The Nano Fluid Effect on the Plethora of Thermal Efficiency in Evacuated Tube Solar Collector

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Abstract. Nano fluids are the most attractive means to boost heat transfer system efficiency, since they have high thermal conductivity. This research aims to investigate the effects of utilizing Nano fluids (Cu (30 nm) + DW) as the working fluid on the thermal effectiveness of the evacuated solar collector. Experiments for statistical analysis of techniques were Performed using nanoparticles in three volume concentrations (1%, 3% and 5% vol.), solar collector's thermal efficiency was tested at various volume flow rates (30, 60 and 90 Lit/min). This research indicated that percentages improvement of (Cu (30nm) + DW) with working fluid (distilled water) at 5 % volume concentration and different volume flow rates are (15.326%, 16.96% and 19.98%) while these percentages of improvement when used only distilled water at the same volume concentration and various volume flow rates are (2.41%, 4.36%, 5.43%). The high thermal conductivity of the working fluids could enhance solar collector efficiency compared to that of the distilled water. The area under the curve (the thermal efficiency curve) was used as indicator to assess the results of the volume flow rate and nanoparticle concentrations on total collector efficiency. Nano fluids (Cu + DW), at concentrations ratio (1, and 5%vol) and volume flow rates (30, and 90 L/min), Values of thermal solar characteristic value of (FR (τα) – FRUL) are 0.407, 1.156 W/m².k, 0.522 and 0.945 W/m².k, Whereas for distilled water at volume flow rates 30 L/min and 90 Lit/min are 0.252, 0.945 W/m².k, 0.321 and 1.051 W/m².k respectively, where FR (τα) – FRUL are two parameters used to describe how collector works, where FR (τα) is an indication of how energy absorb and FRUL is an indication of energy is lost, the two parameters are constitute the simplest practical collector model, the values indicates that the solar collector efficiency when using Nano fluids (Cu(30)+ DW) is higher than efficiency when using distilled water due to high thermal conductivity for copper. The type of Nano fluid is a key factor for heat transfer enhancement, and improve performance of evacuated tube solar collector.

Keywords: Evacuated solar collector tubes; Performance; Nano fluids; Thermal Performance.
1. Introduction

Solar energy is converted into useful heat energy. Solar energy is amongst the cleanest, inexhaustible energy and cheap forms of renewable energy, Solar energy is now becoming widely used because it is safe and can also be accessed without constraints. In order to capture heat from solar energy, Solar collectors are the systems in use today this can be used for much of the buildings' energy usage, like air conditioning, water heating, swimming pool heating and so on. [1]. There are numbers of techniques to absorb solar radiation, but the evacuated tube method has a particular interest to the researchers because ETSC has higher efficiency than the traditional FPC, especially at low temperatures and insulation presence. An ETSC consists of parallel glass tubes (evacuated-pipes) that has been evacuated, it consists of two pipes one inside casing with the larger, and vacuum is produced between the two tubes that allows the solar radiation to pass through but does not allow the energy to be transferred thus the energy stays inside the internal pipes and absorbs radiation efficiently, making the ETSC the most efficient solar thermal energy collector [2]. Many ways to increase heat transfer by heat exchangers can be split into two groups: active and passive strategies, Passive strategies don’t require exterior force. Using Nano fluids as a medium for heat transfer is a passive strategy to boost heat transfer [3]. Nano fluids are the most attractive mean to boost the heat transfer system efficiency, are created by incorporating Nanoparticles just under 100 nm of metal and metal oxides to the base fluid. For solar collectors, renewable power makes special use of these Nano fluids [4]. Das et al. (2007) [5]; expressed that the Nano fluids could be utilized to enhance heat transfer from solar collectors to storage tanks and to increase the energy density. Otanicar and Golden. (2009) [6]; Reported solar collector experimental results depending on Nano fluids made up of Various Nano-particles such as carbon, graphite and silver; In solar energy systems, when using Nano fluid as an absorption mechanism, performance improvements were up to 5%. Experimental and mathematical findings an initial significant improvement in performance accompanied by an increase in productivity as the volume fraction keeps on increasing. Yong Yang Gan et.al (2018) [7]; Assesses thermal performance and performs an entropy (ETSC) analysis in which Nano fluid TiO₂ have been used as working fluids. Titanium dioxide (TiO₂ Nano fluid formed by scattering small a amounts of TiO₂ nanoparticles into distilled water). Higher thermal conductivity of the TiO₂ Nano fluids may enhance efficiency of solar thermal collector (ETSC) evacuated tube. And conclude the rise in nanoparticles volumetric concentration increases the TiO₂ Nano fluids thermal conductivity. Kamble D.P.1 et. al. (2014). [8]; Studied the Nano fluid's behavior to boost a circular heat pipe's thermal performance. The experiment, made of copper tubing and using hybrid Nano fluid (Al₂O₃ + CuO) with a water base as working fluids, explores the thermal dissipation of the heat pipe under different working conditions. Total thermal performance was predicted for pure water and water based on Nano fluid. The study discusses the impact of the working fluids charged volume ratio, the effect on thermal resistance of the filling volume ratio and of the volume of nanoparticles in the base fluid is also investigated. Contrast to pure water, thermal effectiveness of the heat pipe increases with the growing (Al₂O₃ + CuO) water dependent Nano fluid. Tiwari et al. (2013) [9] Examine the influence of Al₂O₃ Nano fluid's theoretical use as an absorbent medium in a flat solar collector. They also investigate the impact on the collector's efficiency, volume flow rates and particle volume fraction. Their finding revealed that utilizing optimum fraction of the particle volume of 1.5% of Al₂O₃ Nano fluid increases solar collector's thermal efficiency by 31.64% contrasted to water as working fluids. Luie et al. (2011) [10]. Tested CuO Nano Fluid and it was found that the performance of the evacuated solar collector is 30 % greater than of the distilled water. Natarajan and Sathish (2011) [11] also believed to be new method for enhancing solar water heaters efficiency by adding Nano fluids instead of conventional heat transfer fluids.
2. Preparation of Nano fluids (Cu (30nm) +DW)

The Nano fluid studied is formed by nanoparticles of copper (cu (30 nm)) and two – step process applies to the base liquid by dispersing pre-weighted amounts of dry nanoparticles. The acidity (PH) of Nano fluid has been calculated in a standard procedure. The mixtures were then ultrasonically mixed [100 kHz, 300 W at 25 – 30°C, Toshiba, England] for two hour to break up any particle aggregates. The acidic pH is much less than the isoelectric point [iep] of these particles, thus ensuring positive surface charges on the particles. The surface enhanced repulsion between the particles, which resulted in uniform dispersions for the duration of the experiments, as shown in Figure (1), Figure (2) shows Nano fluids which containing copper (Cu (30 nm)).

![Figure 1: The preparation process of Nano fluids](image1)

![Figure 2: The Nano fluid (Cu (30nm) +DW)](image2)

3. Experimental setup

Figure (3) displays the setups schematic view. An ETSC system consisting of 10 hollow tubes was added as shown in Figure (4), while heat exchanger was added to another hand which is used for heating process (transfer the heat from heating fluid to cooling fluid in the storage vessel), its
consists of helical copper coil with 13 mm inner diameter, an outer diameter of 16 mm, 18 turns and total length of 10 m. Coil immersed in 60 L storage vessel insulated by a reflective fiberglass sleeve the storage has an inside diameter of 370 mm, outside diameter of 385 mm and a length of 1000 mm. Circulation water pump used to transfer Nano fluids at different speeds. In addition, several thermocouples were also connected to the heat exchanger and on solar collector inlet and outlet.

**Figure 3a:** The test rig

**Figure 3b:** Display Solar heating unit block diagram
Figure 4: Evacuated tube solar collector (ETSC)

Figure 5: Heat exchanger from inside and outside

Figure 6: Circulation water pump
4. Measuring Apparatus

4.1 Pressure gauge

Two pressure gauges with (0 — 150), (0 — 400) mbar ranges are mounted in the inlet and outlet of the exchanger to measure the difference at these stages, as shown in Figure (7). The readings of these two gauges should be registered in order to calculate the pressure drop and other relevant parameters.

![Figure 7: pressure gauges](image)

4.2 Temperature measurement

Real-time data logger SD card, 12 channel temperature recorder model: [BTM — 4208SD]. Thermocouple type K was used according to most common type of thermocouple, thermocouple grade wire, −454 to 2,300°F (−270 to 1260°C) Accuracy of thermocouple type K (± 2.2°C or ± 75%), special Limits of error: (± 1.1°C) or 0.4%. Also it's cheap, precise, and reliable and has a wide range of temperature.

![Figure 8: data logger](image)

4.3 Solar power meter

The solar radiation was measured by digital solar meter type Make – Lutron, Made in Taiwan. Model No.: [SPM – 1116 SD] as shown in Figure (9), the solar power meter with accuracy ± 10 W/m². The solar meter measures the total solar radiation which falls on the inclined surface of the solar collector.
4.4 Flow Meter

Water variable-area flow meter (Rotr meter) with a range of (20 – 70) LPM to measure the volumetric flow rate of the system shown in Figure (10). Was installed in vertical position adjacent to the pump outlet. The transparent flow meter casing is fabricated from a Perspex glass. The range of flow meters is suitable for the pump operation range. The flow meter with full scale accuracy (± 4 percent).

5. Analysis of data and validation

Useful thermal energy, temperature distribution, and efficiency of the collector was determined using equations (1– 7) which were derived from [12], [13] and [14]. The equation for useful thermal energy (Qu), as:

\[
Q_U = A_c F_R [I \alpha \tau - (T_{nf,in} - T_a)]
\]  

(1)

The heat energy is converted into thermal energy of water in the pipes as:

\[
Q = \dot{m} C_p (T_{nf,o} - T_{nf,i})
\]  

(2)

Then

\[
\dot{m} C_p (T_{nf,o} - T_{nf,i}) = A_c F_R [I \alpha \tau - (T_{nf,in} - T_a)]
\]  

(3)

Therefore,

\[
(T_{nf,o} - T_{nf,i}) = \left(\frac{A_c F_R}{\dot{m} C_p}\right) [I \alpha \tau - U_L (T_{nf,in} - T_a)]
\]  

(4)

F_R may be obtained from
\[ F_R = \frac{mC_p}{A_c U_L} \left[ 1 - \exp \left( \frac{A_c U_L}{mC_p} \right) \right] \]  
(5)

Then the collector effectiveness was got by utilize the relation,

\[ \eta_{s,c} = \frac{Q}{A_c I} \]  
(6)

Substitute Equation (2) and Equation (3) in the Equation (5) yields,

\[ \eta_{s,c} = F_R \left[ \alpha \tau - \frac{U_L(T_{nfim}-T_a)}{l} \right] \]  
(7)

Since \( F_R, \alpha \tau \) & \( U_L \) are constant,

\[ \eta_{s,c} = \alpha \left[ \frac{(T_{nfim}-T_a)}{l} \right] \]  
(8)

6. Nano fluid thermal measurement-physical properties

The empirical relationship used in research to compare Nano fluid properties with practical readings. The previous equations were used to calculate thermal transfer-physical properties at average Nano fluid temperatures. Volume fraction (\( \Phi \)) of the nanoparticles specified by [15].

\[ \Phi = \frac{V_p}{V_p + V_f} = m \frac{\pi}{6} d_p^{-3} \]  
(9)

Density [16]

\[ \rho_{nf} = \rho_{nf} \Phi + (1-\Phi) \rho_{DW} \]  
(10)

Viscosity [16]

\[ \mu_{nf} = (1-\Phi)\mu_{DW} + \Phi \mu_{DW} \]  
(11)

Specific heat [17]

\[ c_{nf} \rho_{nf} = \Phi (\rho_s c_p) + (1-\Phi)(\rho_{DW} c_{DW}) \]  
(12)

an efficient model for conductivity in Equations (13) [17]

\[ \frac{K_{nf}}{K_{DW}} = \left[ \frac{c_{nf}}{c_{DW}} \right]^{0.023} \left[ \frac{\rho_{nf}}{\rho_{DW}} \right]^{-0.358} \left[ \frac{\mu_{nf}}{\mu_{DW}} \right]^{-0.126} \]  
(13)

| Particles of Nano scale | density (Kg/m³) | Specific heat (J/kg k) | thermal transmittance (W/m² k) | \( \beta \times 10^3 \) (k') | \( \alpha \times 10^3 \) (m²/s) |
|------------------------|-----------------|------------------------|-------------------------------|--------------------------|--------------------------|
| Copper (cu)            | 8933            | 385                    | 401                          | 1.67                     | 11.7                     |
| Distilled water        | 997.1           | 4179                   | 0.613                         | 21                       |                          |

Table 1. Thermal –physical properties of the Nano fluids used [18].
7. Measurement of Nano fluid Thermal Properties

Many of the physical characteristics of Nano fluids (Cu + DW) and distilled water required for evaluation useful energy, thermal energy, collector effectiveness and the convective heat transfer. Dynamic viscosity ($\mu$) measured with a digital viscometer. model (DV-II+pro) as shown in Figure (11), Thermal conductivity measured by using (HOT DISK Tps 500 of KIJTALEY) as shown in Figure (12), Specific heat are measured by using apparatus of specific heat (ESD –201) as shown in Figure (13), as well as measuring the density by weighing sample and the volume it as shown in Figure (14). All physical characteristics are evaluated at various volume concentrations (1%, 3%, and 5 % vol.).

8. Results and Discussion

The primary goal of the job is to make better solar collector's thermal efficiency. Performance of the evacuated solar was discussed in details when the nanoparticles were applied to the collector at concentration (1%, 3% and 5%) and volume flow rates (30, 60, 90) L/min. Useful heat gain is related to how collectors can accumulate a quantity of energy it can be calculated by equations (1) and (2) respectively. Useful heat is gained by collectors at different inlet temperatures, volume flow rate (30, 60 and 90 L/min) and volume fraction (1, 3 and 5%vol) are shown in Figs (15), heat gained when using pure water are (40.058W, 42.6212W, 47.308W, 58.805W, 68.252W, 73.3055W, 74.6237W, 81.434W) for the volume flow rate (30 L/min). By adding the Nano fluids (Cu + DW) to the distilled water and at concentration (3 %) and at volume flow rate (30 L/min) noted the heat gained increased and became (54.118W, 55.876W, 62.247W, 69.053W, 75.063W, 78.8721W, 79.3106W, 84.43W) respectively,
Nano fluids (Cu + DW) at 5 %vol., has shown better results in comparison to distilled water about same flow rate, this means that, by increasing the concentration rate, the amount of heat gain is increased. The efficiency improvement values have been increased gradually as show in Figs (16), Notice that the efficiency enhancement increases as volume concentration and volume flow rates values increased, also it was noticed the effectiveness of collector when utilizing Nano fluids (Cu (30nm) + DW) better than that for distilled water due to high thermal conductivity of copper relative to distilled water. From another hand Table. (2) Show the levels of active enhancement of ETSC when using (Cu (30nm)) with distilled water as working fluids. The Nano fluids (Cu + DW), at concentrations (1% vol., and 5%vol) and volume flow rates (30, and 90 L/min), values of thermal solar properties (FR (τα), – FRUL) are 0.407, 1.156 W/m².k, 0.522 and 0.945 W/m².k, Whereas for distilled water at volume flow rates 30 L/min and 90 L/min are 0.252, 0.945 W/m².k, 0.321 and 1.051 W/m².k respectively. This meant that using of Nano fluids (Cu + DW) as a working fluid can enhance the productivity of collectors, other parameter for collector effectiveness comparison is ‘A’ (Area under the curve×100) which is better methods of recording effectiveness of the collector which implies the entire domain of the collector efficiency (X0 – X max), Area under the curve×100 (A) at various volume rates and volume concentration shown in Table 3. Figs (17) show the difference temperature between inlet and outlet collector and the flow rate for the Nano fluids (Cu (30nm) +DW) at volume concentrations (1, 3 and 5 % vol.), it could be shown that comparison increased. The error rate was calculated in practical data by root mean square and it did not exceed ± 4%. The difference in temperature between inlet and outlet is being smaller with distilled water when the Nano fluid concentration was being increased. The error rate was calculated in practical data by root mean square and it did not exceed ± 4%.

Figure 15: Gain beneficial heat of solar Collector at several Φ for Nano particles (Cu) with DW at different flow rates
Figure 16: Efficiency Collector of Nano particles (Cu) with DW at various flow rates

Figure 17: temperature changing between input and output solar collector at several \( \Phi \) for nanoparticles (Cu) and distilled water
Table 2: the enhancements results

| Components                  | Volume friction (Vol %) | volume flow rate L/min | Enhancement % |
|-----------------------------|-------------------------|------------------------|---------------|
| Distilled water             | 0%                      | 30                     | 2.41%         |
|                             | 0%                      | 60                     | 4.36%         |
|                             | 0%                      | 90                     | 5.43%         |
| Nano fluids (Cu(30nm)+Dw)   | 1%                      | 30                     | 13.44%        |
|                             | 3%                      | 60                     | 14.28%        |
|                             | 5%                      | 60                     | 15.32%        |
|                             | 1%                      | 90                     | 13.38%        |
|                             | 3%                      | 90                     | 14.17%        |
|                             | 5%                      | 90                     | 19.68%        |

Table 3: the experimental result

| Concentration (% Vol) | Q (LPM) | Model          | Area under curve X100 (A) | R²  |
|-----------------------|---------|----------------|---------------------------|-----|
| Nano fluid (Cu (30nm) +DW) |         |                |                           |     |
| 1                     | 30      | \( \eta = -1.156 \times 10^4 + 0.407 \) | 1.35 | 0.975 |
| 3                     | 30      | \( \eta = -1.163 \times 10^4 + 0.421 \) | 1.36 | 0.970 |
| 5                     | 30      | \( \eta = -1.192 \times 10^4 + 0.444 \) | 1.38 | 0.982 |
| 1                     | 60      | \( \eta = -1.201 \times 10^4 + 0.465 \) | 1.39 | 0.984 |
| 3                     | 60      | \( \eta = -1.215 \times 10^4 + 0.484 \) | 1.41 | 0.971 |
| 5                     | 60      | \( \eta = -1.225 \times 10^4 + 0.506 \) | 1.43 | 0.986 |
| 1                     | 90      | \( \eta = -1.233 \times 10^4 + 0.513 \) | 1.44 | 0.978 |
| 3                     | 90      | \( \eta = -1.245 \times 10^4 + 0.534 \) | 1.45 | 0.982 |
| 5                     | 90      | \( \eta = -1.257 \times 10^4 + 0.552 \) | 1.45 | 0.985 |
| Distilled water (Dw)   | 0       | \( \eta = -0.945 \times 10^4 + 0.252 \) | 1.29 | 0.984 |
| 0                     | 30      | \( \eta = -0.974 \times 10^4 + 0.274 \) | 1.24 | 0.978 |
| 0                     | 60      | \( \eta = -1.050 \times 10^4 + 0.312 \) | 1.27 | 0.978 |

9. Conclusions

The thermal enhancement of solar collector performance was investigated with Nano fluids (Cu (30nm) +DW) as working fluid. The nanoparticles used in investigate with particles concentration ratios (1, 3 and 5 % vol.) and the based working fluid was distilled water. The summary results are as follows:

1. The Nano fluids (Cu + DW), at concentrations (1% vol., and 5%vol) and volume flow rates (30, and 90 L/min), the values of thermal solar properties (FR (τα), – FRUL) are 0.407, 1.156 W/m².k, 0.522 and 0.945 W/m².k. Whereas in the case of distilled water at volume flow rates 30 L/min and 90 L/min are 0.252, 0.945 W/m².k, 0.321 and 1.051 W/m².k respectively.
2. Use of Nano fluids (Cu (30nm)) as a working fluid could improve thermal performance of evacuated tube solar collector compared with distilled water, especially at high inlet temperature.
3. The increase in the rate of concentration result an increase in heat gain.
4. The nature and size of nanoparticles play a vital role in optimizing the rate of heat transfer and improving the efficiency of the (ETSC).

Nomenclature:

\( V_p \) Volume of nanoparticle (m\(^3\)).
\( V_f \) Volume of fluid (m\(^3\)).
\( C_p \) Specific heat at constant pressure (J/kg K).
\( C_{pdw} \) Heat capacity of distilled water (J/kg K).
\( C_{ps} \) Heat capacity of nanoparticles (J/kg K).
\( K_{nf} \) Thermal conductivity of Nano fluid (W/m K).
\( K_{DW} \) Thermal conductivity of distilled water (W/m K).
\( Q_u \) Rate of useful energy gained (W).
\( Q_{coll} \) Heat rate from solar collector (W).
\( A_c \) Surface area of solar collector (m\(^2\)).
\( F_R \) Heat removal factor.
\( I \) solar radiation (W/m\(^2\)).
\( U_L \) Overall heat loss (W/m\(^2\)°C).
\( DW \) distilled water.
\( U_i \) Overall loss coefficient of solar collector (W/m\(^2\) K).
\( h_{fi} \) Heat transfer coefficient inside the tube (W/m\(^2\) K).
\( ETSC \) evacuated tube solar collector.
\( FLC \) flat plate collector.

Greek symbols

\( \mu_{DW} \) The Viscosity of distilled water (m\(^2\)/s)
\( \rho_{af} \) The density of Nano fluid (kg/m\(^3\))
\( \rho_{DW} \) The density of distilled water (kg/m\(^3\))
\( \mu_{af} \) The Viscosity of Nano fluid (m\(^2\)/s)
\( \alpha T \) The transmittance - absorptance product

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