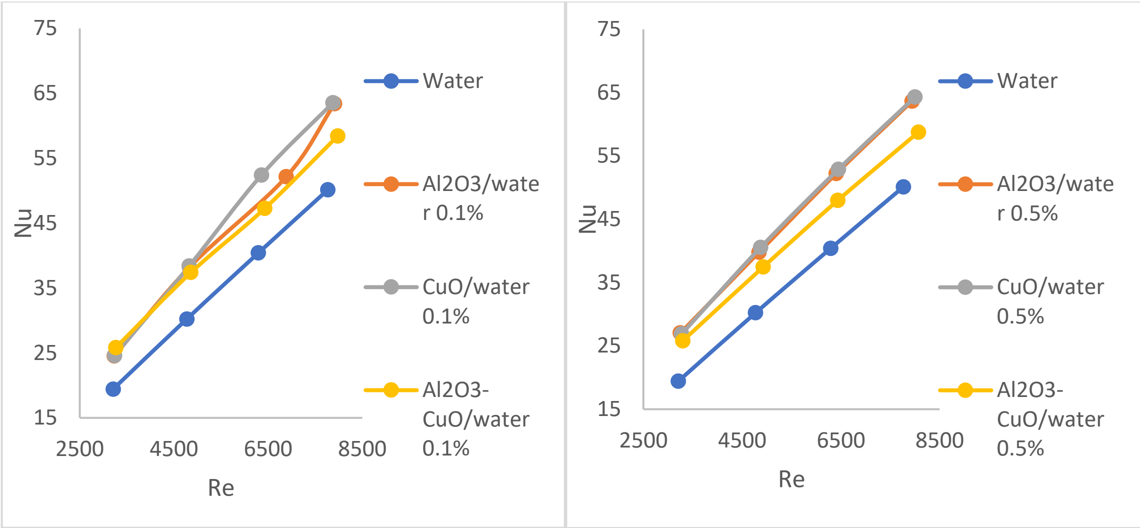
**Figure 4.** The relation between heat transfer with flow rate for (Water, CuO/water, $Al_2O_3$/water, and $Al_2O_3$-CuO/water) at Ø (0.1% and 0.5%).

Figure (4) shows the rate of heat transfer that was carried out according to the flow rate of water and Nano fluids at flow rates (100,150,200,250) l/h and in volumetric concentrations (0.1% and 0.5%). Where the comparison was made in figure (a) between the rate of heat transfer (water, $Al_2O_3$/water Nano fluid, CuO/water Nano fluid, and $Al_2O_3$-CuO/water hybrid Nano fluid) at (Ø=0.1%), and in figure (b) in the case (water, $Al_2O_3$/water Nano fluid, CuO/water Nano fluid, and $Al_2O_3$-CuO/water hybrid Nano fluid) at (Ø=0.5%). It has been observed that the heat transfer rate of single and hybrid fluids increases with increasing of the flow rate. In the case of water, the rate of heat transfer increases with the increase in the flow rate to a certain limit. The heat transfer rate begins to decrease with increasing of the volumetric flow rate, and the highest rate of heat transfer is for the hybrid Nano fluid.




(a) (b)

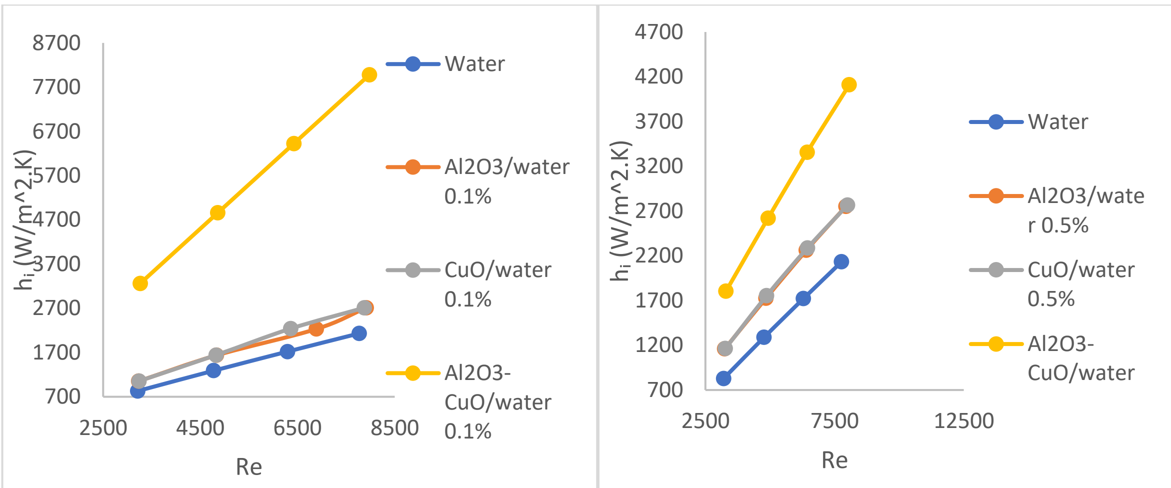
**Figure 5.** The relation between the Nusselt number with flow rate for (Water, CuO/water, $Al_2O_3$/water, and $Al_2O_3$-CuO/water) at Ø (0.1% and 0.5%).




(a) (b)

**Figure 6.** The relation between the Nusselt number with Re for (Water, CuO/water, $Al_2O_3$/water, and $Al_2O_3$-CuO/water) at Ø (0.1% and 0.5%).

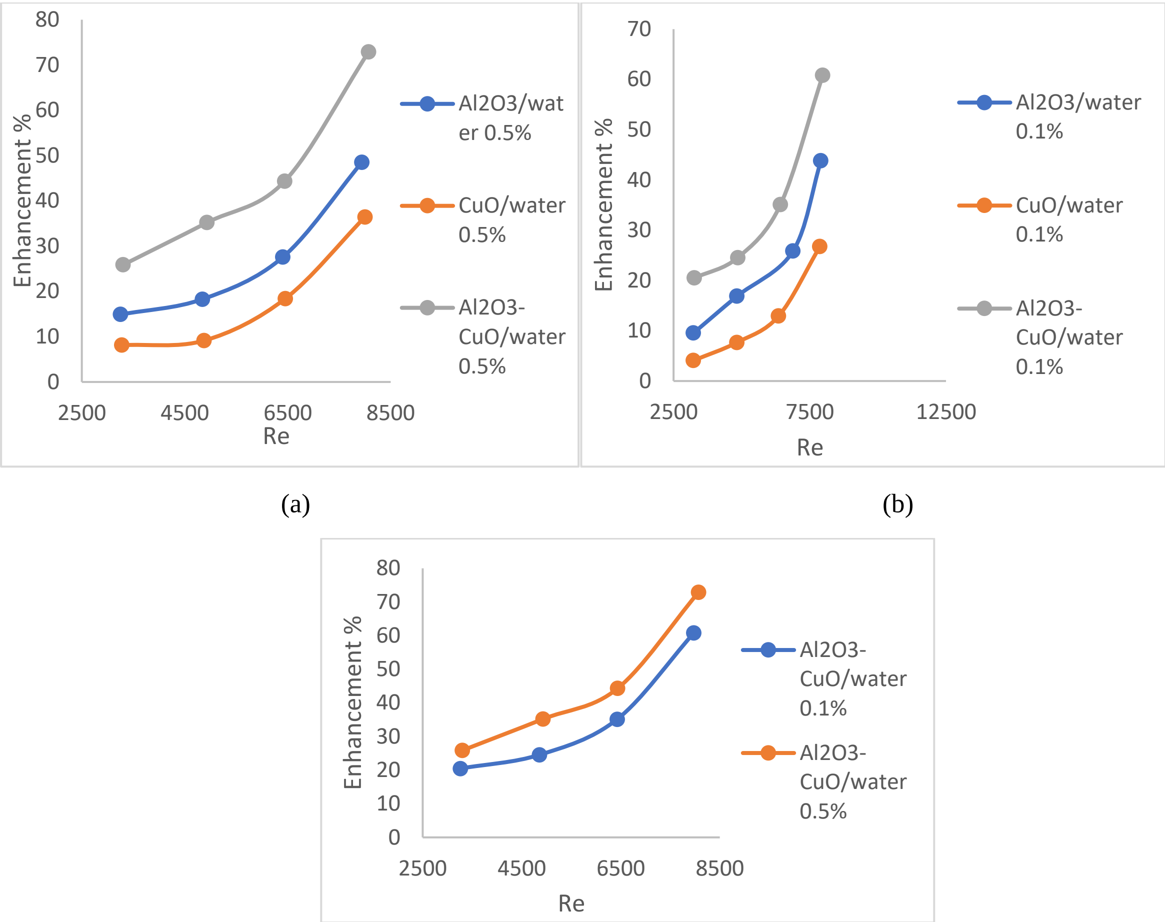
Figures (5) and (6) illustrate the relationship between Nu and the studied volumetric flow rates on the one hand, and between Nu and Re on the other hand, as in Figure (a), a comparison was made between (water, $Al_2O_3$/water Nano fluid, CuO/water Nano fluid, And $Al_2O_3$-CuO/water hybrid Nano fluid) at (Ø=0.1%). And in Figure (b) a comparison was made between (water, $Al_2O_3$/water Nano fluid, CuO/water Nano fluid, And $Al_2O_3$-CuO/water hybrid Nano fluid) at (Ø=0.5%). Experiments showed an increase in the Reynolds number and Nu and the overall heat transfer coefficient with increasing the volumetric concentration of nanoparticles.




(a) (b)

**Figure 7.** The relation between the Re with heat transfer coefficient ($h_i$) for (Water, CuO/water, $Al_2O_3$/water, and Al2$O_3$-CuO/water) at Ø (0.1% and 0.5%).

Figure (7) shows the relationship between the Reynolds number and the heat transfer coefficient. The comparison was made between (water, $Al_2O_3$/water Nano fluid, CuO/water Nano fluid, And $Al_2O_3$-CuO/water hybrid Nano fluid) at concentrations (0.1% and 0.5%). Through the comparison, it was found that the highest heat transfer coefficient at $Al_2O_3$-CuO/water hybrid Nano fluid at the two volumetric concentrations and that the heat transfer coefficient increases with an increase in Reynolds number. The results proved that the heat transfer coefficient increases with the increase in volume concentration for all cases due to the enhancement of the heat transfer process as a result of improving the thermophysical properties of the fluid.

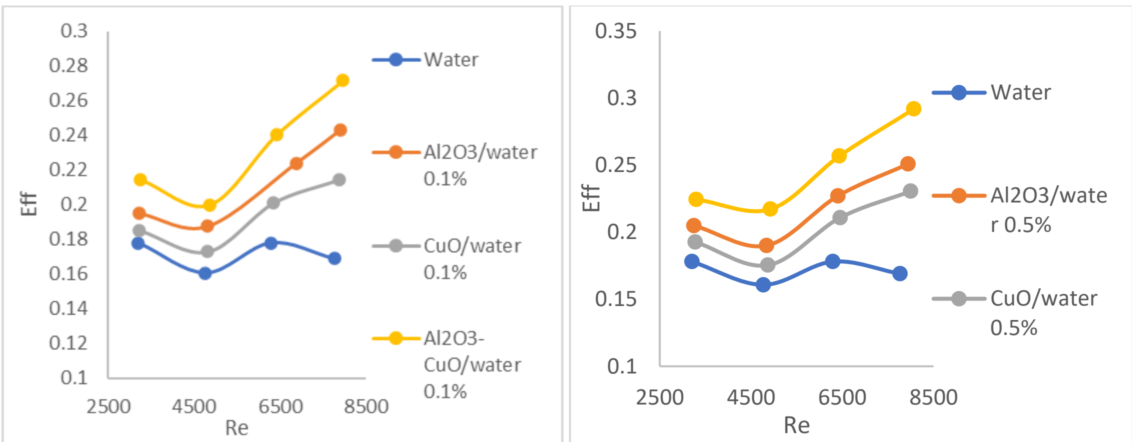



(a) (b)

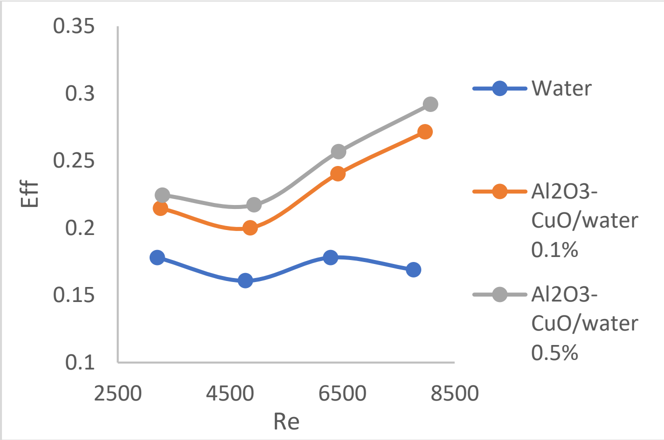
(c)

**Figure 8.** The relation between the Re with the enhancement of heat transfer rate for (Water, CuO/water, $Al_2O_3$/water, and Al2O3-CuO/water) at Ø (0.1% and 0.5%).

Figure (8) shows the relationship between the Reynolds number and the enhancement in the heat transfer rate. In Figure (a) the comparison was made between (water, $Al_2O_3$/water Nano fluid, CuO/water Nano fluid, And $Al_2O_3$-CuO/water hybrid Nano fluid) at (Ø=0.1%). As for figure (b) the comparison was made between (water, $Al_2O_3$/water Nano fluid, CuO/water Nano fluid, And $Al_2O_3$-CuO/water hybrid Nano fluid) at (Ø=0.5%). Through the comparison and results, it was confirmed that the highest enhancement in the heat transfer rate is at the hybrid Nano fluid and the highest concentration (0.5%) and that the enhancement in the heat transfer rate increases with increasing Reynolds number.




(a) (b)

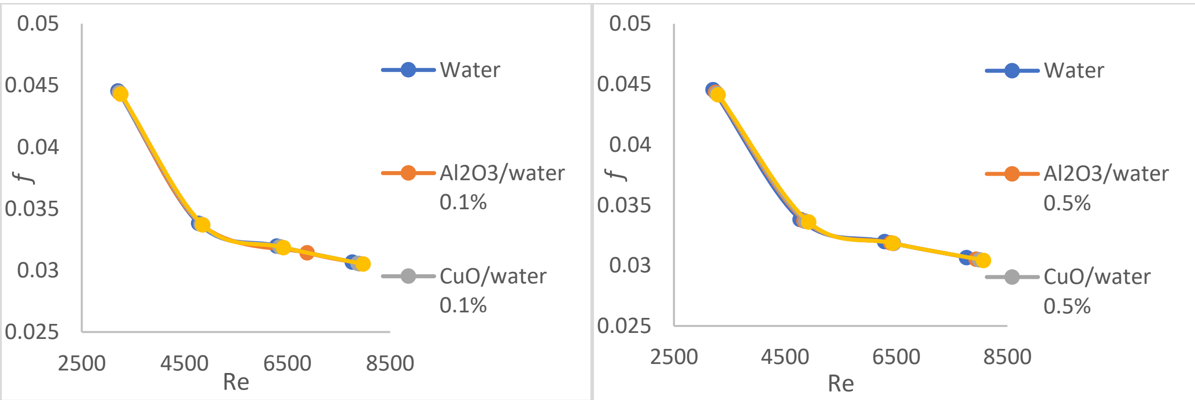



(c)

**Figure 9.** The relation between the Re with Effectiveness for (Water, CuO/water, $Al_2O_3$/water, and Al2O3-CuO/water) at Ø (0.1% and 0.5%).

Figure (9) shows the relationship between the Reynolds number and the effectiveness of the heat exchanger, where the comparison was made in figures (a) between (water, $Al_2O_3$/water Nano fluid, CuO/water Nano fluid, And $Al_2O_3$-CuO/water hybrid Nano fluid) at (Ø=0.1%), figure (b) between (water, $Al_2O_3$/water Nano fluid, CuO/water Nano fluid, And $Al_2O_3$-CuO/water hybrid Nano fluid) at (Ø=0.5%), and figure (c) represents the comparison between the state of water and $Al_2O_3$-CuO/water hybrid Nano fluid at Volumetric concentrations (0.1% and 0.5%).

The comparisons showed that the best and highest effectiveness of the heat exchanger at the hybrid Nano fluid and that the effectiveness increases with increasing Reynolds number, and when comparing the hybrid Nano fluid at the two concentrations, it was found that at the higher concentration (0.5%) the highest effectiveness of the exchanger.



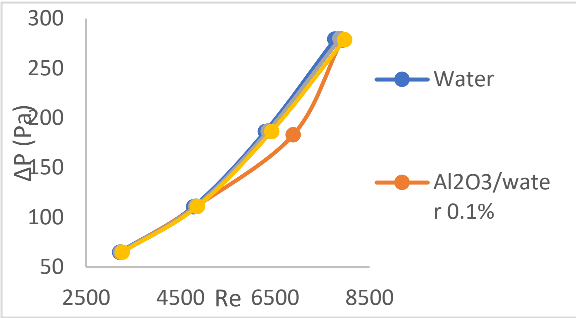

(a) (b)

**Figure 10.** The relation between the Re with Friction factor for (Water, CuO/water, $Al_2O_3$/water, and Al2O3-CuO/water) at Ø (0.1% and 0.5%).

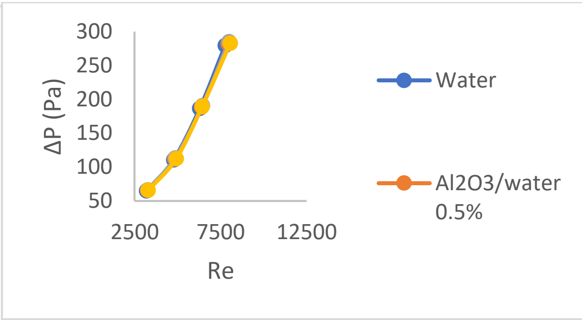
Figure (10) illustrates the relationship between the friction factor and the Reynolds number, where the comparison was made between (water, $Al_2O_3$/water Nano fluid, CuO/water Nano fluid, And $Al_2O_3$-CuO/water hybrid Nano fluid) at the two concentrations studied. From the results, it was noticed that the friction factor decreased for the range of the studied Reynolds number. Meanwhile, as the value of the volumetric concentration of nanoparticles increases, the friction factor also rises to values similar to the Reynolds number. The friction factor increases due to the large number of nanoparticles which increase the shear strength and thus increase the viscosity of the working fluid.

Figure (11) illustrates the relationship between Reynolds number and pressure drop. The comparison was made in Figure (a) between (water, $Al_2O_3$/water Nano fluid, CuO/water Nano fluid, And $Al_2O_3$-CuO/water hybrid Nano fluid) at a concentration (0.1%). As for figure (b) between (water, $Al_2O_3$/water Nano fluid, CuO/water Nano fluid, And $Al_2O_3$-CuO/water hybrid Nano fluid) at a concentration (0.5%).

It was observed that the pressure drop for all cases increased with increasing Reynolds number.




(a)




(b)

**Figure 11.** The relation between the Re with ΔP for (Water, CuO/water, $Al_2O_3$/water, and Al2O3-CuO/water) at Ø (0.1% and 0.5%).

CONCLUSIONS

In the present work, the effect of using single and hybrid Nano fluids as coolants instead of the base fluid on the thermal performance of a double-tube counter flow heat exchanger has been studied experimentally.

From the results obtained, the following main points can be deduced:

- The heat transfer rate is increased by adding nanoparticles to the base fluid, and the heat transfer rate is increased by increasing the nanoparticle concentration.
- The effect of the type of nanoparticles on the heat transfer rate, where α-$Al_2O_3$ (20nm)/water Nano fluid had a higher heat transfer rate than the heat transfer rate of CuO (50nm)/water Nano fluid.
- The results showed that the utilizing of hybrid Nano fluid $Al_2O_3$-CuO/water hybrid Nano fluid significantly improved the thermal performance. And the highest improvement in the heat transfer coefficient and thermal conductivity at $Al_2O_3$-CuO/water hybrid Nano fluid and concentration (Ø=0.5%) is (1.1766 and 0.6391), respectively. And the maximum percent enhancement in heat transfer rate is (72.87%) at $Al_2O_3$-CuO/water hybrid Nano fluid and concentration (Ø=0.5%).
- There is a positive effect of employing the hybrid type Nano fluid compared to the single type Nano fluid.
- The rate of heat transfer, Nu, and ΔP increase with the increase of flow rate and Re.
- The highest pressure drop of the inner tube ΔP is (285.299 Pa) at CuO/water Nano fluid and with concentration (Ø=0.5%) at (flow rate=250 l/h and Re=8000.7599), where it was observed that ΔP increases with increasing nanoparticle concentration.
- The highest effectiveness of the heat exchanger is (0.29188) when using $Al_2O_3$-CuO/water hybrid Nano fluid at (Ø=0.5%).

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