Experimental Determination of Water, Water/ Ethylene Glycol and TiO$_2$-SiO$_2$ Nanofluids mixture with Water/Ethylene Glycol to Three Square Multilayer Absorber Collector on Solar Water Heating System: A Comparative Investigation

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Abstract. This paper investigates three square multilayer absorber solar collector in Solar Water Heating System (SWHS) experimentally. The main aim was to study the output temperature of the solar absorber collector based on distilled water (DW), water/ ethylene glycol (W/ EG) and TiO$_2$-SiO$_2$ nanofluids. An experimental apparatus for testing absorber solar collector was designed and built at Universiti Malaysia Kelantan (Jeli Campus). By using the two-step method, TiO$_2$-SiO$_2$ nanofluids with ratio 30:70 and volume concentration at 1.0%. For W/ EG the ratio is 60:40. The effect working fluid was studied experimentally on the output temperature of three square multilayer absorber solar collector in SWHS with Angle of Sunlight (AoS) at 45°, volume flow rate at 3 litres per minute (LPM) and varies Intensity of Light (IoL) at 300, 500 and 700 W/m$^2$. The output temperature is determined through the experimental results by using this apparatus. The result reveals that the output temperature of the solar absorber collector is TiO$_2$-SiO$_2$ nanofluids with 1.0% of volume concentration as a best working fluid at each intensity of light.

Keywords: solar collector, water heating, nanofluids, intensity

1. Introduction

Renewable energy comes from continuously replenishing natural processes [1, 2]. It derives directly from the sun or heat generated deep within the earth in its different forms. The definition includes electricity and heat from solar, wind, sea, hydropower, biomass, geothermal resources, and renewable biofuels and hydrogen [3]. Renewable sources of energy are classified into three categories: direct solar energy, indirect solar energy and non-solar renewable energy [4].

Most renewable sources of energy derived from solar radiation. Natural solar energy refers to the conversion of solar thermal and photovoltaic solar energy [5]. Indirect solar energy comprises wind, wave, and biofuels [6]. Non-solar renewable energy sources are those that do not rely on solar radiation. Two non-solar renewable sources of energy are tidal and geothermal. Renewable energy has become a critical engineering sector, as fossil fuel resources have diminished, and environmental concerns have
increased. There is no doubt that a large proportion of the energy the human race consumes would come from several renewable sources in the future.

A solar water heater is a device capable of heating water by sunlight. It not only allows for substantial energy savings as, contrary to natural gas or fuel oil, but solar power is also free. Besides, it is a way of producing hot water for year-round sanitation without emitting any CO₂. Although solar water heating systems (SWHS) have been in decades, SWH technologies can be run efficiently and affordably in any environment with today’s technological advances. The plans are specifically designed for different climatic and geographical areas of the country, depending on the heating needs SWHS can be classified into five primary types: direct circulation systems, indirect water heating systems, drain-back systems, air systems and pool heaters [7]. If some form of heat pump arrangement is used, the solar heating system will provide all the heat needed throughout the year. The heat pump can therefore be considered an efficient and relatively inexpensive auxiliary heat source. Naturally, the economy will be improved if the same heat pump system is used for both winter heating and summer cooling.

A solar collector is a flat box, consisting of three main parts, a transparent cover, tubes carrying a refrigerant, and an insulated back plate. The solar collector works on the principle of the greenhouse effect; incident solar radiation is transmitted through this surface to the transparent cover of the solar collector [8]. Usually the inside of the solar collector is evacuated; the energy contained in the solar collector is trapped and heats the coolant contained in the tubes. Typically the pipes are made of copper, and black is painted on the back plate to help absorb solar radiation [9]. The solar collector is usually insulated to avoid heat loss, the. Solar collector characterization is based on experimental techniques in addition to the validation of similar models. For different complexities, both methods can be implemented [10].

A nanofluid is a mixture in the base fluid of nanoparticles suspended. It is an advanced heat transfer fluid with superior heat transfer properties [11, 12]. Recent nanotechnology advances produce fluids that have better thermal properties than conventional fluids [13, 14]. The frequency at which a substance transfers heat is thermal conductivity. It is a significant factor in increasing the efficiency of nanofluid in heat transfer, and it has been extensively studied by researchers [15, 16]. The rate of heat transfer by solids is much higher than that by liquids and gasses, which is why nanofluids have higher thermal conductivity values compared to their base fluids [15, 17, 18]. Viscosity is the critical parameter for determining the coefficient of convective heat transfer. Understanding the nanofluid of viscosity mechanisms is worrying due to the lack of a general mathematical model predicting viscosity activity in nanofluids. Several mathematical models have been developed to predict the viscosity of nanofluids. Nanofluids can be used in engine cooling, solar water heating, cooling devices for heat exchange, improving chillers heat transfer efficiency, and so on.

Nanofluids performed well and showed satisfactory results which prompted the researchers to think about the suspension in the base fluid of various combinations of nanoparticles that were later developed and called hybrid nanofluids [15]. Thermal conductivity is the most glittering nanofluid property that has required researchers attention most. These are because of the genuinely complex and important thermophysical property, but unfortunately, experimental studies and theories have not yet explained the hybrid nanofluids of increased thermal conductivity. Research has revealed the following important factors that have influenced hybrid nanofluids of thermal conductivity. In recent years, there have been many advancements in this field, but the most significant was its progress towards hybrid nanofluids [19-21]. The experts made a step forward at that time and started analyzing advanced nanofluids.

A result based on the effect of the working fluid is used in the solar collector is still new, especially by using nanofluids in the system. However, we still need to research to make sure that the use of nanofluid in solar thermal engineering devices improves their efficiency. Hence, this study aims to study the effect of solar water heater based on the difference of working fluid used. In this experiment, it is attempted to determine the output temperature of the three square multilayer absorber solar collectors at different working fluids between distilled water (DW), water/ethylene glycol (W/EG) and TiO₂-SiO₂ nanofluids with 1.0% of volume concentration.
2. Materials and Method

2.1. Nanoparticles Materials and Base Dilution
The average diameters for TiO$_2$-SiO$_2$ nanoparticles obtained from US Research Nanomaterials, Inc. were 50 and 22 nm with weight concentrations of 40 and 25 wt. %. Table 1 shows the properties of the selected nanofluids. However, distilled water and ethylene glycol were used as liquid-based, and the mixture ratio used was in the ratio (60:40). Table 2 shows the characteristics of the ethylene glycol.

| Table 1. Nanoparticle Properties [21] |
|--------------------------------------|
| Type of nanoparticle | Diameter, (nm) | Weight concentration, $\omega$ (%) | Volume concentration, $\varnothing$ (%) | Specific heat, $C$ (J/Kg.K) | Density, $\rho$ (kg/m$^3$) |
|----------------------|----------------|-------------------------------------|-------------------------------------|--------------------------|------------------------|
| TiO$_2$              | 50             | 40                                  | 13.62                               | 692                      | 4230                   |
| SiO$_2$              | 30             | 25                                  | 13.06                               | 745                      | 2220                   |

| Table 2. Physical and Chemical Properties of Ethylene Glycol [22] |
|---------------------------------------------------------------|
| Parameter                                | Value          |
| pH                                      | 5.5-7.5        |
| Melting Point (°C)                        | -13            |
| Boiling Point (°C)                        | 197.6          |
| Vapor pressure (mmHg)                     | 0.12           |
| Density (kg/m)                            | 1113           |
| Molar Mass (g/mol)                        | 62.07          |

2.2. Thermo-physical Properties Measurement
Figure 1 shows the KD2 Pro is used as a property analyst to measure the thermal conductivity of a sample from Decagon Devices, Inc., USA. After two hours through the sonication process, data were collected for a temperature range of 30 to 70 °C.

![Figure 1. Apparatus and Instrument used in thermal conductivity measurement.](image)

Figure 2 shows the Brookfield LVDV-III Ultra Rheometer is used to measure the viscosity of nanofluids. This method is used in viscosity measurement by several researchers [21, 23, 24]. At temperatures between 30 °C and 70 °C, viscosity was measured, and 30 min was allowed to stabilize the temperature, and its value was recorded at stable conditions.
2.3. Experimental Setup

Figure 3 shows a simple schematic overview of components for solar absorber collector which consists of a few essential elements such as collecting tank, solar submersible pump, collector, control panel, 12 pieces of the spotlight, interface of Arduino Uno, K-type thermocouple and data logger. A solar submersible pump is connected to a collecting tank to circulate the working fluid through the system. The collector consists of three square multilayers (0.23 × 0.23 m; 0.33 × 0.33 m; 0.43 × 0.43 m) and insulated by spraying with the flat black spray. K-type thermocouples are used and fixed at the inlet, outlet and three square multilayer absorber solar collector of solar water heating system.

2.4. Experimental Procedure

The experiment started with distilled water being filled into the supply tank, followed by W/ EG and then TiO$_2$-SiO$_2$ nanofluids. Solar simulators replace sunlight as these experiments are conducted in a
lab. By exposing the solar collector absorber to the sunlight for 15 minutes of heating, data of solar collector is collected. Then, the light on the solar simulator is turned off for the cooling process for 15 minutes. The data obtained is recorded by the data logger every 2 minutes for up to 30 minutes. The data taken are as follows:

- **a. Input temperature** \(T_{in}\)
- **b. Output temperature** \(T_{out}\)
- **c. Ambient temperature** \(T_{at}\)
- **d. Absorber temperature** \(T_{ab}\)

### Table 3. Detail description of the solar radiation test rig

| No. | Description                  | Specification                                                  |
|-----|------------------------------|----------------------------------------------------------------|
| 1   | Absorber solar collector     | Triple square multilayer                                       |
| 2   | Thermocouple                 | K-type                                                         |
| 3   | Pyranometer                  | Apogcc Logan UT SP-110                                         |
| 4   | Spotlight                    | Halogen 500 W (12 pieces)                                      |
| 5   | Data logger                  | ADAMView Advantech Data Acquisition                            |
| 6   | Solar submersible pump       | Max 7LPM                                                       |
| 7   | Dimmer                       | Setting up Intensity Light (300, 500 & 700 W/m²)               |
| 8   | Interface Arduino Uno        | Coding system                                                  |
| 9   | Arduino Uno                  | Reading up-flow meter (LPM)                                    |
| 10  | Supply tank                  | 5L                                                             |
| 11  | Controller                   | Controlling the speed of the pump (by Voltage and Current)     |

**Figure 4.** Experimental setup at Angle of Sunlight (AoS) 45°.

### 3. Results and Discussion

Experiments were performed to compare the response of the three square multilayer absorber solar collector to the fluid difference between distilled water, water/ethylene glycol (W/EG) and TiO₂-SiO₂.
nanofluids with 1.0% of volume concentration. The intensity of Light (IoL) varies starting by 300, 500 and 700 W/m². All data obtained is through data logger with a k-type thermocouple, which is attached to absorber collector for getting output temperature.

3.1. Effect of working fluid

The results are shown in Figure 5 the output temperature in the working fluid using TiO₂-SiO₂ nanofluids with 1.0% of volume concentration higher compared to W/EG and DW. The output temperature at the beginning of the cooling process obtained on working fluid TiO₂-SiO₂ nanofluids with 1.0% of volume concentration is 34.9 °C. It maintains the temperature rise to 35.3 °C and always continues until the end of collecting data.

![Figure 5](image_url)

**Figure 5.** Temperature output of the absorber with solar radiation 300 W/m².

The volume flow rate of 3 LPM is observed consistently on a three square multilayer solar collector absorber through a tank in a closed-loop system assisted by a pump to complete the working fluid cycle. Figure 6 shows the output temperature in working fluid distilled water is lower compared to W/EG and TiO₂-SiO₂ nanofluids with a volume concentration of 1.0%. However, the onset of cooling process output temperature for distilled water and W/EG did not show much difference of 31.2 and 32.5 °C respectively compared to the output temperature of TiO₂-SiO₂ nanofluids with a volume concentration of 1.0% of 34.6 °C.
The output temperature obtained is based on the angle of sunlight (AoS) 45° lighting to the solar collector absorber. The average result got shows that TiO$_2$-SiO$_2$ with a volume concentration of 1.0% is the highest. Similarly, Figure 7 shows that the output temperature for TiO$_2$-SiO$_2$ with a volume concentration of 1.0% is 34.9 °C after the start of the cooling process. Followed by 33.6 °C by W/EG and the last one is DW, which is 32.4 °C. Then the output temperature will show constant value until the end of the cooling process at 30 minutes. The output temperature at 30 minutes is 32.4, 33.1 and 35.5 °C for DW, W/EG and TiO$_2$-SiO$_2$ with a volume concentration of 1.0% respectively.
Therefore, it can be concluded that the working fluid on the three square multilayer absorber collector affects the data for the output temperature. The mass flow rate in the solar collector absorber provides an increase in temperature output rapidly based on the type of working fluid used. Therefore, copper pipes can transfer heat to the working fluid through a convection heat transfer and thus increase its temperature. M. Norhafana et al. [25] in the study of solar collector absorber using working fluid distilled water has shown an increase in heat transfer also found in the study conducted.

4. Conclusions

In this study, experimental determination to study the comparison of distilled water (DW), water/ethylene glycol (W/EG) and TiO$_2$-SiO$_2$ nanofluids as working fluid in three square multilayer absorber solar collector of Solar Water Heating System. In conclusion, the solar collector of three square multilayers of solar absorber collector is proven to play a vital role when it comes to adapting in multidirectional solar radiation with different radiation intensity of 300, 500 and 700 W/m$^2$. The heat transfer performance by TiO$_2$-SiO$_2$ nanofluids with 1.0% of volume concentration showed the highest temperature output obtained, followed by water/ethylene glycol (W/EG). The lowest heat transfer performance is seen in distilled water (DW).

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