Performance Improving for the Flat Plate Solar Collectors by Using Nanofluids: Review Study

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In this paper, the literature will be reviewed, and various research works conducted to improve the thermal performance of flat panel 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 Al₂O₃ particles due to their ease of availability and high thermal conductivity. As for hybrid nanofluids, the best fluids are (CuO + Al₂O₃/water) for the same reason above. As a result of design improvements and the use of nanofluids, temperatures up to (75°C) were obtained.

1. Introduction

According to previous studies, the world's tendency to development lead to increases the demand for fossil fuel, consequently environmental pollution and global warming increase [1, 2]. Which now concern 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 the energy that comes from the sun. [4]. Solar energy has recently emerged as a means of producing both thermal and electrical energy via solar panels and cells. Because it is a non-depleted 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 have recently been extensive research on solving the energy problem, and among these studies are studies 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 using as working fluids, the nanofluids are prepared by ultrasonic treatment [10]. There are many studies conducted to assist researchers and to address the challenges that will face the development of these collector 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.
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, which 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 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 plate 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 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 is applied to them. According to the solar collector's design, the tubes come in a variety of shapes. The protecting bottle that lets sun radiation 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. 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 nanomaterial’s 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 quickly freezes and oxidizes, 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. 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, 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 grows. friction on the surface of the fluid. Porous materials feature pores on their surfaces and thermal conductivity is high; they are utilized in solar collector systems to promote heat transfer and thermal performance by increasing low pressure drop and 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 that has a larger heat transfer area than conventional collectors. Through the results, the highest thermal efficiency was up to (55%) at radiation intensity (800 and 900 watts / m²). Fig. 4 shows the assembly of a triangular sun thermal collector that is flat.

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

Zhou et al. [16] examined when adding TIM with the effect of weather, 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 occurred 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%. The authors concluded that using TIM in cold climates, the results were better due to the higher permeability of the coating, which in turn would absorb more incident solar energy, causing poor performance compared to other conventional machines. Fig. 5 shows structure of (F.P.S.C) with TIM.

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

Filipovic et al. [17] Polymeric materials have been used 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 is less efficient, 30% less than the efficiency 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 box for testing.

![Fig. 6. 3D model of the test box [17]](image)

To solve the problems of high heating and freezing with the collector, Wang et al. [18] use a dual-coupled collector (PCM). When the temperature of the water rises a lot, The PCM (high-melting) absorbs heat and transforms during melting from a solid-state substance to a
liquid-state substance on other hand, storing excess heat. 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, Fig. 7.

Zhou et al [19] proposed the characteristics of 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 illustration of heat transfer patterns in PA-FPSC.

Balaji et al [20] study the improving 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 an The thermal performance booster from an experimental standpoint.

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

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

Fig. 9. Experimental view of thermal performance enhancer [20]
Kanimozhi et al. [21] experimentally studied when a porous medium was used 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 VFPSC 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]](image)

Felipe et al. [23] conducted a 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 a (vortex generator with rectangular) wings at an attack angle was 45° with 750 W/m² produced maximum heat transfer efficiency however, problems with significant pressure drop persisted. Fig. 11 shown the computational domain with a delta wing and a rectangle wing Vortex generator types.

![Fig. 11. computational domain with a delta wing and a rectangle wing Vortex generator types [23]](image)

K.Balaji et al [24] did a practical study by analyzing the effect of rod and inserting the tube type within 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 effect of submerged working fluid flow on efficiency. discovered 3% Increase in collector efficiency compared to standard collector. Fig. 12 shows a cross section of the toroidal profiles. Fig. 13 shows, before the glass cover is installed, a drawer-type assembly device.

![Fig. 12. Abaqus-modeled toroidal profile cross section [25]](image)
M. Ammar et al. [26] Study numerically Parallel interface transparent dielectric materials superimposed on flat solar air collectors. Upon numerical analysis (CFD), in the results showed raise in thermal efficiency ratios, which reached (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.

S.A Sakhaei, MS Valipour. [27] presented an experimental study when using corrugated helical tubes. The ratio (e/DH) ranges between (0.05 - 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 and number. 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 summary of previous works on problems and solutions to raise the efficiency of (F.P.S.C).
**Table 1. Previous works of problems and solutions to increase the efficiency of the (F.P.S.C)**

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Type of study</th>
<th>the problem</th>
<th>the solution</th>
<th>Findings and remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tadahmun et al [14]</td>
<td>EXP</td>
<td>Low absorption of solar radiation</td>
<td>Use a wavy, absorbent surface</td>
<td>The thermal efficiency of the solar collector increased by (59, 65, 67%) at mass flow rates (0.005, 0.0091, and 0.013 kg/s) respectively</td>
</tr>
<tr>
<td>Visa et al [15]</td>
<td>NUM</td>
<td>Lack of thermal space</td>
<td>Design a flat, triangular solar collector that has a larger heat transfer area</td>
<td>The results showed that the highest thermal efficiency reached (55%) at radiation intensity (800 and 900 watts/m²).</td>
</tr>
<tr>
<td>Filipović et al. [17]</td>
<td>EXP</td>
<td>Economic cost</td>
<td>Using polycarbonate sheets as absorber and wooden box as base</td>
<td>The thermal collector performed less efficiently, with its efficiency dropping to 30% less than a typical FPSC.</td>
</tr>
<tr>
<td>Wang et al. [18]</td>
<td>EXP</td>
<td>The working fluid outlet temperature is low</td>
<td>Use a dual-coupled collector (PCM).</td>
<td>The researchers discovered a slight improvement in the (F.P.S.C) thermal performance</td>
</tr>
<tr>
<td>Zhou et al [19]</td>
<td>EXP</td>
<td>The working fluid freezes.</td>
<td>Use a PCM filled with antifreeze</td>
<td>They claimed that a 15mm thick PCM module was a reasonable choice to get the most out of the PCM</td>
</tr>
<tr>
<td>Balaji et al [20]</td>
<td>EXP</td>
<td>Reduced heat transfer</td>
<td>Use an applicator and tube</td>
<td>Achieving thermal efficiency of 72%</td>
</tr>
<tr>
<td>Kanimozhi et al. [21]</td>
<td>EXP</td>
<td>Low thermal efficiency</td>
<td>Use a porous medium and agitator</td>
<td>Thermal efficiency rises to (63.8%), and when the porous medium is not used in the system, the efficiency rate reaches (56.6%). The percentage of increase in thermal efficiency reached (69.1%), while the FPSC efficiency reached (58.6%).</td>
</tr>
<tr>
<td>Fan et al. [22]</td>
<td>EXP</td>
<td>Low thermal efficiency</td>
<td>Using a unique letter-shaped multi-channel wave absorption device V</td>
<td>When using wings (rectangular vortex generator) with an angle of attack of 45° with 750 W/m², maximum heat transfer efficiency is achieved, however, pressure drop problems persist</td>
</tr>
<tr>
<td>Felipe et al. [23]</td>
<td>EXP</td>
<td>Disturbance in flow and lack of heat transfer</td>
<td>Use the rod and insert the tube type inside the axial direction of the tube containing the working fluid</td>
<td>The heat transfer coefficient increased and the rate of heat transfer from the liquid increased significantly.</td>
</tr>
<tr>
<td>K.Balaji et al [24]</td>
<td>EXP</td>
<td>Low heat transfer coefficient</td>
<td>3% increase</td>
<td>In the efficiency of the collector compared to the standard collector</td>
</tr>
<tr>
<td>R.W. Moss et al. [25]</td>
<td>EXP</td>
<td>Low thermal efficiency</td>
<td>Vacuum absorber</td>
<td>An increase in thermal efficiency rates, reaching 81%.</td>
</tr>
<tr>
<td>Ammar et al. [26]</td>
<td>NUM</td>
<td>Lost heat</td>
<td>Addition of transparent insulating materials with parallel and overlapping interfaces</td>
<td>Thermal efficiency increased to (61.59%)</td>
</tr>
<tr>
<td>S.A Sakhaei, MS Valipour. [27]</td>
<td>EXP</td>
<td>Low thermal efficiency</td>
<td>Use corrugated spiral tubes.</td>
<td>Thermal efficiency increased compared to the bare corridor.</td>
</tr>
<tr>
<td>R. Kansara et al. [28]</td>
<td>EXP</td>
<td>Low thermal efficiency</td>
<td>Fitting the inner fins and porous media in the path of the airflow</td>
<td></td>
</tr>
<tr>
<td>LLC Sakhaei, and M. Valipour [29]</td>
<td>EXP</td>
<td>Store excess energy.</td>
<td>Use of spiral collector liquid passage and phase change materials</td>
<td>An increase in the efficiency ratio by (39.8). %).</td>
</tr>
</tbody>
</table>
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 properties thermal of the base fluid of Working fluids to create devices generating high heat flow for effective thermal dissipation [30]. The ground nanoparticles is added to the base liquid to form the nanofluid. Metals (Cu, Ag, Au), nitride ceramics SiN and AlIN, SiC and CuO, Al₂O₃ and TiC, and SiO₂ and TiO₂ are all examples of nitride ceramics. are examples of nanoparticle materials. The major parameters are working fluid viscosity (µ), thermal conductivity (K), fluid density (ρ), and specific heat capacity (C) influencing heat transfer in fluids containing nanoparticles [31]. When preparing nanofluids, several factors such as the volume and weight in terms of volumetric concentration ratio of nanoparticles in terms of nanoparticle, the amount of the working fluid must be considered, the method of good mixing, and the surfactants. All of these elements contribute to the base fluid’s stability. In a conventional fluid, it is one of the most important requirements for producing a usable nanofluid. To achieve a consistent, stable suspension, several techniques are used in general, Ultrasonic equipment, pH control, and the addition of stabilizers are all included [32, 33]. Nanoparticles suspended in liquids cling together due to the van der Waal 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 because of their stability, chemical or physical treatments Surface modification of suspended particles, addition of surfactant, or application of considerable force to suspended particle assemblies are examples of such modifications. Should be used to solve the problem of nanoparticles instability [34]. In general using nanofluids, As the temperature rises, the thermal conductivity (K) rises with it. When the heat transferred between the nanofluid and the absorbent plate increased, the convective and radiant losses decreased. Due to the mixing of nanoparticles with the base liquid, the optical absorption capacity increased. After using the nanoparticles, in comparison to water, the nanofluid's absorption coefficient increased. Consequently, the coefficient of convective heat transfer will improve. Hence a small size solar collector may be used when using nanofluids. The significant increase in viscosity, makes the physical properties better. Furthermore, because to the nanoparticles’ enormous surface area in comparison to volume, rises the heat transmission between the nanoparticles and the base fluid. Good thermal diffusion will be occur then improving in heat transfer will be resulted.

4.1. Literature review for addition of nanomaterial’s 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 (AIN), (SiN.), oxide ceramics (Al₂O₃) and (CuO), carbide ceramics (SiC) and (TiC), (TiO₂) and (ZnO). Genk et al [35] use Al₂O₃ 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 (Al₂O₃ / 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 TiO₂/H₂O 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%), while the percentage of water efficiency was (16.28%). Tong et al. [39] studied a comparison of two flat solar collectors and two nanofluids (Al₂O₃ 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 (Al₂O₃) was used as the working fluid in the FPSC, the efficiency was (21.9%) greater than when using water. To water, the use of Al₂O₃ and CuO nanofluid in (FPS.C) lead to improved thermal efficiency. When 1.0 Vol% (Al₂O₃ 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/l min 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 (Al₂O₃) on it and used sodium dodecyl sulfate (SDS) to disperse nanoparticles. The concentrations used in the nanofluid (Al₂O₃) 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 the collector's efficiency has improved. by (21.32%) when the volume fraction (Al₂O₃) has grown from (0.1% to 0.3%). Maouassi et al. [42] investigated numerically the effect of nanofluid particles (SiO₂) to increase the collector's efficiency of (FPSC) type of forced convection. The effect of nanofluid (SiO₂) 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 (FPSC), 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 (Al₂O₃ 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-Jabr et al [45] presented an experimental study when they prepared deionized aqueous nanofluids (SiO₂) 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 by an experimental examination performed on (FPSC). Various nanofluids were prepared by adding particles of the following materials (Al₂O₃, CuO, and TiO₂) 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 (TiO₂/water). Y. did. Khatib et al [48] presented an experimental study when I use 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 (TiO₂)/(CF-MWCNTs/DW) through which the efficiency of (FPSC) is verified. The experimental results indicated that the use of TiO₂/CF-MWCNTs improved the efficiency of the collector by (9% and 26%) at the lowest temperature. Heat and temperature rise (5%). Michael et al. [35] studied the influence of the physical properties of a nanofluid consisting of (0.1% by weight) liquid. A hexagonal tube was used in the FPSC with a concentration of 0.4% has been greatly enhanced by the multi-layered MWCNTs. The 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 (aluminum, 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 2%. 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%). Youssif 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>
<thead>
<tr>
<th>Researcher</th>
<th>Type of Study</th>
<th>Base fluid type</th>
<th>Type Nanoparticles</th>
<th>Size (nm)</th>
<th>Concentration</th>
<th>Solar Collector Area</th>
<th>Findings and remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.M. Genc et al [35]</td>
<td>Exp</td>
<td>Water</td>
<td>Al₂O₃</td>
<td>10-30nm</td>
<td>1%, 2% and 3% wt</td>
<td>1.993m²</td>
<td>the thermal efficiency improved by (83.90%).</td>
</tr>
<tr>
<td>M. Mirzaei et al. [36]</td>
<td>Exp</td>
<td>Water</td>
<td>Al₂O₃</td>
<td>20nm</td>
<td>1% wt%</td>
<td>1.88m²</td>
<td>The efficiency has increased by (23.6%)</td>
</tr>
<tr>
<td>F. Kiliç et al. [37]</td>
<td>Exp.</td>
<td>Water</td>
<td>TiO₂</td>
<td>44 nm</td>
<td>2 wt%</td>
<td>1.82m²</td>
<td>The efficiency was improved to (48.67%)</td>
</tr>
<tr>
<td>S.K. Verma et al. [38]</td>
<td>Exp.</td>
<td>MWCNTs with water</td>
<td>CuO and MgO</td>
<td>42 nm</td>
<td>0.25% to 2.0%wt</td>
<td>2m²</td>
<td>The efficiency improved by (21.9%)</td>
</tr>
<tr>
<td>Y. Tong et al. [39]</td>
<td>Exp.</td>
<td>Water</td>
<td>Al₂O₃ and CuO</td>
<td>0.5–15 wt</td>
<td>2m²</td>
<td>Maximum Thermal efficiency was (69.24%),</td>
<td></td>
</tr>
<tr>
<td>S. Choudhary et al [40].</td>
<td>Exp.</td>
<td>Ethylene glycol:Deionized water.</td>
<td>ZnO</td>
<td>35 nm</td>
<td>0.2%-1%wt</td>
<td>2.1m²</td>
<td>The efficiency of (21.32%) at a volumetric concentration of (0.1% to 0.3%),</td>
</tr>
<tr>
<td>N.S. Rajput et al [41].</td>
<td>Exp</td>
<td>distilled water</td>
<td>Al₂O₃</td>
<td>10-15nm</td>
<td>0.1 to 0.3wt%</td>
<td>1.95 m²</td>
<td>The thermal efficiency increased by (18%)</td>
</tr>
<tr>
<td>A. Maouassi et al. [42]</td>
<td>Num.</td>
<td>Water</td>
<td>SiO₂</td>
<td>≤ 50 nm</td>
<td>1%, 3%, 5% and 10%wt</td>
<td>1.5m²</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Previous work use of nanofluids in (F.P.S.C) using a mono nanofluid.
Farajzadeh et al [57] investigated the effect of using a hybrid nanofluid consisting of, (Al₂O₃:H₂O) with a 20 nm size and a concentration of (0.1% vol) and it was mixed with another nanofluid which is (TiO₂:H₂O) 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 (Al₂O₃, ZnO, TiO₂,) and three hybrid nanofluids (Al₂O₃ + TiO₂, TiO₂ + 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 Al₂O₃/ 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 Al₂O₃, TiO₂, SiO₂ 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/min), each concentration requiring a different approach. The results showed that the hybrid (MWCNT/Al₂O₃) was effective. Thermal efficiency enhanced by (26%, 29%, 18%) depending on the flow rates respectively. 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 (Al₂O₃) hybrid was effective. The results were demonstrated using three types of different volumetric flow rates (0.5, 1.0, and 1.5 L/min) 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 an increase in the lighting efficiency by (68.7%) at the flow rate (1.5 l/min), radiation intensity (400 W/m²), and an inclination angle (25°). Zafar et al [62] investigated the use of (Fe₃O₄)/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 (2.1 l/min and 3.1 l/min), and (4 l/min) in multiple volumetric concentrations. The findings suggest that thermal efficiency can be improved. until it reached (85%). Montaser et al [65]. The effect of (Al₂O₃/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%. Prakasham et al [66] investigated the feasibility of evaluating the performance of (F.P.S.C) Hybrid and single nanofluids (Fe₃O₄, ZnO/water distilled) are used. The results showed that using water distilled (ZnO-F exO₃) 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 Fe₃O₄ / 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). Vedanth et al [68] studied the effect of using hybrid nanofluids (CuO + Al₂O₃/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 examined when using a corrosion-resistant steel enclosure up to (87°C). Qingyang Xiong et al [69] employed hybrid (Ag-Al₂O₃) 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 + Fe₃O₄) 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. (19.8%). Okonkwo et al. [71] investigated experimentally and numerically a (FPS.C) with (Al₂O₃ 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. The efficiency and thermal energy were obtained by (22.19% and 23.26%) for (PR = 4 and PR = 1) respectively. Bedri J. et al. [73] investigated experimentally when hybrid nanofluids containing CuO nanoparticles and MgO nanoparticles were used. Flat Plate Solar Water Heater (FPS.H) 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 (F.P.S.H) 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 + Fe₃O₄) nanoliquid/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 the Reynolds number (1413) and (0.3 vol%). Engy E. et al [76] investigated the use of aqueous nanofluids such as MWCNTs, Al₂O₃, TiO₂, SiO₂, and CuO with four volumetric concentration ratios (0.5%, 0.025%, 0.01%, and 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 Fe₄O₄/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 has enhanced its thermal efficiency by (28.09% at 0.3% vol). Table 3 summarizes previous work using nanofluids in FPS.C using hybrid nanofluids.

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Type of study</th>
<th>Base fluid type</th>
<th>Type Nanoparticles</th>
<th>Size (nm)</th>
<th>Concentration</th>
<th>Solar collector Area</th>
<th>Findings and remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>E. Farajzadeh et al. [57]</td>
<td>Exp.</td>
<td>Water</td>
<td>Al₂O₃ and TiO₂</td>
<td>20nm and 15nm</td>
<td>Both (0.1wt%)</td>
<td>1.85m²</td>
<td>the Nano scale concentration (0.1%) improved the thermal efficiency by (19% and 21%) and 26% increasing the maximum pressure in the second model of about (48% and 16%)</td>
</tr>
<tr>
<td>K. Farhana et al. [58]</td>
<td>Num.</td>
<td>Water</td>
<td>Al₂O₃ and TiO₂ and ZnO with hybrid nanofluids (Al₂O₃/TiO₂) and</td>
<td>0.1wt%</td>
<td></td>
<td>1.94m²</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Previous work has been done on the use of nanofluids in (F.P.S.C) using a hybrid nanofluids
<table>
<thead>
<tr>
<th>Study</th>
<th>Method</th>
<th>Nanofluid Components</th>
<th>Nanofluid Concentration</th>
<th>Results/Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jawea et al. [59]</td>
<td>EXP</td>
<td>(TiO₂/ZnO) and (ZnO / Al₂O₃).</td>
<td>35nm, 0.1%</td>
<td>An improvement was observed in the efficiency ratio.</td>
</tr>
<tr>
<td>Engy et al. [60]</td>
<td>EXP</td>
<td>MWCNT/Al₂O₃</td>
<td>0.5%, 0.025%, 0.01%, 0.005%</td>
<td>The efficiency improved by (26%, 29%, 18%) Liters/minute. Respectively</td>
</tr>
<tr>
<td>Kuwar et al. [61]</td>
<td>Num.</td>
<td>Cu-MWCNTs/water</td>
<td></td>
<td>Thermal performance improvement when using nanofluid as working fluid.</td>
</tr>
<tr>
<td>Zafar et al. [62]</td>
<td>Num.</td>
<td>MWCNT + Fe₃O₄</td>
<td>various nanofluid</td>
<td>The results show that increasing the heat transfer coefficient by (26.3%) increases thermal efficiency.</td>
</tr>
<tr>
<td>Sujit et al. [63]</td>
<td>EXP</td>
<td>CuO and MgO with MWCNTs</td>
<td>from 0.25% to 2.0% wt</td>
<td>The thermal efficiency of CuO hybrid was better than that of MgO</td>
</tr>
<tr>
<td>Omar et al. [64]</td>
<td>EXP</td>
<td>CF-GNPs nanoplatelets / hexagonal boron nitride (h-BN)</td>
<td>different concentrations</td>
<td>Thermal efficiency ratios improved by (85%) as a result of the findings.</td>
</tr>
<tr>
<td>Montasser S et al. [65]</td>
<td>EXP</td>
<td>Al₂O₃/CuO</td>
<td>0.5-2 nm, 25-75 (wt)</td>
<td>The results showed an increase in thermal efficiency values by 45%. The results show that employing (Zn-Fe₃O₄) nanoparticle / aqueous hybrid nanofluid at a concentration of (0.5vo%) produces the optimum thermal efficiency.</td>
</tr>
<tr>
<td>Prakasam et al. [66]</td>
<td>NUM</td>
<td>Fe₃O₄/water and Zn-Fe₃O₄/water</td>
<td>0.5wt</td>
<td>The usage of the hybrid nanofluid at lower Re lowered the heat transfer rate while slightly boosting the supply temperature. Significant increase in heat transfer coefficient (26.3%), with minimal loss in pressure drop owing to friction (18.9%). The use of alumina-water at a concentration of (0.1%) resulted in a (2.16%) increase in thermal efficiency.</td>
</tr>
<tr>
<td>Hossein Nabi et al.2022[67]</td>
<td>NUM</td>
<td>SWCNT-CuO / H₂O</td>
<td>1-5 wt</td>
<td>The largest concentration effect occurred at Reynolds number 4000 at 5% concentration, resulting in an 8.79% increase in HTC.</td>
</tr>
<tr>
<td>Vednath et al. [68]</td>
<td>EXP</td>
<td>CuO + Al₂O₃/water</td>
<td>different concentrations</td>
<td>The temperature of the stainless steel container's thermal energy storage system was raised to (87 °C).</td>
</tr>
<tr>
<td>Qingang Xiong et al. [69]</td>
<td>NUM</td>
<td>Ag-Al₂O₃ hybrid</td>
<td>different concentrations</td>
<td>The usage of the hybrid nanofluid at lower Re lowered the heat transfer rate while slightly boosting the supply temperature. Significant increase in heat transfer coefficient (26.3%), with minimal loss in pressure drop owing to friction (18.9%). The use of alumina-water at a concentration of (0.1%) resulted in a (2.16%) increase in thermal efficiency.</td>
</tr>
<tr>
<td>Zafar Said et al. [70]</td>
<td>EXP and NUM</td>
<td>MWCNT + Fe₃O₄</td>
<td>different concentrations</td>
<td></td>
</tr>
<tr>
<td>Eric C. Okonkwo et al. [71]</td>
<td>EXP and NUM</td>
<td>alumina and alumina-iron/water</td>
<td>0.05%, 0.1% and 0.2%</td>
<td></td>
</tr>
</tbody>
</table>
The method of preparation has a major role in obtaining good results to increase the efficiency rates of the 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 Al₂O₃) 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 the hybrid coolant would be more expensive and the preparation method is complex and the 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.

### 5. Conclusions

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 the development of flat plate solar collectors. Taking into account the following suggestions:

- Conducting studies by changing the dimensions and measurements of the collectors, such as the thickness and the 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.

### 5. Results and Discussion

By studying the literature related to the research of flat solar collectors, it is possible to obtain many methods that contributed to obtaining good results to increase the efficiency rates of the solar collectors. The most important of them are:

<table>
<thead>
<tr>
<th>Name</th>
<th>Method</th>
<th>Fluids</th>
<th>Type/Concentration</th>
<th>Volume Fraction</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yassin Khetib et al. [72]</td>
<td>EXP and NUM</td>
<td>water</td>
<td>DWCNTs-TiO2/water</td>
<td>1 to 3wt</td>
<td>2m²</td>
</tr>
<tr>
<td>Kedri Janardhana et al. [73]</td>
<td>EXP</td>
<td>water</td>
<td>CuO + MgO</td>
<td>0.1wt</td>
<td>2.1m²</td>
</tr>
<tr>
<td>Zafar Said et al. 2022[75]</td>
<td>EXP</td>
<td>water</td>
<td>Cu-MWCNT</td>
<td>different concentrations</td>
<td>2m²</td>
</tr>
<tr>
<td>Engy Elshazly et al. [76]</td>
<td>EXP</td>
<td>water</td>
<td>MWCNT + Fe₃O₄</td>
<td>0.5%, 0.025%, 0.01%, 0.005%</td>
<td>2.1m²</td>
</tr>
<tr>
<td>LessonB. Saleh et alx. [77]</td>
<td>EXP</td>
<td>water</td>
<td>MWCNTs, Al₂O₃, TiO₂, SiO₂ and CuO walled carbon nanotubes + Fe₃O₄</td>
<td>0.05% to 0.3%</td>
<td>2m²</td>
</tr>
<tr>
<td>Intissar Harrabi et al. [78]</td>
<td>NUM</td>
<td>water</td>
<td>(MgO and CuO/multi-walled) oxide–nanofluidic carbon nanoparticles</td>
<td>0.2v% and 0.6v%</td>
<td>2.1m²</td>
</tr>
</tbody>
</table>

The results reveal that when Re grows, so does the average Nusselt number (Nuave). According to the findings, with a flow velocity of (0.0167 kg/s), the hybrid nanofluid boosted (F.P.S.H ) efficiency by (43.3%). The hybrid nanofluid boosted the performance of the SEHs. The maximum thermal efficiency of 63.84% was achieved. The results showed an efficiency increasing by 26%, 29%, and 18%.

The collector achieved better thermal efficiency. The findings revealed that employing nanofluids improved the collector's performance by 5.14%.
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, because they prevent the agglomeration of nanoparticles, which has a positive effect on thermal efficiency.

Wider use of hybrid nanoparticles due to their high heat transfer efficiency.

Development of hybridization of copper oxide and aluminum oxide nanostructures due to their high thermal conductivity coefficient.

The optimal choice of pH because of its positive effect on increasing the thermal efficiency of the flat plate solar collector.

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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