# Experimental Study of Spiral Heat Exchanger Performance in V- Trough Tube Collector by using Mono and Hybrid Nanofluids

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## ABSTRACT

This article presents an experimental study of the performance of spiral heat exchanger in V – trough tube collector by using mono Nano fluid (metal and oxide metal) (Zn(30)+Dw),($ZrO_2$(60)+Dw) and hybrid Nano fluids (Zn(30)+$ZrO_2$ (60)+Dw). The method used in this study to enhanced heat transfer and pressure drop by used the spiral tube heat exchange in V– trough tube solar collector and the mono Nano fluid (metal and oxide metal) and hybrid Nano fluids instead of the distilled water. The concentrations of mono and hybrid nanoparticles used are (1 , 3, 5 vol %). Three types of nanoparticles used in this paper Zinc (Zn (30nm)) , Zirconium oxide ($ZrO_2$) (60nm)) and hybrid nanoparticles Zinc (Zn (30nm)) , Zirconium oxide in addition the pure fluid (distilled water). The impact of different parameters were taken in this article such as size and type, Dean Number, Reynolds number, concentration, mono and hybrid Nano fluids temperature on heat transfer coefficient and pressure drop. The results indicated that by using heat exchanger consist of shell and spiral tube enhanced the heat transfer performance and the pressure drop due to the curvature of the spiral tube. The heat transfer coefficient and pressure drop will increasing by using mono Nano fluid (metal and oxide metal) (Zn(30)+Dw), ($ZrO_2$(60)+Dw) and hybrid Nano fluids (Zn(30)+$ZrO_2$(60)+Dw) instead of the pure fluid (Dw). The experimental results showed that the maximum increase of 44.32% (Zn + Dw), 35.42% for (Zn +ZrO2 + Dw) and 25.13 % (ZrO2+ Dw) in Nusselt number ratio for a range of Reynolds numbers between 200 and 800. This study indicated that the mono Nano fluid (metal and oxide metal) (Zn+Dw),($ZrO_2$+Dw) and hybrid Nano fluids (Zn+$ZrO_2$+Dw) are a Newtonian fluid as well as shear stress increases with shear rate. The shear stress of mono Nano fluid and hybrid Nano fluids increases with concentration of nanoparticles for both counter flow and parallel flow. The type and size mono and hybrid nanoparticles play an important role in enhancement of heat transfer rate. Further to the performance index are used to present the matched flow and heat transfer technique.


**Keywords**: V- trough tube collector, Mono Nano fluids, Hybrid Nano fluid, Spiral heat exchange

## INTRODUCTION

The heat exchanger is a device used to heat transfer between two fluids and inside numerous industrial applications such as transportation and electronics, power plants, production and chemical processes. The methods for the elimination of the thermal load in this application by used enhancement of heat transfer. The literature survey was good through indicated that these methods depends on structure variation, heated surface vibration, fluid suction and implementation magnetic fields [1, 2].However, the cooling of the very important things in this application to improve heat transfer especial in generation systems microelectronic. The problems of cooling



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process appear in thermal properties of the fluids and to avoid these problems used Nano fluids and hybrid Nano fluid. The Nano fluids consist of nanoparticles and base fluid (distilled water, oil and ethylene glycol further the Nano fluid have good thermal properties such as high time stability, high thermal conductivity , low penalty in pressure drop increasing. Many studies have been conducted on the flow and thermal properties of Nano fluids. Most the experimental and theoretical investigations concentrated on different factors like concentration and size of nanoparticles, Brownian motion and mixture temperature. These investigations indicated effect these factors [3 – 6]. Furthermore these investigations indicated that the thermal conductivity and convective heat transfer increasing with the nanoparticles concentration and temperature of mixture also it was indicated that larger improvement in thermal conductivity due to nanoparticles size [5 – 7]. Many of the studies are focused on improvement thermal properties of Nano fluids and turbulent and laminar flow for Nano fluids. Roughly all of these investigations focused on the enhancement convective heat transfer for Nano fluids. [8 – 11 ] investigated of characteristics heat transfer of Nano fluids in straight tube with a constant heat flux at the wall, horizontal tube with and without wire coil inserts at constant heat flux. Experimental results showed that Nano fluids give substantial enhancement of heat transfer rate compared to base fluid. Also they noticed claimed that the friction factor for the Nano fluids at low volume fraction did not produce extra penalty in pumping power. The hybrid Nano fluid is new type of Nano fluid consists of two or more than two of nanoparticles in base fluid (conventional fluids). The hybrid Nano fluids can be prepared by different types of nanoparticles (two or more than two) in base fluid and composite (hybrid) nanoparticles in base fluid. The hybrid materials have compound physical and chemical properties of different materials at the same time which give homogeneous phase properties. The made hybrid nanomaterial offer wonderful physical and chemical properties that do not exist in each element separately. Many investigations have been conducted on the properties of the hybrid nanoparticles [12] and carbon nanotubes (CNTs) hybrid nanoparticles have been used in most application such as sensors of electrochemical, biosensors, Nano catalysts, etc. [13], but the use of this hybrid nanomaterial in Nano fluids has not developed as such. However the use of hybrid nanoparticles in Nano fluids did not advanced as such. The works of hybrid Nano fluids are very compartment and numerous of experimental investigations are still being done. The major objective of hybrid nanoparticles aggregation is to obtain the properties of its composite materials. The single material does not possess all the appropriate properties and required for especial purposes such as good thermal properties or rheological properties. The hybrid Nano fluids have good thermal conductivity compared with individual Nano fluids due to synergistic effect. Experimental investigated in circular tube with uniform heat flux to obtained heat transfer coefficient and pressure drop for fully developed turbulent flow. The hybrid Nano fluid type used in this investigated was multiwall nanotube, Iron oxide and water (MWCNT + $Fe_3O_4$) + water. The maximum improvement was 31.1% in Nu while a penalty pumping power of 1.18 times [14]. Experimental studies in tube in the tube type counter flow (heat exchanger). The type of hybrid Nano fluid used in these studies was cupper, Titanium Oxide and water (Cu+$TiO_2$ – water). This study indicated that the Nu and overall heat transfer coefficient were increased by 82%, 49% and 68% respectively [15].

The aims of this article is to appraisal the heat transfer characteristics and flow in coil heat exchanger to both parallel and counter flow arrangements by using hybrid Nano fluids through V – trough tube collector. Furthermore to study the effect of hybrid nanoparticles concentration, Reynolds number, hybrid Nano fluid temperature, size and type of hybrid nanoparticles.

## Mono and hybrid Nano fluids preparation

The preparation of mono and hybrid Nano fluids by using two step method, in this study used three types of Nano fluids which including mono Nano fluid (Zn (30) + Dw), ($ZrO_2$ (60) + DW), hybrid Nano fluid (Zn (30) + Z $rO_2$ (60) +DW). These types used with four different concentration with (Φ = 1, 2, 3, and 5 vt %).The nanoparticles and hybrid nanoparticles mixing with pure water to obtain on these types of Nano fluids. Figure (1) Show (Zn (30) + Dw) , (Z $rO_2$ (60) + DW) and hybrid Nano fluid (Zn (30) + Z $rO_2$ (60) +DW).

**Figure (1) Show Nano fluids (Zn + Dw) and (Z $rO_2$ + Dw) and hybrid Nano fluids (Zn + Z $rO_2$ + Dw)**

**Experimental setup for spiral heat exchanger**

The solar energy system consists of the V – trough tube solar collector (six tubes), helically coiled tube heat exchanger, pump, and flow meter. This study concentrated on spiral heat exchanger in solar energy system as shown in Fig (2). The schematic view of rig is display in figure (3). The spiral heat exchanger consists of test section containing shell and spiral tube, pump [Bosch 2055 – AE], ball valve, flow meter (Dwyer series MMA mini – master flow meter) having a range of (5 – 20 LPM). The heat exchanger is manufacture of cupper and ID of 16 mm, OD of 20 mm and ID of shell 375mm, OD 490 mm and 1015 mm length. The loop of shell side consists of storage vessel of 60 L capacity and thermostat. Four K – type thermocouples of 0.10 $^0$C accuracy are used to measure inlet and outlet temperatures of shell and spiral tube side. Hot water passes through shell side while hybrid Nano fluid and mono Nano fluids passes through spiral tube side. The mono Nano fluids (Zn + Dw) , ($ZnO_2$ + Dw) and hybrid Nano fluids ( Zn + $ZnO_2$ + Dw) at volume concentration was circulated through the spiral tube side. The controlling of distilled water temperature by using thermostat attached in storage of distilled water. The two cases used in experiments are parallel flow condition and then counter flow condition.

**Figure (2) Stages of building heat exchanger**

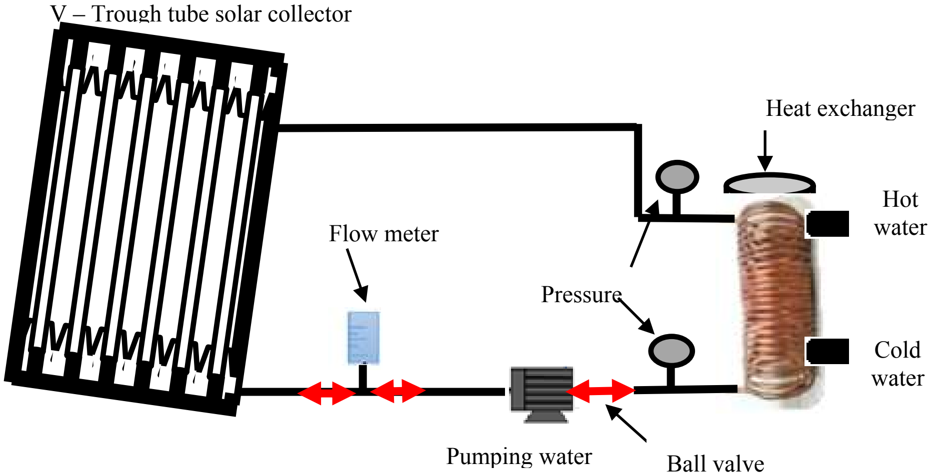



**Figure (3) The experimental set up schematic**

**Estimation of mono and hybrid Nano fluid thermo physical properties**

The thermal physical properties of **mono and** hybrid Nano fluid are calculated by equations. Volume fraction as follows:

$$\Phi_{np} = \frac{Vnp}{Vnp + Vbf}$$

Density [16].

$$\rho_{hb,nf} = \Phi_{np1}\rho_{np1} + \Phi_{np2}\rho_{np2} + \left(1 - \Phi_{np1} - \Phi_{np2}\right)\rho_{Dw} \quad \ldots.(1)$$

Viscosity [16].

$$\mu_{hb,nf} = \left(1 + 2.5\left(\Phi_{np1} + \Phi_{np2}\right)\right)\mu_{Dw} \quad \ldots.(2)$$

Specific heat [16].

$$\rho_{hb,nf}Cp_{hb,nf} = \Phi_{np1}\rho_{np1}Cp_{np1} + \Phi_{np2}\rho_{np2}Cp_{np2} + \left(1 - \Phi_{np1} - \Phi_{np2}\right)\rho_{Dw}Cp_{Dw} \quad \ldots.(3)$$

Recently Huang et al.[17] presented an effective thermal conductivity model (Eq.4)

$$\frac{k_{hb,\,nf}}{k_{Dw}} = \left[\frac{Cp_{hb,\,nf}}{Cp_{Dw}}\right]^{-0.023}\left[\frac{\rho_{hb,\,nf}}{\rho_{Dw}}\right]^{1.358}\left[\frac{\mu_{Dw}}{\mu_{hb,\,nf}}\right]^{0.126} \quad \ldots.(4)$$

**Data processing**

The mono Nano fluid, hybrid Nano fluid and distilled water of heat transfer can be determined from Eqs.(5) and (6). The average heat transfer is taken for this analysis Fouling factor was not taken into account.

$$Q_{Dw} = m_{Dw}\, Cp_{Dw}\left(T_{in} - T_{out}\right)_{Dw} \quad ....(5)$$

$$Q_{nf} = m_{nf} Cp_{nf}\left(T_{in} - T_{out}\right)_{nf} \quad ....(6)$$

$$q = \frac{Q_{Dw} + Q_{nf}}{2} \quad ....(7)$$

The following equation used to calculate the coefficient of overall heat transfer, Uo , [19]:

$$U_o = \frac{q}{A_o\, LMTD} \quad .... (8)$$

LMTD is the log mean temperature difference can calculate by used the following equation

$$LMTD = \frac{\left(\Delta T_2 - \Delta T_1\right)}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)} \quad ....(9)$$

$$Q = h_i A_i \left(T_w - T_b\right) \quad ....(10)$$

$$Nu_i = \frac{h_i d_i}{k_{nf}} \quad .....(11)$$

The coefficient of overall heat transfer can be related to the inner and outer coefficients of heat transfer by the following equation [19]:

$$\frac{1}{U_o} = \frac{A_o}{A_i h_i} + \frac{A_o \ln\left(\frac{D_i}{d}\right)}{2\pi K L} + \frac{1}{h_o} \quad ....(12)$$

The Nusslet number in shell side is determined by the following equation.

$$Nu_o = \frac{h_o D_h}{k_{nf}} \quad ....(13)$$

The hydraulic diameter of shell is calculated from the following formula:

$$D_h = \frac{4\left(V_{shell} - V_{tube}\right)}{\pi\left(D + d\right)\left(L_{sheel} + L_{tube}\right)} \quad ....(14)$$

The friction factor of laminar flow inside spiral tube to range of Dean Number (De) of (11.6 < De < 2000) is correlated as: [20].

$$De = Re\sqrt{\left(\frac{d}{De}\right)} \quad .....(15)$$

The performance index, ζ, is defined as follows:

$$\zeta = \frac{\left(\dfrac{Nu_{nf}}{Nu_{st,bf}}\right)}{\left(\dfrac{\Delta p_{nf}}{\Delta p_{st,bf}}\right)} \quad ....(16)$$

**Results and Discussion**

The dependability and the precision of the experimental system has been conducted in measured the coefficients of heat transfer and pressure drop of distilled water as the working fluid. The experimental results to these tests are compared with results of [20 – 22]. The used types in experiments as follows mono Nano fluid (metal) (Zn + Dw) , mono Nano fluid (oxide metal) ($ZnO_2$ + DW) and hybrid Nano fluid (Zn + Z $rO_2$+DW). A good agreement between theoretical and experimental values for h and Δp as shown in figures (5 – 6). On other hand in case Δp the deviation between these values was −2.1 % and + 2.3 %. The flow characteristics in spiral tube of heat exchanger was mono Nano fluid (metal) (Zn + Dw), mono Nano fluid (oxide metal) (Z $rO_2$+ DW) and hybrid Nano fluid (Zn + Z $rO_2$ +DW) for laminar flow conditions. The two specific cases of the data for heat transfer and pressure drop are not achieved at the same Reynolds numbers due to viscosity of distilled water in three types of Nano fluids is dependent on temperature and concentration of nanoparticles ( mono nanoparticles and hybrid nanoparticles). The counter flow against parallel flow overall heat transfer coefficients are plotted in Figures. (7 – 9) for mono Nano fluid (metal) (Zn + Dw), mono Nano fluid (oxide metal) (Z $rO_2$ + DW) and hybrid Nano fluid (Zn + Z $rO_2$ +DW). These figures showed that a reasonable agreement between these values. The increases in $U_o$ for counter flow were 25 – 43 % more than that of parallel flow for these types of Nano fluids at 5vol % concentration. Further the increases in $U_o$ for counter flow were 5 – 12 % more than that of parallel flow for three types of Nano fluids at 1vol %. The variations of flow direction in overall heat transfer insignificant due to the primary flow in tube side and generation of secondary flow are always perpendicular to the shell side flow. The changing of flow condition does not affect by heat transfer therefor the results for the configuration of parallel flow was similar to the configuration of counter flow. The rates of heat transfer in the counter flow are much higher than in the parallel flow due to rise log mean temperature difference. Figures (10 – 12) reveal the variation of inner Nusselt number against Dean Number for mono Nano fluid (metal) (Zn + Dw), mono Nano fluid (oxide metal) ($ZrO_2$+ DW) and hybrid Nano fluid (Zn + $ZrO_2$ +DW) with different concentrations of nanoparticles and flow configuration. These figures indicated that insignificant impact on inner Nusselt number when used two types of flow configuration and mono Nano fluid (Zn + Dw), mono Nano fluid (Z $rO_2$ + DW) and hybrid Nano fluid (Zn + Z $rO_2$ +DW) are circulated. This is due to coefficient of inner heat transfer is the same and any the flow configuration between spiral tube and shell. Furthermore the centrifugal force and generation of secondary flow did not get negative impact as well as the inner Nusselt number increases with concentration of nanoparticles result coefficient of inner heat transfer and higher thermal conductivity. The addition of nanoparticles for Zinc (Zn) and Zirconium oxide ($ZrO_2$) in distilled water lead to enhancement the thermal conductivity and the convective heat transfer coefficient. The higher volume concentrations of the nanoparticles for both the thermal conductivity of the mixtures mono Nano fluid (Zn + Dw), mono Nano fluid ($ZrO_2$ + DW) and hybrid Nano fluid (Zn + Z $rO_2$ +DW) and the disturbance effect of the nanoparticles will increase. The higher volume concentrations with higher Nusselt number for three types of Nano fluids will occurs. Figures. (13 – 15) indicated that the ratios of Nusselt number of mono fluid (metal and oxide metal) and hybrid Nano fluids with 5 vol % to that of base distilled water as a function of Reynolds number for spiral tube. The mono fluids (metal) have better heat transfer performance that mono fluids (oxide metal) and hybrid Nano fluids (Zn + Z $rO_2$ +DW) when they flow inside spiral tube. The experimental results showed that the highest Nusselt number ratios are obtained for the spiral tube at the same range of Reynolds numbers. The experimental results showed that the maximum increase in terms coefficient of heat transfer of 55.45% for (Zn + Dw) , 40.25% for (Zn +$ZrO_2$ + Dw) and 31.14 % for ($ZrO_2$ + Dw) at concentration of 5 vol % compared with distilled water. In addition to the maximum increase of 44.32% (Zn + Dw), 35.42% for (Zn +$ZrO_2$ + Dw) and 25.13 % ($ZrO_2$+ Dw) in Nusselt number ratio for a range of Reynolds numbers between 200 and 800. The reasons for the maximum increase go to the chaotic motion of the mono nanoparticles and hybrid nanoparticles inside coil tube. the shear rate at wall of the spiral tube was high and the non – uniformity of the shear rate through the cross section will increasing then the changing of the shear rate leads to the mono nanoparticles and hybrid nanoparticles are more motivated. Figures (16 – 18) indicated that the measured pressure drop for mono fluid (metal and oxide metal) and hybrid Nano fluids at different concentration and Reynolds number. This figures showed significant increase in pressure drop of mono fluid (metal and oxide metal) and hybrid Nano fluids at 1vol % compared with the distilled water. This enhancement tends to continue for the mono Nano fluid (metal and oxide metal) and hybrid Nano fluids with higher concentration. This is due to mono nanoparticles and hybrid nanoparticles existing in distilled water will increases dynamic viscosity relative to the distilled water. The viscosity is direct proportional with pressure drop, therefore higher value of pressure drop leads to significant increases in viscosity value. Moreover at higher and lower Reynolds numbers (flow rates) the pressure drop increased in mono Nano fluid and hybrid Nano fluid may be due to the migration and chaotic motion of mono and hybrid nanoparticles in the pure fluid. The pressure drops in pure fluid, mono and hybrid Nano fluids are almost the same. Nevertheless the rate of pressure drops for mono and hybrid Nano fluids increasing at concentrations of 1, 3, 5 vol% but is less than 1vol% when used instead of pure fluid. The maximum improvement in pressure drops of 18. 2 % (Zn + Dw), 13.4 % (Zn +$ZrO_2$+ Dw) and 8.4 % ($ZrO_2$+ Dw) at concentrations of 1vol % when used instead of distilled water. The improvement in coefficient of heat transfer and pressure drop by used mono and hybrid Nano fluids in spiral heat exchanger in V- trough tube solar collector. it had to be find a technique to determine the performance through the enhancement in pressure drop and heat transfer by used performance index, $\zeta$. When the performance index is greater than 1 this means that the enhancement in heat transfer is greater than pressure drop where can be used in practical applications. Figures (19 – 21) showed that the performance index is greater than 1 for mono Nano fluid (metal and oxide metal) and hybrid Nano fluids at 1, 3, and 5 vol % concentrations. The maximum performance index of 1.6, 1.35 and 1.1 are obtained for the mono Nano fluid (metal and oxide metal) and hybrid Nano fluids at counter flow with 5 vol % concentration. These Figures indicated that the performance index is greater than 1 for all volume concentrations (1, 3, and 5 vol %) while in case of distilled water the rate of increasing in pressure drop is lower than increasing in heat transfer coefficient. These figures showed when applying spiral tube a more effective method to enhance the convective heat transfer compared with distilled water when using mono Nano fluid (metal and oxide metal) (Zn+Dw),($ZrO_2$+Dw) and hybrid Nano fluids (Zn+$ZrO_2$+Dw). Figures.(22 – 24). Depicted the shear stress versus shear rate for mono Nano fluid (metal and oxide metal) (Zn+Dw),($ZrO_2$+Dw) and hybrid Nano fluids (Zn+$ZrO_2$+Dw) at ($\Phi$= 1, 3, and 5 vol %). These figures indicated that this types used in study are a Newtonian fluid as well as shear stress increases with shear rate. The shear stress of mono Nano fluid (metal and oxide metal) (Zn+Dw), ($ZrO_2$+Dw) and hybrid Nano fluids

($Zn+ZrO_2+Dw$) increases with concentration of nanoparticles for both counter flow and parallel flow.

**Nomenclature**

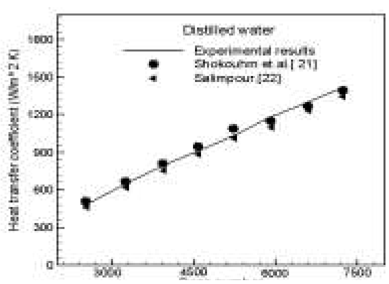
| | |
|---|---|
| $A_o$ | The surface area ($m^2$) |
| q | the heat transfer rate (J/kg) |
| $\Delta T1$ | inlet temperature difference ( $^0C$ ) |
| $\Delta T2$ | The outlet temperature difference ( $^0C$ ) |
| Cp | Specific heat (J/kg K) |
| Di | The inner diameter of the shell (m) |
| d | Diameter of the coil (m) |
| K | The thermal conductivity of the cupper ($W/m^2$ K) |
| L | The length of heat exchanger (m) |
| Nu | Nusselt number |
| Pr | Prandtl number |
| Re | Reynolds number |
| $\Delta P$ | Pressure drop (Pa) |
| f | Friction factor |
| De | Dean number |
| $U_0$ | Overall heat transfer coefficient ($W/m^2$ K) |
| $k_n$ | Thermal conductivity of nanofluid ($W/m^2$ K) |

**Greek symbols**

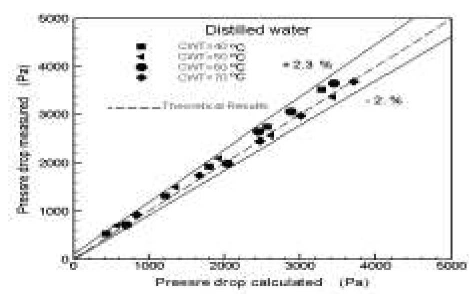
| | |
|---|---|
| $\Phi$ | Nanoparticle volume fraction |
| $\gamma$ | Shear rate ( $s^{-1}$) |
| $\mu_n$ | Dynamic viscosity nano fluid $N.s/m^2$ |
| $\zeta$, | Performance Index |
| $\rho_{nf}$ | The density of nanofluid ($kg/m^3$) |
| $\rho_{DW}$ | The density of distilled water ($kg/m^3$) |
| $\mu_{nf}$ | The Viscosity of nanofluid ($m^2/s$) |

**Subscripts**

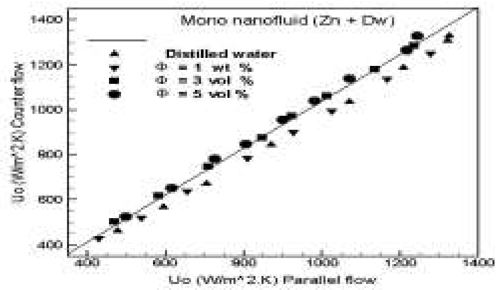
| | |
|---|---|
| nf | Nanofluid |
| st | Spiral tube |
| i | inner |
| o | outer |
| bf | Base fluid |



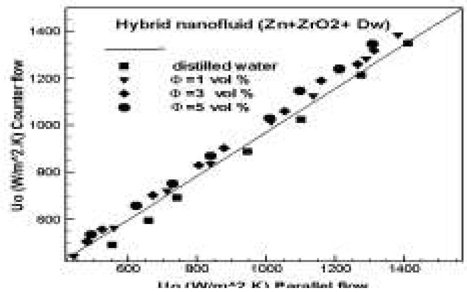

**Figure( 5). Comparison between calculated and measured heat transfer coefficient of Dw [21,22]**




**Figure(6). Comparison between theoretical and experimental pressure drop of Dw at CWT**




**Figure(7). Comparison of $U_0$ of counter and parallel flow configuration Zn +Dw) Mono Nano fluid**




**Figure(8). Comparison of $U_0$ of counter and parallel flow configuration for ($Zn + ZrO_2$+ Dw) Hybrid Nano fluid**

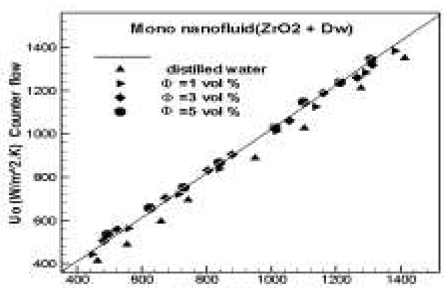



**Figure (9). Comparison of $U_0$ of counter and parallel flow configuration ( $ZrO_2$+ Dw) Mono Nano fluid**

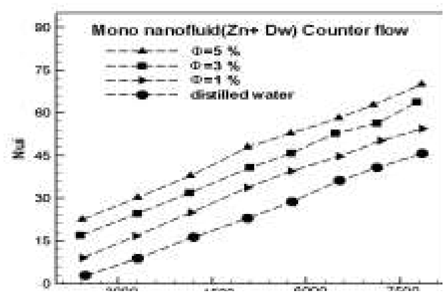



**Figure (10). Change of inner Nusselt number for Mono Nano fluid (Zn+Dw) with counter flow**

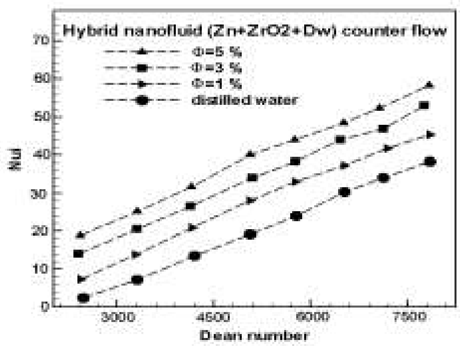



**Figure (11). Change of inner Nusselt number for hybrid Nano fluid ($Zn+ZrO_2$+Dw) with counter flow**

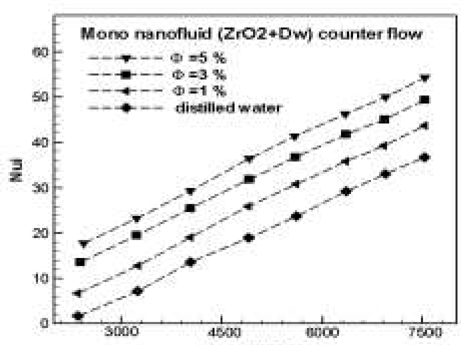



**Figure (12). Change of inner Nusselt number for Mono Nano fluid ($ZrO_2$+Dw) with counter flow**

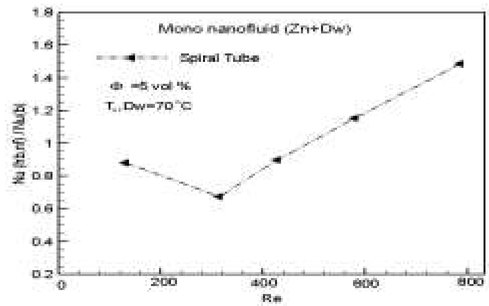



**Figure (13) The Nu ratio versus Re to Mono Nano fluid (Zn+ Dw) in spiral tube at Φ=5 vol %**

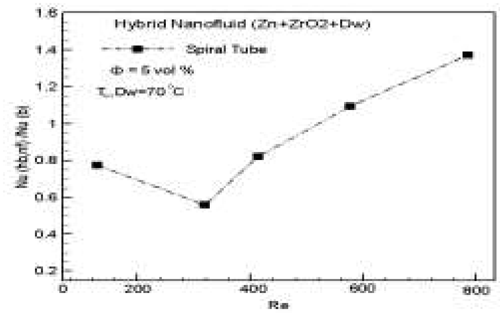



**Figure (14) The Nu ratio versus Re to hybrid Nano fluid (Zn+ $ZrO_2$+Dw) in spiral tube at Φ=5 vol %**

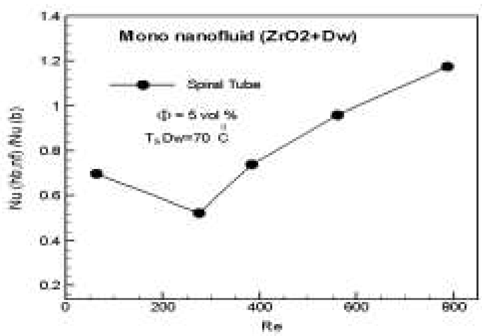



**Figure (15) The Nu ratio versus Re to Mono Nano fluid ($ZrO_2$ + Dw) in spiral tube at Φ=5 vol%**

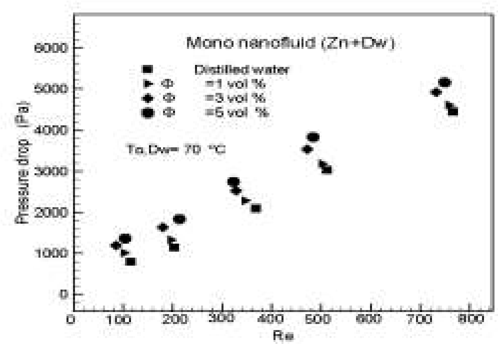
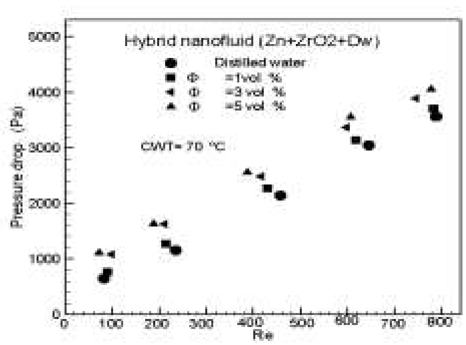
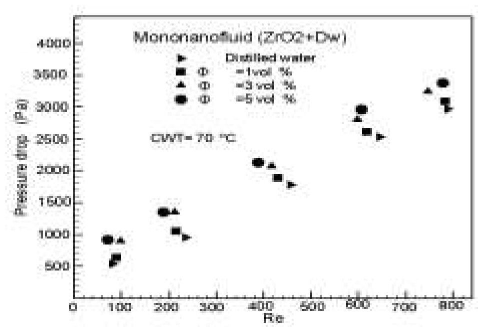



**Figure (16) Pressure drop versus Re to Mono Nano fluid (Zn + Dw) with counter flow at different Φ**




**Figure(17). Pressure drop versus Re to hybrid Nano fluid (Zn +ZrO2+ Dw) with counter flow at different Φ**




**Figure(18). Pressure drop versus Re to Mono Nano fluid (ZrO2+ Dw) with counter flow at different Φ**

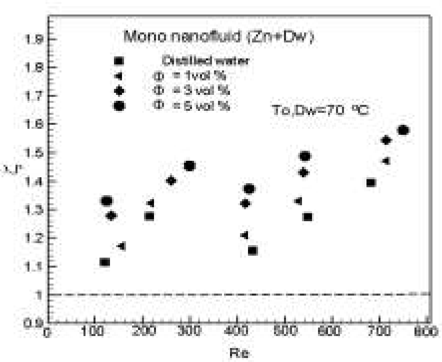



**Figure (19) The performance index versus Re to mono Nano fluid (Zn+ Dw) with counter flow at different Φ**

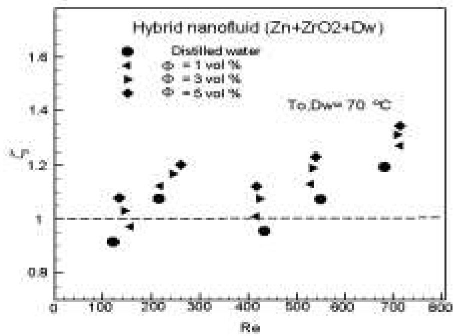



**Figure (20) The performance index versus Re to hybrid Nano fluid (Zn+ZrO2 + Dw) with counter flow at different Φ**

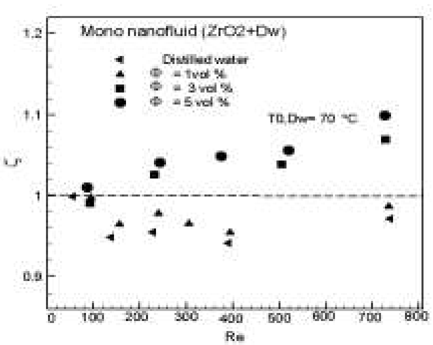



**Figure (21) The performance index versus Re to mono Nano fluid ($ZrO_2$ + Dw) with counter flow at different Φ**

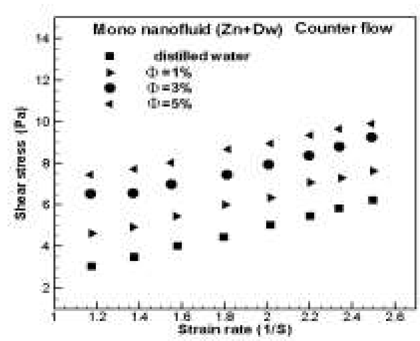



**Figure.(22). Shear stress versus shear rate for mono Nano fluid (Zn+Dw) with counter flow**

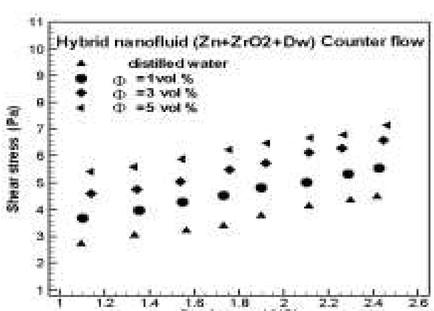



**Figure. (23) Shear stress versus shear rate for hybrid Nano fluid (Zn+$ZrO_2$+ Dw) with counter flow**

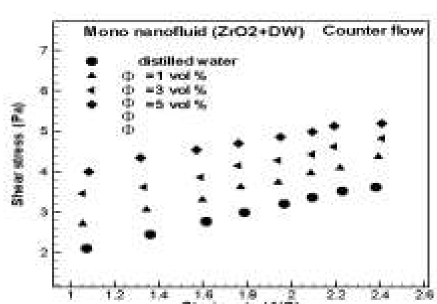



**Figure.(24). Shear stress versus shear rate for mono Nano fluid (ZrO2+Dw) flow with counter**

## CONCLUSIONS

1. The heat transfer characteristic of mono Nano fluid (metal and oxide metal) (Zn+Dw),($ZrO_2$+Dw) and hybrid Nano fluids (Zn+$ZrO_2$+Dw) in spiral tube of heat exchanger is better than distilled water.
2. The type and size mono and hybrid nanoparticles play an important role in heat transfer enhancement.
3. The shear stress of mono Nano fluid (metal and oxide metal) (Zn+Dw), ($ZrO_2$+Dw) and hybrid Nano fluids (Zn+$ZrO_2$+Dw) increases with concentration of nanoparticles for both counter flow and parallel flow.
4. The mono Nano fluids (metal and oxide metal) (Zn+Dw),($ZrO_2$+Dw) and hybrid Nano fluids (Zn+$ZrO_2$+Dw) conduct as the Newtonian fluid for ($\Phi$ = 1, 3 and 5 vol %). Moreover no significant effect of changing flow direction on coefficient of overall heat transfer.
5. The performance index of the mono Nano fluids (metal and oxide metal) (Zn+Dw), ($ZrO_2$+Dw) and hybrid Nano fluids (Zn+$ZrO_2$+Dw) flow is greater than the performance index of the pure fluid.
6. The pressure drop of mono Nano fluids (metal and oxide metal) (Zn+Dw),($ZrO_2$+Dw) and hybrid Nano fluids (Zn+$ZrO_2$+Dw) is greater than the pressure drop of distilled water.

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