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Improving Flat-Plate Solar Collectors' Thermal Performance with Nanofluids: A Comprehensive Review

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Abstract

Nanofluids have been employed in a variety of practical applications within the field of heat transfer. There are numerous applications for cooling lubricants, including vehicle radiators, solar and nuclear energy systems, biomedical devices, heating, ventilating, conditioning of air, storage refrigeration, engine cooling, and transformers. The effects of unconventional fluids when combined with traditional fluids for heat transfer have been the subject of extensive scientific research. The results of these studies have demonstrated that the combination enhances heat transfer performance to a level that surpasses that of conventional working fluids. These investigations collectively demonstrate that nanofluids are capable of exceptional heat transfer. It is necessary to adopt a comprehensive approach that integrates both practical application and conceptualization in order to optimize the efficacy of flat plate solar collectors. The results of this study show that the potential for efficiency improvements to range from twenty percent to eighty-five percent can be achieved by increasing the concentration of nanofluids and the bulk flow rate. This paper aims to summarize the scientific progress made in the field of application of nanofluids to enhance the thermal performance of flat plate solar collectors.

Keywords: Flat plate solar collector, Nano-fluids, Thermal Performance.

1-Introduction

With temperatures that are lower than 150 degrees Celsius, flat-plate heaters are able to fulfill the heating requirements of a variety of industrial processes. These solar collectors have an impressive potential to raise the temperature of the working fluid from 30 to 100 degrees Celsius over the temperature of the surrounding environment. One of the fundamental ideas is that the channels that are contained within the collector make it possible for the working fluid to have an efficient conveyance of solar energy. In recent times, nanofluids have received interest as a viable solution for operational fluids that aim to improve thermal efficiency or solar collector fluids. It has the potential to achieve significant energy and cost savings.

There are multiple benefits to renewable energy sources, such as less emission, are becoming increasingly important as pollution levels continue to rise and coal supplies continue to decrease at a rapid pace. A number of different sources [1, 2, 3, 4, 5, 6] point to the fact that there is an immediate want for energy solutions that are both green and economical. Yousef et al. investigated a flat solar collector that was 2 meters in size and was augmented using

MWCNT-H_2O nanofluids in order to overcome these problems. The efficiency of the flat solar collector increased by 83% when the rate of mass flow was changed from (0.0167 to 0.05) kg/s, while the concentration of nanofluid was changed from (0.2 to 0.4) vol%, and the diameter of nanoparticle was adjusted from (10 to 30) nm. [7]

The researchers Dutta et al studied natural magneto-hydrodynamic convection and the creation of entropy in "rhombic enclosures" that contained nanofluids of copper water. The simulations that are performed numerically include a wide range of enclosure orientations, nanofluid volume percentages, Rayleigh and Hartmann numbers. At higher Rayleigh numbers, the data suggest that magnetic fields have a considerable impact on heat transfer. On the other hand, when the Rayleigh numbers are smaller, the interaction between the Hartmann number and the concentration of the nanofluid has a greater impact on thermal dynamics and the number of entropy produced. With the help of a two-dimensional recto-trapezoidal enclosure, this study investigates the interaction between absorber plate fins and natural convection. Cu-water nanofluid is used in the experiment. It is characterized by an inclination angle of sixty degrees, a top wall that is adiabatic, a bottom temperature that is high, and vertical walls that are freezing. There is a spectrum of Rayleigh numbers ($10^3 \leq Ra < 10^6$) and solid volume fractions ($0 \leq \varphi \leq 0.1$) that are utilized in order to evaluate streamlines, isotherms, and heat transfer rates for Cu-water nanoparticles. These approaches are implemented to evaluate these phenomena [8]. By demonstrating that larger nanoparticle volume fractions and rising Rayleigh numbers enhance streamlines, Dutta and Biswas found that heat transfer rates rose by more than twenty percent at $Ra = 10^6$, and by thirty percent with Cu-water nanofluid at $Ra = 10^3$ [9].

According to the findings, nanofluids have a huge potential to be used as an enhanced solar collector and as a source of energy that can be utilized in a more sustainable manner. According to the most recent findings, a more environmentally friendly and sustainable energy future is not only possible, but nanofluids are also positioned to play a significant role in bringing about this transformation.

2.Models of The Efficiency of the Flat-Plate Solar Collectors (FPSC) and The Usable Energy Gain (Qu) Of The Solar Collectors

One of the most essential requirements for conducting thermal performance analysis of flat plate solar collectors using nanofluidic implementation model. As follows, the mathematical formula of this model was published in the papers of [1, 3, 9]. These publications also include the following: The following is an approximation of the density as well as the specific heat capacity:

$$\rho_{nf} = (1-\varphi)\rho_w + \varphi\rho_p \tag{1}$$

$$Cp_{nf} = \frac{(1-\varphi)(\rho C_p)_w + (\rho C_p)_p \varphi}{(1-\varphi)\rho_w + \varphi\rho_p} \tag{2}$$

The Flat plate solar collector operational efficiency gain (Qu) calculated by:

$$Q_u = \dot{m} \times Cp_w(T_o - T_i) = \tau\alpha \times I_t \times A_c - U_L A_c (T_P - T_a) \tag{3}$$

The solar water collector with a flat plate has an hourly efficiency of ηsc.

$$\eta_{sc}\% = \frac{Q_u}{I_t A_c \Delta t} = F_R \tau\alpha - F_R U_L \left(\frac{T_i - T_a}{I_t}\right) \quad (4)$$

To examine the use of a carbon nanotube (CNT) nanofluid to an area-based solar collector with a deployed area of 0.34 square meters, Vijayakumar et al. conducted a study. The nanofluid was characterized by a diameter of (1) nanometer and variable weight proportions of (0.6%, 0.5%, and 0.4%). During a concentrated effort at a rate of (0.5%), the findings of this experiment suggested a significant increase in efficiency of 39% of the time [10] Chaji et al. conducted an additional controlled experiment in which they investigated the application of (TiO_2) nanofluid, which was designed to have a diameter of (20) nm and was coupled with water as a basic fluid. On a solar collector that was (1) square meter in size, a variety of weight ratios, including (0.3%, 0.2%, 0.1%, and 0%), were utilized, along with rates of volumetric flow were (36, 72, and 108) dm^3/h. This is depicted in Figure 1. It was found that the incorporation of nanoparticles into this framework led to a significant increase about (15.7%) in the efficiency of collector, particularly, when the flow rate was (108) dm^3/h. Using copper nanofluids that were mixed with ethanol and had diameters of (10) nanometers [11].Zamzamian et al. conducted an examination on a "flat solar collector" that had an area (0.67) square meters. Between (0.2%) and (0.3%) is the range of the volumetric concentrations. With a concentration of (0.3 vol%) and flow rates ranging from (0.016 to 0.050 kg/s), the collector was able to achieve its maximum efficiency, highlighting the positive impact that these factors had on the collector's overall performance. [12]

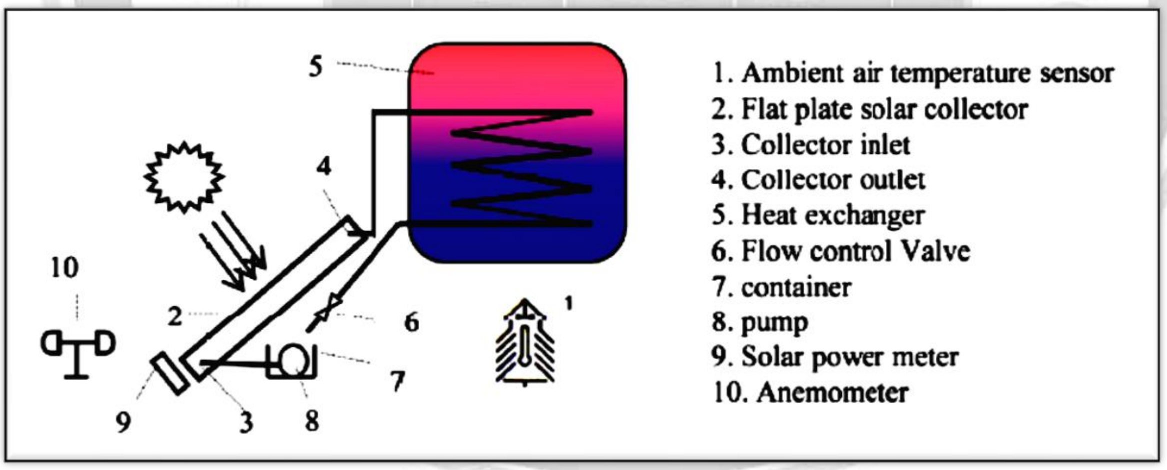

Fig. 1. The experimental set up schematic [11]

In addition, Nasrin and Alim conducted an experiment in which they integrated nanoparticles of varying sizes (Al_2O_3, CuO, and TiO_2) with distilled water in order to construct a solar collector has a surface area of (1.51 m^2), as depicted in Figure 2. The three different nanoparticles concentrations were used as laminar flow condition as (0.2, 0.4, and 0.8) vol%. Additionally, the rate of mass flow was (4 kg/min) applied, which completed the process. The

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experiment's findings indicated that the augmentation of heat transfer rates is highly improved inside the base liquid when nanoparticles are distributed uniformly throughout the space. Nanofluids have a tremendous potential to improve the efficiency of solar collectors, as demonstrated by the research efforts. These nanofluids also provide essential insights into optimizing energy consumption strategies and supporting sustainable practices. [13]

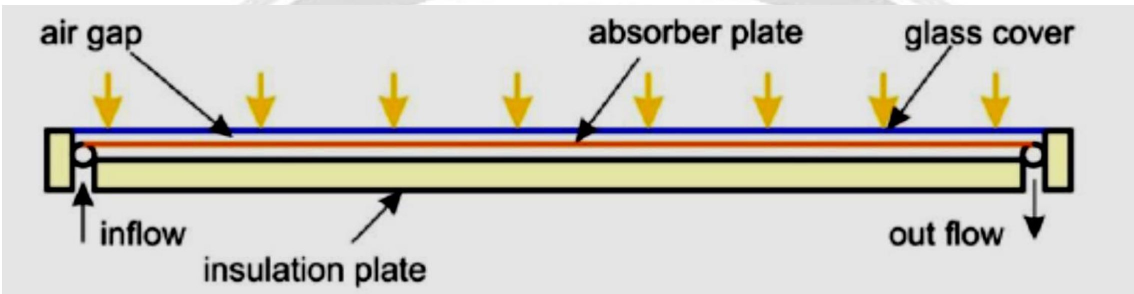

Fig. 2. The experimental set up schematic [13].

When compared to particles made of aluminum oxide (Al_2O_3) and titanium oxide (TiO_2), copper particles (Cu) have a comparatively higher rate of heat transmission. Each type of particle has its own set of features that are distinct from those of the others, and the surface temperature gradient shifts depending on the type of particle that is used. The employment of copper oxide (CuO) in conjunction with distilled water has been found to result in the most substantial boost of efficiency, reaching 87.8%. This was identified after careful investigation. Compared to the efficiency of distilled water on its own, which is (52.5%) lower, this is a significant improvement.

For the goal of solar water heating in the home, Moghadam et al. conducted an experiment into the impacts of a CuO–water nanofluid in a flat-plate solar collector. The nanofluid was used to heat the water. A nanofluid with 0.4 vol% CuO nanoparticles is 21.8 percent better at collecting charge than water alone at a mass flow rate of 1 kg/min. This figure is based on a comparison between the two types of fluids. In solar water heating systems, nanofluids have the ability to improve collector performance and boost thermal characteristics, as indicated by the outcomes of the particular study that was conducted. [14]

An additional experiment that Michael and Iniyan carried out involved the utilization of a solar collector that had a surface area of (2.184) square meters spanning throughout its entirety. In order to achieve this goal, they made use of a CuO nanofluid combined with water as the primary fluid. The distance of the diameter sacculated for nanofluid was 0.3 to 0.4 nanometers Through the application of a natural thermal load at the rate of 0.1 kg/min by setting volumetric concentration to 0.05%, an efficiency of 57.98% was achieved. Thus, it implies that the functional performance of the Changsha natural thermal load was superior to that of the Ningbo artificial thermal load [15]. Shojaeizadeh et al. conducted a study on the performance of a 1.51

m^2 flat solar collector using Al_2O_3 nanofluid with distilled water. The volumes of the nanofluid were as follows, from 0.090696 up to 0.1423%, whilst its dimension was between 15nm (10 nm). Combined energy was observed to have a variable effect due to the adjustment of other parameters. The outcome of this clinical examination disclosed the possibilities to increase energy effectiveness for coupled nanofluids with water owing to the availability of these nanofluids itself [16]. Said et al. performed an experiment on a flat area (1.84 m^2) of solar collector as shown in Figure 3. Using laminar flow at a rate of mass flow (0.5 kg/min), they utilized a TiO_2 nanofluid that had 21 nm as diameter, and two volumetric concentrations (0.1% and 0.3%) throughout the experiment. Polyethylene clay and pent ethylene glycol (PEG) in the liquid used as surfactants, which resulted in a considerable increase of 76.6% in the efficiency percentage when compared with water as the basic fluid at the time [17].

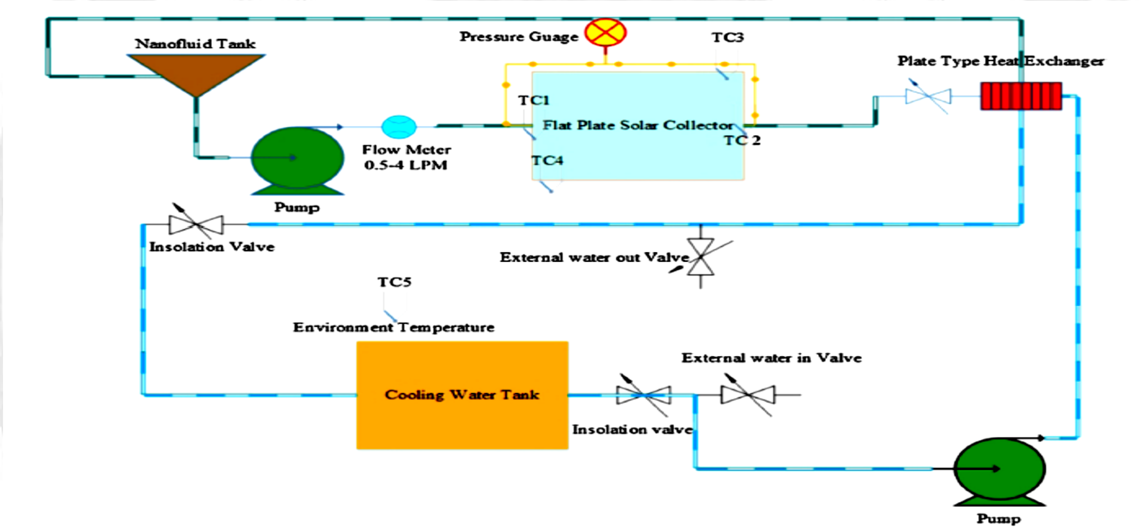

Fig. 3. Schematic presentation of the experimental setup [17].

In a single year, Meibodi et al. conducted two distinct experimental researches. Both of these studies were independently conducted. The initial research made use of a solar collector that was flat and measured 1.59 square meters in areas. Within the scope of the experiment, the nanofluid SiO2/EG-water utilized had a diameter of ten nanometers and volumetric concentrations of half a percent, seven point seven percent, and one point one percent. At some point in their process they experienced a" turbulent flow", mass flow rate (2.7 kilograms per minute). They found a substantial enhancement in efficiency, ranging from 4% to 8%, in comparison to water as the base fluid. The data showed this marked improvement. The researchers used a flat collector with an area of two square meters to do this test. They also utilized a nanofluid based on SiO2 with a 10-nanometer particle size and volumetric concentrations of 0.2%, 0.4%, and 1.5%. During this experiment, a 3 kg/min of mass flow was maintained for the overall process and the status of flow was created as turbulent [18]. In contrast, using the device comparing frequency to use water as the base fluid prove that displayed high significant efficiency percentage 23.5% gain . [15]

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Vakili et al. conducted a study. Experimental average performance summary on 0.36 m2 solar collector, used for domestic water heating This research project aimed at enhancing efficiency of the solar collectors. Analysis of the results mentioned a trend that was quite noticeable in the data as it was seen that collector efficiency increased commensurately with an increasing nanofluid weight percentage. This was a major finding. The maximum possible value for collector efficiency at this flow rate (0.015 kg/s) was unexpected for the both base fluid and nanofluids as compared with other studies. The above compounds were employed in zero-loss efficiencies of 83.5%, 89.7% and 93.2% at weight fractions of the nanofluids equal to 0.0005,0.001 and 0.005 respectively. In contrast, the base fluid has a zero-loss efficiency figure of seventy percent, which is quite humble. Using these values, efficiencies were calculated with impressive precision [19]. Verma et al. an experiment was performed on flat solar collector of size 0.375 square meter. This experiment was conducted in order to investigate the influence of different volumetric ratios of MgO nanofluid–water on the performance of the collector. Additionally, it had74.5J as the heat efficiency at 0.75 percent concentration along with the volumetric flow rate of 1.5 cubic meters per minute where are markable boost of 9.34% on heat was noted in accordance to the reasoning applied in the study (94). For instance, this was the case when it was at 0.75 percent. Furthermore, with the same volumetric concentration and mass flow rate, nanofluid yielded 32.23% higher availability efficiency of the collector compared to water as a base fluid. This was an improvement compared to the use of water. However, for a concentration of 0.75 percent, the calculated entropy created was 0.0611 W/K which is several orders of magnitude lower than the flow rate of 0.1394 W/K. The figure is quite unlike the 1.5 percent concentration, which turned out to be 0.071 W/K. [20]

Verma et al conducted a study to improve the effectiveness of solar collectors. It was then used for a project in the year ago. They used a flat solar collector with an area of 0.375 square meter for testing purposes. They focused on a plethora of coupled nanoparticles with water at different concentrations and sizes in these studies. Over the course of their investigation they implemented a volumetric concentration equal to.75 percent, an inlet mass flow velocity of.025 kilos per second and an estimate of the available energy. The researchers found that the use of TiO2-H2O, SiO2-H2O, CuO-H2O, Al2O3-H2O, Gra-phene-H2O and MWCNTs–H2O as main and auxiliary fluids resulted in significant improvements of thermal efficiency in the system. When these liquids were compared to water, the proportionate improvements that were observed, respectively, were: 5.74, 6.97, 10.86, 16.67, 21.46 and 29.32 percent. In addition, for all the combinations hereinabove cited, the solar collector produced a lower amount of entropy than the other collectors in ranges of 4.08% to 5.09%, 8.28% to 12.64%, and 16.97% to 23.4%, respectively. It was so for all discussed combinations. [21]

Jouybari et al. also performed an extra research, Investigating thermal performance for 0.8m2 solar collector. To improve the performance of the collector, researchers chose to use a functionalized SiO2 nanofluid with 7-nanometer diameters integrated into its base fluid made up of water. The researchers investigated three concentrations of nanoparticles: 0.2% (w/v), 0.4%, and 0.8%. The purpose was to make a laminar flow environment. In their experiment, they also used a flow rate of 1.5 thousand pounds per minute. The results of the study showed that there was a direct proportionality relationship between the heat transmission and concentration of nanoparticles in the base liquid. In addition, the type of suspended solid that was tested in the experiment clearly affected the efficiency of flat surface collector. Compared to the water as a base fluid, production increased by eight percent. This represented a much larger increase [22]. Sundar et al. A second experiment on the flat and turbulent flow solar collector of two square meters was conducted separately [23]. They used an Al_2O_3 nanofluid at volume fractions of 0.1% and 0.3%, and the flow rate they used was 5 kg/s [12]. This consequently produced an impressive 18% efficiency gain over the previous method which exploited water as the primary medium.

Kilicar et al. interrogate the effects of 44 nm diameter, 0.2 %vol and mass flow rate (2) kg/min a TiO_2 Triton X-100 nanofluid on efficiency of flat solar collector with an area equal to 1.82 m^2. This is the same nanofluid that was used in the experiment described above. The researchers concluded that the performance of a flat solar collector could be increased by up to 34.43 percent over water alone with inclusion of CeO_2 nanofluid at various mass flow rates and volumetric concentrations. [24]

This was the conclusion reached by the researchers. Researchers Sharafeldin and Gróf, discovered in their research conducted that, there is a linear connection between the thermal efficiency of the collector and the concentration of nanoparticles in the mass flow [25]. In another study that was carried out by Tong et al., nanofluids of varying concentrations were utilized in order to assess the impact that these nanofluids had on the efficiency of a flat solar collector that measured 2 square meters in size. A volumetric concentration of 0.1% Al_2O_3 nanofluid was found to produce the best efficiency, which resulted in an amazing efficiency rating of 21.9%. This was discovered through the process of quantitative analysis. When compared to the usage of water as the base fluid, the utilization of nanofluids, namely those with a volumetric content of 0.1 vol% Al_2O_3 or 0.5 vol% CuO, resulted in a significant increase in the quantity of energy that was accessible by 56% and 49.6%, respectively. In other words, however when is it used with water. In addition, the results indicated maximum and minimum entropy when water was used as a test fluid and nanofluid including 0.1 vol% Al_2O_3, respectively. [26]

The present investigation shows that by mixing nanoparticles into water, these nanofluids could enhance considerably the efficiency of flat plate solar collectors. This is especially true in the case of 0.1% volumetric Al_2O_3 nanofluid content. Choudhary et al. Solution with different latent heat thermal energy storage system is used with a 2.1m^2 flat solar collector for better performance of the solar collector of about an hour [27]. For example, performed an experimental study using ZnO nanoparticles size (50 nm) with flow rate (30-150) dm^3/h, in (water and ethylene glycol). [27]

This was done in order to carry out the investigation. What the researchers aimed to accomplish was to make the solar collector as efficient as possible. As the flow rate was increased, the thermal efficiency of the collector also increased reaching to a maximum (69.24%) at a rate of flow (60 dm^3/h) and a volumetric concentration of nanofluid that was 1%. This was possible since the flow rate was increased. A significant increase in production of 19.24% was achieved as a consequence of this, in contrast to the utilization of distilled water on its own. Within a "flat solar collector" with a surface area of 1.51 square meters, Okonkwo et al. conducted an assessment that utilized single and hybrid nanofluids (Al2O3 and Al2O3-Fe) in conjunction with water as a basic fluid. Water was also included in the evaluation. The study results showed that using nanofluids provide a better estimation of the entropy generated than water. The minimum and maximum of the entropy turned out to be 5.541% W/ K and 5.725% W/K, while using nanofluid obtaining a higher ratio of based fluid yield enhances flat solar collector thermal efficiency up to 2.16 % with finely nanoparticle (Al2O3) at concentration 0.1 vol%. In contrast, a reduction of 1.79% in efficiency was obtained with the use of hybrid nanofluid. Hybrid nanofluids also showed an increase of 6.9% in the availability efficiency compared to that of a single nanofluid. [28]

Alklaibi et al. performed an experiment in order to enhance the heat transfer process and increase performance is placed on 3 m2. It was done using a flat solar collector with diamond-based nanofluid and water as the base fluid. At the mass flow rate of 0.02 kg/s, several volume concentrations (0.2%, 0.4%, 0.6%, 0.8% and1%) were examined. The results obtained from the study indicated that upon using a concentration of 1 volume percent nano-diamond fluid in water as base fluid, the performance of flat solar collector was enhanced by 69.8 per cent as compared to that for water only based conventional fluids. [29]

Hawwash et al. an experimental study was carried out in which flat solar collectors with an area of 2.1 m2 were assessed. They utilized Al2O3 nanofluid with a particle size of 20 nm and a mass flow rate of 5.51 kg/min. As far as the distilled water is concerned, 0.1 percent to 0.3 percent were used for volume concentrations of nanofluid only. Using this method, efficiency of warmer water in Egypt's hot atmosphere was more at 0.18%. By the results of a theoretical study performed with ANSYS 17 software, it was concluded that the presence of nanoparticles in the fluid, leads to decrease pressure and increase efficiency while decreasing temperature at collector output. Nanofluids of two types were prepared, the first one contains titanium dioxide and second contains aluminum dioxide. [30]

Farajzadeh et al. [31] conducted a theoretical and experimental study on the performance of a 2 m² flat plate solar collector using nanofluids. Nanofluids were characterized using 20 nanometer particles and a surfactant enhancer, cetyltrimethylammonium bromide (CTAB). These groups used the same volumetric flow near to 2.0, 2.0 and 1.5 dm3 per minute respect male type vented flash back into mini reactor system [16]. Using nanofluids instead of water enhanced the performance of flat solar collectors by 19%, 21% and 26% in flow rates ‹750, between 750–1000 and >1000 l/h respectively. The study results showed that increasing the concentration of nanoparticles had a beneficial effect on efficiency which increased by 5%. Consistency between CFD and numerical simulations established validity [31].Alawi et al. performed an investigation of a planar solar collector, who conducted their work using different amounts of graphene powder in distilled water. The characteristics that were studied include mass fluxes (0.5, 1 and 1.5) kg/min, temperatures of (30, 40 and 50) °C, and intensities for radiation (500,750 and 1000) watts per square meter. The results of the study revealed that mass flow caused a reduction in heat distribution, circulation and GrNPs volume fraction. [32]

It was shown that the integration of CeO2 nanofluid at varying mass flow rates and volumetric concentrations resulted in a 34.43% improvements in efficiency. When compared to water-based collectors, flat solar collectors that made use of nanofluids had exhibited higher performance. These collectors have realized efficiency improvements of 19%, 21%, and 26% over a range of flow rates. At concentrations (0.075 and 0.1) weight percent, respectively, at a flow rate of 0.025 kilograms per second, efficiency levels (13% and 12.5%) were met in contrast to water. Following the verification and validation of the efficiency of the flat solar collector through the use of MATLAB simulations, it was found that the insertion of nanofluids led to an overall rise in efficiency alongside the flow of water. In enclosure that is filled with a copper-water nanofluid, Dutta et al. explored the transfer of thermal energy that is driven by magneto-hydrodynamic buoyancy. The bottom of the enclosure is subjected to a continual heating process, while the vertical wall maintains a constant cold temperature, and the curving wall is enclosed with insulation. Within the parameter range (103 ≤ Rayleigh number (Ra) ≤ 106), (0 ≤ Hartmann number (Ha) ≤ 100), and (0 ≤ volume fraction of nanoparticles (ϕ) ≤ 0.05), the findings demonstrate that the average "Nusselt number" rises with increasing ϕ and declines with increasing Ha, especially at elevated Ra values of 105 and 106. Furthermore, the modification of the sector angle of the enclosure has an effect on the heat transfer rate in conjunction with Ra, ϕ, and Ha, thereby pointing out the interrelated effects of geometry and other parameters on variations in heat transfer [33]. The convective-radiative heat exchange that Keerthi et al. investigated involves a radial-profile wet porous fin that is exposed to a hybrid nanofluid that is flowing at a constant velocity. Different combinations of nanoparticle shapes are investigated in this investigation, and the mixture model is utilized in order to assess the thermophysical properties of the nanoparticles. Quantitative methods are utilized in order to do a graphic analysis of the effects that numerous parameters have on energy distribution, thermal gradient profiles, and thermal fin efficiency. The volume percentage of nanoparticles and the shape factor have a major impact on efficiency. The combination of spherical particles and platelets with the highest value was recorded, which highlights the potential of nanotechnology to improve extended surface technology [34]. From one-dimensional simulations to three-dimensional computational fluid dynamics (CFD) simulations, Mohamad and Zelentsov applied a variety of optimization strategies. A hybrid strategy that incorporates a one-dimensional model with three-dimensional tools is used to combine the methodologies through the use of a hybrid approach. [35]

3. Nanofluids

As a potentially useful method for enhancing the efficiency of flat plate solar collectors, nanofluids, which are composed of nanoparticles that are dispersed throughout base fluids, have recently come to the forefront. By including nanoparticles that have a high thermal conductivity, such as metal or oxide nanoparticles, it is possible to significantly improve heat absorption and transfer within the collector, which ultimately results in an increase in the overall efficiency of energy conversion. Different groups of nanofluids, such as metal-based (copper and silver), oxide-based (alumina and titania), and hybrid nanofluids are adaptive solutions that can be manipulated to adjust the performance of flat plate solar collectors in harmony with operational conditions and requirements [6]. Farhana et al. is diagnose the properties of some flow parameters related to nanofluids and hybrid nanofluids during flow passing through riser tubes and internal header tubes of a flat plate solar collector. Computational fluid dynamics (CFD) modelling was used in the study and it involved nanofluids like Al2O3, TiO2, and ZnO. The hybrid nanofluids including Al2O3+TiO2, TiO2+ZnO and ZnO+Al2O3, were also added. [36]

The modelling technique was finalised using a three- dimensional framework and the k-epsilon turbulence model which was configured with Standard and Standard Wall Functions. A consistent frame of reference and a fixed ratio of computational effort were retained throughout the modeling process. In this study water was used as base fluid and both, nanofluids and hybrid nanofluids were fixed with a constant volume fraction of 0.1%. The method that was used for the study consisted of an energy equation and a single-phase viscous model. Three distinct design models were used Model A, Model B, and Model C all designed to have immutable input and output sizes. Across the three possible scenarios, the tally of riser tubes per scenario was two, three, seven, and twelve. The same number of header tubes was used in all three scenarios.

Farhana et al conducted an extensive research and made important discoveries. In contrast, Model B displayed substantially elevated maximum dynamic pressures of nanofluid and hybrid nanofluid than those from the above-discussed two models, reaching a significant increase of about 48% and 16%, respectively. That was confirmed since the model showed an option increase. In addition, Model B showed the greatest increase in the velocity magnitude for both the nanofluids and the hybrid nanofluids. One of the biggest revelations was that results of the study indicated that model A had the highest turbulence kinetic energy among nanofluids (5.5%); and model B among hybrid nanofluids (18%); as indicated by the research studied from Farhana and other Model B has more performance compared to Model A and Model According to the study results, there is a possibility of using nanofluids as an effective way to improve the performance of solar collector panels. The degree of augmentation can be affected by decisions regarding the nanoparticle and model that are used. [36]

This table provides the findings that were derived from various references.

Reference	Year	Type of the study	Nanofluids used	Findings
Yousef et al.[7]	(2012)	Experimental	MWCNT/H_2O	The effectiveness of the planar solar collector was improved by 83% as a consequence of an increase in the mass flow rate and the concentration of the nanofluid.
Vijayakumar et al. [10]	(2013)	Experimental	CNT/H_2O	This resulted in a 39% gain in efficiency when the volume fraction was set at 0.5%.
Chaji et al.[11]	(2013)	Experimental	TiO_2/H_2O	The efficacy of the solar collector increased in relation

				to the volumetric flow rate.
Zamzamian et al.[12]	(2014)	Experimental	Cu/C_2H_6O	The collector efficiency is increased by nanofluids, and they also absorb power factor.
Nasrin and Alim [13]	(2014)	Experimental	TiO_2, CuO, Al_2O_3 / H_2O	The most significant increase in efficiency was achieved by copper oxide when combined with distilled water (87.8%), whereas the results for aluminium oxide and titanium oxide were lower (71%). as contrast to water that is unadulterated.
Moghadam et al. [14]	(2014)	Experimental	CuO/ H_2O	In comparison to water, the efficacy rate was 21.8% higher.
Michael and Iniyan [15]	(2015)	Experimental	CuO / H_2O	The solar collector is 57.98% efficient in comparison to a forced load at a discharge rate of 0.1 kg/s.
Shojaeizadeh et al. [16]	(2015)	Experimental	Al_2O_3/ H_2O	Increase the energy efficacy of nanofluids mixed with water and modify other parameters to influence the combined energy.
Said et al. [17]	(2015)	Experimental	SWCNTs / H_2O	The results demonstrated a 76.6% increase in efficacy when water was used as the starting point.
Meibodi et al. [18]	(2015)	Experimental	SiO_2/EG/H_2O	The findings demonstrated a 4-8% increase in efficiency in comparison to operating with water.
Vakili et al.[19]	(2016)	Experimental	Graphene nanoplatelets / H_2O	The planar solar collector operates at its most efficient with a mass flow rate of 0.015 kg/s.
Verma et al.[20]	(2016)	Experimental	MgO / H_2O	At a concentration of 0.75% and a flow rate of 1.5 dm3/min, the heat efficacy of

				the collector increased by 9.34%.
Verma et al. [21]	(2017)	Experimental	(MWCNTs, graphene, CuO, SiO2, TiO2, Al2O3)/ H_2O	Solar collectors with the highest conceivable efficiency.
Jouybari et al. [22]	(2017)	Experimental	SiO_2 / H_2O	As the concentration of nanoparticles in the base liquid increased, the rate of heat transmission also increased.
Sundar et al.[23]	(2018)	Experimental	Al_2O_3 / H_2O	Efficiency was 18% higher than that of water.
Kiliç et al. [24]	(2018)	Experimental	TiO_2 +Triton X-100 / H_2O	In contrast to operations with water, the results indicated a 34.43% increase in efficiency.
Sharafeldin and Gróf [25]	(2018)	Experimental	CeO_2 / H_2O	Thermal efficacy of the collector is determined by the mass flow rate and the volumetric concentration of nanoparticles.
Tong et al.[26]	(2019)	Experimental	CuO, Al_2O_3 / H_2O	The efficacy of solar collectors was enhanced by nanofluids in water.
Choudhary et al.[27]	(2020)	Experimental	ZnO / DW+EG	A flat solar collector's thermodynamic efficiency increases as the flow rate increases to 150 dm3/h, and its departure temperature is 45.47 oC.
Okonkwo et al.[28]	(2020)	Experimental	Al_2O_3-Fe, Al_2O_3 / H_2O	The availability efficacy of a hybrid nanofluid is increased by 6.9% in comparison to that of a single nanofluid.
Alklaibi et al.[29]	(2021)	Experimental	Diamond / H_2O	The entropy generated by nanofluid was higher than that of water.
Hawwash et al.[30]	(2018)	Theoretical and experimental	Al_2O_3 / H_2O	The discharge temperature and efficiency of solar collectors were improved by the increased concentrations

				of water nanoparticles.
Farajzadeh et al.[31]	(2018)	Numerical and experimental	TiO_2-Al_2O_3 / H_2O	Instead of water, the efficiency of planar solar collectors was enhanced by 19-26% by the use of nanofluids. Performance increase by 5% when the concentration of nanoparticles is between 0.1 vol% and 0.2 vol%.
Alawi et al.[33]	(2021)	Theoretical and experimental	Graphene / H_2O	Heat transmission was enhanced by increasing the volumetric concentration of GrNPs and the fluid mass flow rate. The flat solar collector was 13% efficient at 0.075 wt.% and 0.1 wt.%, but it was only 12.5% efficient at 0.025 wt.%.
Farhana et al.[36]	(2019)	Theoretical	ZnO, TiO_2, Al_2O_3 and hybrid nanofluids ZnO+Al_2O_3, ZnO+TiO_2, Al_2O_3+ TiO_2 / H_2O	Using three scenarios: two, seven, and twelve riser tubes to improve the thermal performance of the flat plate solar collector.

4. Conclusion

The incorporation of nanofluids into a solar collector has been discovered by a large number of researchers to significantly improve the efficiency of the collector, which in turn leads to developments such as the following:

1) Enhanced flow rate in a volumetric medium: the flow rate within a solar collector increased when nanofluids are utilized as the working fluid. This is because nanofluids have a higher molecular weight than conventional fluids. This increase in flow rate is one of the factors that contributes to the overall improvement in overall efficiency of the collector.
2) Increased efficiency with increased fluid concentration and absorbed power: the efficiency of the solar collector is further improved when the concentration of nanofluids in the collector

increases, along with the absorbed power factor. This means that the collector achieves a higher level of efficiency. In order to achieve greater thermal performance and energy absorption, higher concentrations of nanofluids are required. This ultimately leads to an increase in total efficiency.

3) Flat plate collectors are among the most affordable solar technologies for water heating and space heating applications. Their relatively simple design and widespread availability make them a cost-effective solution, especially for residential and small-scale commercial purposes.

Researchers were able to identify these essential aspects that favourably impact the performance of solar collectors by utilizing nanofluids that were mixed with water. This has paved the way for more efficient and effective utilization of solar energy.

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تحسين الأداء الحراري للمجمعات الشمسية ذات اللوح المسطح باستخدام السوائل النانوية: مراجعة شاملة

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الخلاصة

لقد تم استخدام السوائل النانوية في مجموعة متنوعة من التطبيقات العملية في مجال نقل الحرارة. هناك العديد من التطبيقات لمواد التشحيم المبردة، بما في ذلك مشعات المركبات، وأنظمة الطاقة الشمسية والنووية، والأجهزة الطبية الحيوية، والتدفئة، والتهوية، وتكييف الهواء، والتبريد التخزيني، وتبريد المحرك، والمحولات. كانت تأثيرات السوائل غير التقليدية عند دمجها مع السوائل التقليدية لنقل الحرارة موضوعًا لبحوث علمية مكثفة. وقد أظهرت نتائج هذه الدراسات أن هذا المزيج يعزز أداء نقل الحرارة إلى مستوى يتجاوز مستوى السوائل العاملة التقليدية. وتثبت هذه التحقيقات مجتمعة أن السوائل النانوية قادرة على نقل الحرارة بشكل استثنائي. ومن الضروري تبني نهج شامل يدمج كل من التطبيق العملي والتصور من أجل تحسين فعالية المجمعات الشمسية ذات اللوحة المسطحة. تظهر نتائج هذه الدراسة أنه يمكن تحقيق إمكانية تحسين الكفاءة من عشرين بالمائة إلى خمسة وثمانين بالمائة من خلال زيادة تركيز السوائل النانوية ومعدل التدفق الشامل. تهدف هذه الورقة إلى تلخيص التقدم العلمي المحرز في مجال تطبيق السوائل النانوية لتحسين الأداء الحراري للمجمعات الشمسية ذات اللوح المسطح.

الكلمات الدالة: المجمع الشمسي ذو اللوح المسطح، السوائل النانوية، الأداء الحراري.