Angle of inclination and radiation intensity variation effects on the flat plate solar collector's performance using graphene oxide (GO)-water nanofluid

A A Permanasari¹², S A Putra¹, P Puspitasari¹², S Sukarni¹², S N A Zaine³, and W Wahyunengsih⁴

¹Department of Mechanical Engineering, Faculty of Engineering, Universitas Negeri Malang, Jl. Semarang No 5, Malang 65145, Indonesia
²Centre of Advanced Materials for Renewable Energy (CAMRY), Universitas Negeri Malang, Jl. Semarang No 5, Malang 65145, Indonesia
³Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, 32610, Bandar Seri Iskandar, Perak, Malaysia
⁴Development of Islamic Society Department, State Islamic University Syarif Hidayatullah Jakarta, Indonesia

avita.ayu-ft@um.ac.id

Abstract. Flat Plate Solar Collector is a special heat exchanger instrument that transforms solar radiation energy into heat energy. Various attempts have been completed to improve the flat plate solar collector's performance. One of them is by developing advanced heat transfer fluid with better thermophysical properties than base fluid. Further, the flat plate solar collector's inclination angle and radiation intensity were investigated to identify the most optimal solar radiation angle of incidence. This study discusses the use of a 0.006% graphene oxide-water nanoparticle toward the nanofluid's thermophysical properties, sufficient radiation intensity of flat plate solar collector performance, as well as the inclination angle of flat plate solar collector toward the collector's performance. The used radiation intensity variations were 415 W/m², 515 W/m² and 615 W/m². Meanwhile, the radiation used in this study was from a sun simulator 750 W/m². In each radiation intensity variation, the inclination angle test of 30°, 45°, and 60° for the flat plate solar collector were carried out. This study was expected to discover the best performance of graphene oxide-water nanofluid usage, collector's inclination angle variation, and radiation intensity variation.

1. The first section in your paper

Solar energy is one of the renewable energy alternatives with a massive capacity that remains minimally utilized. Solar energy usage in the industrial and daily fields is classified into photovoltaic, photothermal, and photochemistry [1]. As a tropical country passed by the sun the whole year, Indonesia has the opportunity to apply photothermal daily; thereby, solar-powered water heater or solar collector is one of the alternative energy usage massively investigated by experts, recently [2].

Solar collector operates using solar radiation heat energy to infuriate the liquid fluid within the collector pipe and is divided into three categories of flat plate collector, pipe collector, and HPSC [3]. Flat plate solar collector is the most commonly used water heater system classified as a low-temperature
device (<100°C). The flat plate solar collector's performance depends on the solar radiation absorbance, which later transferred into the working fluid within the solar collector pipe in the form of energy [4]. The low heat conductivity on conventional heat transfer fluid, such as water, oil, and ethylene glycol, severely limits solar collector performance; thus, an advanced heat transfer fluid with a higher conductivity is developed in this research [5]. The small solid particle suspension within the fluid is an innovative means that escalates the fluid's thermal conductivity. Various types of powder, such as metallic, non-metal, and polyamic particles, can be added to the solution to expand the solar collector's heat transfer efficiency [6].

Nanofluid and nanoparticle were first introduced by Choi in 1995 to enhance the thermal conductivity by dispersing the 1-100nm metal particle. They were also used to improve the base fluid's heat transfer. Researchers investigating the effect of nanoparticle concentration report the intensified thermal conductivity and the increased nanoparticle concentration [8]. Several nanoparticles, such as CuO, MgO, MWCNT, TiO₂, Al₂O₃, and ZnO, have been investigated using basic water fluid. ZnO nanoparticle encounters 22% widen thermal conductivity from an additional 0.005% ZnO concentration to the base fluid [9]. The significant increase of fluid's thermal conductivity and heat transfer coefficient are known as exceptional nanofluid's physical effect. The solid phase metal possesses a higher thermal conductivity than conventional fluid [10]. Therefore, metal nanoparticles suspended within the fluid is a solution that better improve the thermal conductivity than the pure fluid [4].

According to the ideas mentioned above, this research is required to escalate the solar collector's performance. This study uses 0.006% concentration Graphene Oxide (GO) nanofluid base fluid combined with distilled water. This study was carried out by various radiation intensity and inclination angles on a 30cm² area dimension solar collector instrument. The effects of radiation intensity and inclination angle variation on the flat plate solar collector's heat transfer using Graphene Oxide (GO)-water nanofluid was analyzed.

2. Method

2.1. Flat plate solar collector
This experimental study used a laboratory-scale flat plate solar collector. The flat plate solar collector's scheme is illustrated in Figure. 1. This study was carried out using base fluid and 0.006% graphene oxide-water nanofluid, as well as radiation intensity and inclination angle variation of flat plate solar collector.

![Figure 1. Flat plate solar collector's scheme](image-url)
2.2. Graphene oxide
The nanoparticle used in this study was graphene oxide. It is a thick layer of the single atom from a highly stable carbon [11]. Graphene has a hydrophobic property, but with the O function group's presence, graphene oxide can be dispersed into the water [12]. Its hydrophilic feature made graphene oxide becomes a suitable material for nanofluid. The specification of graphene oxide is presented in Table 2.

2.3. Base fluid
The base fluid used as nanofluid in this research was distilled water (H$_2$O). The thermophysical properties of distilled water are shown in Table 3.

2.4. Preparation of Nanofluid
The nanofluid was constructed by blending nanoparticle into the base fluid. This research used 500ml of liquid and 0.006% of graphene oxide as the nanoparticle. The nanofluid production was divided into two phases of magnetic stirrer and ultrasonic sonication. During the magnetic stirrer process, the base fluid and nanoparticle were mixed and stirred using a magnetic stirrer for 30 minutes. After that, the nanofluid was sonicated on ultrasonic sonication for 2 hours with a 100% amplitude to minimize the nanoparticle aggregation in the second stage. Consequently, the 0.006% concentration nanofluid was obtained.
 Experimental Preparation

This study involved two stages of the test. The first stage was the thermophysical properties test of base fluid and 0.006% graphene-oxide-water nanofluid; meanwhile, the second test was the flat plate solar collector test. On the first test, the density, viscosity, specific heat, and thermal conductivity were tested. The density test was carried out using a digital scale and measuring cup to reveal the used fluid's mass per unit volume. Simultaneously, the viscosity test was completed using viscometer NDJ-8S DRV to identify the viscosity of both base fluid and 0.006% graphene oxide-water nanofluid. Meanwhile, the thermal conductivity and specific heat tests were conducted using a KD2 pro thermal analyzer. After the thermophysical properties of the base fluid and graphene oxide nanofluid were obtained, the flat plate solar collector test was performed with those fluids acting as its working fluid. The test was carried out indoor using a sun simulator 750 watt, for 60 minutes, with 1 l/m discharge, inclination angles of 30°, 45°, and 60°, and radiation intensity of 415 W/m², 515W/m², and 615 W/m².

 Flat Plate Solar Collector's Performance

The thermal performance of flat plate solar collectors can be tested by concluding the instantaneous efficiency at a different value from the occurring radiation, the surrounding temperature, and the temperature of heat transfer fluid inlet. The instantaneous efficiency is defined as the ratio of attained energy used for solar energy passed on the plate absorber, as shown by Formula (1).

\[ \eta_c = \frac{Q_u}{A_c \cdot I} \]  

in which \( \eta_c \) represents the collector efficiency, \( Q_u \) is the energy obtained by the collector, \( A_c \) is the collector’s surface area, and \( I \) is the radiation intensity attained by the solar collector.

The heat energy absorbed by the collector is defined as the heat energy extraction rate from the working fluid flowing to the flat plate solar collector \( Q_u \) through Formula (2) [12] [13].

\[ Q_u = m \cdot C_p \cdot (T_o - T_i) = \rho \cdot v \cdot A \cdot C_p \cdot (T_o - T_i) \]  

where \( m \) represents the occurring mass flow rate, \( C_p \) is the specific heat, and \( T_o - T_i \) is the temperature difference between input and output.

The highest heat loss coefficient is the function of the various parameter, including the absorber instrument’s temperature, temperature ambient, wind velocity, the emissivity of the absorber and cover glass plate, the inclination angle, and so forth [14]. All of the loss can be estimated using Formula (3-5).
\[ U_L = U_b + U_t + U_e \]  
\[ U_t = \left( \frac{N}{c} \right) \frac{1}{T_{pm} - (N+f)} + \frac{1}{h_w} + \frac{\sigma(T_{pm} + T_a)}{e^{N+0.0059/N}h_w - 1 + 0.133e - N} \]  
\[ U_b = \frac{k}{L} \]  
\[ U_e = \frac{k}{L} \times \frac{\lambda_{edge}}{A_{collector}} \]

in which \( U_b \) is the heat loss coefficient below the collector, \( U_t \) is the heat loss coefficient above the collector, and \( U_e \) is the heat loss coefficient at the side of the collector.

Heat removal factor portrays the ratio of actual beneficial energy increase and the attainment of useful energy if all collector is located at fluid inlet temperature [15]. The \( F_R \) value as the heat removal factor can be calculated using Formula (3).

\[ F_R = \frac{m \cdot C_p \cdot (T_i - T_l)}{A_c \cdot I(\tau \cdot \alpha) - U_L(T_i - T_a)} \]

where \( F_R \) is the heat removal factor, \( \tau \) is the plate's emissivity, \( \alpha \) is the glass emissivity, and \( U_L \) is the overall heat loss coefficient.

Efficiency is the ratio of profitable energy addressed to the occurring energy at the collector aperture. The value of efficiency is dominated by parameters such as transmittance product and absorption glaze of plate's absorption rate, global radiation passed on the collector intensity, water line temperature, and the surrounding air temperature [13] [14]. The collector efficiency can be estimated using Formula (8).

\[ \eta_c = \frac{A_c \cdot F_R \cdot I(\tau \cdot \alpha) - U_L(T_i - T_a)}{A_c \cdot I(\tau \cdot \alpha)} \]

with \( A_c \) representing the collector's surface area, \( F_R \) is the heat removal factor, \( I \) is the radiation intensity, \( \tau \) is the plate's emissivity, \( \alpha \) is glass emissivity, \( U_L \) is the total heat loss, \( T_i \) is the inlet temperature, and \( T_a \) is the ambient temperature.

### 3. Results and discussion

#### 3.1. Thermophysical Properties

The flat plate solar collector working parameter requires the utilized working fluid's thermophysical properties. Table 4 presents the results of the thermophysical properties test for the working fluid.

| Working Fluid  | Density (kg/m³) | Specific Heat (J/kg·K) | Dynamic Viscosity (x10⁻³ kg/m·s) | Thermal Conductivity (W/m·K) |
|---------------|----------------|-------------------------|---------------------------------|-----------------------------|
| Water         | 976.512        | 4178.10                 | 0.81                            | 0.557                       |
| GO-Water 0.006% | 987.620        | 4131.36                 | 0.89                            | 0.593                       |

Table 4 demonstrates the expansion of nanofluid's density prior to the addition of graphene oxide. Nanofluid density increases following the rise of nanoparticle volume fraction [16] [17]. In most cases, nanofluid presents a more substantial density increase than base fluid. The more considerable density of the nanoparticle used improves the nanofluid's density. It happens due to the graphene oxide nanoparticle density is higher than the base fluid; therefore, it escalates the nanofluid's density. A decrease of specific heat after the 0.006% graphene oxide nanoparticle was added due to graphene oxide has a smaller specific heat than the basic water fluid. Thus, the addition of nanoparticle into the base fluid provokes a linear reduction toward the nanofluid volume fraction with the declined used nanoparticle's specific heat. The reduced nanofluid's specific heat decreases the energy required to increase the substance's temperature in that nanofluid [18] [19].
The data also shows that the escalated viscosity due to the addition of graphene oxide nanoparticles. It is caused by graphene oxide nanoparticle inclusion that leads to the collision among nanofluid molecules due to the rise of nanoparticles in the fluid. Thus, the addition of 0.006% graphene oxide carries a more considerable effect of the increasing GO-water nanofluid's viscosity value. Researchers also verify that the increase of nanoparticle volume enhances the nanofluid's viscosity level [20] [21]. The fluid's thermal conductivity escalates as the graphene oxide was added. It happens due to the graphene oxide's thermal conductivity is higher than the pure water base fluid. Therefore, the addition of 0.006% graphene fluid brings a linear effect toward the GO-water nanofluid's thermal conductivity. Many researchers have proven that adding a small number of solid particles increases the thermal conductivity significantly, linear to the volume concentration [21] [23].

3.2. Flat Plate Solar Collector's Performance
The highest heat loss coefficient is the function of various parameters, involving the absorber instrument's temperature, temperature ambient, wind velocity, the absorber's emissivity, cover glass plate, the inclination angle, and so forth [14] [13]. In which UL represents the total loss of the flat plate solar collector (FPSC) that is equal to the above, below, and side loss. Table 3 presents the calculation of the overall heat loss coefficient.

| Intensity (W/m²) | β (°) | U_t (W/m².K) | U_b (W/m².K) | U_e (W/m².K) | U_L (W/m².K) |
|------------------|------|--------------|--------------|--------------|--------------|
| 415              | 30   | 4.871025     | 0.9          | 0.179        | 5.95         |
|                  | 45   | 4.796483     | 0.9          | 0.179        | 5.87         |
|                  | 60   | 4.687639     | 0.9          | 0.179        | 5.76         |
| 515              | 30   | 5.015327     | 0.9          | 0.179        | 6.09         |
|                  | 45   | 4.940032     | 0.9          | 0.179        | 6.01         |
|                  | 60   | 4.829892     | 0.9          | 0.179        | 5.90         |
| 615              | 30   | 5.173208     | 0.9          | 0.179        | 6.25         |
|                  | 45   | 5.097281     | 0.9          | 0.179        | 6.17         |
|                  | 60   | 4.986031     | 0.9          | 0.179        | 6.06         |

Table 5 shows that there is a decrease of overall heat loss coefficient following the increase of flat plate solar collector's inclination angle. This is caused by the Ut value affected by the amount of inclination angle. A bigger inclination angle reduces the top loss coefficient so that the heat obtained by FPSC is more significant, and the UL is also declined following the reduced heat loss [23]. During the FPSC test, the highest UL value of 6.25 W/m².K was obtained at the inclination angle of 30° and radiation intensity of 615 W/m². In contrast, the lowest UL value of 5.76 W/m².K was found at the inclination angle of 60° and 415 W/m² intensity.

Table 6 illustrates that the upsurge of Qu that is in line with the rise of occurring radiation intensity. The Qu value is affected by three primary aspects, namely mass flow rate, specific heat, and ΔT between the input and output. The increase of Qu value toward radiation intensity occurs due to the rising temperature that escalates FPSC’s surface temperature; that high-temperature difference results in bigger energy being passed [13]. Besides, the addition of graphene oxide-water nanofluid also influences the Qu value. The graphene oxide-water enhances the thermal conductivity so that the heat grows bigger, causing a considerable temperature difference and affecting the Qu value. At the same time, the heat removal factor's rise following the more substantial light intensity. Heat removal value increase is affected by the expanded Qu value following the escalated FPSC radiation intensity. The heat removal factor represents the ratio of acceptable actual heat value and the ideal useful heat value. Additionally, the input temperature also influences the heat removal factor; thus, a higher input fluid temperature means a more considerable heat removal factor value (FR) [23].
Table 6. The Estimation Results of $Q_u$ and FR

| Fluid                        | Inclination Angle (°) | Intensity (W/m²) | $Q_u$ (Watt) | FR  |
|------------------------------|-----------------------|------------------|--------------|-----|
|                              |                       |                  |              |     |
|                              | 30                    | 415              | 22.223       | 0.668|
|                              |                       | 515              | 28.118       | 0.675|
|                              |                       | 615              | 34.467       | 0.687|
|                              | 45                    | 415              | 22.902       | 0.676|
|                              |                       | 515              | 28.798       | 0.692|
|                              |                       | 615              | 35.601       | 0.701|
|                              | 60                    | 415              | 23.583       | 0.716|
|                              |                       | 515              | 29.932       | 0.721|
|                              |                       | 615              | 36.508       | 0.739|
|                              |                       |                  |              |     |
|                              | 30                    | 415              | 16.099       | 0.459|
|                              |                       | 515              | 21.314       | 0.493|
|                              |                       | 615              | 26.302       | 0.506|
|                              | 45                    | 415              | 17.232       | 0.501|
|                              |                       | 515              | 22.674       | 0.533|
|                              |                       | 615              | 28.116       | 0.551|
|                              | 60                    | 415              | 17.91306     | 0.518|
|                              |                       | 515              | 22.90151     | 0.537|
|                              |                       | 615              | 28.34345     | 0.552|

Table 7. Results of Flat Plate Solar Collector's Efficiency Estimation

| Fluid                        | Inclination Angle (°) | Intensity (W/m²) | Efficiency (%) |
|------------------------------|-----------------------|------------------|----------------|
|                              |                       |                  |                |
|                              | 30                    | 415              | 60.65          |
|                              |                       | 515              | 61.84          |
|                              |                       | 615              | 63.48          |
|                              | 45                    | 415              | 62.21          |
|                              |                       | 515              | 64.11          |
|                              |                       | 615              | 65.15          |
|                              | 60                    | 415              | 64.36          |
|                              |                       | 515              | 65.83          |
|                              |                       | 615              | 67.24          |
|                              |                       |                  |                |
|                              | 30                    | 415              | 43.94          |
|                              |                       | 515              | 46.88          |
|                              |                       | 615              | 48.44          |
|                              | 45                    | 415              | 47.03          |
|                              |                       | 515              | 49.87          |
|                              |                       | 615              | 51.78          |
|                              | 60                    | 415              | 48.89          |
|                              |                       | 515              | 50.37          |
|                              |                       | 615              | 52.21          |

Data in Table 7 indicates that the improved efficiency following the heightened flat plate solar collector's inclination angle. That happens because the heat removal factor and overall heat loss coefficient (UL) values positively affect efficiency. Consequently, a higher FR value means a bigger FPSC's efficiency value due to the increased ratio between the FPSC's acceptable heat and the ideal heat [24] [25]. The broadening FPSC's efficiency value is also linear to the extended light intensity and FPSC's inclination angle due to the reduced overall heat loss coefficient. It is caused by the decreased
wasted heat that improves the FPSC’s efficiency value [23]. The highest intensity value has been identified at 615 W/m² intensity with a 60° inclination angle and 67.24 % of nanofluid. In contrast, the lowest intensity is at 415 W/m² intensity with a 30° inclination angle and a base fluid of 43.94 %. The substantial FPSC's value represents its improved performance, faster water heating process, and higher temperature. Therefore, graphene oxide-water nanofluid is beneficial to increase the flat plate solar collector's efficiency.

4. Conclusion

This present research concludes that the addition of 0.006% graphene oxide-water nanofluid increases the nanofluid's thermophysical properties that improve the flat plate solar collector's performance. The most substantial efficiency of using the amount of 0.006% graphene oxide-water (67.24%) is found at a 60° inclination angle and 615 W/m² radiation intensity.

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