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REVIEW ARTICLE - MECHANICAL ENGINEERING

Performance Improvement of Flat Plate Solar Collectors Using Nanofluids: A Review Study

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Abstract

In this paper, the literature will be reviewed, and various research works conducted to improve the thermal performance of flat plate solar collectors will be summarized. It will be summarized in more than one way. Firstly, by design using different methodologies and methods to improve the efficiency and the thermal performance of the solar collector by introducing twisted strips that cause increased mixing. Fluids and friction for FPSCs. To increase heat transfer as well as use porous materials to enhance heat and improve the effectiveness of absorption panels to absorb as much solar radiation as possible as well as thermal insulation methods to reduce losses to surrounding areas. And improve the permeability of the glass cover. Secondly, the use of nanofluids enhances the performance of flat solar collectors instead of the core fluid, and its effect is to improve the thermophysical properties such as thermal conductivity by summarizing previous research using mono nanofluids and hybrid nanofluids. Through studies and research related to the use of mono nanofluids, it was noted that the best nanofluids are those that use CuO and Al_2OIn this paper, the literature will be reviewed, and various research works conducted to improve the thermal performance of flat plate solar collectors will be summarized.$_3$ particles due to their ease of availability and high thermal conductivity. As for hybrid nanofluids, the best fluids are (CuO + Al_2O_3/water) for the same reason above. As a result of design improvements and the use of nanofluids, temperatures up to (75C°) were obtained.

Publisher: Middle Technical University

Keywords: Flat Plate Solar Collector; Thermal Efficiency; Working Fluids; Heat Transfer; Nanofluid.

1. Introduction

According to previous studies, the world's tendency to develop leads to an increased demand for fossil fuels, consequently increasing environmental pollution and global warming [1, 2]. This now concerns not only environmental conservation organizations but the entire world [3]. All of these factors encouraged energy-related researchers to look for effective solutions. One of the energy alternatives in this area is solar energy [4]. Solar energy has recently emerged as a means of producing both thermal and electrical energy via solar panels and cells. It is a non-depletable energy source that is also environmentally friendly [5]. Studies have shown that the fall of the sun's rays on the earth for one hour produces enough energy to power the world for a full year [6]. There has recently been extensive research on solving the energy problem, and among these studies are those on solar energy [7]. Solar thermal systems include collectors, which are gadgets that turn solar energy into heat that is transferred by a liquid through a heat exchange process. Heat is absorbed and transferred by this liquid [8]. In contrast, according to studies, the incorporation of nanoparticles into these liquids improved heat transfer efficiency, which in turn increased the effectiveness of the energy collection systems. [9]. For use as working fluids, the nanofluids are prepared by ultrasonic treatment [10]. Many studies have been conducted to assist researchers and to address the challenges that will face the development of these collectors in the future [11].

2. Renewable Energy

is the energy generated from natural sources, which is continuously renewed at a rate greater than its consumption. Such as sunlight, wind energy, hydroelectric energy, land energy, and bioenergy. One of its most important features is that it is available in most countries of the world. It does not pollute the environment and is economical, since to ensure its continued existence, uncomplicated technologies are used for its production and reduce thermal emissions.

Nomenclature & Symbols			
FPSC	Flat Plate Solar Collector	CFD	Computational-Fluid Dynamics
MWCNT	Multi Walled Nanotube	SEHs	Solar Energy Harvesting System
DW	Distilled Water	Re	Reynolds Number
DDW	Double Distillation Water	GHE	Greenhouse Gas Emissions
GNPS	Global Natural Product Social	HTF	Heat Transfer Fluid
EXP	Eexperimental	W	Watt
NUM	Numerical	L	Liter
MOPSO	Multi-Objective Particle Swarm Optimization	Min	Minute
TAC	Total Annual Cost	M	meter
TIM	Transparent Insulating Material	Nm	Nanometer
PCM	Phase Change Material	A	Area (m^2)
(P/DH)	Pitch Ratios	φ	Volume Percentage
(e/DH)	Roughness Height to Diameter Ratios	h	Heat Transfer Coefficient
SDS	Sodium Dodecyl Sulphate	μ	Viscosity
NPs	Nanoparticles	K	Thermal Conductivity
FR	Flow Rate	ρ	Fluid Density
SFPC	Single Flat- Plate Collector	C	Specific Heat Capacity
ASHRAE	Association of American Engineers in Refrigerating, Heating and Air Conditioning		

- *Solar* energy: They are rays of light and heat that are issued as a result of the interaction in the center of the sun, and reach the surface of the Earth in the form of a beam of rays with different wavelengths. What is primarily important is radiation with wavelengths in the range (0.25 to 3.0 micrometers). This component of electromagnetic radiation contains the majority of the energy emitted by the Sun, with the Earth receiving 174 pet watts of incoming solar energy (solar radiation). About 30% of this radiation is reflected into space, while the rest is absorbed by clouds, oceans and landmasses.

3. Solar Collectors

A solar collector is a type of heat exchanger that converts solar energy into heat. The basic principle of a solar thermal collector is that when sunlight falls on the roof, some of it is absorbed, heating the surface. Which in turn heats the working fluid and increases thermal efficiency. The efficiency of the collector depends not only on the absorption of solar radiation but also on how it minimizes heat loss and radiation to the surroundings. It is one of the types of solar collectors. Firstly, the evacuated heat tube heater. Secondly, vacuum tube. Third, the parabolic solar collector. Finally, the flat solar collector, which will be dealt with in our current research.

3.1. Flat plat solar collector (F.P.S.C)

It is one of the best types of solar collectors. It converts thermal energy emitted from the sun into heat by heating a heat-absorbing plate and transferring liquid. It is typically made up of several components, the most important of which are tubes that transfer heat to the liquid that flows inside them. They are made of metals that have good heat conduction coefficients, such as copper or aluminium, and the heat-absorbing plates, which are the second component, absorb the heat produced by solar radiation. High-heat conductivity metals like copper or aluminium are also present in these panels. A selective coating that is in direct contact with the tubes and plates enhances the absorption of solar energy falling on the pipes and is applied to them. According to the solar collector's design, the tubes come in a variety of shapes. The protective covering that allows sunlight to reach the heat-absorbing component is another crucial component. Due to this bottle's feature, cold air cannot enter the absorption plate, preventing convection currents from causing heat loss. Because plastic materials are and light permeable more affordable than glass, they are sometimes utilized in collector instead of glass. The installation of insulation, such as glass wool at the back and sides, to stop heat loss is a common choice for this purpose. It is also possible to use liquids like water or oil, and nanomaterials can be added to these liquids to improve heat conduction efficiency. Water is frequently used due to its abundance, high thermal capacity, and incompressibility. Water, on the other hand, has issues because it can quickly freeze and oxidize, causing pipe damage. A (F.P.S.C) scheme is depicted schematically in Fig. 1. Ganjehkaviri and Jaffer [12], Two methodologies were used to investigate a flat plate solar collector's design and thermo economic analysis. A typical flat-plate collector was chosen as the initial method, and (MOPSO) stands for multi-objective particle swarm optimization. The algorithm was used to concurrently enhance total annual cost (TAC) and thermal efficiency. In the second technique, the constructed notion was implemented for the FPC by examining the same set of possibilities for the standard FPC's specified decision variables. For the traditional and the constructed FPC, design six parameters, as well as system specifications, are chosen. For these two procedures, the Pareto optimum front was calculated and compared. In thermal efficiencies greater than (0.54), the constructed Pareto optimum upper outperforms the standard FPC results.

3.2. Literature review for flat plate solar collector (FPSC) design techniques

Glass cover coating, thickness, high transmittance, emissivity, and coated and uncoated glass cover all influence the thermal performance of FPSC. The glass cover's thermal properties, such as transmittance, absorbance, and reflectance, have an immediate impact on the collector thermal performance. The greater the separation between the glass cover and the absorber plate, the more shadowing the wall creates, lowering the coefficient of natural convection. Passive approaches to improve heat transmission performance in solar collectors include the use of tapes twisted, wire coils, and foam. The addition of twisted tapes to the fluid improves mixing in the FPC working fluid by generating helical whirl, this accelerates the heat transmission process. The presence of the warped tapes increases friction on the surface of the fluid. Porous materials feature pores on their surfaces and have high thermal conductivity; they are utilized in solar collector systems to promote heat transfer and thermal performance by reducing pressure drop and enhancing flow mixing. Tadahmun et al . [14] conducted solar water heater experiments with a corrugated absorbent surface. The tank's water temperature was 58 °C in the winter and 78 °C in the spring as a result of the test, and the solar collector's thermal efficiency was (59, 65, and 67%) at mass flow rates of (0.005, 0.0091, and 0.013 kg/s), respectively. Fig. 2 depicts a cross-section design schematic with the dimensions of the solar water heater integrated. Fig. 3 depicts a solar water heater integrated experimental setup, including measuring points.

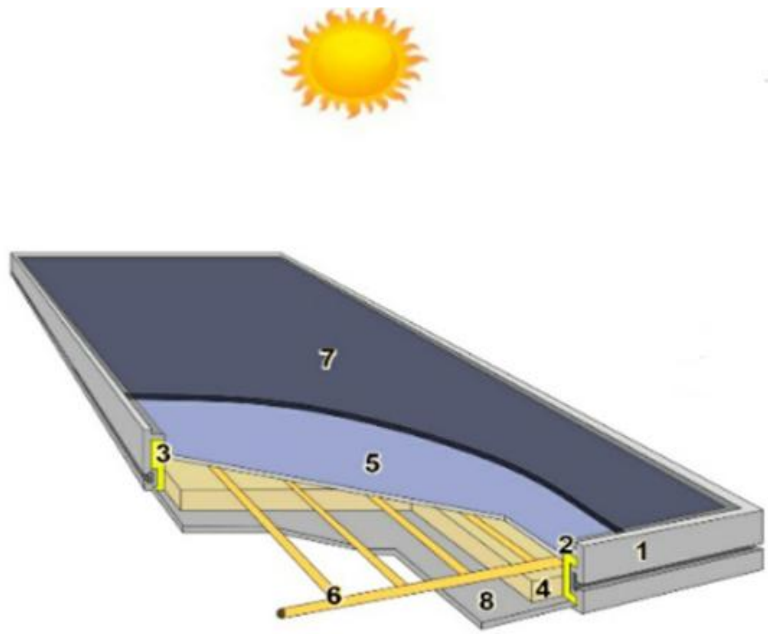


Fig. 1. Schematic drawing for the flat plate collector [13]; 1) Aluminium frame, 2) Silicone seal, 3) Side wall thermal insulation, 4) Back wall thermal insulation, 5) Absorber plate, 6) Copper tubes, 7) Glass cover, 8) Aluminum back

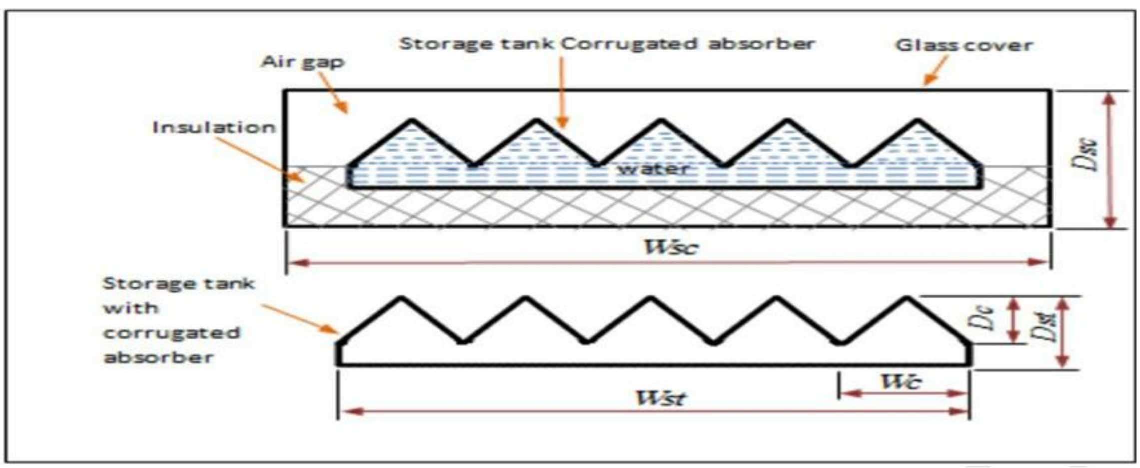


Fig. 2. The integrated solar water heater's diagram cross section with intended dimensions [14]

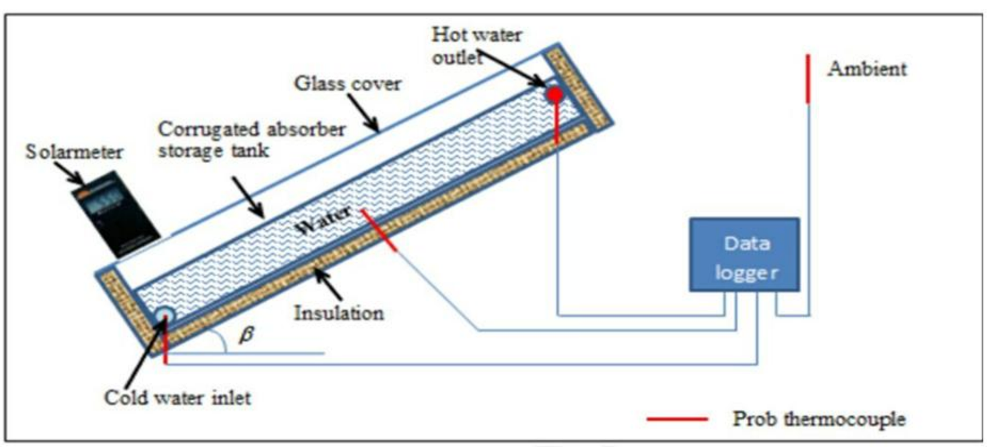


Fig. 3. The experimental configuration for an integrated solar water heater with measuring points [14]

Visa et al. [15] designed a triangular flat-panel solar collector, which has a larger heat transfer area than conventional collectors. According to the results, the highest thermal efficiency was up to 55% at a radiation intensity of 800 and 900 watts/m². Fig. 4 shows the assembly of a flat triangular solar thermal collector.

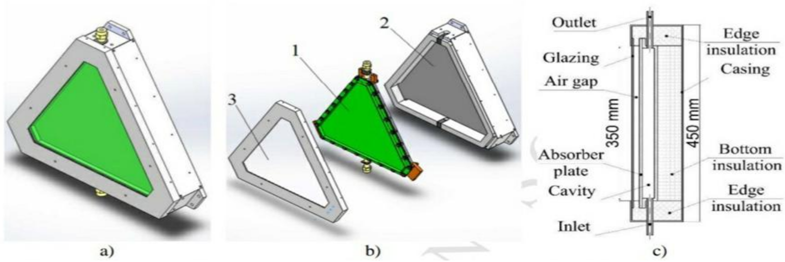


Fig. 4. a) Triangle flat solar thermal collector assembly, b) exploded view, and c) collector's cross-section [15]

Zhou et al. [16] examined the effect of adding TIM and weather conditions to boost the flat plate solar collector's efficiency. The authors demonstrated how TIM decreased frontal heat loss. The loss of heat from natural convection was greatly reduced when there was wind influence. However, they emphasized that the TIM's transmittance should be higher than 80% because collectors with TIMs below 80% performed poorly compared to other conventional machines. The authors concluded that using TIM in cold climates yielded better results due to the higher permeability of the coating, which in turn would absorb more incident solar energy. Fig. 5 shows the structure of the (F.P.S.C) with TIM.

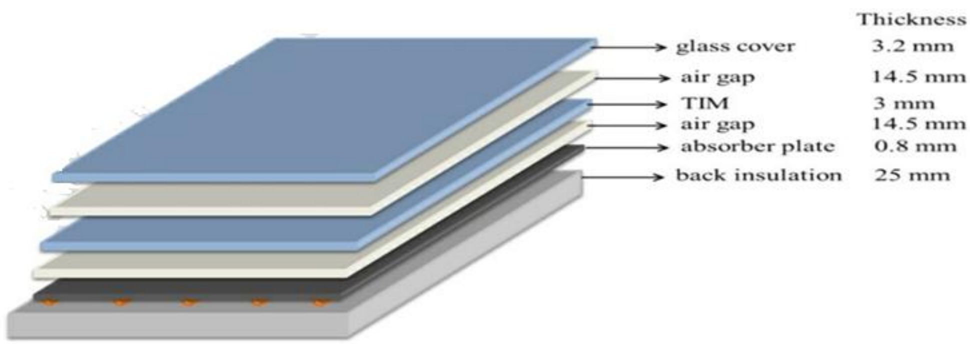


Fig. 5. Structure of the (F.P.S.C) with TIM [16]

Filipovic et al. [17] used polymeric materials as a way to reduce the overall cost of the complex. In addition, they used polycarbonate sheets as absorbent material and a wooden box as the base. However, they found that the performance of the thermal collector was 30% less efficient than that of a typical FPSC. However, the cost of FPSC has been significantly reduced by the use of polymeric materials and wood materials. Fig. 6 shows a 3D model of the test box.

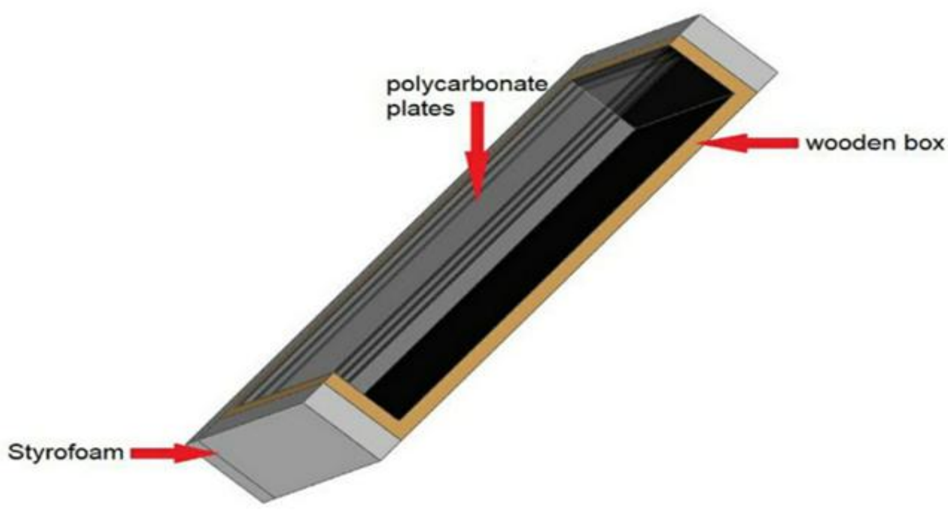


Fig. 6. 3D model of the test box [17]

To solve the problems of high heating and freezing with the collector, Wang et al. [18] used a dual-coupled collector (PCM). When the temperature of the water rises significantly, the PCM (high-melting) absorbs heat and transforms from a solid-state substance to a liquid-state substance, thus storing excess heat. The low melting point PCM freezes slowly and removes heat at low temperatures, which prevents the compound from freezing. The researchers discovered a slight improvement in the (F.P.S.C) thermal performance, as shown in Fig. 7.

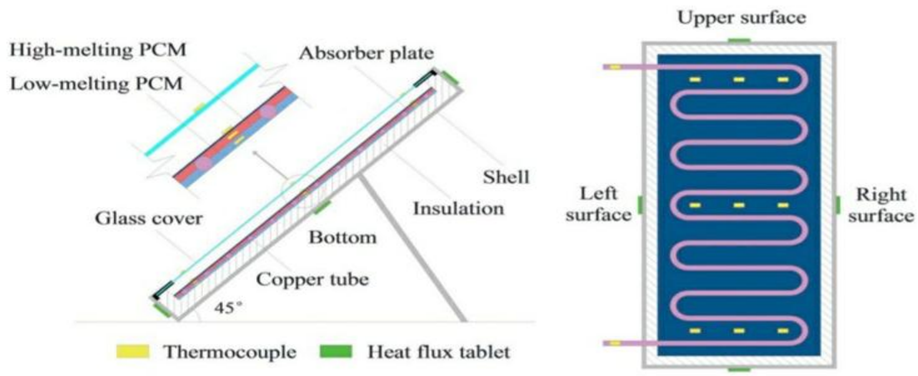


Fig. 7. The (PCM) collector structure and sensor locations.[18]

Zhou et al. [19] proposed the characteristics of a flat PCM solar collector system filled with antifreeze, and according to the results, the standard FPSC system will freeze when daily temperatures drop below 5°C. The average daily temperature must be between (0 and 5°C) with an anti-freeze system added to the flat collector to work. To avoid freezing, the collector needed at least 30% of its thermal energy to be trapped by the PCM. In addition, they claimed that a 15mm thick PCM module was a reasonable choice to make the most of the PCM. Fig. 8 illustrates heat transfer patterns in PA-FPSC.

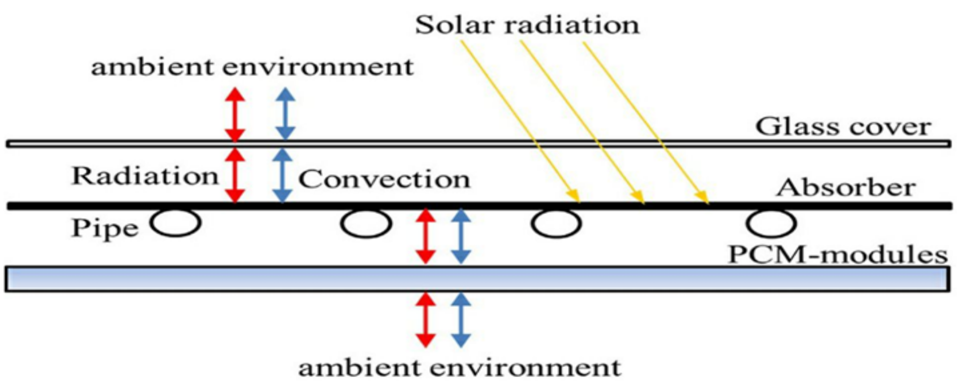


Fig. 8. The influence of phase-change temperature on optimal heat transfer coefficient between (PCM) layer and pipes.[19]

Balaji et al. [20] studied the improvement of heat transfer by using a rod and tube. Because the rod has a higher heat capacity than the tube (72% efficiency achieved), the authors claimed that using it was preferable to using it. These thermal enhancers function more effectively, on average, at lower Reynolds numbers. In solar water systems to improve heat capacity or heat transfer area, and increase heat transfer speed, and used the porous material (with high thermal conductivity) and porosity. Fig. 9 shows a thermal performance booster from an experimental standpoint.

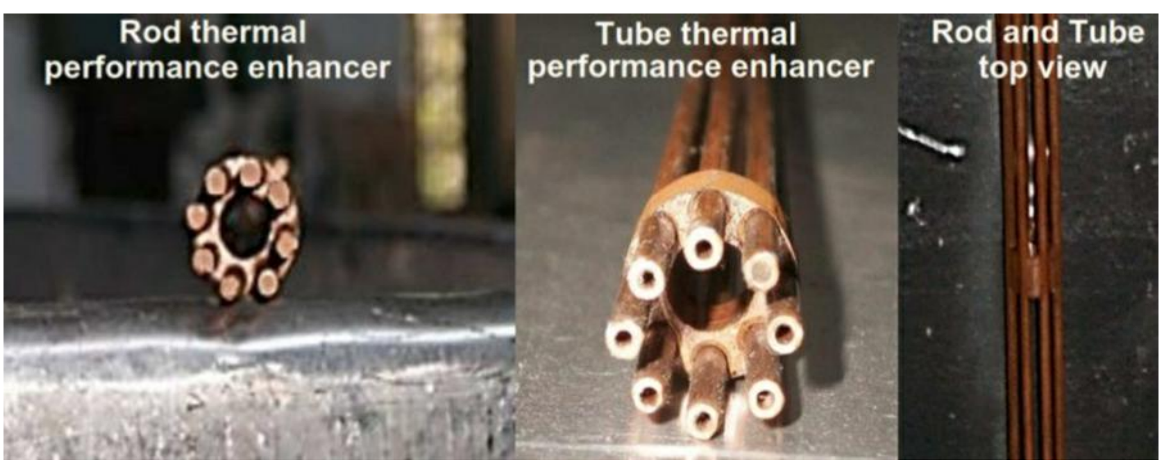


Fig. 9. Experimental view of thermal performance enhancer [20]

Kanimozhi et al. [21] experimentally studied the use of a porous medium to increase the thermal performance of FPSC. The porous medium was gravel, and the agitator was an aluminum metal plate. The researchers concluded that using an agitator and porous media would improve the heat transfer area. When the pressure decreases, the thermal efficiency increases to (63.8%), and when the porous medium is not used in the system, the efficiency percentage reaches (56.6%). Fan et al. [22] designed a unique V-shaped multi-channel corrugated absorber VFPSC and compared it with paper and TFPSC. The efficiency results of VFPSCT were higher than those of TFPSC, as its efficiency reached 69.1%, while the efficiency of TFPSC reached 58.6%. The thermal efficiency of the collector also increases with increasing mass flow rate (Fig. 10).

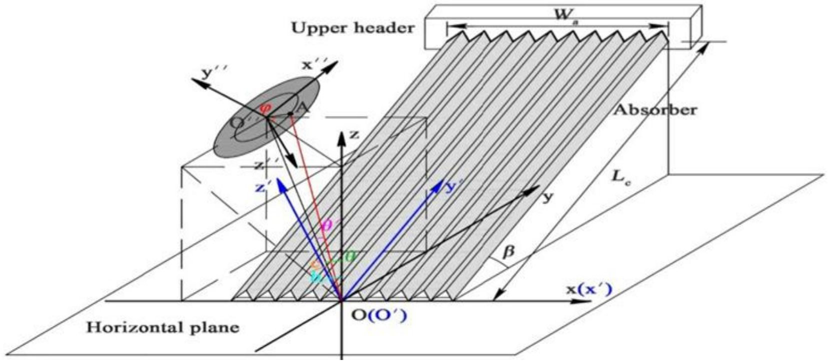


Fig. 10. Sketch of the (VFPC) optical model [22]

Felipe et al. [23] conducted work on a collector that uses tabulators (longitudinal vortex generators) to maintain turbulence in the flow while using the rectangular winglet and delta winglet shapes to improve heat transmission in an FPSC. When using vortex generators with rectangular wings at an attack angle of 45° and 750 W/m2, maximum heat transfer efficiency was achieved; however, problems with significant pressure drop persisted. Fig. 11 shows the computational domain with delta wing and rectangular wing vortex generator types.

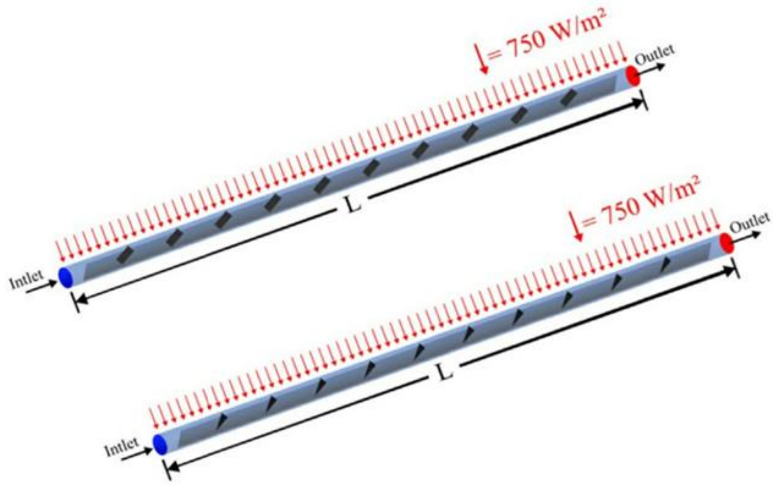


Fig. 11. Computational domain with a delta wing and a rectangle wing Vortex generator types [23]

K. Balaji et al. [24] conducted a practical study by analyzing the effect of a rod inserted along the axial direction of the tube containing the working fluid. As a result, the heat transfer coefficient increased, and the rate of heat transfer from the liquid increased significantly. R.W. Moss et al. [25] studied the effect of a vacuum absorbent phase on the efficiency of submerged working fluid flow and discovered a 3% increase in collector efficiency compared to a standard collector. Fig. 12 shows a cross-section of the toroidal profiles. Fig. 13 shows a drawer-type assembly device before the glass cover is installed.

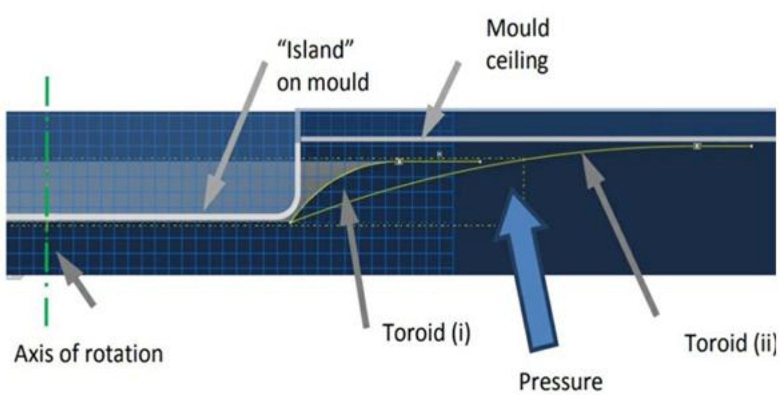


Fig. 12. Abaqus-modeled toroidal profile cross-section [25]

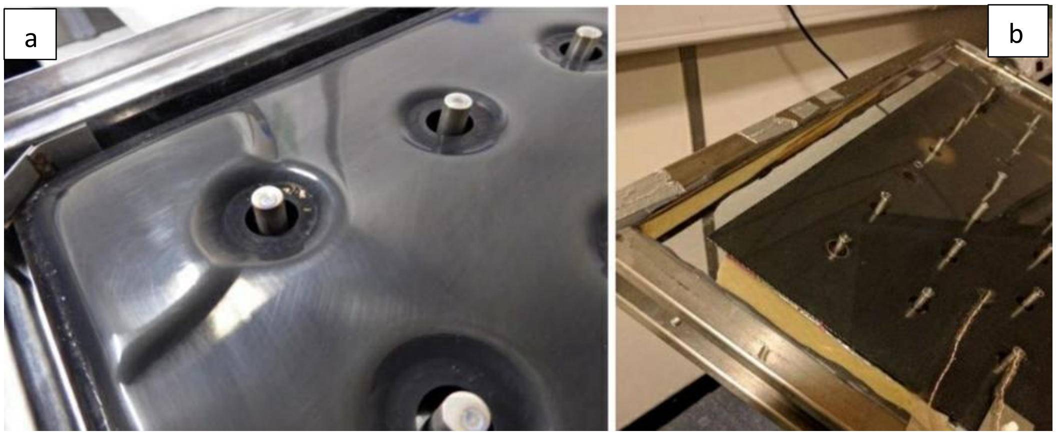
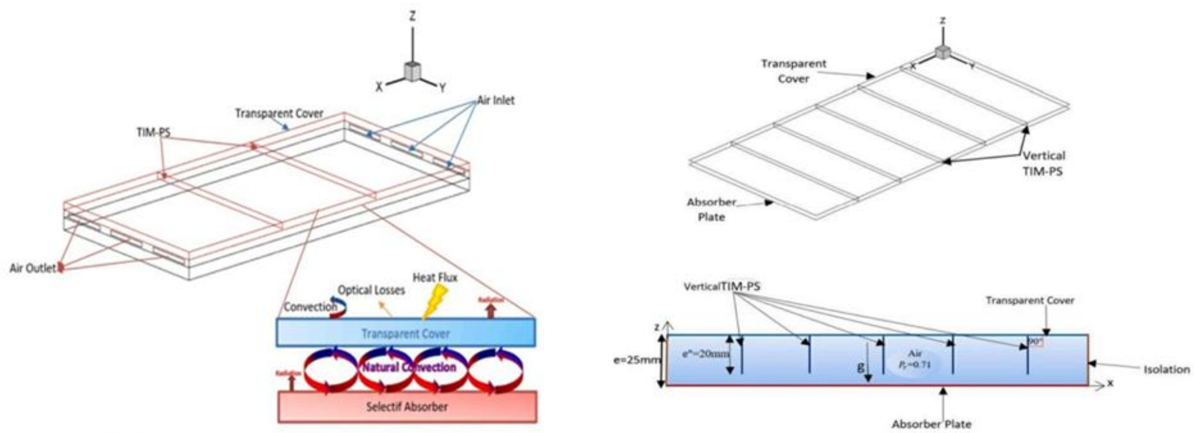


Fig. 13. (a) Tray collector before attaching the cover glass, using a stainless steel tray enables the pins to be spot welded in place, (b) Completed “symmetrical” enclosure [25]

M. Ammar et al. [26] studied numerically parallel interface transparent dielectric materials superimposed on flat solar air collectors. Upon numerical analysis (CFD), the results showed a raise in thermal efficiency ratios, reaching 81%. Also, the transparent insulating materials and the arrangement of the interface have the advantage of increasing the possibility of thermal conductivity very significantly. Fig. 14 shows the complex configuration Featuring two TIM-PS and detailed forward losses sandwiched between the absorber plate and the clear cover.



(A) (B)

Fig. 14. A) Collector configuration with two (TIM-PS), B) Sandwiched Vertical (TIM-PS) Configuration [26]

S.A Sakhaei, MS Valipour. [27] presented an experimental study when using corrugated helical tubes. The ratio (e/DH) ranges between 0.05% and 0.7%. According to the results, the experimental ratio had the highest efficiency (61.59%) when (e/DH) was equal to 0.15 and (P/DH) was equal to 0.3. Fig. 15. Corrugated risers are shown. It also provides a wide range of options to adjust the height, number of arrangements, and porosity to achieve optimal results. Arrangement and porosity to achieve optimal results. R. Kansara et al. [28] installed the inner fins and porous media in the fluid-working airflow path of a flat-solar panel collector to block air and make turbulence because the air could absorb the heat trapped in the porous media. The thermal efficiency increased compared to the bare passage. LLC Sakhaei and M. Valipour [29] studied the use of spiral collector fluid passage and phase change materials in a flat solar collector to store excess energy. They found an increase in the value of the heat removal factor so that the turbulence in the flow is due to the spiral undulation of the inner surface of the pipe passages, and as a result, they obtained an increase in the efficiency ratio by (39.8 %). Table 1 provides a summary of previous works on problems and solutions to raise the efficiency of (F.P.S.C).

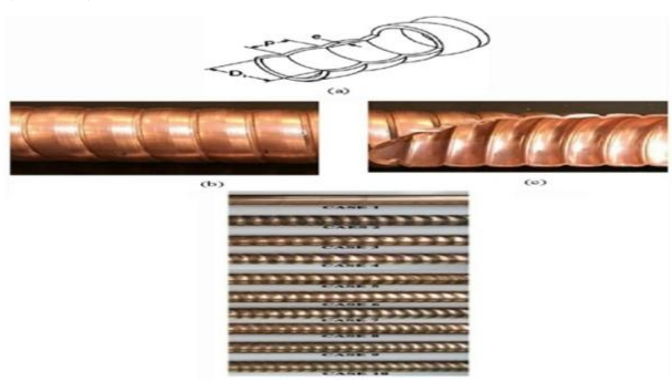


Fig. 15. Corrugated risers; a) inside view of the corrugated tube, b) outside-riser tube view, c) inside-riser, d) definition of geometry [27]

Table 1. Previous works of problems and solutions to increase the efficiency of the (F.P.S.C)

Researcher	Type of study	the problem	the solution	Findings and remark
Tadahmun et al [14]	EXP	Low absorption of solar radiation	Use a wavy, absorbent surface	The thermal efficiency of the solar collector increased by 59%, 65%, and 67% at mass flow rates of 0.005, 0.0091, and 0.013 kg/s, respectively.
Visa et al [15]	NUM	Lack of thermal space	Design a flat, triangular solar collector that has a larger heat transfer area	The results showed that the highest thermal efficiency reached 55% at radiation intensities of 800 and 900 watts/m².
Zhou et al [16]	EXP	Low ambient temperature and high winds	Use TIM	TIM reduces frontal heat loss. Heat loss occurred from natural convection.
Filipovi'c et al. [17]	EXP	Economic cost	Using polycarbonate sheets as absorber and wooden box as base	The thermal collector performed less efficiently, with its efficiency dropping to 30% less than a typical FPSC.
Wang et al. [18]	EXP	The working fluid outlet temperature is low	Use a dual-coupled collector (PCM).	The researchers discovered a slight improvement in the FPSC thermal performance.
Zhou et al [19]	EXP	The working fluid freezes.	Use a PCM filled with antifreeze	They claimed that a 15mm thick PCM module was a reasonable choice to get the most out of the PCM
Balaji et al [20]	EXP	Reduced heat transfer	Use an applicator and tube	Achieving thermal efficiency of 72% .
Kanimozhi et al. [21]	EXP	Low thermal efficiency	Use a porous medium and agitator	Thermal efficiency rises to (63.8%), and when the porous medium is not used in the system, the efficiency rate reaches (56.6%).
Fan et al. [22]	EXP	Low thermal efficiency	Using a unique letter-shaped multi-channel wave absorption device V	The increase in thermal efficiency reached 69.1%, while the FPSC efficiency reached 58.6%.
Felipe et al. [23]	EXP	Disturbance in flow and lack of heat transfer	The use of longitudinal vortex generators and the use of rectangular airfoils and delta airfoils	When using wings (rectangular vortex generator) with an angle of attack of 45° and 750 W/m², maximum heat transfer efficiency is achieved; however, pressure drop problems persist.
K.Balaji et al [24]	EXP	Low heat transfer coefficient	Use the rod and insert the tube type inside the axial direction of the tube containing the working fluid	The heat transfer coefficient increased and the rate of heat transfer from the liquid increased significantly.
R.W. Moss et al. [25]	EXP	Low thermal efficiency	Vacuum absorber	There was a 3% increase in the efficiency of the collector compared to the standard collector.
m. Ammar et al. [26]	NUM	Lost heat	Addition of transparent insulating materials with parallel and overlapping interfaces	Thermal efficiency rates increased, reaching 81%.
S.A Sakhaei, MS Valipour. [27]	EXP	Low thermal efficiency	Use corrugated spiral tubes.	Thermal efficiency increased to 61.59%.
R. Kansara et al. [28]	EXP	Low thermal efficiency	Fitting the inner fins and porous media in the path of the airflow	Thermal efficiency increased compared to the bare corridor.
LLC Sakhaei, and M. Valipour [29]	EXP	Store excess energy.	Use of spiral collector liquid passage and phase change materials	An increase in the efficiency ratio by 39.8%.

4. Nanofluid

Nanofluid technology is regarded as one of the most important developing technologies in thermal engineering today, drawing major research efforts. The primary goal of nanotechnology is to obtain better thermal properties of the base fluid of working fluids to create devices generating high heat flow for effective thermal dissipation [30]. The ground nanoparticles are added to the base liquid to form the nanofluid. Metals (Cu, Ag, Au), nitride ceramics SiN and AlN, oxide ceramics CuO, Al_2O_3, TiC, and SiO_2, and TiO_2 are all examples of nanoparticle materials. are examples of nanoparticle materials. The major parameters influencing heat transfer in fluids containing nanoparticles are working fluid viscosity (μ), thermal conductivity (K), fluid density (ρ), and specific heat capacity (C) [31]. When preparing nanofluids, several factors such as the volume and weight in terms of volumetric concentration ratio of nanoparticles, the amount of the working fluid, the method of good mixing, and the surfactants must be considered. All of these elements contribute to the base fluid's stability, which is one of the most important requirements for producing a usable nanofluid. To achieve a consistent, stable suspension, several techniques are used, including ultrasonic equipment, pH control, and the addition of stabilizers [32, 33]. Nanoparticles suspended in liquids cling together due to the van der Waals force. This force keeps the nanoparticles from sinking to the bottom of the liquid., preventing a homogeneous mixture from forming. Because the nanofluid thermal conductivity is greatly improved due to their stability, chemical or physical treatments such as surface modification of suspended particles, addition of surfactant, or application of considerable force to suspended particle assemblies should be used to solve the problem of nanoparticle instability. These treatments should be used to solve the problem of nanoparticle instability [34]. In general, when using nanofluids, as the temperature rises, the thermal conductivity (K) rises with it. When the heat transferred between the nanofluid and the absorbent plate increases, the convective and radiant losses decrease. Due to the mixing of nanoparticles with the base liquid, the optical absorption capacity increases. After using the nanoparticles, in comparison to water, the nanofluid's absorption coefficient increases. Consequently, the coefficient of convective heat transfer will improve. Hence, a small-sized solar collector may be used when using nanofluids. The significant increase in viscosity makes the physical properties better. Furthermore, due to the nanoparticles' enormous surface area in comparison to volume, the heat transmission between the nanoparticles and the base fluid rises. Good thermal diffusion will occur, resulting in an improvement in heat transfer.

4.1. Literature review for addition of nanomaterials to the base fluid

4.1. Mono nanofluid

These are materials to which nanoparticles of only one type are added during the manufacture of these materials. As a result, the nanomaterial showed significant improvement in the thermal conductivity properties of the material. Types of materials include nanoparticles (Cu, Ag, Au, ceramic nitride (AlN), (SiN.), oxide ceramics (Al_2O_3) and (CuO), carbide ceramics (SiC) and (TiC), (TiO_2) and (ZnO). Genk et al. [35] use Al_2O_3 nanoparticles and mix them with distilled water as a base fluid for use as nanofluids in flat plate solar collectors (FPSCs). They reached experimental results using water and three volume concentrations: 1%, 2% and 3%. With a mass flow rate of 0.004 to 0.06 kg/s, an increase in external flow temperature (7.20%) and an increase in efficiency was obtained at a low critical flow rate of 0.016 kg/s. Mirzai et al. [36] employed a nanofluid made up of (Al_2O_3 / water) particles in a (F.P.C), with (0.1%) volumetric concentration and size a particle (20 nm), and flow rates of (1, 2, and 4 l/min). The outcomes of the experiments when the nanofluid was utilized, the compound's thermal characteristics and thermal efficiency enhanced in comparison to water. The outcomes of the experiments showed that at a flow rate of 2 l/min, The collector's efficiency increased by 23.6 %. Kelish et al. [37] experimented using nanofluid that is titanium dioxide TiO_2/H_2O nanoparticles in (FPSC). volumetric concentration (2% vol). It was found that the highest efficiency of nanofluids is (48.67%) and the highest efficiency of pure water is (36.20%). Verma et al. [38] presented a study using FPSC and nanofluids added to it. It consists of (MgO, CuO, and MWCNTs) with different concentrations ranging from (0.25 - 2.0%) and with a flow rate ranging between (0.5-2.0 l / min). As a result, the effectiveness of the system is improved. With a volumetric concentration of 0.75-1.0% and a mass flow rate (0.025-0.03 kg/s), the efficiency was better. When using a nano liquid containing (particles) MgO at a rate of (25.1%), the percentage of water efficiency was (16.28%). Tong et al. [39] studied a comparison of two flat solar collectors and two nanofluids (Al_2O_3 and CuO) with a volumetric concentration (1%), and a good value for thermal efficiency was obtained. Energy efficiency, entropy generation, energy efficiency, and external energy destruction were calculated and compared. When the nanofluid (Al_2O_3) was used as the working fluid in the FPSC, the efficiency was 21.9% greater than when using water. To water, the use of Al_2O_3 and CuO nanofluid in (FPS.C) leads to improved thermal efficiency. When 1.0 Vol% (Al_2O_3 nanofluid., (FPS.C) was used, the optimum performance was achieved. Chowdhury et al. [40] investigated when I used and tested a nanofluid (ZnO / ethylene glycol: distilled water) to enhance (FPSC) efficiency when it worked at volumetric flow rates ranging from (30 l/hr to 150 l/hr) and with a volumetric concentration ranging from (0.2-1 Vol%) Results indicate. The highest thermal efficiency that can be obtained is (69.24%) at 60 l/ inch) for a volumetric concentration of (1% ZnO), which was higher by (19.2%) than using the base liquid. Rajput et al. [41] studied to improve the efficiency of a solar collector and investigated the effect of nanofluid (Al_2O_3) on it and used sodium dodecyl sulfate (SDS) to disperse nanoparticles. The concentrations used in the nanofluid (Al_2O_3) ranged between (0.1 and 0.3 %vol). And with varying mass flow rates ranging from (1 to 3 l/min). The thermal conductivity values were between (0.610 to 0.622 W/m.k). The results were good, as the thermal collector's efficiency has improved. by (21.32%) when the volume fraction (Al_2O_3) has grown from (0.1% to 0.3%). Maouassi et al. [42] investigated numerically the effect of nanofluid particles (SiO_2) to increase the collector's efficiency of (FPSC) type of forced convection. The effect of nanofluid (SiO_2) was compared with the working fluid (water) at four volumetric concentrations (1, 3, 5 and 10%) with the (Re). ranges from (25 to 900). The indication the higher the nanoparticle concentration, the better the results. concentration and the (Re), the greater the rates of heat transfer, which promotes an increase in the efficiency of the collector. Hawash et al. [43] examined the effect of nanofluids (alumina) through different volume concentrations ranging from (0.1-3% vol). Through experimental and numerical findings, and after examining the distilled water and nanofluids (alumina), the experimental and numerical findings when using the (ANSYS 17) program showed an increase in the collector's thermal efficiency when increasing the percentage of the alumina nanofluid. The numerical outcomes also showed that when the volumetric concentration (0.5% vol) was a good improvement in the efficiency of (FPCS), and any further raise in volumetric concentrations This will have a detrimental influence on thermal efficiency. Krishna et al. [44] used Software-Ansys (Fluent) to simulate (FPSC) in which different nanofluids (Al_2O_3 and CuO) are used to determine which one improves the efficiency of the collector the most. The probe was performed at different concentrations (flow rates and volume) as well. The results indicated a significant increase in energy as well as a rise in useful heat, which led to an increase in the thermal efficiency of the collector. Al-Jabri et al. [45] presented an experimental study when they prepared deionized aqueous nanofluids (SiO_2) to investigate the performance of (FPSC) by adding a channel filled with porous metal foam. The nanofluid volume concentrations varied (0.2%, 0.4%, and 0.6% vol). Combined efficiency improvement by (8.1%). As a result, when using nanofluids and porous media, an undesirable increase in pressure drop was found. Ziyadanogullari et al. [46] Studied an experimental examination performed on (FPSC). Various nanofluids were prepared by adding particles of the following materials (Al_2O_3, CuO, and TiO_2) at volumetric concentrations in the volume range (0.2, 0.4, 0.8%) with distilled water, and at a volumetric flow rate of (250) liters/hour. The results showed that when using nanofluids, the performance improved at the efficiency of the solar collector. Bazdidi-Tehrani et.al. [47] presented a numerical study to study the effect of a nanofluid consisting of (titanium dioxide) particles with water by forced turbulent convection. Through (flat polygonal solar collector). Rigid (flat) sheets were simulated during the movement of nanofluids through regular and polygonal channels. The results showed a significant improvement in increasing the efficiency of (FPSC) with increasing the size of nanoparticles, and the rate of increase in the efficiency of the polygonal channel was higher by (10%) than the efficiency of the regular channel. The nanofluidic CuO/water has a higher thermal efficiency than the nanofluid (TiO_2/water). Khatib et al. [48] presented an experimental study that used a nanofluid consisting of particles (boehmite and alumina) with a flat solar collector so that the flow is turbulent concerning the nanofluid. A hexagonal sectional tube was used in the FPSC and compared to the core tube. The mass flow rate ranged from (0.25 to 1 kg/sec), and the volumetric concentration was in the range (0-4% volume), and the tube shape was (circular and hexagonal). The results showed that the hexagonal tube was effective. Increases thermal efficiency better than circular outlet. Hussein et al. [49] studied the influence of the physical properties of a nanofluid consisting of (TiO_2)/(CF-MWCNTs/DW) through which the efficiency of (FPSC) is verified. The experimental results indicated that the use of TiO_2/CF-MWCNTs improved the efficiency of the collector by (9% and 26%) at the lowest temperature. heat and temperature rise, respectively, compared with distilled water (DW). The results also indicated that when working with a volumetric concentration (0.1% by weight) and a flow rate of (4 l/min), a significant increase in (FPSC) (84%) was observed. Compared to the traditional working fluid. Kyatsirirwat et al. [50] An evaluation study when using silver and water nanofluids to study the performance of (FPSC). Where the silver particles were concentrated with distilled water at (1000) and (10000 ppm), and the results showed an increase in thermal conductivity and a higher rate of heat transfer compared to the results at (1000 ppm). Chaji et al. [51] presented a study when using (Triton-X100) and (Cetyl-Trimethyl-lammonium Bromide) to maintain surface tension with nanoparticles (TiO_2) with water. The results indicated that when a surfactant was added, foam was formed in the nanofluid, which reduced the efficiency, and as a result, they stopped using the surfactant. Vijayakumar et al. [52] studied the effect of nanofluids with variable mass flow rates and weight fractions, with a single wall (1 nm). They analyzed the data and discovered that the single-walled carbon nanotubes and aqueous nanofluids achieved an efficiency (39%), which was judged to be within a respectable efficiency range. Said et al. [53] Evaluation of efficiency when examining the thermophysical properties of ethylene glycol and aqueous nanofluids, as well as aqueous alumina nanofluids. According to the results of characterization of different volumetric concentrations of nanofluids for both solutions, the stability of nanofluids (alumina/water) is more efficient than that of nanofluids (ethylene glycol/water). Colangelo et al. [54] studied the effect of different nanoparticles to test the stability of nanofluids such as (aluminium, zinc and iron oxide). Because of the nanofluid's superior stability, aluminum oxide was chosen over the other two. Two distinct tubes (FPSC) were constructed using transparent tubes of vertical and ascending dimensions (22 mm and 10 mm, respectively) placed at an angle. At the concentration (3% alumina nanoparticles), the thermal conductivity increased by 6.7%, while the convective heat transfer coefficient (h) increased by 25%. Michael et al. [55] investigated the use of (CuO / distilled water) in the operation of a (FPSC). In addition, volumetric quantities in the range (0.05% CuO). When forced circulation was replaced by spontaneous circulation, the efficiency increased by (6.3%). Youssef et al. [56] used an experimental study when using multiple layers of carbon nanotubes to achieve volumetric concentrations ranging between (0.2% and 0.40%), while Triton-X100 was used as a surfactant (a substance that reduces surface tension of liquids) and nanofluids aqueous as a surfactant (a substance that reduces the surface tension of liquids) and aqueous nanofluids. Fluid heat transfer in (FPSC). The results showed that the surfactant helped stabilize the nanofluids for up to 10 days with higher efficiency; Thus, the performance of the solar collector is improved. The efficiency of the solar collector with a concentration of 0.4% has been greatly enhanced by the multi-layers of carbon nanotubes. Table 2 summarizes previous work using nanofluids in FPSC using a mono nanofluid.

Table 2. Previous work on the use of nanofluids in (F.P.S.C) using a mono nanofluid

Researcher	Type of Study	Base fluid type	Type Nanoparticles	Size (nm)	Concentratio n	Solar Collector Area	Findings and remark
A.M. Genc et al. [35]	Exp	Water	Al_2O_3	10-30nm	1%, 2% and 3% wt	1.993m²	The thermal efficiency improved by 83.90%.
M. Mirzaei et al. [36]	Exp	Water	Al_2O_3	20nm	0.1 wt%	1.88m²	The efficiency increased by 23.6%.
F. Kiliç et al. [37]	Exp.	Water	TiO_2	44 nm	2 wt%	1.82m²	The efficiency improved to 48.67%.
S.K. Verma et al. [38]	Exp.	Water with MWCNTs	CuO and MgO	42 nm	0.25 to 2.0 wt%	2m²	The efficiency improved by 21.9%.
Y. Tong et al. [39]	Exp.	Water	Al_2O_3 and CuO		0.5%-15 wt	2m²	
S. Choudhary et al. [40]	Exp.	Ethylene glycol: Deionized water	ZnO	35 nm	0.2%-1%wt	2.1m²	Maximum Thermal efficiency was (69.24%),
N.S. Rajput et al. [41]	Exp	distilled water	Al_2O_3	10-15nm	0.1 to 0.3wt%	1.95 m²	The efficiency was 21.32% at a volumetric concentration of 0.1% to 0.3%.
A. Maouassi et al. [42]	Num.	Water	SiO_2	≤ 50 nm	1%, 3%, 5% and 10%wt	1.5m²	The thermal efficiency increased by 18%.
A. A. Hawwash et al.[43]	Num.	double distilled water (DDW)	Alumina	20 nm	(0.1%)to (3%)wt	2.25m²	Efficiency increased by 18%.

Continue Table 2. Previous work on the use of nanofluids in (F.P.S.C) using a mono nanofluid							
Krishna et al. [44]	Nu	Water	Al_2O_3 and CuO	1-100 nm	0.1-3% wt	2m²	Good improvement in the efficiency
H.J. Jouybari.et al. [45]	Exp.	Water	SiO_2/deionized	20-30nm	0.2%, 0.4% and 0.6%wt		Thermal efficiency was recorded at 8.1%.
Ziyadanogullari, et al.[46]	Exp.	distilled water	AI_2O_3, CuO, and TiC	1—100 nm	0.2, 0.4, and 0.8wt%	2m²	When working with nanofluids, the efficiency increased compared to water.
Bazdidi et al. [47]	Num	Water	TiO_2	5nm	<5%wt		Efficiency increases with a higher Reynolds number.
Y. Khetib et al [48]	Exp	Water	(boehmite and alumina)		(0-4%wt)	2m²	The hexagonal pipe was effective and increased the thermal efficiency more than the circular outlet.
O.A. Hussein et al [49]	EXP.	distilled water	(CF/MWCNTs) and grapheme	15 nm	0.8%wt	2.07m²	The thermal efficiency increased by (85%)
Kiatsiriroat et al [50]	EXP	water	Ag (silver)	20nm	0.1 & 1 wt%	0.015m²	Significantly enhance the calorific value of the collector
Chaji et al [51]	EXP	water	TiO_2	20nm	0, 0.1, 0.2 & 0.3 wt%	0.1m²	Reduced efficiency compared to MWCNT.
Vijayakumaar et al [52]	EXP	water	Single walled carbon nanotube	1.0nm	0.4, 0.5 & 0.6 wt%	0.34 m²	A significant increase in collector efficiency at a concentration of 0.5 vol%.
Said et al [53]	EXP	Water & Ethyl Glycol (EG)/	Al_2O_3	13nm	0.05–0.1 vol%	N/A	When using nanofluid (water/Al_2O_3), the efficiency values are enhanced better than using nanofluid (EG-water/Al_2O_3).
Colangelo et al [54]	EXP	water	Al2O3, ZnO& Fe2O3	45, 60, & 30nm	1.0,2.0and3.0vol%	N/A	The possibility of using nanofluid (Al_2O_3/water) is better than using water as a base liquid.
Michael & Iniyan et al [55]	EXP	water	CuO	0.3 & 0.21 nm	0.05 vol%	20.8m²	The results showed that utilizing a nanofluid (CuO/water) boosted thermal efficiency values much more than using water as a working fluid.
Yousefi et al [56]	EXP	water	Multiple layered carbon nanotube	10–30nm	0.2 & 0.4 wt.%	2m²	At 0.4 wt%, a good increase in performance was found.

4.2. Hybrid nanofluids

Farajzadeh et al. [57] investigated the effect of using a hybrid nanofluid consisting of. ($Al_2O_3H_2O$) with a 20 nm size and a concentration of (0.1% vol), and it was mixed with another nanofluid, which is (TiO_2HO) size 15 nm and concentration (0.1% vol), and the experimental results indicated that the thermal efficiency increased by 19% and 21%, and 26%, respectively, compared to water. The collector's thermal efficiency improves by (5%) if the concentration is of the mixture was increased in a range (0.1% to 0.2% vol) as shown by the numerical results. (CFD) High agreement with the experimental results. Farhana et al. [58] conducted a comparison study of three nanofluids (Al_2O_3, ZnO, TiO_2,) and three hybrid nanofluids (Al_2O_3 + TiO_2, TiO_2 + Al2O3 + ZnO, ZnO) to study their effect on the flat plate complex. At a constant concentration (0.1% by volume), 3D modeling was performed in three models (model A, B, and C). Model B obtained the best increase for both nanofluids and hybrid nanofluids, with 48% and 16%, respectively. Jawea et al. [59] studied the result of employing a hybrid nanofluid formed (CuO and $Al2O_3$/ distilled water) on (FPSC). Where the (Re) was about (700 and 2300), and at a concentration of (0.1% vol). Thermal efficiency increased, according to the findings. when using hybrid and nanofluids, 3.86% and 4.23%, respectively, when compared to water. Engy et al. [60] experimentally examined the effect of using hybrid nanofluids (MWCNTs with Al_2O_3, TiO_2, SiO_2 and CuO) in FPSC. Use four volume concentrations of each type of nanofluid (0.5%, 0.025%, 0.01%, and 0.005%) and three different flow rates (1.5, 2.5, and 3.3 L/m), each concentration requiring a different approach. The results showed that the hybrid (MWCNT/Al_2O_3) was effective. Thermal efficiency enhanced by (26%, 29%, 18%) depending on the flow rates respectively. Kuwar et al. [61] studied empirically when each focus required a different approach. The researchers investigated the effect of hybrid nanofluids (Cu/MWCNTs) on the performance of the flat collector unit (HSE). The results showed that the MWCNT (Al_2O_3) hybrid was effective. The results were demonstrated using three types of different volumetric flow rates (0.5, 1.0, and 1.5 l/m²) and three values of solar radiation intensity (400, 600, and 700 W/m²), in addition to three inclination angles of the collector (25°, 30° and 35°). The results showed a significant increase in the lighting efficiency by 68.7% at the flow rate 1.5 l/min, radiation intensity 400 W/m², and at an inclination angle of 25°. Zafar et al [62] investigated the use of (Fe_3O4)/water hybrid nanofluids (using MWCNT) to examine FPSC performance. The results showed an increase in the thermal conductivity coefficient by 26.3% through the use of different flow rates and concentrations. The pressure decreased by (18.9%). From a numerical point of view, and based on the experimental results, the comparison was in good agreement. Sujit et al [63] examined the performance investigation of a (F.P.S.C) Action by hybrid nanofluids (CuO and MgO with /MWCNTs). Volumetric concentrations in varying proportions range from (0.25% to 2.0% vol) and volumetric flow rate range (0.5 l/min) to (2 l/min). The findings demonstrated an increase in thermal efficiency of (25.1%) for the hybrid nanoliquid (CuO). Its results were better than the hybrid nanoliquid (MgO) in comparison to water. The PEG number also increased, which is an indicator based on quality. Omar et al [64] evaluated the efficiency of a (FPSC) with the possibility of using hybrid nanoparticles (CF-GNPs with (h.B.N) / distilled water) by using volumetric flow rates of (2 l / min and 3 l / min), and (4 l / min) in multiple volumetric concentrations The findings suggest that thermal efficiency can be improved. until it reached (85%). s. Montaser et al [65]. The effect of (Al_2O_3/CuO) was studied as the hybrid nanoparticles were suspended in a mixture of ethylene glycol/water (25:75 wt). For nanofluids, the particle size percentages (0.5%, 1%, 1.5%, and 2%) were studied. The results showed that increasing the weight by nanoparticles enhanced the compound's effectiveness by 45%. Prakasam et al. [66] investigated the feasibility of evaluating the performance of (F.P.S.C) Hybrid and single nanofluids (Fe_2O_4, ZnO/water distilled) are used. The results showed that using water distilled (ZnO-F e_2O_4) hybrid nanofluids with a particle concentration of (0.5%) improved the outcomes. The thermal performance of the solar collector rose by 6.6% in comparison to water. whereas the usage of Fe_2O4 / aqueous nanofluids raised solar collector thermal performance by (7.83%). Hussein et al. [67] Studied Numerical Performance (F.P.S.C). Modeling and simulation by CFD software of a variety of hybrid nanofluids. And volumetric concentrations in the range (1-5%) and with different Reynolds numbers, and the results showed an increase in the efficiency rate of (8.79%) at the volumetric concentration (5% by volume) and (Re) of (4000). Vednath et al. [68] studied the effect of using hybrid nanofluids (CuO + Al_2O_3/distilled water) for a solar collector (HTF). Solar collectors (FPS.C) are much more efficient than using nanoscale liquid solar collectors. When working with a hybrid nanofluid in an (FPSC), the temperature of the thermal energy storage system was improved when using a corrosion-resistant steel enclosure up to (87C°). Qingang Xiong et al. [69] employed hybrid (Ag-Al_2O_3) nanoparticles. At lower (Re), the use of the hybrid nanofluid reduced the heat transfer rate while marginally raising the supply temperature. Zafar Saeed and others [70] An experimental study of the effect of (MWCNT + Fe_2O_4) aqueous hybrid nanofluids to study the thermal performance of (FPSC). Different nanofluid concentrations and flow rates are used. A significant increase in the heat transfer coefficient (26.3%) was recorded, with a slight friction leading to a decrease in pressure. (18.9%). Okonkwo et al. [71] investigated experimentally and numerically a (FPSC) operating with (Al_2O_3 and alumina-iron/water) hybrid nanofluids at nanoparticle concentrations of (0.05%, 0.1%, and 0.2%). The findings revealed that using alumina-water at a concentration of (0.1%) improved the compound's thermal efficiency by (2.16%). Yassin K. et al. [72] numerically studied the possibility of using a hybrid nano-solution composite of TIG and (DWCNTs-TiO2)/aqueous (HNF). And in different volume concentrations with values ranging from (1 to 3% vol) and Reynolds numbers from (7000-28000). The results indicate an increase in efficiency. The efficiency and thermal energy were obtained by (22.19% and 23.26%) for (PR = 4 and PR = 1) respectively. Kedri J. et al. [73] investigated experimentally when hybrid nanofluids containing CuO nanoparticles and MgO nanoparticles were used. Flat Plate Solar Water Heater (FPSH) with concentrations of (0.2%, 0.1% CuO) and (0.1% MgO). With two varying flow rates (0.0167 kg/s and 0.0334 kg/s). According to the results, the flow rate of the hybrid nanofluids (0.0167 kg/s) led to an increase in the efficiency of FPSH by 43.3%.Kuwar Mausam et al. [74] investigated the impact of using Cu-MWCNTs/aqueous hybrid nanofluid with Three varying flow rates (0.5 l/min and 1.0 l/min, and 1.5 l/min), intensities (400, 600, and 700 W/m²), and tilt angles (25°, 30°, and 35°). The hybrid nanofluid improved the SEHs' performance, with a maximum instantaneous efficiency of 68.7% at a flow rate of (1.5 l/min), a density of (400 W/m²), and a (25°) inclination angle. Zafar Saeed et al. [75] studied the use of (MWCNT + Fe_3O4) nanofluid/aqueous hybrid nanofluid to test thermal efficiency a (FPSC). The Reynolds number of nanoparticles varies depending on their concentration. The highest thermal efficiency of 63.84% was achieved at a Reynolds number of 1413 and 0.3 vol%. Engy E. et al. [76] investigated the use of aqueous nanofluids such as MWCNTs, Al_2O_3, TiO_2, SiO_2, and CuO with four volumetric concentration ratios (0.5%, 0.025%, 0.01%), 0.005%) with three rates. For each concentration, the mass flow is different. The MWCNT/Al2O3 (50:50%) hybrid increased efficiency by (26, 29, and 18%) for (1.5, 2.5, and 3.3 l/min) respectively. B. Saleh et al. [77] studied experimentally so that they modeled the flow of multi-walled nanotubes (hybrid Fe_3O4 + carbon nanotubes) in flat solar collectors experimentally. The experiments were conducted at volumetric flow rates ranging from (0.1 l/min to 0.75 l/min) and concentrations ranging from (0.05% to 0.3%). The compound enhanced its thermal efficiency by 28.09% at 0.3% vol. Table 3 summarizes previous work using nanofluids in FPSC using hybrid nanofluids.

5. Results and Discussion

By studying the literature related to the research of flat solar collectors, many methods have been identified that contribute to increasing the efficiency rates of solar collectors. The most important of them are:

- When designing a flat plate solar collector, the climatic conditions in which the solar collector will operate must be taken into account
- To design the collector, pipes with high thermal conductivity must be used, preferably made of copper or aluminum.
- The use of mono nanofluids and hybrid nanofluids improves the thermal performance of flat plate solar collectors. It has been observed that the best nanofluids are those using (CuO and Al_2O_3) particles due to their easy availability as well as their high thermal conductivity.
- It has been observed that hybrid fluids have higher efficiency than homogeneous fluids, but they also have some disadvantages, including that their preparation method is complex and their cost is high.

- Nanomaterials affect the efficiency of pumps, so that when they are added to liquids, their viscosity increases, causing a decrease in pump pressure.
- Thermal efficiency increases through proper dispersion of nanoparticles to properly absorb sunlight.

The addition of nanoparticles to the base fluid increases the thermal efficiency due to the increased surface area of the working fluid. In summary, most of the research presented found that using nanotechnology in solar collectors as a working fluid has significant benefits. Sometimes, they use a single nanofluid, and other times, they use a hybrid nanofluid. Thermal efficiency has been greatly influenced by nanotechnology. It has been noted that hybrid fluids have higher efficiency than homogeneous fluids, but they also have some disadvantages, including that their preparation method is complex and their cost is high. Therefore, the thermophysical properties must be determined before choosing the nanofluid, because it helps in examining thermal conductivity. For example, it is one of the thermal properties of nanofluid. The thermal conductivity must be chosen so that it increases with increasing temperatures, and the appropriate flow rate must also be determined. As well as the concentration of nanoparticles, the appropriate concentration must be obtained, and the method of preparation has a major role in fluidity of fluid transfer and increased heat transfer. The reliability of nanofluids has a critical thermal performance behavior, so it should not agglomerate or precipitate. The angle of inclination for the solar collector has a direct effect on the work of the solar collector. The more the inclination angle is appropriate, the better the collector will receive the sun's rays, which leads to improving the efficiency of the collector. Finally, most studies focus on moment-to-moment evaluation, and long-term studies should be emphasized.

Table 3. Previous work has been done on the use of nanofluids in (F.P.S.C) using a hybrid nanofluids

Researcher	Type of study	Base fluid type	Type Nanoparticles	Size (nm)	Concen tration	Solar collector Area	Findings and remark
E. Farajzadeh et al. [57]	Exp.	Water	Al_2O_3 and TiO_2	20nm and 15nm	Both (0.1wt%)	1.85m²	the Nano scale concentration (0.1%) improved the thermal efficiency by (19% and 21% and 26%)
K. Farhana et al. [58]	Num.	Water	Al_2O_3 and TiO_2 and ZnO with hybrid nanofluids (Al_2O_3/TiO_2) and (TiO_2/ZnO) and (ZnO / Al_2O_3).		0.1wt%	1.94m²	increasing the maximum pressure in the second model of about (48% and 16%)
Jawea et al. [59]	EXP	Water	water/copper-aluminum hybrid	35nm	0.1%	2m²	An improvement was observed in the efficiency ratio.
Engy et al. [60]	EXP.	Water	MWCNT/Al_2O_3		0.5%, 0.025%, 0.01%, 0.005%	2.1m²	The efficiency improved by (26%, 29%, 18%) liters per minute, respectively.
Kuwar et al. [61]	Num.	Water	Cu-MWCNTs/water			2m²	Thermal performance improvement when using nanofluid as working fluid.
Zafar et al. [62]	Num.	Water	MWCNT + Fe_3O_4		various nanofluid concentrations	3m²	The results show that increasing the heat transfer coefficient by (26.3%) increases thermal efficiency.
Sujit et al. [63]	EXP	water	CuO and MgO with MWCNTs		from 0.25% to 2.0% wt	2m²	The thermal efficiency of CuO hybrid was better than that of MgO
Omar et al. [64]	EXP	water	CF-GNPs nanoplatelets / hexagonal boron nitride (h-BN)	Different size	different concentrations	2m²	Thermal efficiency ratios improved by (85%) as a result of the findings.
Montasser S et al. [65]	EXP	water	Al_2O_3/CuO	0.5-2 nm	25-75 (wt)	2m²	The results showed an increase in thermal efficiency values by 45%.
Prakasam et al. [66]	NUM	water	Fe_2O_4/water and Zn-Fe_2O_4/water		0.5wt	2m²	The results show that employing (Zn-Fe2O4) nanofluid / aqueous hybrid nanofluids at a concentration of (0.5 wt%) produces the optimum thermal efficiency.
Hossein Nabi et al.2022[67]	NUM	water	SWCNT-CuO / H_2O		1-5 wt	2m²	The largest concentration effect occurred at Reynolds number 4000 at 5% concentration, resulting in an 8.79% increase in HTC.

Continue Table 3. Previous work has been done on the use of nanofluids in (F.P.S.C) using a hybrid nanofluids							
Vednath et al. [68]	EXP	water	CuO + Al_2O_3/water	Different size	different concentrations	2m²	The findings suggest that a (CuO + Al2O3/water) distilled hybrid nanofluid can be used to evaluate the efficiency of a flat plate solar collector. The temperature of the stainless steel container's thermal energy storage system was raised to (87 °C).
Qingang Xiong et al. [69]	NUM	water	Ag-Al_2O_3 hybrid	Different size	different concentrations	2m²	The use of the hybrid nanofluid at a lower Reynolds number lowered the heat transfer rate while slightly boosting the supply temperature.
Zafar Said et al. [70]	EXP and NUM	water	MWCNT + Fe_3O_4	Different size	different concentrations	2m²	Significant increase in heat transfer coefficient (26.3%), with minimal loss in pressure drop owing to friction (18.9%).
Eric C. Okonkwo et al. [71]	EXP and NUM	water	alumina and alumina-iron/water		0.05%, 0.1% and 0.2%	2.1m²	The use of alumina-water at a concentration of (0.1%) resulted in a (2.16%) increase in thermal efficiency.
Yassin Khetib et al. [72]	EXP and NUM	water	DWCNTs-TiO2/water		1 to 3wt	2m²	The results reveal that when Re grows, so does the average Nusselt number (Nuave).
Kedri Janardhana et al. [73]	EXP	water	CuO + MgO		0.1wt	2.1m²	According to the findings, with a flow velocity of 0.0167 kg/s, the hybrid nanofluid boosted FPSH efficiency by 43.3%.
Kuwar Mausam et al [74]	NUM	water	Cu-MWCNTs	Different size	different concentrations	2m²	The hybrid nanofluid boosted the performance of the SEHs
Zafar Said et al. 2022[75]	EXP	water	MWCNT + Fe_2O_4	Different size	different concentrations	2m²	The maximum thermal efficiency of 63.84% was achieved.
Engy Elshazly et al. [76]	EXP	water	MWCNTs, Al_2O_3, TiO_2, SiO_2 and CuO		0.5%, 0.025%, 0.01%, 0.005%	2.1m²	The results showed an efficiency increase of 26%, 29%, and 18%.
Lesson B. Saleh et al. [77]	EXP	water	walled carbon nanotubes + Fe_2O_4		0.05% to 0.3%	2m²	The collector achieved better thermal efficiency.
Intissar Harrabi et al. [78]	NUM	water	(MgO and CuO /multi-walled) oxide–nanofluidic carbon nanoparticles		0.2v% and 0.6v%	2.1m²	The findings revealed that employing nanofluids improved the collector's performance by 5.14%.

5. Conclusion

Flat plate solar collectors have gone through many stages of development through the design and operation processes. This paper discusses those stages, as flat plate solar collectors are expected to play an important role shortly to meet the global needs for thermal energy and achieve further progress in their development. Taking into account the following suggestions

- Conducting studies by changing the dimensions and measurements of the collectors, such as the thickness and length of the pipes, as well as the type of metals used in their manufacture.
- Developing the ability of insulating materials to reduce heat loss.
- Use basic fluids other than water, such as engine oil.
- Thermal efficiency is greatly improved when nanofluids are used. It is possible to study the use of nanoparticle volume concentrations at higher values without affecting pump operation.
- The use of nanotechnology is not limited to working fluids only, as it can be used in the manufacture of glass covers and coatings for absorbing panels to contribute to absorbing more heat.
- The use of Brownian tubes, especially with nanofluids, is beneficial because they prevent the agglomeration of nanoparticles, which has a positive effect on thermal efficiency.

- There is a wider use of hybrid nanoparticles due to their high heat transfer efficiency.
- The development of hybridization of copper oxide and aluminum oxide nanostructures due to their high thermal conductivity coefficient.
- The optimal choice of pH important because of its positive effect on increasing the thermal efficiency of the flat plat solar collector.
- There is the possibility of reducing the agglomeration of nanofluids through the use of anti-stress materials through the use of hybrid nanoparticles.

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