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ORIGINAL RESEARCH PAPER

Efficiency enhancement in a triangular solar flat plate collector by using Al_2O_3-water nanofluids: An experimental study

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ABSTRACT: In this research, a flat plate solar collector with a triangular geometry, which is designed and built by the author and based on the ASHRAE93-2010 standard, has been experimentally studied. The triangular solar collector has no riser and has spiral tubes containing fluid from the inlet to the outlet of the collector. To study water and Al_2O_3-water nanofluid in concentrations of 0.1, 0.2 and 0.3% and different flow rates from 0.0063 to 0.0378 lit/s have been used, which has been studied experimentally based on environmental criteria such as temperature and radiation and effective thermal parameters such as concentration and flow. Studies show that the triangular solar collector, due to its stable geometry and due to the reduction of the tube length in relation to the area, has a suitable performance for water heaters and can also be used. Time constant for triangular solar collector was between 2.5-4.5 minutes in flow rate ranges. The average efficiency increase when using nanofluids instead of water was about 12.4% and the maximum efficiency obtained at a concentration of 0.3% and a flow rate of 0.0378 was more than 68.3%. Also, in measuring the pressure drop in the collector, it was found that the pressure drop was very small and less than 0.1 bar.

KEYWORDS: *Efficiency; Experimental; Flat plate; Nanofluid; Triangular solar collector.*

INTRODUCTION

Today there are few places in the world that are not aware of the capabilities and the need to use renewable energy. Solar energy is one of the renewable energies that has been considered by humans since ancient times and has been used in various ways [1-3].

One of the applications of solar energy is the use of heating systems that use the sun's radiant energy and convert it into usable heat by an intermediary. This heat exchange takes place in a device called a solar collector.

The heat medium in solar collectors is a fluid that commonly uses water or air.

The simplest type of solar collector is the flat plate collector, which can be found in various designs and geometries. The higher the heat exchange from the radiation reaching the collector to the working fluid, the better and more suitable the efficiency and performance of the collector, which depends on various factors such as adsorbent, pipes containing the working fluid, type of fluid, geometry, glass coating and other factors [4-6].

Increasing the efficiency of flat plate collectors is one of the topics that researchers frequently research.

Saffarian et al. [7] theoretically evaluated a flat plate collector in terms of pipe arrangement and the effect of various factors such as pressure drop, heat transfer coefficient and efficiency in them and showed that the use of U-shaped pipe arrangement in comparison with The rest of the models performed better.

Noghreabadi et al. [8] presented a new model of three-dimensional solar collector with conical geometry. In this experimental study, the adsorbent was a conical back collector with which the operating fluid pipes were connected to the absorber in a spiral from bottom to top. The results of this study indicated proper thermal performance and a maximum efficiency of 60%.

Moravej et al. [9] introduced a circular flat plate collector and tested it experimentally under the ASHRAE standard. In this collector, the pipes were woven in a spiral in the absorber circle from the margin to the center of the circle, and after this path, the fluid came out in the center of the circle and from under the collector. The results of the study were based on significant efficiency growth, especially at high fluid velocities.

Another important method of increasing the efficiency of flat plate collectors, which has been highly regarded by researchers in recent years, is the use of nanofluids instead of ordinary water or fluids in collectors.

In a comprehensive study of solar flat plate collectors that used nanofluids to increase efficiency, Zayed et al. [10] in most studies, this nanofluid was in the concentration range of 0.025% to 2% and the flow rate was 1-8.8 kg/min, and the efficiency increase was between 6.3% and 37.3%.

Sint et al. [11] performed a theoretical study using CuO-water oxide nanofluids at a volume concentration of 0.1% to 3.5%. He used nanoparticles with a size between 140-140 nm

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Nomenclature

Greek symbol

A_c	Surface area of solar collector(m^2)	T_a	Ambient temperature (K)
C_p	Heat capacity (J/kg K)	T_i	Inlet fluid temperature of solar collector (K)
DT	Difference between inlet and outlet temperatures (°C)	T_0	Outlet fluid temperature of solar collector (K)
F_R	Heat-removal factor	$T_{O,i}$	Collector outlet initial coolant temperature (K)
G_T	Global solar radiation (W/m^2)	$T_{O,}\tau$	Collector outlet coolant temperature after time t (K)
$\dot{m}$	Mass flow rate (kg/s)	U_L	Overall loss coefficient of solar collector (W/m^2 K)
Q_u	Rate of useful energy gained (W)	$\tau\alpha$	Absorption-transmittance product
S_η	Uncertainty of efficiency (%)	η_i	Instantaneous collector efficiency
		τ	Time constant of conical collector

and reported an increase in efficiency of up to 5% and finally introduced a concentration of 2% as the best concentration. Sharafeldin and Grof [12] conducted an experimental study on CeO_2-water in three different concentrations with a nanoparticle size of about 40 nm and showed that the efficiency in the laminar flow increases to 10.74%.

Jouybari et al. [13] conducted an experimental study on nanofluid SiO_2-water in both laminar and turbulent flow regimes in a solar collector and reported that the best values for the volume concentration percentage in both flow regimes are 0.6%.

Also, a significant increase in the efficiency of the collector was presented in the experimental research of Saide et al. In the use of SWCNT-water nanofluids, which increased the efficiency of the collector by about 53%.

Mirzaei [14] studied the effect of nanofluid on the thermal performance of the flat plate collector and studied it experimentally in different flow rates and used a quadratic function to estimate the coefficient of performance and loss coefficient in the flat plate collector. He reported an increase in efficiency of up to 80% in flow rate 4 lit/min.

Sundar et al. [15] conducted a thorough study on the use of wire coil in the solar flat plate collector simultaneously with the use of nanofluid as the operating fluid.

In his research, items such as economic value due to dimensional reduction, heat transfer measurement and collector efficiency were investigated in different wire winding models.

The results showed that using this model of coil wire reduces the dimensions of the solar collector by about 27.66% for the use of water as a working fluid and 39.33% for the use of water-alumina nanofluid with 0.3% concentration.

Sakhaei and Valipour [16] performed an experimental study on thermal performance and changes in heat transfer parameters in a flat plate collector using corrugated helical risers.

The experimental results showed that the maximum collector efficiency was 61.59% and the friction coefficient increased to 97.6%. The maximum thermal efficiency of the collector is obtained at Reynolds number 5153.

In another study, Moravej et al. [17] experimentally investigated the increase in the square and collector efficiency of the solar flat plate using water nanoparticles and titanium dioxide of the rutile type.

The maximum efficiency reported in the results of this study was 78%.

In this research, a flat plate collector with triangular geometry without riser, designed and built by the author and has a zigzag tube arrangement in various conditions, including temperature changes and flow using ordinary water and Al_2O_3-water nanofluid in three Different concentrations have been studied experimentally according to the ASHRAE standard.

Table 1
The technical specifications and features of the triangular collector.

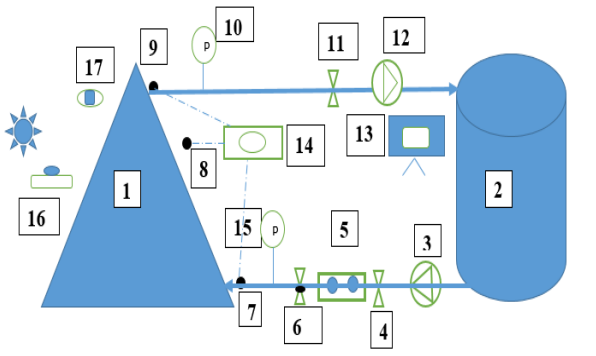
Specifications	Materials	Dimensions and units
Type	Triangular flat plat collector	Black color
Frame	Aluminum-white color	Frame area=0.606 m^2
Absorber	Black flat plate with 1.25 mm thickness	Absorber area=0.500 m^2
Glazing	Single flat glass	6 mm thickness
Collector tilt angle	45 degree with ground	-
Insolation	Wood in three sides	Wood thickness=22 mm
Weight	Total weight without fluid	28 kg
Piping	Cupper tubes	Inner diameter=8.6 mm

MATERIALS AND METHODS

Experimental setup

The collector used in this research is a flat plate collector with a triangular geometry that has an absorber with an isosceles triangle and spiral pipes without a riser are connected to it for fluid. The fluid inlet is from the bottom and exits the collector after following the zigzag path. This collector has a frame made of wood and was made by the author in Payame Noor University. The technical specifications and features of the triangular collector, including the dimensions, sizes and types of materials, are shown in Table 1.

For conducting the tests, the ASHRAE standard has been used and the laboratory set-up and the arrangement of the equipment have been done based on what is presented in Figure 1.



Number	Name of device	Number	Name of device	Number	Name of device
1	Triangular collector	5	Flow meter	13	Logger humidity
2	Tank	6	Control valve	14	Data logger
3,12	Pump	7,8,9	Thermocouples	16	Solar meter
4,11	Valve	10,15	Pressure gauge	17	Wind speed meter

Fig. 1. Setup of the experiment

Figure 2 shows a real photo of the test scene, which includes a solar triangular collector at the test site at Payame Noor University of Aghajari. Experiments have been performed in different conditions and on different days of spring and summer 2020, despite the prevailing conditions in the university due to Covid-19 disease, and the best results have been extracted and presented.



Fig. 2. Real photograph of collector testing in Payame Noor University of Aghajari

The geographical characteristics of the place test site specifications of the experiments are presented in detail in Table 2.

Table 2
Test site specifications.

Country, city	Iran, Aghajari
Location	Payame Noor University
Latitude	$30^0\ 69'\ 08''$
Longitude	$49^0\ 82'\ 40''$
Altitude	122 m above the sea

Table 3 indicates the specifications of all instrumentation and quantity measuring instruments, as opposed to the names of the devices and the measurement accuracy of each separately.

Table 3
Specifications of measurement instruments.

Devices	Model	Parameter	Unit	Accuracy	Actual photo
Thermo meter data logger	lutron	Fluid and ambient teperatures	^{0} C	0.1	
Rotameter	Km450	Flow rate	gpm	0.1	
Wind speed meter	lutron	Wind speed	m/s	0.1	
Solar power meter	Tes-132	Incident sun radiation	W/m^2	1	
Pressure gauge	Pekunzi	Pressure of fluid	bar	0.1	
Heumidity indicator	Htc-110	h	%	1%	
Thermoco uple	K type	temperature	mV/^{0} C	0.004	

Nanofluid preparation

Basically, the preparation of nanofluids from nanoparticles is possible in two methods, single-stage and two-stage, which today in many studies, the two-stage method is used technically. But in addition to determining

the type of preparation method, the degree of stability and proper distribution of nanoparticles in nanofluid are two key points [6-9]. In the present study, aluminum oxide nanoparticles with purity of 99.99% and size between 5-8 nanometers have been used to prepare alumina-water nanofluids in three concentrations of 0.1, 0.2 and 0.3%. The nanoparticles are from American model with US7150 number and deionized water base fluid distributed by ultrasonic device and prepared by Nano Sadra Company. Figure 3 shows the TEM image of the nanofluid and Figure 4 shows the actual sample of the volume required.

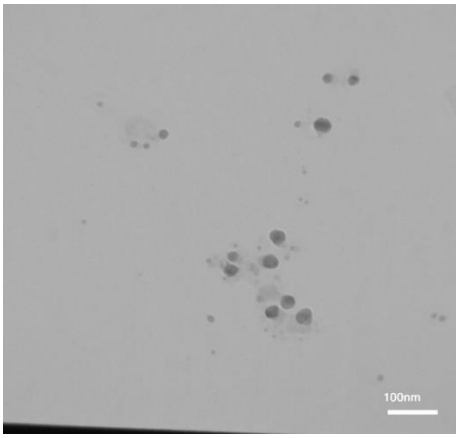


Fig. 3. TEM photo of produced Al_2O_3-Water nanofluid

For the nanofluid used before the tests, the necessary studies were performed visually for clustering and stability.



Fig. 4. Al_2O_3-Water nanofluid in 3 concentration

Also the specifications of nano particle and base fluid is illustrated in Table 4.

Table 4
Properties of base fluid and nanoparticles.

Material	C_P (J/kg K)	K (W/m K)	ρ (W/m^3)
Water	4180	0.613	998
Al_2O_3	880	35	3890

TESTING METHODS

Test procedure

Table 5 describes the ambient conditions in ASHRAE 93-2010 [18] standard for collector tests. Based on Figure 1, the operating fluid after leaving the storage tank, is directed by the pump to the inlet at the bottom of the collector and before entering the fluid flow rate, inlet temperature and pressure are recorded.

After entering the collector and along the spiral path in the triangular collector, it exits from the top and at the outlet, temperature and pressure are measured, then the fluid returns to the tank.

Temperature and humidity as well as wind speed are also measured separately. In order to accurately collect data in the direction of the ASHRAE standard, it should be noted that the determination of collector performance in stable and quasi-stable conditions can be investigated that researchers have proposed the use of a time-constant parameter.

In other words, the actual efficiency of the collector can be measured and reported when the collector is relatively stable in terms of heat.

To reach this state, the thermal transition mode must be passed. The amount of time required to pass the transition mode is based on a time constant criterion according to equation1 [8].

$$\frac{e}{T_{O,i} - T_i} = \frac{1}{T_{O,\Gamma} - T_i} \quad (1)$$

Where Ti is the inlet temperature to the collector, $T_{O,i}$ is the output temperature of the collector in steady state and $T_{o,\Gamma}$ is the output temperature of the collector after time Γ [3, 19].

For practical use of the above equation in the present study, a dark-colored carpet was placed in front of the collector and on the glass wall, and the time it took for the outlet temperature to reach 0.367% of the inlet temperature was measured.

Table 5
Environmental conditions according to standard [18].

Variable	Absolute limits
Total solar irradiance normal to sun(W/m^2)	790(minimum)
Diffuse fraction (%)	20
Wind speed	2.3<U<4.8
Incidence angle modifier	98%<normal incidence, value<102%

Figure 5 shows the amount of this time constant for different flow rates.

Obviously, after this time, the collector will enter a quasi-steady state and the measurement data related to the performance of the solar triangular collector will be reliable. According to these numbers, in data experiments, data

collection started after 5 minutes, which is a good time in terms of thermal steady state of the collector.

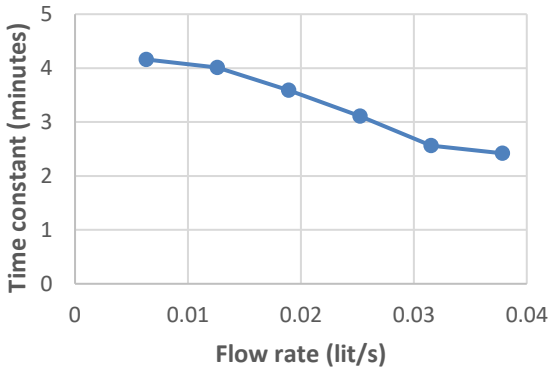


Fig. 5. Time constant for triangular solar collector

GOVERNING EQUATIONS

One of the evaluation criteria of solar collectors is to evaluate their efficiency, which is calculated as the ratio between the useful thermal energy obtained and the amount of solar radiation received. According to the use of ASHRAE standard in this research, in order to find a more accurate amount of efficiency, the thermal performance of the collector at different temperatures of the fluid entering the collector should be investigated. Equation 2 can be written to calculate the useful energy obtained from the collector [19].

$$Q_u = A_c[F_R G_T(\tau\alpha) - F_R U_L(T_i - T_a)] \quad (2)$$

In the above equation, F is the same as the loss coefficient in the collector and is obtained based on equation 3.

$$F_R = \frac{\dot{m}C_p(T_o - T_i)}{A_c[G_T(\tau\alpha) - U_L(T_i - T_a)]} \quad (3)$$

Therefore, the amount of useful energy extracted from the collector can be introduced as follows [8, 19].

$$Q_u = \dot{m}C_p(T_o - T_i) \quad (4)$$

In fact, the useful energy obtained from the collector is equal to the amount of heat given to the working fluid, which is calculated from the amount of specific heat for the liquid fluid at the pre-boiling temperature. Considering that both water-working fluid and alumina-water nanofluid are used in the triangular collector, the specific heat of nanofluid can be calculated from equation 5 [14,15,17].

$$C_{p,nf} = C_{p,np}(\varphi) + C_{p,bf}(1 - \varphi) \quad (5)$$

Where $C_{p,np}$ is the heat capacity of the nanoparticles, φ is the volume fraction of the nanoparticles, and $C_{p,bf}$ is the heat capacity of water as a base fluid. Data on specific heat of water and nanoparticles and other specifications can be found in Table 5. Also, considering that the energy reached to the collector is the same as solar energy, the efficiency of the collector can be written as equation 6 [19].

$$\eta_i = \frac{Q_u}{A_c G_T} = \frac{\dot{m}C_p(T_o - T_i)}{A_c G_T} \quad (6)$$

Due to equation 3 and 6, the collector efficiency can also be written as equation 7 [19].

$$\eta_i = F_R(\tau\alpha) - F_R U_L\left(\frac{T_i - T_a}{G_T}\right) \quad (7)$$

According to equation 7, if the yield values are plotted as a function and based on the variable (Ti-Ta) /G_T), the resulting curve consists of a line whose intersection with the vertical axis is the value of $F_R(\tau\alpha)$. This value represents the maximum collector efficiency and occurs when the temperature of the incoming fluid to the collector is equal to the ambient temperature. The intersection of this line with the horizontal axis is called the collector stagnation point at which the cumulative efficiency reaches zero and occurs when the flow rate in Flow rate becomes zero. The slope of the line is equal to $F_R U_L$, which represents the amount of energy loss from solar collection [19].

Uncertainty analysis

It is clear that errors in all measurements are inevitable in experiments. The types of errors in calculations and measurements in the present study include device calibration error, visual reading of cultivars, as well as the type of devices used. Data errors include temperature, solar radiation, area and flow rate measurement. To calculate the uncertainty in the experiments, the ROOT SUM SQAURE METHOD (RSSM) method was used, which is presented in equation 8 [6-9].

$$S = \sqrt[2]{\left(\frac{\Delta u_1}{u_1}\right)^2 + \left(\frac{\Delta u_2}{u_2}\right)^2 + \left(\frac{\Delta u_3}{u}\right)^2 + \cdots} \quad (8)$$

Therefore, for the present study, according to Relationship 6, we can write:

$$S_\eta = \sqrt[2]{\left(\frac{\Delta \dot{m}}{\dot{m}}\right)^2 + \left(\frac{\Delta DA}{DA}\right)^2 + \left(\frac{\Delta DT}{DT}\right)^2 + \left(\frac{\Delta G_T}{G_T}\right)^2} \quad (9)$$

According to the calculations and measurements, the amount of uncertainty calculated for the above data for Flow rate, area, temperature and solar radiation, respectively, is 5.5%, 0.01%, 0.2% and 3.1%, respectively.

These numbers in relation to equation 9 can be claimed that the uncertainty of calculating the efficiency of collectors is about 6.3%.

RESULTS AND DISCUSSION

In order to increase the accuracy and according to ASHRAE standard, tests have been performed on different days and under different conditions. In order to observe the stability conditions of the collector and also to perform the test with water and Al_2O_3-water nanofluid in different concentrations, the test process started before noon and ended after three hours from the beginning. Data collection is done once every 20 minutes, which is a good time period both in terms of passing the time constant and quasi-stability of the collector and considering that some data such as wind speed, temperature or humidity should be read visually. Although the test was performed on different days and hourly intervals, the best and most reliable ones were selected and presented.

Figure 6 shows the changes in solar radiation and ambient temperature around the triangular collector during the test. As can be seen in this figure, the amount of radiation is constantly increasing, which indicates that it is before noon to start the experiment.

Also, the air in the test area was completely sunny and warm, and the sky was free of clouds during the test. In the vertical axis on the left of this diagram, the ambient air temperature is presented in summer, which has a relatively high temperature due to high radiation and the geography of the place.

The maximum radiation and temperature recorded in the spring and summer of 2020 at the test site and data collection days were 949 W /m^2 and 50.1^0 C, respectively.

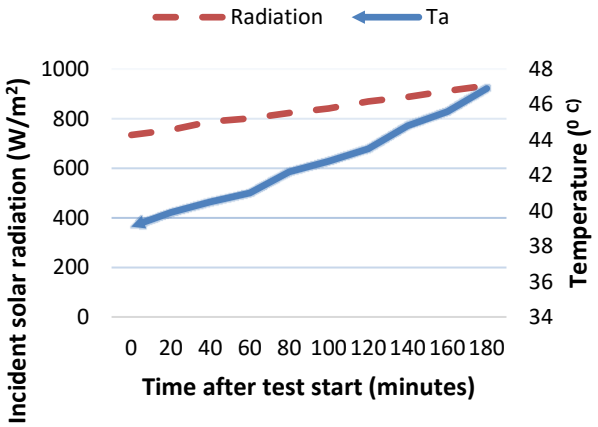


Fig. 6. Ambient temperature and incident solar radiation via tests

Figure 7 shows other environmental conditions including wind speed and relative humidity at the test site. Due to the climatic conditions of the test site, the changes in these two parameters were not relatively large and had acceptable conditions during the test hours.

One of the features of the triangular solar collector is its physical stability against wind speed, which is more tolerant of wind speed compared to rectangular collectors.

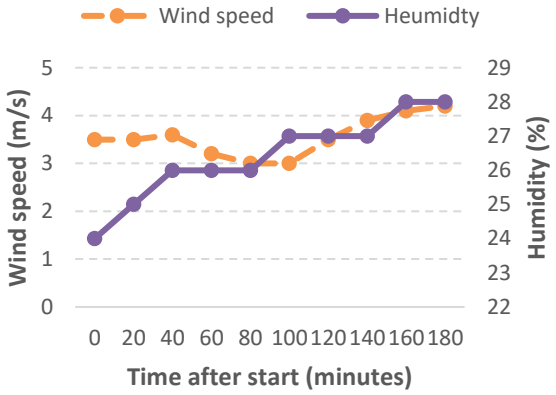


Fig. 7. Wind speed and air humidity via tests

In Figure 8, ordinary water is used as the operating fluid in a triangular solar collector, which is its efficiency calculated and plotted by measuring the inlet and outlet temperatures of the collector and equation 7, the efficiency of the collector and its operating temperature.

As can be seen in the figure, with increasing radiation over time, the growth efficiency increases, but its growth in the early times is more than the end times due to the increase in temperature and temperature difference between ambient temperature and inlet temperature to the collector and also increase heat loss at higher temperatures.

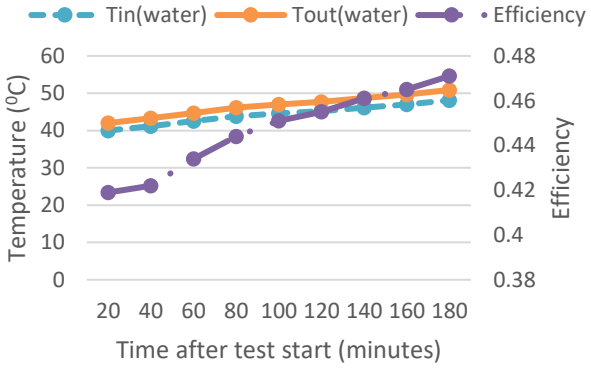


Fig. 8. Inlet, outlet and efficiency of triangular solar collector via time with using water as working fluid

Figures 9, 10 and 11 show the temperature changes and efficiency of the triangular solar collector using Al_2O_3-water nanofluids with concentrations of 0.1, 0.2, and 0.3%, respectively.

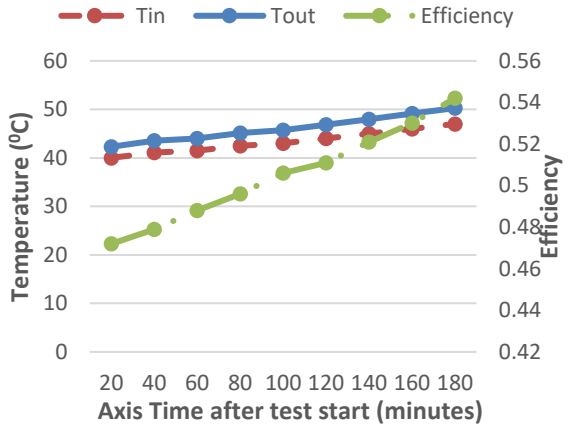


Fig. 9. Inlet, outlet and efficiency of triangular solar collector via time by using Al_2O_3-water nanofluid with 0.1% concentration as working fluid

What is clear in this diagram compared to the use of water as a working fluid is the relative growth of the collector efficiency and the improvement of its thermal performance.

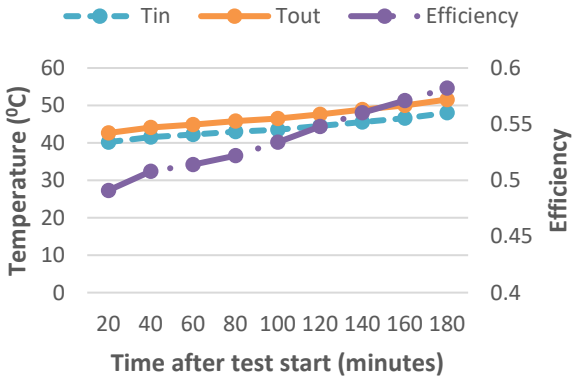


Fig. 10. Inlet, outlet and efficiency of triangular solar collector via time by using Al_2O_3-water nanofluid with 0.2% concentration as working fluid

There is also a relative difference between the difference between inlet and outlet temperatures, which at higher times and consequently at higher heat and radiation, the performance of using nanofluids is better compared to water. If at a concentration of 0.3%, the collector efficiency has exceeded 0.6, which is an acceptable value compared to the rectangular flat plate collector, which has more pipes and even multiple risers.

The maximum efficiency obtained for each of the above fluids was 57.1%, 63.3%, 65.2% and 68.3% for water, and Al_2O_3-water nanofluids with concentrations of 0.1, 0.2 and 0.3%, respectively.

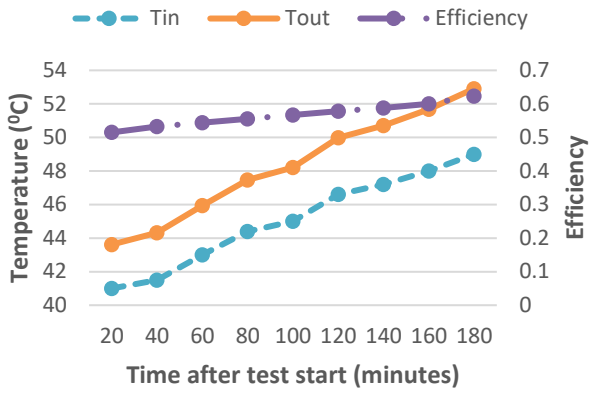


Fig. 11. Inlet, outlet and efficiency of triangular solar collector via time by using Al_2O_3-water nanofluid with 0.3% concentration as working fluid

Figure 12 examines the effect of flow on the performance of a triangular solar collector. According to this figure, as the flow rate increases, both when using water and Al_2O_3-water nanofluid as the operating fluid, the collector efficiency increases, and the higher the nanovial concentration, the greater the increase. The reason for these changes is that with increasing flow rate Reynolds number and as a result heat transfer to the fluid increases and efficiency increases. But when using nanofluids, in addition to the direct effect of the Reynolds number, the movements of suspended nanoparticles such as Brownian motions have a direct effect on increasing the heat transfer to the operating fluid.

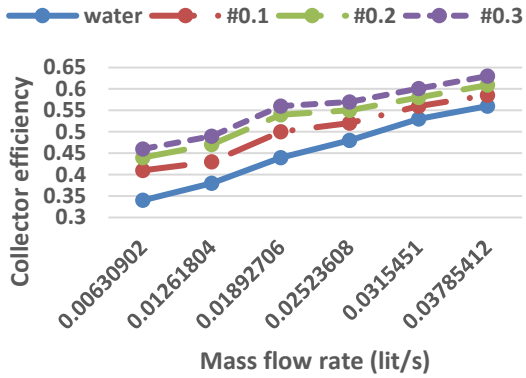


Fig. 12. performance of triangular solar collector via flow rate by using water and Al_2O_3-water nanofluid (with 0.1, 0.2 &0.3% concentrations) as working fluid

Figure 13 shows the average efficiency of a triangular collector based on the nanofluid concentration.

As can be seen in this figure, there is a significant increase in the use of nanofluids compared to the use of ordinary water as the operating fluid, but the growth ratio of nanofluids itself is less growth between different concentrations, which can be said to be approximately 0.3% of water. There is a 12.4% increase in efficiency.

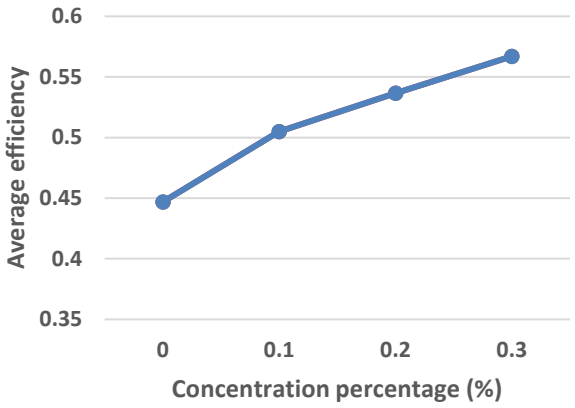


Fig. 13. Triangular solar collector efficiency versus nanofluid concentrations

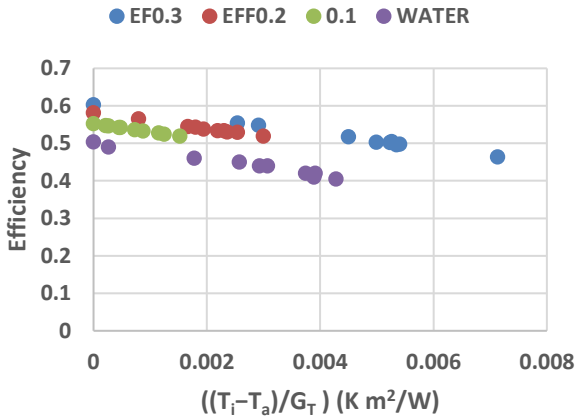


Fig. 14. Triangular collector performance versus reduced temperature parameter by using water and Al_2O_3-water nanofluid (with 0.1, 0.2 &0.3% concentrations) as working fluid

Table 6 also provides a comparison of different studies conducted by some researchers on the use of nanofluids in different concentrations, flow rates and conditions. At the end of this study, the results can be compared, especially in increasing efficiency considered.

Table 6
Summery of other experimental studied in using Al_2O_3-water nanofluid in flat plate solar collectors.

Researcher	Nano Fluid	Flow Rate	concentrations	Performance enhancement
Yousefi et al. [20]	Al_2O_3-water	1-3 lit/min	0.2%	28.3%
Gupta et al. [21]	Al_2O_3-water	2 lit/min		8.1%
Farajzadeh et al. [22]	Al_2O_3-water	2.5 lit/min	0.1%	19%
Rajput et al. [23]	Al_2O_3-water	1.3 lit/min	0.3%	21.32%
Hawwash et al. [24]	Al_2O_3-DDW	5.4 kg/min	0.1-0.3%	18%
Hajabdollahiard premnath [25]	Al_2O_3-water	7.2 kg/min	0.1-1%	2%
Colangelo et al. [26]	Al_2O_3-water	1.3 kg/min	0.5-2%	30%
Sundar et al [27]	Al_2O_3-water	5 kg/min	0.1-0.3	18%
Present study	Al_2O_3-water	2.2 kg/min	0.1-0.3	12%

In Figure 14, using the data obtained from the experiments as well as equation 7, a linear regression is obtained based on the efficiency and the temperature reduction parameter.

The calculated working fluids, the result of each of these regressions are presented in Table 7. Obviously, these parameters are the same as the parameters of equation 7, where the slope determines the collector losses and the value of frta is equal to the maximum efficiency.

Table 7
Linear curve fitting of Fig. 13

Concentrations	$F_R(\tau\alpha)$	F_RU_L
0(net water)	0.501	21.633
0.1%	0.552	21.618
0.2%	0.580	20.925
0.3%	0.603	19.636

CONCLUSIONS

In this research, a flat plate triangular solar collector without a riser has been experimentally studied according to the ASHRAE standard. Experiments have been performed using water and Al_2O_3-water nanofluid at concentrations of 0.1, 0.2 and 0.3% in different flow rates and different environmental conditions. The result of the study can be summarized as follows:

- The triangular collector has the same behavior as other conventional water heaters in terms of parameters affecting the collector efficiency.
- Time constant for triangular solar collector was less than 5 mintues.
- The use of Al_2O_3-water nanofluid increases the efficiency of the collector and the higher the concentration of nanoparticles from 0.1% to 0.3%, the higher the efficiency of the collector.
- For both nanofluids and water as the operating fluid, the efficiency increases with increasing radiation, but its growth is higher when using nanofluids due to the effective effects of nanoparticles at high temperatures.

- As the flow rate increases due to the increase in Reynolds number, the collector efficiency increases in all cases, but when using nanofluids, especially higher concentrations, a significant increase in efficiency occurs due to the increase in unpredictable movements of nanoparticles, including Brownian motion.
- The maximum efficiency recorded for the triangular collector was 68.03% and the average efficiency difference between using of water or Al_2O_3-water nanofluid was 12.4%.
- The results of the pressure drop test show that the pressure drop in the triangular collector is negligible due to the reduction in pipe length and is less than 0.1 bar.

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