An experimental investigation on the effect of hybrid Nano fluid (Al+Al₂O₃/distilled water) on the thermal efficiency of evacuated tube solar collector

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Abstract: The objective of this research is to explore experimentally the impact of using (Al+Al₂O₃/distilled water hybrid Nano fluid) as the working fluid on the thermal efficiency of the evacuated tube solar collector with inner cylindrical coil within the vertical tank. The nanoparticles volume fraction was 1, 3, and 5% with the (50 nm) dimension of nanoparticles. The performance of the evacuated tube solar collector (ETSC) utilizing (Al+Al₂O₃) hybrid Nano fluid and water was compared to the flow rate within the coil ranged from 15, 30, and 45 l/hr.m². The results of the current research showed that the highest effectiveness of the solar collector 24.89% for mass flow rate of Nano fluid 45 l/hr.m² and nanoparticles volume fraction of 5% vol. Findings show that (Al+ Al₂O₃) hybrid nanofluids could be utilized in an ETSC as working liquids to absorb heat from solar radiation and effectively transform solar energy into thermal energy.

Keywords: Solar collector, performance, Hybrid Nano fluids, evacuated tube solar collector.

1. Introduction.
Solar energy is transformed into useful heat energy. Many writers observed that ETSCs have significantly efficiencies than FPCs, particularly at low temperatures application. Because of their tubular absorber it has great performance, especially in low radiation conditions, throughout the year according to the flat plate solar collector, ETSCs have less convection heat lost and less cost as Kalogirou [1], Morrison et al. [2], Zambolin and Del Col [3], and Ayompe et al. [4] when noticed the effectiveness of the evacuated tube solar collector became greater than the efficiency of the flat plate solar collector when the experiments were performed under the same circumstances. The effectiveness of the heat pipe evacuated tube solar collector tube seemed to be higher than the that of the U-tube evacuated tube solar collector type with 8% Tong and Cho [5]. Rely upon the work of Sabih a et al [6] a medium raise in outlet temperature when utilize evacuated tube solar collector was about 25 to 40% contrast to FPCs collector. In actual conditions, Liu et al. [7] reviewed the heat transfer characteristics of the evacuated tube collector. In many other cases, they found that the heat transfer coefficient was about 0.4 to 0.6 W / m² K. Luie et al. [8] examined CuO nanofluid and having been found that the evacuated tube solar collector’s effectiveness is 30% greater than Deionized water. Hussain et al. [9] utilize the Nano fluids based on water from Ag and ZrO₂. They found that the evacuated tube solar collector has top efficiencies form the comparative to Nano fluids from ZrO₂ to. The impact of using Al₂O₃ Nano fluid in an evacuated tube collector was reviewed by Al – Mashat and Hasan[10-13] they found that the collector's performance was highly according to the concentration of nanoparticles and an increase of 28.4% for 1% vol was reported. Hüseyin Kaya et.al [14] were discussed the efficiency of Zinc oxide / Ethylene Glycol-Pure Water as operation.
liquid. Examined experimentally carried out at various volume concentrations (1.0 %, 2.0%, 3.0 % and 4.0 %), Zinc oxide nanoparticles have been linked to the EG-PW foundation liquid, the largest collector performance was found to be 62.87 % more than EG-PW as a working fluid for 3.0 vol. percent and mass flow rate of 0.045 kg/s. Also, for the mass flow rates of 0.03 and 0.02 kg/s, this amount is 5.2% and 6.88% larger than the operation liquids. Y. Yang Gan et.al [15] studied the evaluates the thermal efficiency and conducts an ETSC entropy analysis in which TiO₂ nanofluid was applied as operating fluid. Titanium dioxide (TiO₂) nanofluid is generated by scattering a tiny quantity of TiO₂ nanoparticles into distilled water. Pak and Young I. Cho [16] examine the thermal performance of nanoparticles TiO₂ and Al₂O₃ dispersed in distilled water flowing through the horizontal circular tube. Where Titanium dioxide TiO₂ and Alumina respectively were using nanoparticles with a diameter of 13 nm and 27 nm. Soudhe Iranmanesh et.al [17] Were investigated experimentally the impact of graphene Nano platelets with distilled water nanofluid on the thermal performance of (ETSC). The mass proportion of GNP was regarded to be 0.025%, 0.5%, 0.075% and 0.1 wt%. The physical and thermal characteristics of graphene nanoplatelets nanofluids involve stability; specific heat capacity, viscosity, and thermal conductivity have been explored.

2. Experimental work
This research aims to explore to investigate experimentally the heat transfer characteristics and flow of the evacuated tube solar collector using hybrid suspensions. As well as studying the impact of concentration of hybrid nanoparticles, size of hybrid nanoparticles, and type of suspensions and temperature of hybrid suspensions on the efficiency ETSC collectors. Figure 1 show the block diagram of ETC whilst the Figure 2 displays the equipment’s which used in solar thermal device. The work is achieved under Baghdad, Iraq (33.33°latitude and 44.14 °longitude), the ETSC consist of 10 evacuated tubes where table 1 showed the characteristics ETSC, and on the other hand, Figure 3 revealed the vertical heat exchanger. Circulation water pump Germany – made for the transfer hybrid nano suspensions in different speed was also used. Moreover, several of the measuring devices, Connecting several thermocouples to the heat exchanger on input and output solar collector, The flow measurement was inserted from another side with a range of (20— 70) LPM to measure the system's volumetric flow rate. Table 1: ETC – collector Solar Specification

| Table 1. Evacuated tube solar collector specification |
|-----------------------------------------------------|
| **Out tank material** | **White color steel** | **Capacity** | **100L** |
| Vacuum tube | 47mm*1.5 series glass | insulation | High density pressure |
| Serial number | 0811JS | Inner tank material | SUS3042b food grade 0.41mm |
| Manufacture date | 13.Feb.2018 | Frame angle | 40° |

**Figure 1.** Solar heating unit block diagram  
**Figure 2.** Evacuated tube solar collector shadow system.
3. Method and characterization of preparation.
The nanoparticles used in this work are aluminum (Al (50 nm)) and aluminum oxide (Al₂O₃ (50 nm)). The mixture is established by applying, two steps, the first one is achieved by adding pre-weighted amounts of dry nanoparticles in distill water. In the second step the mixtures is exposed to ultrasonic mixing using ultrasonic mixer with the following specification 100 kHz, 300 W at 25 – 30 °C, Toshiba, England. The aims of using the ultrasonic mixer are to break down any nanoparticle aggregates. Figure 4 shows the mixing procedure of the Nano fluids. While the thermo physical properties of the Nano fluids is shown in table 2.

![Figure 3. Heat exchanger](image)

**Figure 3.** Heat exchanger

![Figure 4. The preparation process of hybrid Nano fluid.](image)

**Figure 4.** The preparation process of hybrid Nano fluid.

![Figure 5. Hybrid nanofluids mixtures. White mixture is (Al+Al₂O₃+DW). and transparent liquid is distilled water](image)

**Figure 5.** Hybrid nanofluids mixtures. White mixture is (Al+Al₂O₃+DW). and transparent liquid is distilled water.
Table 2. The thermo physical properties of hybrid Nanoparticle.

| Base fluid                  | \( \rho \) (kg/m\(^3\)) | \( C_p \) (J/kg k) | \( k \) (W/m k) | \( \beta \times 10^5 \) (k-1) | \( \alpha \times 10^5 \) (m\(^2\)/s) |
|-----------------------------|-----------------------------|---------------------|-----------------|-------------------------------|----------------------------------|
| Distilled water             | 997.1                       | 4179                | 0.613           | 21                            |                                  |
| Aluminum (Al)               | 2707                        | 896                 | 236             | 2.4                           | 973                              |
| Aluminum Oxide (Al\(_2\)O\(_3\)) | 3970                        | 765                 | 40              | 0.85                          | 131.7                            |

4. Data analyses and validation
There are more parameters have been calculated such as collector efficiency, useful heat energy using mathematical expressions

The expression for heat energy useful (Qu), is:

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

(1)

The heat energy is transformed into thermal energy of water in the tubes, as:

\[
Q = \dot{m} C_p (T_{hb,in} - T_{hb,f})
\]  

(2)

Then the collector efficiency is obtained by using the formula

\[
\eta_{s,c} = \frac{Q_u}{A_C I}
\]  

(3)

5. Estimation of hybrid nanosuspensions thermo physical properties
In this study, mathematical relationships were used to calculate hybrid Nano suspensions physical properties compared to hybrid Nano fluid properties measurements [18]. The following equations estimated the fluid dynamics Hybrid Nano fluid physical characteristics at median temperature of the hybrid Nano suspensions. The density of hybrid Nano fluids can be estimated by formula [18].

\[
\rho_{hb, nf} = \Phi_{np1} \rho_{np1} + \Phi_{np2} \rho_{np2} + (1 - \Phi_{np1} - \Phi_{np2}) \rho_D
\]  

(4)

Also the viscosity calculated by using Equation, [18]

\[
\mu_{hb, nf} = [1 + 2.5 (\Phi_{np1} + \Phi_{np2})] \mu_DW
\]  

(5)

From another hand the specific heat can be estimated by equation), [18].

\[
\rho_{hb, nf} C_p_{hb, nf} = \Phi_{np1} \rho_{np1} C_p_{np1} + \Phi_{np2} \rho_{np2} C_p_{np2} + (1 - \Phi_{np1} - \Phi_{np2}) \rho_DW C_p_{DW}
\]  

(6)

Thermal conductivity was estimated by using Equation, [18].

\[
\frac{k_{hb, nf}}{k_{DW}} = \left[ \frac{C_p_{hb, nf}}{C_p_{DW}} \right]^{-0.023} \left[ \frac{\rho_{hb, nf}}{\rho_{DW}} \right]^{1.358} \left[ \frac{\mu_{hb, nf}}{\mu_{DW}} \right]^{0.126}
\]  

(7)

6. Results
Firstly, the collector was examined as when the working fluid is distilling water. Figures indicate that the performance curves of the solar collectors under Standard with (Al (50nm) + Al\(_2\)O\(_3\) (50nm)) with distilled water hybrid Nano fluids at concentrations (1, 3, 5% vol) and mass flow rate (15, 30 and 45 L/hr.m\(^2\)). It was discovered that the hybrid (Al + Al\(_2\)O\(_3\)) with DW at 5% vol was greater than that for distilled water due to high thermal conductivity compared to distilled water. The hybrid Nano fluids (Al + Al\(_2\)O\(_3\)) at 1% vol still grant comparable with distilled water. The efficiency, improvement values were gradually increased as shown in Figures 6 to 8, Where the percentage of improvement
were increased gradually as shown in table 3 at mass flow rate (15, 30, 45 lit/hr.m²) and volumetric concentrations (1%vol, 3%vol, and 5%vol) respectively. Note that when increasing the volumetric flow rate and volume concentration values, the thermal efficiency improvement also.

The useful heat gains from the solar collectors at various inlet working fluid temperature, volume flow rate (15,30 and 45 L/hr.m²) and volumetric concentrations (1%vol, 3%vol, and 5%vol) respectively. Note that when increasing the volumetric flow rate and volume concentration values, the thermal efficiency improvement also.

In addition, the hybrid nanofluid (Al(50nm)+ Al₂O₃(50 nm)) with distill water at 5%vol has shown more performance relative to distilled water, whereas the hybrid nanofluid at 1% vol showed similar results with distilled water. Several useful heat gains for distilled water at different mass flow rate and different hybrid nanoparticles volume fraction are given in figures were mentioned above. The heat gained when using figures was mentioned above. The heat gained when using distilled water is (40.46 W, 42.98 W, 58.27 W, 68.35 W, 74.15W, and 79.25W) for the flow rate of 15 lit/hr.m², respectively. In addition, hybrid fluids by adding the hybrid nanoparticles (Al/Al₂O₃) have been used with working fluid.

The useful heat gain at the concentration of 3%vol and the flow rate of 30 lit/hr.m² (75.14W, 78.12W, 83.69W, 79.23W) respectively as shown in Figure 9. This means that an increase in the concentration rate results in an increase in the amount of heat gain.

Area under the curve×100 (A) is an alternative way to record the collector effectiveness that indicates the entire domain of the collector efficiency (X₀–Xmax). Quantities Area under the curve×100 (A) at different mass flow rate for distilled water are 1.28, 1.31 and 1.35 respectively. From another hand as shown in table 3 show the percentages of enhancement of effective of ETC by suing (Al/Al₂O₃ (50nm)) with (distilled water) as working fluids.

Table (3). The experimental result for the characteristic of the solar collector.

| Components | Volume fraction (Vol %) | Mass flow rate L/hr.m² | Area under the Curve x100 | Models | R² |
|------------|------------------------|------------------------|--------------------------|--------|----|
| Hybrid Nano-composite | 1 | 15 | 1.36 | η = -1.025 X + 0.672 | 0.984 |
| (Al/Al₂O₃(50nm)+Dw) | 3 | 15 | 1.38 | η = -1.037 X + 0.684 | 0.985 |
| | 5 | 15 | 1.39 | η = -1.079 X + 0.705 | 0.987 |
| | 1 | 30 | 1.41 | η = -1.073 X + 0.694 | 0.993 |
| | 3 | 30 | 1.43 | η = -1.079 X + 0.705 | 0.995 |
| | 5 | 30 | 1.45 | η = -1.085 X + 0.708 | 0.996 |
| | 1 | 45 | 1.47 | η = -1.088 X + 0.712 | 0.992 |
| | 3 | 45 | 1.49 | η = -1.126 X + 0.714 | 0.993 |
| | 5 | 45 | 1.51 | η = -1.143 X + 0.718 | 0.992 |

Figure 6. efficiency Collector of Hybrid Nano fluid (Al/Al₂O₃) with DW at various Φ

Figure 7. efficiency Collector of Hybrid Nano fluid (Al/Al₂O₃) with DW at various Φ
7. Conclusions
The main concluded points of this study may be summarized as following:

1. The type and size hybrid nanoparticles play a main role in refinement of heat transfer rate and enhancement performance of evacuated solar collector.

2. The solar collector efficiency was improvement by utilizing hybrid suspension (Al/Al$_2$O$_3$(50nm)+Dw) according to small particle size of aluminum and oxide aluminum as well as have good thermal conductivity for.

3. Utilize of hybrid suspension (Al/Al$_2$O$_3$ (50nm) +Dw) as a working fluid could become better thermal performance of evacuated solar collector contrast with distilled water, especially at high inlet temperature.

4. The rise in the concentration rate results in an increase in the quantity of heat gain.

5. The heat transfer characteristic in coil tube is better than distilled water by using Nano fluids.

6. The performance index of the hybrid nanofluid flow inside the coil tube is greater than the performance index of the base fluid. The high performance index suggests that applying both of the heat transfer enhancement techniques studied in this investigation is a good choice in practical application.

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