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Exergy of flat plate solar collector with nanofluid flowing under climatic of Kirkuk city

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Abstract

Thermosiphon flow of flat plate solar collector (FPC) is one of the economic strategies of renewable energy. The aim of this study is to reduce the exergy destruction and improve energy efficiency of FPC under climatic conditions of Iraq. The CuO nanoparticles suspended in pure water has been utilized due to high thermal properties with 0.1%, 0.5% and 1% volume concentrations. Results show that the outlet temperature is increased with increasing solar radiation earlier then decreased after 12 P.M. similar behavior of solar radiation. The thermal efficiency is increased as solar radiation increased then decreased after 12 P.M. as the solar radiation behavior. It was noticed that the efficiency of using nanofluids has the same behavior as using purified water with deviation 15%. The amount of 1.0 vol% of nanofluid with pure water as the working fluid reaches the greatest thermal efficiency which is 69.06%. The 1% nanofluids concentration has better efficiency. The results show up the nanofluids was better than pure water due to their dispersion and thermophysical property predictions.

1. Introduction

There is a lot of clean solar energy available. A popular method of transforming solar radiation into usable heat is the use of flat plate collectors or FPCs. One typical application of FPCs is to heat water for domestic applications. The majority of FPCs contain liquids, such as water, ethylene glycol, propylene glycol, and others. The FPC's efficiency is limited because these fluids naturally have lower thermal conductivity than nanofluids. Due to its ease of usage and installation, FPC performance has been extensively examined.

The concept of nanofluids, characterized by their high thermal conductivity and first described by Choi [1], has been the subject of numerous published investigations into its possible application in various thermal devices. Fluid flows containing MWCNTs and water in a U-bend heat exchanger with two pipes are examined in[2]. Thermodynamic studies have shown that circulating nanofluids composed of carbon nanotubes and water can increase the thermal efficiency of solar collectors by as much as 5%[3]. Improved heat transfer coefficients of up to 30% were observed in experimental work employing thermosiphon solar collectors that use water-based Al_2O_3 nanofluids as their working fluid [4]. The heat transmission capabilities of nanofluids are better than those of conventional fluids [5].

An experimental study on thermosiphon-based solar collectors employing water-based CuO nanofluids as the working fluid demonstrated an 18% improvement in thermal efficiency [6]. Thirty percent and twenty-two percent increases in collector efficiency, respectively, were observed for TiO_2/water and Al_2O_3/water[7]. Circulating a CeO_2/water nanofluid increases a solar collector's efficiency by 10.74% compared to water alone [8].

مجلة العلوم والتطـــبيقات الهــندسية

Journal of Science and Engineering Application

ISSN 2521-3911

Ziyadanogullari et al. [9] found that nanofluids containing water-dispersible Al2O3, CuO, and TiO2 with loadings of 0.2%, 0.4%, and 0.8% by volume produced greater thermal efficiency. The thermal efficiency of flat plate collectors can be increased by 58% when using Al2O3/water nanofluids, as reported by Sundar et al.[10], and by 64.15 percent when using core-rod inserts with a p/d ratio of 1.79 inside the collector tubes, as reported by[11] .

According to [12], a solar collector with air flowing inside the tubes achieves a thermal efficiency of 49%. To achieve a thermal efficiency of up to 69.54%, Choudhary et al. [13]used a ZnO nanofluid based on a 50EG:50 W mixture in a fluidized bed combustion chamber (FPC). The use of MgO/water nanofluid in flat plate solar collectors increases their energetic efficiency by 32.23% [14]and by 29.32% [15] when MWCNT/water nanofluid is used. Working fluids, including Al2O3/water nanofluid, in flat plate solar collectors can increase energy efficiency by as much as 20.3% [16]. Increases of 28.3% and 37.38% in thermal efficiency, respectively, were seen when Al2O3/water nanofluid and MWCNT/water nanofluid were utilized in FPCs[17] and [18], respectively.

In a flow-through filter press (FPC), Sundar et al.[19] discovered a 26.64% improvement using a 0.3% volume fraction of ferric oxide/water nanofluids. The greatest thermal efficiency for the TiO2/water nanofluid flowing in the flat plate solar collector was determined to be 48.67% [20]. One kilogram per minute of CuO/water nanofluid increases the flat plate column efficiency by around 21.8% [21]. Utilizing graphene oxide nanofluid as the operating fluid in a solar flat plate collector (FPC) increases the collector efficiency by 7.3% compared to DI water[22].

According to research [23], fluidized bed combustion (FPC) using an Al2O3/water nanofluid and longitudinal strip inserts achieves a thermal efficiency of 84%. An increase of 13.48% in thermal efficiency over water was seen when WO3/water nanofluids were used in a flat-plate solar collector[24]. According to reference [25], adding 0.3% vol. of Cu/EG nanofluids to an FPC reduced the FRUL parameter by 39% for a mass flow rate of 1 lit/min and 45% for a mass flow rate of 0.5 lit/min. Adding 4% volume of Cu/water nanofluid to FPC improves the heat transfer coefficient by 76.5 and 72.1 percentage points compared to water, respectively, according to a theoretical study [26].

Using an Al2O3/water working fluid increases the maximum flat plate collector exergy efficiency from water by approximately 1%, according to[27]. According to an experiment[28], using magnesium oxide or ethylene instead of glycol-distilled water increased how well a flat-plate solar collector retains heat by 16.7 percent. For the same performance By substituting MWCNT/water nanofluids for water, Faizal et al. [29] calculated a 37% reduction in FPC size. Additionally, FPC's thermal efficiency has been observed to rise experimentally by as much as 44.61% compared to water, according to Kashyap et al.[30].

Analyzing the differences between the two FPC operating fluids, Thermodynamic efficiency is 11.15 percent and 5.81 percent higher for Al2O3/water and ZnO/water, respectively, compared to water, as demonstrated by Arikan et al. [31]. According to Arikan et al. [31], the thermodynamic efficiency is 11.15 percent greater for Al2O3/water and 5.81 percent higher for ZnO/water when compared to water. At a volume concentration of 0.05% CeO2/water nanofluids in an FPC, Stalin et al.[32] discovered a 28.07% improvement in thermal efficiency and a 5.8 percent improvement in exergy efficiency.

The experimental thermal efficiency of Alklaibi et al., [33] by using ND/water nanofluids in a flat plate collector has shown a thermal efficient enhancement of 12.7 % compared to water. They also observed at 1.0 vol% of ND/water nanofluid in an FPC, the thermal entropy generation decreased by 5.541 W/ K, whereas for water it is 5.725 W/K. You can study FPC's thermal efficiency (1) by making different nanofluids flow, like Al2O3, Cu, CeO2, ZnO, TiO2, SiO2, and MWCNT/water.

مجلة العلوم والتطـبيقات الهـندسية

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On the other hand, research on the subject of FPC thermal efficiency about natural circulation using nanofluids (nano-diamonds) was lacking. A lot is unknown regarding the thermal efficiency, energy generation, frictional entropy, and flow of high-thermal conductivity MWCNT nanofluids in an FPC. MWCNTs, which have values of around 1000 W/mK, provide the highest thermal conductivity of any nanomaterial. With MWCNTs, not only is stability improved, but Young's modulus is also increased, and they are cheap and easy to mass-produce. This study created and used MWCNT nanofluids in FPC based on water because of the growing interest in these nanomaterials.

Thermosiphon (natural) flow of various MWCNT/water nanofluids in the FPC is discussed in the article. Exergy, thermal entropy, friction entropy, and thermal efficiency are also discussed. To create the nanofluids, 0.1, and 0.3 percent loading were utilized. The trials were conducted outdoors from 9:00 a.m. to 4:00 p.m. Furthermore, it is critical to understand heat transmission, the Nusselt number, the friction factor, and pumping power. Under a 5% variance, we derive equations for the Nusselt number and the friction factor, and we use literature data to validate our conclusions.

2. Flat plate collector.

2.1. Test rig setup

The studies took place in Kirkuk, Iraq, situated at 35.28° N latitude and 44.23° E longitude. Fig.1 displays a schematic of a thermosiphon solar flat plate collector. The collector is thoroughly explained in Supplementary Table 1, and the base fluid water and CuO/water nanofluids are circulated between the collection and the tank. The tank is equipped with a coil heat exchanger designed for residential usage. The collector has a surface area of 1 square meter and consists of nine risers. The difference between the interior and exterior diameters of absorber tubes is 11 mm.

The tank can hold up to 45 liters. Six K-type resistance thermometers were used to measure the air temperature, the fluid temperature at the tank's intake and outflow, and the fluid temperature at the designated surface position of the solar collector. Several sensors are connected to an Arduino data recorder. Electromagnetic flow sensors quantify the mass flow rate of the fluid exiting the main pipe. The Daystar solar meter was used to measure the sun's radiation reaching the collecting area. The TS-51 equipment by Inc. monitors the thermal conductivity of the working fluid; the Archimedes principle is used to estimate density; a vibrio - viscometer is used to measure viscosity; and so forth.

The testing period ran from 9:00 a.m. until 4:00 p.m. UTC. Natural convection was the only method able to circulate the working fluid in the collector-storage tank loop in this situation. Copper oxide and water nanofluids are rare topics in the literature. The goal of this study is to look at the first law of thermodynamics (calculating thermal efficiency) and the second law of thermodynamics (calculating energy efficiency) when CuO and water nanofluids are used as working fluids in a solar flat plate collector that is set up to work with thermosiphon (natural circulation). Two fluids are cycled in a heat exchanger inside a tank: one in a closed circulation loop via the flat plate collector and the other in a water-based secondary loop. By circulating the heated CuO/water nanofluids via cold water in the heat exchanger tank warm water may be collected at the output for washing dishes or clothing. The solar collector with flat plates that are attached to the tank allows the CuO nanofluid to naturally move between the two. There are eight risers and a collector surface area of 1*1 m^2. There is a 9.5 mm inner diameter and a 22.5 mm outer diameter for the absorber tubes. There are 45 liters of hot water storage space in the tank. In the table, you can see all the specs for the solar flat plate collector. Inlet and outlet fluid temperatures and ambient air temperature the working fluid's mass flow rate is measured using the YF,

مجلة العلوم والتطـــبيقات الهـندسية

Journal of Science and Engineering Application

ISSN 2521-3911

S201 sensor model. This water pressure gauge is less than 1.75 MPa. Utilizing the Archimedes principle for density measurement and a conductivity meter type TS-51 for thermal conductivity, the working fluid is evaluated. Between the hours of 8 in the morning and 5:30 p.m., tests were carried out. When this occurs, natural convection can handle.

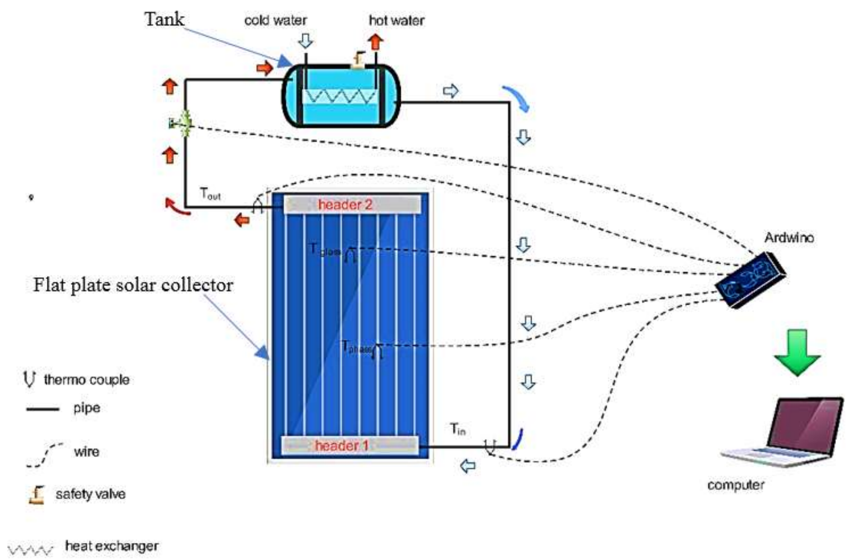


Fig. 1. Schematic of test rig.

NO.	Parts of the system	NO.	Parts of the system
1	A thermocouple sensor to measure the temperature of water entering the solar collector (pure water system and nanofluid system)	9	Electric mixer for nanofluid mixing
2	A thermocouple sensor to measure the temperature of water leaving the solar collector (pure water system and nanofluid system)	10	The safety valve for both tanks
3	A thermal sensor to measure the temperature of the absorption plate for two water and nanofluid systems	11	Nanofluidic flow control lock
4	A thermal sensor to measure the temperature of the glass cover of two water and nanofluid systems	12	Water flow control lock
5	Two keys to operate the system: the pure water system and the nanofluid system	13	A device for measuring radiation intensity for both systems
6	Computer to read data	14	Two tanks to collect pure water and nanofluid
7	The mass flowmeter for both systems	15	Insulated copper pipes for both systems
8	Faucets for both systems	16	Ultrasound device

Fig. 2. Photograph of flat plate collector.

2.2. Materials and methods

Research comparing a flat solar collector utilizing nanofluids with one utilizing liquid water Improving the efficiency of a solar-assisted hot process stream using nanofluids The system consists of

مجلة العلوم والتطـبيقات الهـندسية

Journal of Science and Engineering Application

ISSN 2521-3911

two main components. A CuO-water FPSC can generate a nanofluid stream at a moderate temperature in the initial portion. By absorbing solar radiation, this stream is heated.

Once the nanofluid stream has passed through a double-pipe heat exchanger (H.E.), any surplus heat is transferred to the industrial stream, therefore cooling it. After cooling, it returns to the FPSC. The industrial stream is heated in the heat exchanger and then sent to the heater to achieve the desired temperature. Studying the collector characteristic curve is the most effective method to understand the impact of nanofluid on heat absorption. The thermal efficiency of a tilted FPSC was tested in conditions similar to those of CuO nanoparticles, each with a diameter of 40 nm. This was done to find out how nanoparticles affect heat absorption. The CuO/water sample was prepared using a two-step process with a concentration of 0.1 vol%. The object was exposed to sound waves for 120 minutes to prevent clustering. The sample exhibited no visual instability, even after multiple hours.

The initial step involved in the study was the experimental assessment of the thermal efficiency of the water fluid. Initial analysis of the experimental data showed that, over time, lower flow rates led to improved efficiency. The thermal and CuO/water combinations were retested. The efficiency diminishes with time in a manner consistent with the behavior of the base fluid, which is water. The correlation between flow volume and water and CuO/water sensitivity is a significant indicator of the distinction. Increasing the flow rate reduces efficiency in water-based fluids but is beneficial for nanofluids.

The nanoparticle volume is directly related to the flow rate, and greater flow rates lead to improved heat transmission. Comparing water and CuO/water shows that both decrease over time. The decrease in CuO/water is somewhat more pronounced due to CuO increasing the convective coefficient and hence the total heat loss coefficient. 1. The effectiveness of a water-equipped solar collector declines as the flow rate increases, making the FPSC most efficient at lower flow rates. Conversely, the sensitivity flow rate is negative for CuO/water. The sensitivity of the device enhances its efficiency, resulting in an increased flow rate. A collector filled with CuO or water is more effective than one filled with water alone. The CuO/water value exceeded that of water at 60, 120, and 240-liter hours. Comparing the maximum efficiency is a direct method to evaluate the effectiveness of FPSCs. The addition of CuO resulted in efficiency increases of 14.28%, 29.85%, and 43.1%.

3. Data reduction

According to the ASHRAE 93-2003 standard [35], the useable energy Qu [36] is the amount of energy that the working fluid absorbs and can be used to define the efficiency of a solar collector in steady-state operation.

$$Qu = m\,Cp(To - Tin) \qquad (1)$$

In the solar collector, m is the mass flow rate of the working fluid, and Ti and To are the temperatures of the fluid entering and leaving the collector, respectively. According to equation (2), there is a relationship between global solar radiation (G_T), collector area (A_c), and instantaneous collector performance (η_i) [35].

$$\eta i = \frac{Qu}{AcGT} = \frac{m\,Cp(To - Tin)}{AcGT} \qquad (2)$$

مجلة العلوم والتطـبيقات الهـندسية

Journal of Science and Engineering Application

ISSN 2521-3911

The second law of thermodynamics evaluates the exergy analysis, thermal entropy, and frictional entropy. The overall exergy of a system decreases as its irreversibility increases and its entropy rises. Use these equations to find the exergy efficiency of the system [36].

$$\dot{E}x_{heat} - \dot{E}x_{work} - \dot{E}x_{mass,in} - \dot{E}x_{mass,out} = \dot{E}x_{dest} \quad (3)$$

The terms that are used are exergy in heat (Ex heat), work (Ex work), mass inlet (Ex mass, in), mass outlet (Ex_{mass}, out), and exergy destructed (Ex $_{dest}$).
It may be calculated the Ex_{heat} heat using Eq. (4) as

$$\dot{S}_{gen,th} = m\,Cp \ln\left(\frac{To}{Ti}\right) - \left(\frac{\dot{Q}\,s}{Ts}\right) + \left(\frac{\dot{Q}\,o}{Ta}\right) \quad (4)$$

The exergy efficiency of the solar collector, which is defined as the ratio of the useable exergy output to the total exergy input, may be estimated [36] as:

$$\eta_{ex} = 1 - \frac{Ta\,\dot{S}\,gen}{\left[1 - \left(\frac{Ta}{Ts}\right)\right]\dot{Q}\,s} \quad (5)$$

For calculating the rate of heat transfer absorbed by water and CuO/water nanofluids:

$$\dot{Q} = \dot{m}\,Cp(Tout - Tin) = U_o\,A_o\,(T_{surface} - T_{mean}) \quad (6)$$

4. Results and discussion:

The experiment and testing of solar collector has been conducted under the climatic conditions of Kirkuk city of republic of Iraq. It was observed that the outlet temperature is entering the solar collector in 25°C and the flowrate is 0.009 kg/sec for pure water as shown in Fig. 6. The results of outlet temperature are numerically recorded along one month June 2022 and reduced for four days: 01/06, 10/06, 21/06, and 27/06 as average from nine o'clock A.M until four o'clock P.M. It can be seen that the temperature is increased from the sun rise and the recording data from 9 A.M. till the mid-day at 12.30

P.M. which is represented the optimum solar intensity. The behavior of temperature was decreased after mid-day due to reduce the intensity solar.

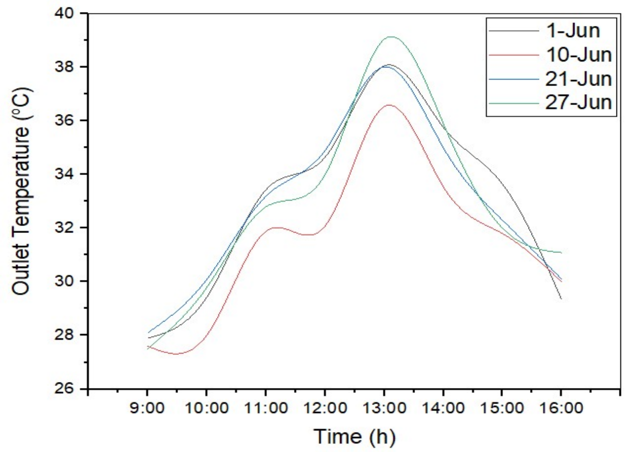


Fig. 6. Outlet temperature with time for pure water**.**

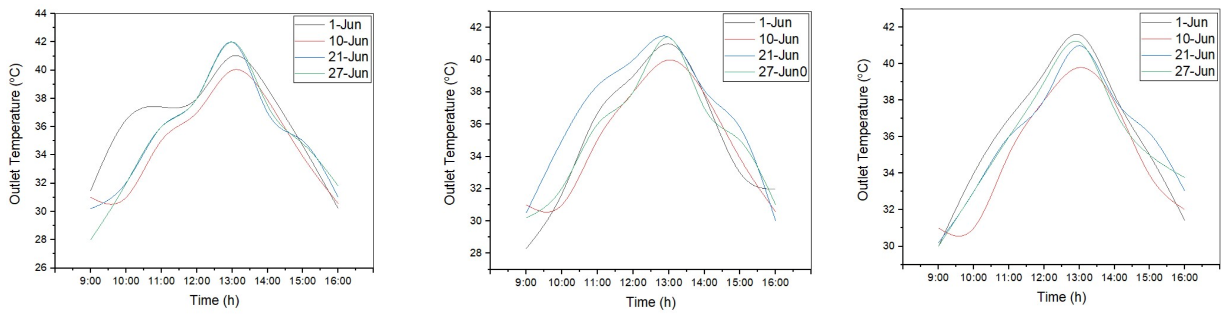
The time-depended of the outlet temperature for water and diamond nanofluids are utilized at concentrations of 0.1%, 0.5 %, and 1 % respectively, as seen in Fig.7. The outlet temperature is determined using smart thermometer. It was observed that the outlet temperature of nanofluids has the same behavior with using pure water along June 2022 with different values. The reason for elevated the values of outlet temperature was due to improvement of thermal nanofluid characteristics as compared to base fluid. It can be seen that the 0.1 and 0.5 percent is enhanced the outlet temperature by 8.05% and 8.65% respectively as compared to pure water then the 1 percent has the highest values of outlet temperature as compered the pure water with 10.5%. For the pure water, the results of efficiency were

مجلة العلوم والتطــبيقات الهـندسية

Journal of Science and Engineering Application

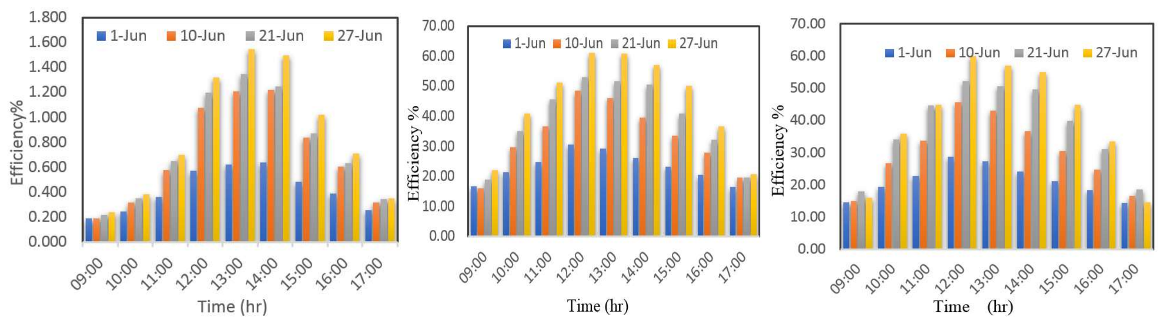
ISSN 2521-3911

numerically monitored along one month June 2022 and reduced for four days: 1/6, 10/6, 21/6, and 27/6 as average from 9:00 a.m. to 4:00 p.m. It can be seen from Fig. 8.



(a) 1% nanofluid (b) 0.5% nanofluid (c) 0.1% nanofluid

Fig. 7. Outlet temperature of nanofluids over the time**.**



(a) 1% nanofluid. (b) 0.5% nanofluid. (c) 0.1% nanofluid

Fig. 8. Collector efficiency of nanofluids over the time.

The efficiency increases with the rising of the sun and the recording of data from 9 a.m. to mid-day at 12.30 p.m., which represents the optimum solar intensity. The solar intensity decrease, therefore, efficiency decreases after midday, also cause slight difference between the temperature entering and exiting the flat plate solar collector. It was observed how the efficiency of water and nanofluids changes over time when they are utilizing at concentrations of 0.1 percent, 0.5 percent, and 1 percent, respectively. The experimental study was used to establish how efficient the system is. Along June 2022, it was noticed that the efficiency of using nanofluids has the same behavior as using purified water, but with different values. The improvement of thermal Nanofluids vs. basic fluids are the cause of the rising values of outlet temperature. This is because nanofluids have a smaller thermal expansion coefficient, when compared to pure water, it is clear that a concentration of 0.1 and 0.5 percent produces an increase in outlet temperature of 8.75 and 9.5 percent, respectively; however, a concentration of 1 percent produces the highest values of outlet temperature, up to 12.02 percent higher than that of pure water.

6. Conclusions

1. The FPSC's thermal performance was analyzed using pure water and nanofluids with variable nanoparticle composition. The experimental data and theoretical results from CFD were validated and it was in good agreement.
2. The sun irradiation steadily climbs to its highest point at 12:30 p.m., when it reaches its maximum value, and then it begins to gradually fall until the conclusion of the test interval.
3. The amount of 1.0 vol% of nanofluid with pure water as the working fluid reaches the greatest thermal efficiency possible, which is 69.06%. In this case up to 12.02% improvement were done over the previous level.
4. Generally, the nanofluids with 1% higher concentration have better efficiency.
5. The results show up the nanofluids was better than pure water due to their dispersion and thermophysical property predictions.

Nomenclature:

symbol	Symbol description	Symbol	Symbol description
A_c	The solar collector's area (m^2)	T_a	Air temperature(k)
cp_{bf}	The base fluid's specific heat (J/kg K)	T_c	Temperature of the glass cover (k)
cp_{np}	The specific heat (J/kg K)	T_o	The temperature outlet fluid(k)
F_R	Factor of heat removal	T_s	Sky temperature (K)
kG_T	Total irradiance of the sun($\frac{W}{m^2}$)	$\dot{m}^{\cdot}$	The mass flow rate of fluid flow (kg/s)
h_b	The heat transfer coefficient.	Nu	Nusselt number
K	Thermal conductivity(W/m. K)	P	fluid pressure (Pa)
		Pr	Prandtl number
Q_u	Gained usable energy rate(W)	U	Velocity components in X directions (m/s).
T	Time(s)	U_L	The solar collector's overall loss coefficient.

Greek symbols:

ρ	Reflectivity for glass and absorber, and fluid density (kg/m^3)
φ	Particle concentration
$\tau\alpha$	Absorptance-transmittance product
μ	The viscosity of the fluid (pa. s)
ε_p	Absorber plate emittance
ρ_{nf}	Density of nanofluid, kg/m^3
ε_g	Glass cover emittance
η_i	Collector thermal efficiency
α	Absorptivity
τ	Transmissivity

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