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Efficiency enhancement of building multi-layer solar collector with SiO_2–TiO_2 hybrid nanofluids

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Research Article

Abstract

Due to the depletion of conventional energy sources and its limitless resources, solar energy is currently being considered as a viable alternative, especially for water heating systems. The thermal performance of multilayer solar collectors for water heating systems can be improved further by introducing hybrid nanofluids as advanced fluids. This study demonstrates the utilisation of hybrid nanofluids in heating systems by employing a multilayer absorber solar collector. The SiO_2–TiO_2 hybrid nanofluids at volume concentrations up to 2.0% were tested at various flow rates (1.7 to 3.7 LPM) and solar radiation intensities (250 to 1000 W/m^2). The thermal performance of the solar collector was assessed by measuring the temperature variation, heat loss, and overall efficiency of the collector. At the optimal volume concentration, the temperature difference for solar collectors employing SiO_2–TiO_2 hybrid nanofluids increased significantly. The optimal volume concentration of 1.5% yields a maximum temperature difference of 9.5 °C. In addition, the efficiency and fluid temperature of the solar collector containing hybrid nanofluids have been enhanced by 22% and 37%, respectively. The SiO_2–TiO_2 hybrid nanofluids with the optimal volume concentration of 1.5% were therefore recommended for maximum efficiency in the solar collector.

Keywords

solar collector;
hybrid nanofluids;
solar water heating system;
solar simulator;
thermal efficiency

Article History

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Building Systems and Components

1 Introduction

Non-renewable energy resources are commonly used as fuels in machinery, automobiles, and industries. However, rapid urbanisation causes the depletion of fossil fuels and natural gas, thereby reducing energy resources (Yin 2009). For instance, solar energy, which has the advantages of being pollution-free and emitting no greenhouse gases into the environment, is one of the alternative solutions to this issue and the most well-known renewable energy that has been discovered in the past century. It is worth noting that solar energy is widely used (Shoeibi et al. 2022), especially in water heating systems, due to its convenience of being renewable and having unlimited resources. The solar water heating system utilizes a natural solar thermal technology. The reflective surface transmits solar radiation while it emits heat and infrared radiations. The solar collector will capture and retain the heat from the sunlight. The heat then passes through a heat transfer medium such as water, antifreeze, and air. The solar water heating system could be one alternative for pollution-free technology to replace other non-renewable energy for water heating system especially for domestic requirements. Basically, this system has a simple operation and only requires thermal energy from the sun for water heating. The system works by increasing the working fluid temperature by putting it in contact with an absorber surface exposed to sunlight.

Due to a shortage of supply to meet the total demand for energy in the building industry, the building sector in emerging nations frequently uses a great deal of energy

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List of symbols

A_C	cross sectional area
A_S	receiving area of the solar collector
C_p	specific heat (kJ/(kg·K))
EG	ehylene glycol
G_T	global solar radiation
g	gravitational acceleration (m/s^2)
h	heat transfer coefficient (W/(m·K))
k	thermal conductivity (W/(m^2·K))
L_C	characteristic length (m)
$\dot{m}$	mass flow rate (LPM)
Nu	Nusselt number
Q_O	heat loss
Q_{rad}	radiation energy
Q_U	useful energy
T_∞	ambient temperature (°C)
T_i	inlet temperature (°C)
T_o	outlet temperature (°C)
T_s	surface temperature (°C)
V	volume
ΔV	additional volume
β	coefficient of volume expansion
η	efficiency (%)
μ	dynamic viscosity (kg/(m·s))
ρ_{bf}	density of base fluid (kg/m^3)
ρ_p	density of nanoparticles (kg/m^3)
σ	Boltzmann constant
ϕ	volume concentration (%)
ω	weight concentration (%)

Subscripts

bf	base fluids
hnf	hybrid nanofluids
r	ratio

(Omar et al. 2022). Consequently, rapid urbanisation has reshaped land use patterns in urban areas, leading to the construction of high-rise buildings to meet the residential demands. However, the solar technology for water heating systems is mostly designed for landed residential areas, especially terrace houses, bungalows, and semi-detached houses. High-rise buildings, such as condominiums and apartments, are facing space limitations to install the solar heating system. Generally, the solar collector requires a considerable amount of space for rooftop installation, which requires many improvements in terms of design to increase performance of the system. Unfortunately, design improvements come at a substantial initial cost. Subsequently, a multilayer absorber solar collector was designed for use in the installation of solar heating systems for high-rise buildings.

In thermal engineering systems especially the devices known as solar collectors (Najafi et al. 2021), improving energy-efficient heat transfer fluids is essential. The solar collectors enable the conversion of solar energy into heat that is absorbed by a fluid flowing into the collector tube system. The heated fluid can then be used in home and industrial settings. The working fluid is a crucial component whose selection is influenced by the application and working temperature (Teles et al. 2019). Heat transmission from solar radiation to the working fluid is necessary for the operation of the solar collectors. However, most typical working fluids are not thermally efficient due to their restricted capacity to transport heat upward, which has a substantial impact on the overall performance of the solar collector. Various researchers have reported the use of nanofluids as heat transfer fluids in heat pipes and solar collector systems (Eidan et al. 2018). Adding nanoparticles to conventional working fluids to create nanofluids improved the thermal characteristics of traditional working fluids (Eidan et al. 2018; Hamid et al. 2018a; Alkanhal et al. 2019; Shafee et al. 2020). The nanofluids are a well-known nanoparticle suspension that is dispersed uniformly in a base fluid and is used in thermal applications as an innovative heat transfer working fluid. The previous research using nanofluids as the working fluids for solar collector is listed in Table 1.

Many studies have been conducted on the thermal physical properties of nanofluids (Keklikcioglu and Ozceyhan 2021; Yıldız et al. 2021), especially their viscosity and thermal conductivity, which are essential for performance evaluation (Murshed and Estellé 2017). Previous studies on performance enhancement have identified that the low thermal conductivity of the working fluids is one of the significant factors that limit the performance of the solar collector system. Performance of engineering systems, particularly the solar systems, is significantly influenced by the stability of nanofluids (Zawawi et al. 2019). This is because unstable nanofluids negatively impact the performance of solar systems due to changes in the thermal physical properties and overall performance of heat transfer. Through significantly higher thermal conductivity, nanofluids have demonstrated their excellent potential for heat transfer enhancement with an acceptable increase in pumping power as compared to the conventional fluids (Bobbo et al. 2014). Additionally, it is necessary to investigate how particle concentration affects the stability and thermal properties

Table 1 Previous studies on different types of solar collector

Classification	Authors	Working fluids	Performance
Parabolic trough solar collectors (PTC)	Siva Reddy et al. 2015	Al_2O_3/H_2O	Increased efficiency by 28.95%
	Kasaeian et al. 2017	MWCNT/EG, SiO_2/EG	MWCNT/EG was more thermally efficient than SiO_2/EG
	Menbari et al. 2016	CuO/H_2O	Nanoparticle volume fraction increased thermal efficiency by 52%
	Marefati et al. 2018	CuO/H_2O, Al_2O_3/H_2O, SiC/H_2O	CuO/H_2O nanofluid was greatest for thermal efficiency, followed by Al_2O_3 and SiC
Flat-plate solar collector (FPSC)	Yousefi et al. 2012b; Colangelo et al. 2013	Al_2O_3/H_2O	At 0.2% weight concentration, efficiency increased by 28.3% 3% of volume concentration increases convective HTC by 25% against base fluid
	Yousefi et al. 2012a; Yousefi et al. 2012c	MWCNT/ H_2O	Efficiency increased at 0.4% weight concentration Increasing the nanofluid PH-difference from the isoelectric point improved efficiency
	Chaji et al. 2013	TiO_2/H_2O	Increased collector efficiency 2.6%–7%
Evacuated tube solar collectors (ETSC)	Ghaderian et al. 2017	CuO/H_2O	With 0.06 vol.% CuO, ETSC performance increased to 51.4%
	Ghaderian and Sidik 2017	Al_2O_3/H_2O	With 0.06 vol% of nanofluids and a mass flow rate of 60 L/h, the maximum efficiency was 57.63%
	Iranmanesh et al. 2017	Graphene/H_2O	With graphene (GNP) of 0.1 wt% nanofluid, the maximum collector efficiency is found to be 90.7%. The GNP nanofluid had a 27.6% increase in thermal conductivity

of nanofluids (Zhang et al. 2021). Therefore, the volume concentration, stability, and thermal properties of nanofluids have great potential for enhancing the heat transfer performance of engineering systems.

Research on nanofluids has progressed tremendously due to its potential in enhancing convection heat transfer coefficients which leads to energy sustainability. Few researchers have tried to integrate or mix more than two different kinds of nanofluids to produce hybrid nanofluids. When two or more nanoparticles are combined to create hybrid nanofluids, their performance is predicted to be superior to that of a single nanoparticle (Zawawi et al. 2017). However, limited information was found regarding the use of hybrid nanofluids in the heat pipe of the solar collector. Numerous researchers have attempted to incorporate various nanoparticles into the working fluids of solar collectors, but the combination of SiO_2 and TiO_2 nanoparticles in multi-layer solar collectors has not been exhaustively studied. Research on the application of SiO_2–TiO_2 hybrid nanofluids to solar collectors is inherently limited and focuses solely on the preparation, output temperature and thermal physical properties of the hybrid nanofluids.

Therefore, the purpose of this paper is to improve the efficiency of multi-layer solar collectors by enhancing the thermal properties of the working fluid using SiO_2–TiO_2 hybrid nanofluids. In this study, hybrid nanofluids are compared to the current conventional fluids used in the application of the solar system. Hence in this paper, the incorporation of SiO_2–TiO_2 hybrid nanofluids as heat transfer fluid to determine the overall efficiency of multilayer collector for solar heating system is proposed.

2 Methodology

The preparation and stability analysis of hybrid nanofluids were the first two main focuses of the methodology. Following that, the multi-layer solar collector is fabricated and investigated through experimentation. Finally, a thermal performance and efficiency analysis of the solar collector is performed. The overall methodology of the present study is summarized and shown in Figure 1.

2.1 Preparation of hybrid nanofluids

The descriptions of the materials and the base fluids can be found in this subsection. The nanoparticles, namely SiO_2 and TiO_2, with average diameter sizes of 22 and 50 nm and weight concentrations of 25% and 40%, respectively, were obtained from U.S. Research Nanomaterials. The properties and original concentration of SiO_2 and TiO_2 nanoparticles are shown in Table 2. Meanwhile, Table 3 presents the common properties of ethylene glycol (EG). The mixture of EG and water was considered to have a volume ratio of 40:60, which constitutes the base liquid for the hybrid nanofluids. The management of risks during the manipulation of nanoparticles must be subjected to stringent controls in order to avoid and minimise exposure to nano hazards.

In the present study, the hybrid nanofluids were evaluated in volume concentration. Therefore, Eq. (1) was used to transform the original weight concentrations of SiO_2 and TiO_2 nanofluids into volume concentrations. Meanwhile, the nanoparticle mixture volume ratio of 50:50 (TiO_2:SiO_2) was considered in the preparation of hybrid

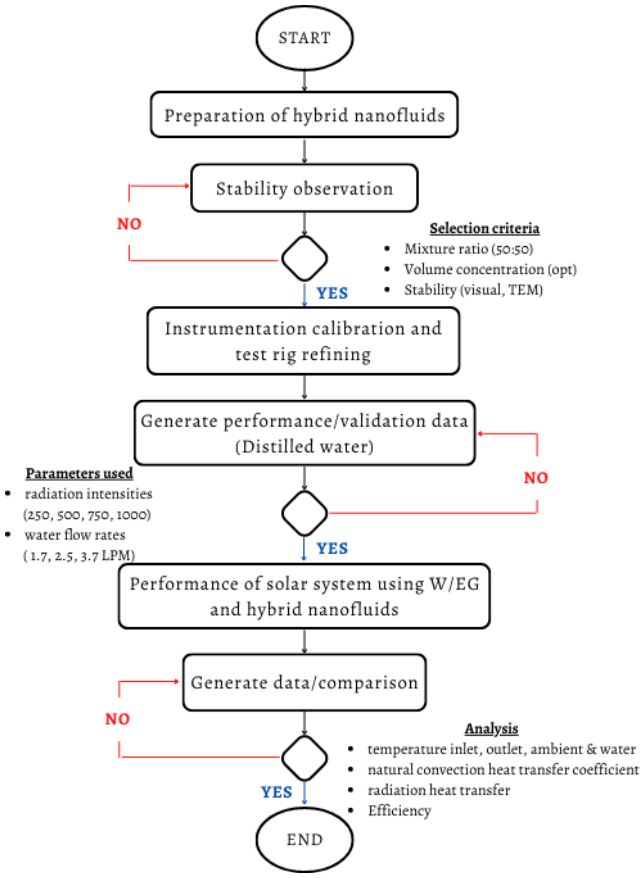


Fig. 1 Flowchart for the investigation of hybrid SiO_2–TiO_2 nanofluids in multi-layer solar collector

Table 2 The properties of SiO_2 and TiO_2 nanoparticles

Type of nanofluids	Diameter (nm)	Density ρ (kg/m^3)	Specific heat C_p (J/(kg·K))	Weight concentration ω (%)	Volume concentration ϕ (%)
SiO_2	22	2220	745	25	13.06
TiO_2	50	4230	692	40	13.62

Table 3 Common properties of ethylene glycol

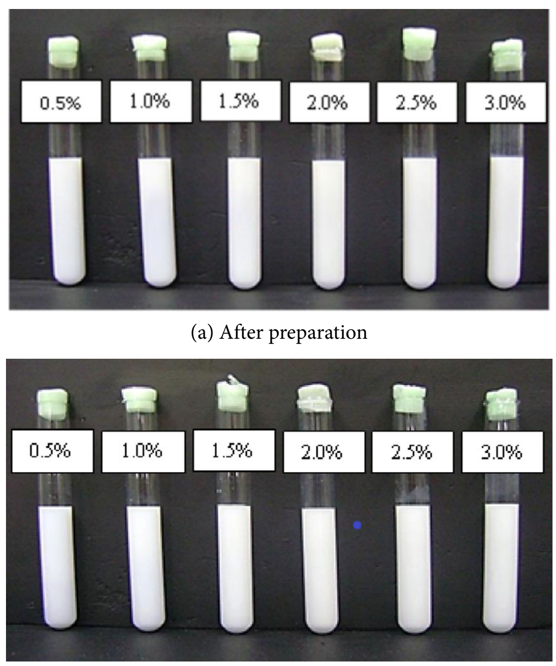
Parameter	Value
pH	5.5–7.5
Vapour pressure (mmHg)	0.12
Melting temperature (°C)	−13
Molar mass (g/mol)	62.07
Boiling temperature (°C)	197.6
Density (kg/m^3)	1113

SiO_2–TiO_2 nanofluids. In addition, Eq. (2) was used to prepare SiO_2–TiO_2 hybrid nanofluids at 0.5 to 2.0% volume concentrations. Firstly, the mixture of EG and water was added to the original SiO_2 and TiO_2 nanofluids to dilute them and prepare a new sample of nanofluids at lower volume concentrations. The new volume concentration of nanofluids underwent an ultrasonication process. This stage is necessary in order to maintain the original stability of the SiO_2 and TiO_2 nanofluids. Then, the SiO_2 and TiO_2 nanofluids were mixed at the nanoparticle mixture ratio of 50:50 to produce SiO_2–TiO_2 hybrid nanofluids. Again, the hybrid nanofluids were stabilised through the ultrasonication process for two hours. A similar process was also undertaken by other investigators in literature (Abdolbaqi et al. 2016; Azmi et al. 2016; Hamid et al. 2016).

$$\phi = \frac{\omega \rho_{\mathrm{bf}}}{\left(1-\frac{\omega}{100}\right)\rho_{\mathrm{p}} + \frac{\omega}{100}\rho_{\mathrm{bf}}} \tag{1}$$

$$\Delta V = (V_2 - V_1) = V_1\left(\frac{\phi_1}{\phi_2} - 1\right) \tag{2}$$

The evaluation of SiO_2–TiO_2 hybrid nanofluids stability was done through visual observation. The stability of suspended hybrid nanoparticles was observed visually for up to 30 days. Figure 2(a) displays the nanofluids sample just after preparation. Figure 2(b) demonstrates the sample after 30 days of preparation, and the hybrid nanofluids were observed to be stable within a month. Meanwhile, Figure 3 presents the transmission electron microscope (TEM) image for SiO_2 and TiO_2 suspended nanoparticles in the EG/water mixture. From Figure 3, it can be observed that the larger particles represent TiO_2 nanoparticles, while the smaller diameters refer to SiO_2 nanoparticles. Based on the figure, TiO_2 nanoparticles are rectangular in shape (50 nm), while SiO_2 nanoparticles are spherical (22 nm).



(a) After preparation

(b) After 30 days

Fig. 2 The visual observation of SiO_2–TiO_2 nanofluids

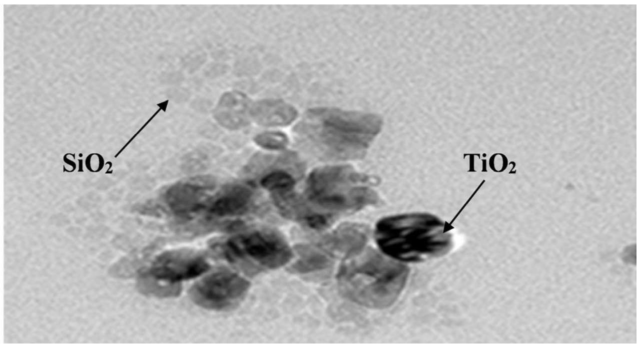


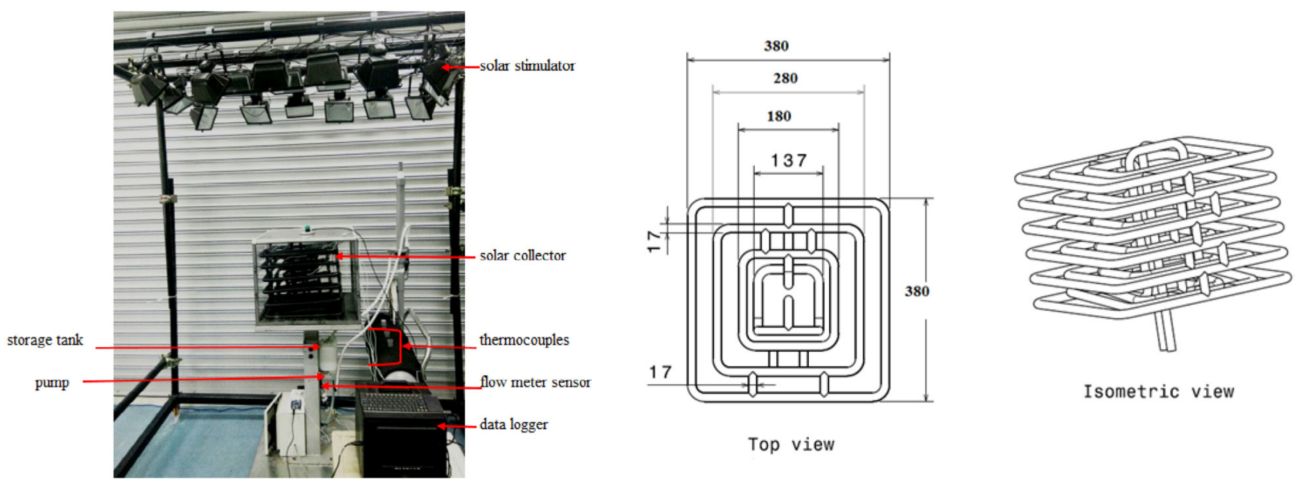
Fig. 3 TEM image of SiO_2–TiO_2 nanofluids

The dispersion of nanoparticles in the base fluid was found to be uniform without any significant agglomeration. The present nanofluids were prepared under ultrasonication for two hours, causing the separation of agglomerated particles and improving the stability of the hybrid nanofluids. Previous studies (Hamid et al. 2018b; Hamid et al. 2019) stablished the stability, properties, and performance of current SiO_2–TiO_2 hybrid nanofluids, which are formulated to enhance heat transfer.

2.2 Fabrication and experimentation study of multi-layer solar collector

The experiment was set under a multidirectional solar simulator at a specific operating condition as shown in Figure 4. Figure 4 shows a complete setup for a solar heating system consisting of a piping system, a water pump, a tank for storage, a control regulator, and a multi-layer solar collector. The working fluids were circulated throughout the system using a water pump that was connected to a storage tank. The collector consists of an 8-meter-long insulated absorber along the fluid flow to minimise the heat loss from the collector. Seven K-type thermocouples were fixed at various locations; four thermocouples were used to measure the surface temperature, while two thermocouples were installed in the pipe to measure the temperatures for the inlet and outlet of the working fluids. The ambient temperature was measured from the last thermocouple. A flow metre was installed between the test section inlet and pump to assess the flow rate of the working fluids. In addition, thermocouples, pyranometers, flow metres, and tachometers were employed as sensors and measuring equipment in the present experimental study for multi-layer solar collector. Table 4 provides a summary of the sensors and equipment with their respective uncertainty values.

A fabricated solar collector consisting of black-coated multilayer absorber tubes is shown in Figure 4(a). There were six layers of absorber tubes made up of three squares of sizes 18 cm × 18 cm, 28 cm × 28 cm, and 38 cm × 38 cm, as illustrated in Figure 4(b). The auxiliary motion of working fluids flowing from the inlet to the absorber layer by layer was then carried to the storage system. However, some specific parts of the incoming radiation were reflected to the sky and some were absorbed by the glass cover. The rest of the radiation was transmitted through the glazing and reached the plate of the absorber in the form of short-wave radiation. In order to increase solar energy collector efficiency at high solar radiation incidences, solar collectors for heating systems in this work were enclosed in an insulated metal box with polycarbonate glazing. In addition, the current study made use of a multidirectional solar simulator made up of 18 rotatable spotlights with 300 W each. The source of radiation was mounted close to the collector.



(a) Multi-layer solar collector (b) Dimensions of the solar collector

Fig. 4 Specifications of multi-layer solar collector for heating system

Table 4 Uncertainties of multi-layer solar collector sensors and measurement devices

Sensors/devices	Range	Uncertainty
Thermocouple (°C)	−40 to 375	±1.5
Pyranometer (W/m^2)	0 to 1000	±0.5
Flow meter (LPM)	0 to 100	±1.0

The present experimental work was undertaken by exposing the solar heating system under the solar simulator. The solar thermal system experimental analysis began with distilled water, then W/EG, and lastly SiO_2–TiO_2 nanofluids. Variation of mass flow rate and solar radiation study were conducted to evaluate the performance of a multilayer solar collector. Experiments were undertaken at four different radiation intensities of 250, 500, 750, and 1000 W/m^2. The solar collector with water was evaluated at different mass flow rates of 1.7, 2.5, and 3.7 LPM. Each test was conducted for 20 minutes to achieve thermal equilibrium in the system. The fluid with the highest flow rate was selected for comparison with other working fluids such as an ethylene glycol/water (40:60) mixture and hybrid nanofluids. Next, the experiment was performed using SiO_2–TiO_2 hybrid nanofluids under a solar simulator for 20 minutes at various concentrations and solar radiations. The initial investigation considered the effects of volume concentration and solar radiation intensity on temperature variation. Each experimental trial was repeated five times under identical conditions to ensure repeatability. Data on the solar collector were gathered by heating the absorber for the solar collector for 20 minutes. Then, the light on the solar simulator was turned off for an additional twenty minutes to facilitate the cooling procedure. The data logger captured data such as water storage temperature (T_1), absorber temperature (T_3 – T_6), water input temperature (T_7), water output temperature (T_8), ambient temperature (T_2) for every 2 minutes for a maximum of 30 minutes.

2.3 Thermal performance and efficiency analysis

Performance evaluation is considered as the degree of input utilization by the collector to analyse the thermal performance of solar heating system. In this study, thermal performance of the collector is determined through experimental works. The mathematical equations used in this study is presented along with the experimental procedure for evaluation of the solar collector system performance under various operating conditions. A precise analysis of a multilayer absorber solar collector is complicated because of many related variables. Efforts have been made to integrate the significant variables into a simple equation to derive a mathematical model that describes the thermal performance. Equations (3) to (6) were used to estimate the thermal conductivity, viscosity, density, and specific heat, respectively of SiO_2–TiO_2 hybrid nanofluids.

$$\frac{k_{\mathrm{hnf}}}{k_{\mathrm{bf}}}=\left(1+\frac{\phi}{100}\right)^{5.5}\left(\frac{T}{80}\right)^{0.01} \tag{3}$$

$$\mu_{\mathrm{r}}=\frac{\mu_{\mathrm{hnf}}}{\mu_{\mathrm{bf}}}=37\left(0.1+\frac{\phi}{100}\right)^{1.59}\left(0.1+\frac{T}{80}\right)^{0.31} \tag{4}$$

$$\rho_{\mathrm{hnf}}=\left(1-\frac{\phi}{100}\right)\rho_{\mathrm{bf}}+\left(0.5\frac{\phi}{100}\right)\rho_{\mathrm{TiO_2}}+\left(0.5\frac{\phi}{100}\right)\rho_{\mathrm{SiO_2}} \tag{5}$$

$$C_{\mathrm{hnf}}=\frac{\left(1-\frac{\phi}{100}\right)\rho_{\mathrm{bf}}C_{\mathrm{bf}}+\left(0.5\times\frac{\phi}{100}\right)\rho_{\mathrm{TiO_2}}C_{\mathrm{TiO_2}}+\left(0.5\times\frac{\phi}{100}\right)\rho_{\mathrm{SiO_2}}C_{\mathrm{SiO_2}}}{\rho_{\mathrm{hnf}}} \tag{6}$$

The inlet and outlet temperatures of working fluid as well as the mass flow rate of water at a given input simulation condition were recorded. At steady-state condition, the average experimental data are considered in the present analysis. Equation (7) was used to analyse the useful energy. Rayleigh number, Ra_L is the product of Grashof number, which describes the relationship between buoyancy and viscosity within the fluid, and the Prandtl number, which describes the relationship between momentum diffusivity and thermal diffusivity. Hence the Rayleigh number itself may also be viewed as the ratio of buoyancy forces and thermal momentum diffusivities. Rayleigh number, Ra_L is expressed by Eq. (8). The average Nusselt number, Nu, in natural convection between the glazing cover and the collector-absorber tubes can be estimated using Eq. (9) (Çengel and Ghajar 2011).

$$Q_{\mathrm{u}}=\dot{m}C_{\mathrm{p}}\left(T_{\mathrm{o}}-T_{\mathrm{i}}\right) \tag{7}$$

$$Ra_{\mathrm{L}}=Gr_{\mathrm{L}}Pr=\frac{gL_{\mathrm{C}}^{3}\beta\left(T_{\mathrm{S}}-T_{\infty}\right)}{\nu^{2}}Pr \tag{8}$$

$$Nu=\frac{hL_{\mathrm{C}}}{k}=\left\{0.6+\frac{0.387Ra_{\mathrm{D}}^{1/6}}{\left[1+\left(0.559/Pr\right)^{9/16}\right]^{8/27}}\right\}^{2} \tag{9}$$

The heat loss by convection heat transfer from the solar collector to surroundings is expressed by Eq. (10). As the collector absorbs heat, its temperature is higher than the surrounding. The heat lost to surrounding occurs through radiation and convection. The heat loss, Q_{O} is strongly affected by overall heat transfer coefficient and surface temperature of the solar collector. In the present analysis, the overall heat transfer coefficient is due to combined mode of radiation and natural convection. The heat transfer coefficient by natural convection is estimated using Eq. (9)

while the radiation heat transfer is analysed using Eq. (11). A common estimate for surrounding temperature, T_{surr} is $T_{surr} \approx T_{ambient} - 6$ (Twidell et al. 2006). The instantaneous thermal efficiency of collector, η was correlated to the beneficial energy gain to the total radiation incident on the collector surface and can be expressed by Eq. (12). Firstly, the test for thermal efficiency was undertaken, then the average data was plotted against solar radiation intensity, G_T.

$$Q_O = hA_S(T_S - T_\infty) \tag{10}$$

$$Q_{rad} = \varepsilon\sigma A_S(T_S^4 - T_{surr}^4) \tag{11}$$

$$\eta = \frac{Q_U}{A_C G_T} = \frac{\dot{m}C_P(T_o - T_i)}{G_T} \tag{12}$$

3 Results and discussion

3.1 Multilayer absorber solar collector with water

This section identifies the optimal flow conditions based on the experimentally determined significant parameters. Figure 5 represents the variation of temperature differences as a function of time at different flow rates. Low flow rates at high temperatures mean that much more heat is absorbed by the system. Thus, the fluid temperature difference is directly proportional to the solar radiation intensity but inversely proportional to the flow rate. The similar observation is also supported by Heris et al. (2006). The graph demonstrates that the temperature differences at the minimum flow rate of 1.7 LPM increased by 40%. This proves that 1.7 LPM is at a slow flow regime where there is no interface, which has an impact on the functionality of the multilayer absorber in the solar collector of the solar water heating system. The thermal performance of a solar collector is affected by both the solar radiation intensity and the working liquid properties. The beneficial energy gain of the collector is significantly influenced by the temperature difference between the inlet and outlet. Consequently, the 1.7 LPM flow rate is determined to be the best flow rate in the current evaluation of the multi-layer solar collector's performance of the water heating system, and additional experiments are carried out to evaluate the system at a constant 1.7 LPM flow rate.

3.2 Multilayer absorber solar collector with EG/water mixture

Figure 6 shows the temperature variation for the EG/water mixture at different solar radiations at 1.7 LPM flow rate of for 20 minutes. The figure shows that the temperature increases gradually with solar radiation intensity. A maximum temperature of 40 °C is achieved after 20 minutes. The increase in temperature that results in an increase in useful heat is attributable to the overall thermal performance of the system. It is noted that a high temperature difference of 6.6 °C occurred at 1000 W/m² but only 2.3 °C difference at 250 W/m². This is due to the increased solar radiation received by the collector, which causes it to absorb more heat. Consequently, it demonstrates that the intensity of solar radiation affects the amount of useful energy in the solar system, with these parameters being proportional to one another. A smaller temperature increase was observed when using water as opposed to EG/water mixture, indicating that EG/water mixture has a higher heat transfer rate than water.

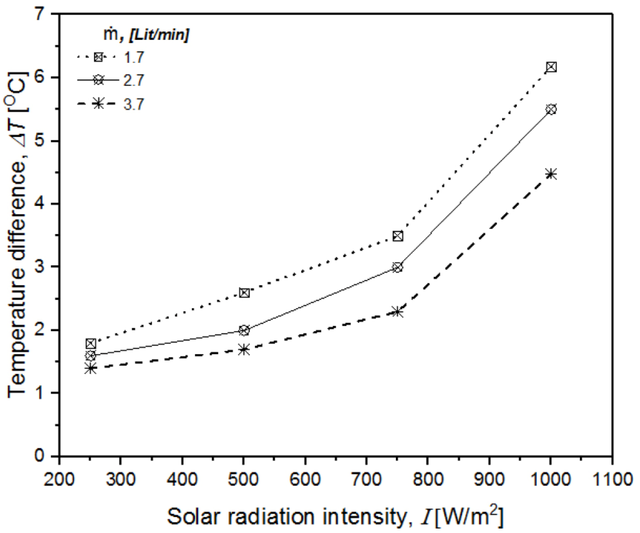


Fig. 5 The temperature difference variation for water at different flow rates and solar radiations

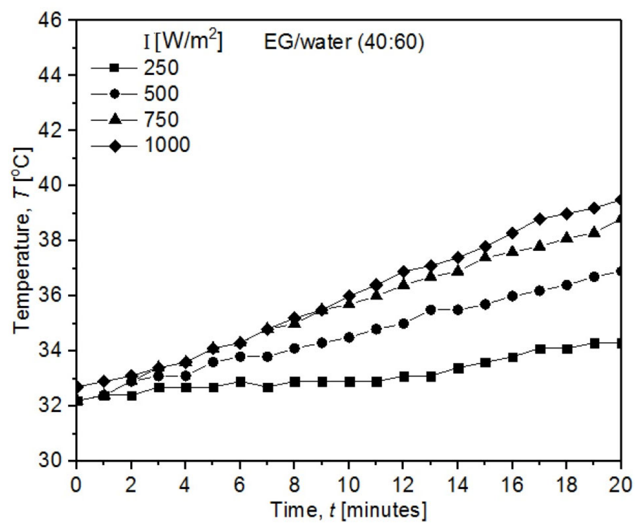


Fig. 6 The temperature variation for EG/water mixture at different solar radiations

3.3 Multilayer absorber solar collector with hybrid nanofluids

3.3.1 Temperature variation at different heat radiation intensities

The temperature variation at different solar heat radiation levels is investigated in this experiment. Figure 7 presents the temperature variation of SiO_2–TiO_2 hybrid nanofluids at a constant 1.5% volume concentration with different solar radiations. The temperature changes gradually with solar radiation intensity. With an increase in the solar radiation, the fluid temperature in the absorber of the solar collector increases accordingly. The experimental data in Figure 7 shows the ascending trends of temperature from 250 up to 1000 W/m^2. It can be observed that at 1.5% volume concentration, the temperature increases to 47 °C at 1000 W/m^2 but only to 35 °C at 250 W/m^2 from the 32 °C initial temperature. The results indicate that the temperature of the collector increases with increasing solar radiation intensity. A similar trend was also observed for the EG/water mixture in Figure 6. Nevertheless, the increase in temperature with hybrid nanofluids is more pronounced than with EG/water mixtures. It is because hybrid nanofluids have superior thermal properties to base liquids (EG/water mixtures), and the thermal conductivity is responsible for the improved heat transfer capability. The existence of various nanoparticle combinations in hybrid nanofluids significantly contributed to the increase of thermal conductivity. This is because the two nanoparticles have different diameters; hence, the gaps and spaces between the particles are reduced, resulting in an increase in heat conductivity owing to homogeneous particle distribution in the based fluids (Sundar et al. 2016).

3.3.2 Temperature variation at different volume concentrations

Experiments with hybrid nanofluids at different volume concentrations were performed at a fixed 1.7 LPM flow rate. Figure 8 shows the variation of temperatures for the multilayer absorber solar collector at a constant solar radiation of 1000 W/m^2. The experimental data shows a positive increment in temperature variation from low concentration to the high-volume concentration of 2.0%. The temperature variation in Figure 8 has shown ascending trends for the experiment with nanofluids up to 20 minutes of operating time. The utilisation of hybrid nanofluids at different volume concentrations has contributed to the enhancement in temperature variation of the collector, compared to water and EG/water mixture from previous experimental data. It is because the nanofluids were established with higher thermal conductivity compared to conventional fluids. Significant thermal conductivity improvements have been reported for nanofluids such as CuO/water nanofluids (Eastman et al. 1996), SiC nanoparticle suspensions in ethylene glycol or water (Xie et al. 2002) and metal nanoparticle suspensions (Yang et al. 2005). According to Kakaç and Pramuanjaroenkij (2009), the thermal properties of working fluids, especially thermal conductivity, make a significant contribution to the temperature increment and further increase in heat transfer rate. In addition, the thermal properties or thermal conductivity of the present hybrid nanofluids are strongly influenced by volume concentration. Therefore, the temperature variation in Figure 8 is enhanced drastically with increasing volume concentration. The improved heat transfer in the current solar collector is due to the greater thermal properties of hybrid nanofluids at higher concentrations.

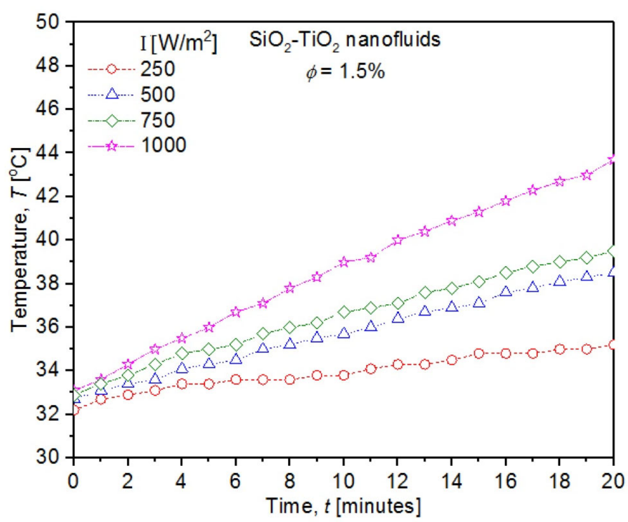


Fig. 7 The temperature variation for SiO_2–TiO_2 hybrid nanofluids with solar radiations variation

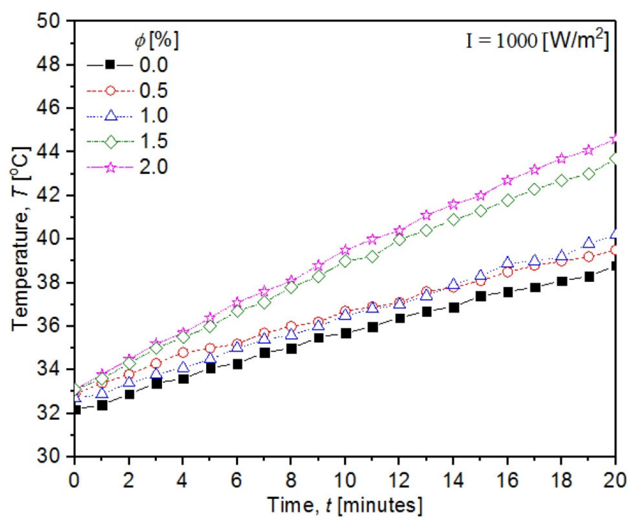


Fig. 8 The temperature variation for SiO_2–TiO_2 hybrid nanofluids with volume concentrations variation

3.3.3 Overall improvement of the temperature difference

The temperature difference variation for SiO_2–TiO_2 hybrid nanofluids at various volume concentrations and solar radiations is shown in Figure 9 and Table 5. The temperature difference increases with the increase of volume concentrations from 0.5 to 1.5%. Therefore, the thermal enhancement of SiO_2–TiO_2 hybrid nanofluids also increases. Thus, by increasing the volume concentration up to 1.5%, the temperature rises further and subsequently improves the solar water heating system performance. However, the results also reveal that a slight decrement in temperature difference at 2.0% volume concentration. At this volume concentration, the hybrid nanofluids is capable to gain more energy but with simultaneous heat losses from the collector. Therefore, 1.5% volume concentration is considered as an optimum value of concentration with the highest temperature difference up to 9.5 °C. The high volume concentration of nanofluids are reported with tendency to agglomerate, and consequently reduce its stability (Ghadimi et al. 2011; Saidur et al. 2011). This stability condition might affect the effective heat transfer capability of the present hybrid nanofluids for solar collector application at high volume concentration.

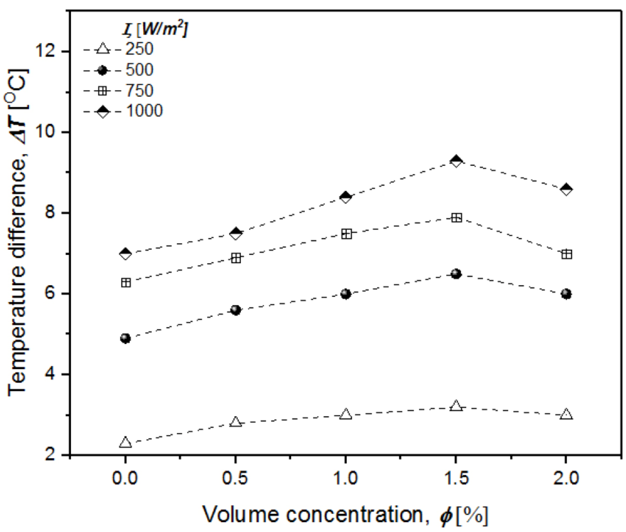


Fig. 9 The temperature difference variation for SiO_2–TiO_2 hybrid nanofluids at different concentrations and solar radiations

Table 5 The temperature difference with different heat radiation of nanofluids and EG/water mixture

Volume concentration ϕ (%)	Temperature difference ΔT (°C)			
	250 W/m²	500 W/m²	750 W/m²	1000 W/m²
EG/water	2.3	4.9	6.3	7.0
0.5	2.8	5.6	6.9	7.5
1.0	3.0	6.0	7.5	8.4
1.5	3.2	6.5	7.9	9.5
2.0	3.0	6.0	7.0	8.6

3.4 Thermal performance of multi-layer absorber with hybrid nanofluids

3.4.1 Useful energy

The intensity and concentration of solar radiation can affect the amount of valuable heat absorbed. The parameters are directly proportional to one another, allowing to produce hot liquids via multilayer absorption. As shown in Figure 10, the increase in solar radiation has increased the value of useful energy from 325 J/s to a maximum of 950 J/s. It was discovered that increasing solar radiation intensity can improve the system's performance. According to Karami et al. (2015), any increase in the volume concentration results in a significant increase in the heat absorption of thermal energy from passing solar radiation through the collector. Therefore, the thermal properties of hybrid nanofluids have the greatest impact on the amount of energy absorbed by the working fluid. Meanwhile, according to Alawi et al. (2018), the effective thermal conductivity of hybrid nanofluids increased linearly with the volume concentration. Thereby, increment of hybrid nanofluids concentration can enhance the heat transfer performance, thus enhancing the useful energy performance of multi-layer solar heating system absorbers.

3.4.2 Convection and radiation losses

Figure 11 presents the heat loss variation from a solar collector at different concentrations and solar radiations. The heat loss increases gradually with solar radiation from the start of the experiment up to 20 minutes of operating time. When increasing the solar radiation, the fluid temperature in the collector increased accordingly. Thus, the high solar radiation intensity allows the collector to operate at high efficiency. However, the rate of heat loss is proportional

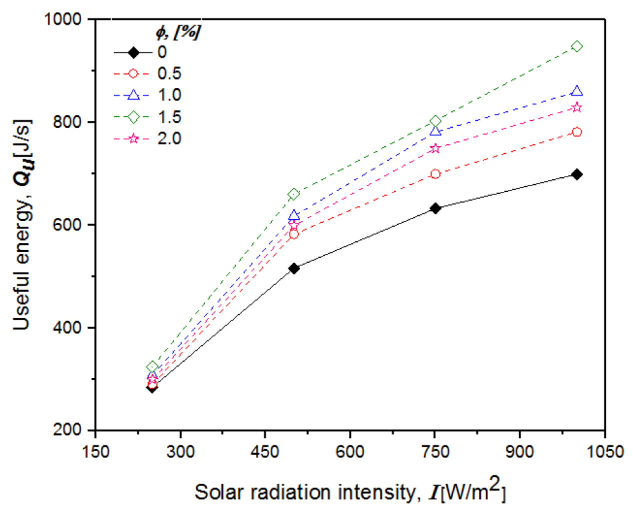


Fig. 10 Useful energy of solar collectors with variation of concentration and solar radiation

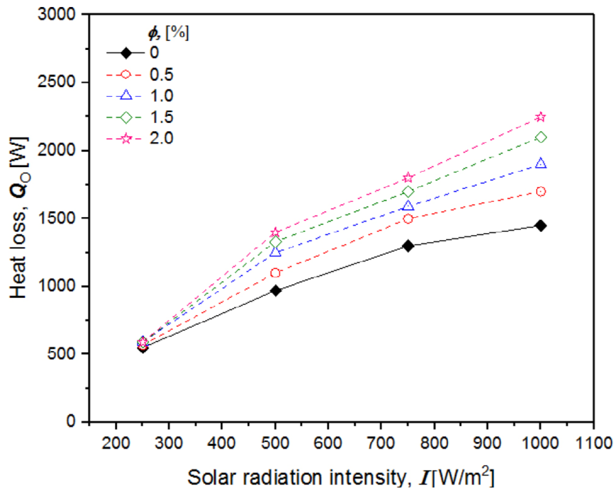


Fig. 11 The heat loss variation from a solar collector at different concentrations and solar radiations

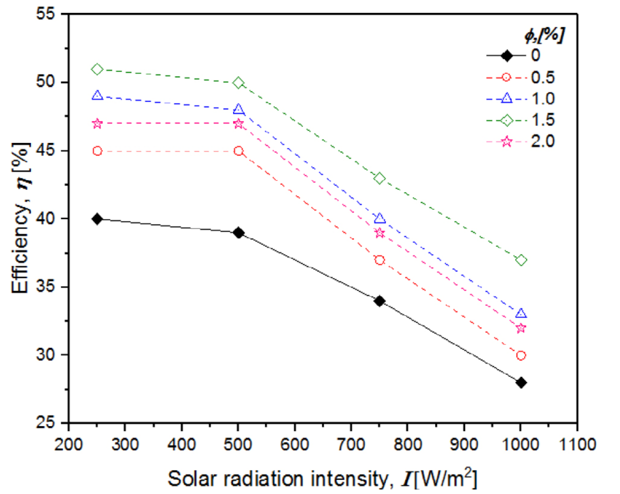


Fig. 12 The solar collector efficiency with a variation of solar radiations and volume concentrations

to the temperature difference between the fluids. The heat loss from the collector was analysed to evaluate the amount of energy absorbed by the system and to determine the efficiency of the performance of the solar collector. The heat loss has risen from the lowest solar radiation and is continuously increasing to the maximum solar radiation. The results show that the maximum heat loss is 2200 W at 1000 W/m^2 with a 2.0% volume concentration. The lower the value of heat losses to the surrounding air, the better the performance of the solar collector. The hybrid nanofluids with lower heat loss result in higher performance of the solar collector. Higher solar radiation intensity reduces system performance because the greater the difference in fluid temperature between the inlet and outlet temperatures, the greater the heat loss to the surrounding area, lowering overall system performance.

3.4.3 Overall efficiency

The overall efficiency of the solar collector with a variation of volume concentration and solar intensity is shown in Figure 12. There is a definitive difference in efficiency for each concentration. The efficiency at 0% volume concentration is 40%, but at 1.5%, the solar collector efficiency is 51%, while the collector efficiency reduces to 47% at 2.0% volume concentration. The solar collector performance increases remarkably with increasing concentrations, indicating better heat transfer performance using the hybrid nanofluids. However, the solar collector performance starts to decrease at a volume concentration of 2.0%. Usri et al. (2015) found that the heat transfer performance of nanofluids decreased with an additional increase in concentration, and similarly, they observed lower performance at 2% volume concentration. In another paper, Chen et al. (2016) stated that the nanofluids at high volume concentration attribute to the increasing attenuation of the radiation intensity passing over the solar collector, which can be translated as an augmentation in overall solar collector efficiency. However, in the present study, the hybrid nanofluids at volume concentrations higher than 1.5% were not beneficial in improving the solar collector's performance and efficiency.

4 Conclusions

This study examines the performance of a multi-layer solar collector employing hybrid nanolubricants of SiO_2–TiO_2 (50:50) in EG/H_2O (40:60). Preparation and evaluation of hybrid nanofluids to determine their stability conditions is undertaken. The thermal performance of the solar collector was evaluated by measuring temperature variation, heat loss, and overall collector efficiency. Several conclusions can be drawn from the experimental findings:

i. With a volume concentration of 1.5% SiO_2–TiO_2 hybrid nanofluids, the efficiency of solar collectors was increased by up to 22% compared to water.
ii. The temperature of the working fluids increased by 37% when SiO_2–TiO_2 hybrid nanofluids were used in the solar collector.
iii. The thermal performance of solar collectors employing hybrid nanofluids decreased when the volume concentration exceeded 1.5%.

Accordingly, it is recommended to use SiO_2–TiO_2 hybrid nanofluids at an optimal volume concentration of 1.5% for high efficiency and better energy gain in multilayer absorber solar collectors than the base fluids of water or the EG/water mixture. Additional research on the collector design optimization, angle of solar stimulator variation, and exposing the solar collector to solar radiation is required to advance the present work.

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