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Using of Nanofluid for Flat Plate Solar Collector Application in Iraq – A summarized Review

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Iraq's abundant solar resources offer a substantial potential for harnessing solar energy. However, improving the efficiency of solar energy systems, especially solar thermal collectors, is a critical step toward increasing the country's reliance on solar power. Nanofluids—suspensions of nanoparticles in base fluids—have emerged as promising heat transfer fluids that can significantly enhance the efficiency of solar thermal systems. In this paper, the use of mono nanofluids in FPSC flat plate solar collectors inside Iraq is studied. This study focuses on knowing the benefits of using nanofluid and their impact on increasing efficiency and also examining the obstacles to the use of these materials, where many studies conducted inside Iraq are reviewed. And also focus on the extent of applications within Iraq's dry and humid climate. Finally, this paper reviews the most important recommendations for optimal nanofluidic use in a flat plate solar collector. Previous studies have shown that water is the most suitable base fluid due to its good thermal conductivity compared to other fluids. As for nanoparticles, MWCNT demonstrated a clear advantage over other particles, reaching an efficiency of over 80%. However, these particles should be used at concentrations not exceeding 5% to avoid damaging the system.

1. Introduction

Flat plate solar collectors are widely used to convert solar energy into thermal energy due to their simplicity, efficiency, low cost and reliability [1]. However, these collectors have limited efficiency due to several reasons, including the low thermal properties of conventional transport fluids such as water or ethylene glycol [2]. To solve this problem, the researchers found that the use of nanoparticles would improve the efficiency of the collector [3]. Nanoparticles, which are suspensions inside the base fluid, are used as a working fluid to enhance heat transfer and increase efficiency due to their superior

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thermal properties, including increased thermal conductivity and heat capacity compared to conventional fluids [4]. This improvement in thermal performance is due to the high surface area of the nanoparticles and their high ability to absorb energy and transfer it into the nanofluid [5]. In solar collectors, nanofluids have a high ability to absorb solar radiation directly with high efficiency, which reflects positively on thermal performance [6]. The use of Al_2O_3/H_2O nanofluid flow in a flat plate solar collector (FPSC) supported by a porous media was proposed. The results showed that the maximum Nusselt number (Nu) value reached 6.80 at a Reynolds number (Re) of 234 and a nanoparticle volume fraction (φ) of 3%. The introduction of rectangular porous blocks with Darcy number (Da = 10^{-2}) increased the thermal efficiency of the system to 70.5%, confirming the effective role of the porous media in enhancing heat transfer and improving the thermal performance of the solar collector [7]. Hosseini et al. investigated experimentally how two different kinds of nanofluids water-based GO and Al_2O_3 affect the solar collector's performance. The system's maximum thermal efficiency was determined to be 32.1% for GO and 63.2% for Al_2O_3 [8]. Venkatesh et al. used 0, 10, 20, and 30% alumina nanofluid at a flow rate of 0.05 kg/s to improve the thermal behaviour of heat exchangers for space heating applications. Test condition (30 vol% concentration of alumina nanofluid) provided a Q of 138 ± 1.52 kJ/Mol and a maximum k of 38.98 ± 0.91 W/m◦C [9]. Sheikholeslami et al. tried employing multi-way twisted tape numerically to use Al_2O_3 in a linear Fresnel reflector. The scientists came to the conclusion that the thermal efficiency of the solar system might be increased by employing such a mix of heat transfer improvement strategies [10]. Choudhary at el. used Fe_2O_3/water-EG nanofluids in an FPSC with flow rates varying from 30 to 150 L/h and volume concentrations between 0.2 and 1%. When compared to water and EG working fluids, thermal efficiency was found to be 15.2% greater [11]. Sundar at el. employed a wire coil and water-based Al_2O_3 nanofluid as a heat transfer augmentation technique for an FPSC. When compared to water, the maximum thermal efficiency of 37.73% was increased [12]. Eltaweel and Abdel-Rehim studied using two types of nanofluid. The results of the investigation indicated that the FPSC in terms of efficiency. Two distinct kinds of nanofluids were used to examine the performance of the FPSC systems. They used carbon nanotubes in ethylene glycol and water. An impressive 64.1% increase in average thermal efficiency, with volume concentrations of 0.01–0.1%, MWCNTs/water nanofluid increased the thermal efficiency of FPSC by 16–34.13% [13]. Alawi et al. examined the impact of employing Penta ethylene glycol-containing graphene nanoplatelets (GNPs/PEG) as a working fluid in an FPSC. A number of input factors were used, including temperatures, sun radiation, volume flow rates, and nanoparticle mass fractions. According to the results, there had been a 13.3% improvement in absorber performance [14]. Genc et al. conducted a transient numerical analysis on flat plate solar water heaters (FPSWH) with mass flow rates of 0.004 kg/s and 0.06 kg/s, and alumina-water nanofluid fractions of 1%, 2%, and 3%, respectively. The results show that FPSWH has a maximum thermal efficiency of 83.9% at a mass flow rate of 0.06 kg/s. A 3% fraction raised the exit temperature by 7.2% at a lower mass flow rate [15]. The collector's efficiency increased by 23.6% at the perfect flow rate of 2 L/m when Al_2O_3 nanofluid with a volume fraction of 0.1% was used at mass flow rates of 1, 2, and 4 L/m [16]. Tong et al. discovered that employing 1.0 vol percent Al_2O_3 nanofluid improved efficiency by 21.9% when compared to water as a heat transfer fluid (HTF). Using 1.0 vol percent Al_2O_3/water and 0.5 vol percent CuO/water nanofluids improved exergy efficiency by 56.9% and 49.6%, respectively [17]. Tang et al. investigated the impact of different nanofluids used as working fluids on the heat collection performance of CFPSC. The findings show that the heat collection stabilization time of the nanofluids with ethylene glycol (EG) as the base fluid was 12.4–28.6% longer than that of the nanofluids with water as the base fluid when CuO and Al_2O_3 were utilized as nanoparticles [18]. Forced circulation FPSWH is not as effective as Multiwall Carbon Nanotubes (MWCNTs) with distilled water on thermosiphon FPSWH. On the thermosiphon FPSWH, maximum energy efficiency improvements of 34.13% and 23.35% were attained with 0.1 weight percent and 0.05 weight percent MWCNTs at 3.5 L/min [19]. Mahbubul et al. shown that a 0.2% volume concentration of a water nanofluid containing single-walled carbon nanotubes (SWCNT) increased the solar collector's efficiency by 10% [20]. Said et al. examined how SWCNT nanofluid affected flat plate solar collectors and found that, in comparison to pure water, the heat transfer coefficient increased by 15.33% [21]. By analysing several nanofluid types on flat plate solar collectors, it was determined that, under the same circumstances, using carbon-based nanofluids rather than another type of nanofluid enhances the energy and operational efficiency of the flat plate solar collectors [22]. Biomed et al.

investigated of nanofluids with particles suspended in the base fluid that range in size from 1 to 100 nanometres. Heat transfer and thermal conductivity are greatly enhanced by the addition of nanofluids. Silicon carbide (SiC) nanofluids were employed in this investigation at percentages of 1%, 2%, 3%, and 4% in the base fluid (ethylene glycol). The thermal characteristics of the nanofluids were examined, including their transfer rate, conductive heat transfer coefficient, and Nusselt number [23]. By altering the flow path's geometry to create spiral, U-shaped, and wavy tubes, the friction factor and the resulting variations in heat transfer were evaluated. According to the results, the HTC could be raised to 78.25% by altering the flow direction in wavy tubes and employing 4% CuO nanofluid [24]. Ajeena et al. studied affects using SiC/DW nanofluids flat plate solar collector's efficiency, distilled water used as base fluid, volume fractions of (0.025, 0.05, 0.075, and 0.1%. The results showed that adding SiC nanoparticles increased the fluid's thermal conductivity by up to 30.3%. At 77.43%, the collector's thermal efficiency was at its highest [25]. Saedodin et al. examined how various turbulence-inducing components affected parabolic solar collectors and found that, in comparison to the simple condition, the thermal efficiency of various shapes might rise by as much as 27.6% [26]. Promvonge and Eiamsa investigated tubes with cone loop turbulators and twisted tape swirl generators and found that using this technique can raise the thermal efficiency by 4–8% and the Nusselt number by 4–10%, respectively [27].

In Iraq, a country that is rich in solar energy, improving solar energy systems, especially thermal energy, is very important [28]. Several studies have been conducted to apply nanofluids as working fluid within the flat plate solar collector in the climate of Iraq. Air was used as the working fluid in the study, and the flow rates entering the solar collector ranged from 0.005 to 0.067 kg/s. The efficiency of solar air heaters can be impacted by a variety of factors, including the collector's length, the number of channels, the depth of the channels, the kind of absorption plate, the quantity and composition of the glass covers, the air intake temperature, and the air velocity. The maximum air mass flow (0.067 kg/sec) has the highest instantaneous efficiency of 81%, while the lowest air mass rate (0.005 kg/sec) has the lowest instantaneous efficiency of 41% [29]. Abd et al. examined how, in a modified SWH with natural convection, inserts such as twisted tapes increase flat plate collector efficiency. Six variations of a passive flow SWH were evaluated under various ambient and solar isolation conditions. There were increases in SWH efficiency of 9.7%, 8.6%, 6.3%, 5.4%, 4.9%, and 4.3% [30]. Utilizing a V-corrugated plate absorber in a sun-drying system, with a maximum thermal efficiency of 71%, allows researchers to examine temperature variations within the drying chamber [31]. Hussein et al. studied using an open-loop system with a constant inlet water temperature, the study investigated the effects of factors such air speed, ambient temperature, solar irradiation, and the presence of metallic wire mesh. There were differences in the inlet water flow rates of 2, 3, 4, and 6 L/min. The findings show that adding wire mesh to the FPSC raised the exit water temperature by 22%. The greatest output temperature (50°C) was recorded utilizing a CuO/H_2O nanofluid with different mass flow rates (0.003 to 0.076 kg/s). The 1% CuO-water nanofluid showed a 32% increase in collector thermal efficiency, outperforming pure water by 11.3% [32]. Gorai et al. examined the impacts of temperature increase parameters, mass flow rates between 0.012 and 0.170 kg/s, and volume percentages of nanoparticles (Cu, CuO, and Al_2O_3 (with water as base fluid) between (0-1%). The water collector was determined to have the highest thermal efficiency of 53.7% at the maximum mass flow rate of 0.1675 kg/s. The maximum efficiency of the nanofluid collector is 70.5% when the nanofluid volume fraction is 0.48 and the highest mass flow rate of 0.1675 kg/s is taken into consideration. It is anticipated that the energy efficiency of the nanofluid collector will surpass that of the water collector by up to 16.8% [33]. Mahdi et al. employed a controlled setup with solar collectors (300 L capacity, 5 L/min flow rate) to produce nanofluid utilizing iron (Fe) and aluminium (Al) nanoparticles. The findings show that Al higher thermal conductivity (205 W/m·K) allows for 28% faster heat dissipation than Fe (80 W/m·K), raises efficiency of Al by an additional 15%, bringing it to 82% thermal efficiency [34]. Abouelsoud et al. employed water and an Al_2O_3/water nanofluid at volume concentrations of 2% and 3% as thermal fluids. The performance of the solar collector was tested using varying thermal fluid flow rates of 1.5, 2.5, and 3.5 l/min. The findings demonstrated that as the water flow rate increases, so does the collector's thermal efficiency. When employing the flow rates of 2.5 and 3.5 l/min as opposed to 1.5 l/min, it rose by 5% and 18.4%, respectively. Additionally, the results demonstrate that, when compared to using water alone as a cooling fluid, the use of Al_2O_3/water nanofluid at concentrations of 2% and 3% increases the thermal efficiency by 27.6% and 38.4%, respectively [35]. Hussein et al. studied in the climate of Kirkuk city, Iraq to evaluate the performance of a flat plate solar collector using a working fluid of a nanofluid composed of CuO/water with a volumetric concentration of 0.25%. The results showed that the use of nanofluids enhances thermal efficiency compared to the use of conventional fluids as working fluid, where the efficiency enhancement reached 31.66% in January and 44.44% in April [36]. Hussein et al. examined the possibilities of Cu-H_2O nanofluids based on Casson. The Rayleigh number (103 $\leqslant$ Ra $\leqslant$ 106), the Casson fluid parameter (0.1 $\leqslant \gamma \leqslant$ 1), the corrugation number (3 $\leqslant$ N $\leqslant$ 10), and the nanoparticle volume fraction (0 $\leqslant \phi \leqslant$ 0.15), are among the variables that are examined in this work. Heat transfer is greatly enhanced by the addition of nanoparticles; for Ra = 105, the average Nusselt number increases by 20% as the volume fraction of nanoparticles rises from 0 to 0.15.A volumetric concentration of 0.25 percent was used to prepare the CuO/Water nanofluid. The two solar collectors were put through practical testing, one with pure water and the other with the nanofluid. At a mass flow rate of 0.015 L/s, the practical efficiency of a 0.25% nanofluid (CuO) reaches its maximum. Heat transfer in tubes filled with fluid is improved by higher mass flow rates. At this flow rate, the collector efficiency increased 44.5% [37]. Qader et al. studied investigates the efficiency of solar energy using TiO_2 nanofluid in solar collectors, conducted in Kirkuk, Iraq. The results show a maximum thermal efficiency of 48.48% for water and 51.23% for the nanofluid [38]. Khudhayer et al. used TiO_2/water and CuO/water nanofluids as working fluids instead of the base fluid (water). The results showed that the CuO/water nanofluid as a working fluid in the FPSC exhibited higher heat transfer performance compared to TiO_2/water nanofluid as well as the base fluid (water) due to the higher thermal conductivity of CuO nanoparticles. The maximum efficiency arrived to be 55% for the CuO/water nanofluid compared to 54% and 50% for 0.1 % (TiO_2/water) and water, respectively [39]. Saeed et al. compared a conventional flat-plate solar air heater to assess the effects of using Al_2O_3-paraffin wax as a nano-PCM storage medium. Different configurations show the highest thermal efficiency values, the wax-supported model reaches 55.9%, the nano-PCM reaches 57.7%, and the suggested model achieves roughly 55.2%, while the traditional model lags at 48.2% [40]. Alwan and Kadhim examined how a solar collector system can be integrated with a storage tank that contains phase change materials (PCM) and water pipes. Peak temperatures at flow rates of 4, 6, and 8 L/m reached 60°C in the winter and 75°C in the summer, indicating an improvement in temperature stability [41]. Abd et al. used paraffin served as the phase change material, and specific Al_2O_3 and TiO_2 nanoparticles were added to it at a mass percentage of 0.5%. Paraffin and nano-paraffin were added to the water tank for the tests, the corresponding energy efficiencies were 37.7%, 41.4%, and 45.8% [42]. Mohammed et al. investigated covering absorber plates with thin films of nanocoating (SiO_2, TiO_2, and ZnO). The collector that was integrated with ZnO thin-film had the greatest recorded efficiency. At midday, the ZnO-coated collector's efficiency was almost 66%, while the traditional system (no thin film) only had 39% [43].

In solar collectors the using of nanofluids offers many advantages. Thermal conductivity and other thermal properties are improved by the integration of nanofluids [44]. The fusion of nanofluids increases heat transfer and gives more efficiency, as well as increases the ability of the working fluid to absorb heat, which increases the absorption of solar incident radiation. It also gives better heat distribution, reduces thermal stresses, and enhances thermal performance in general [45]. However, attention must be paid to addressing some problems and challenges such as the stability of nanoparticles, the potential blockage from the using of these particles, as well as the cost of nanoparticles in order to apply them in practice [46]. Current research focuses on using the best nanoparticles, their concentrations and base fluids to obtain the best thermal performance with fewer challenges.

In conclusion, the using of nanofluids represents a promising way to enhance the efficiency of solar collectors in Iraq by increasing thermal efficiency. Nanofluids can contribute to improving solar energy systems to be more efficient in line with the country's renewable energy goal plans.

In this paper, the focus is on improving the performance of flat plate solar collectors using mono nanofluids in Iraq, with a focus on their impact on increasing thermal performance and system efficiency. In addition, a review of nanoparticles used in the preparation of nanofluids, methods of preparation, benefits and challenges associated with the use of these materials in the hot and humid climate inside Iraq.

Despite progress in the study of mono nanofluids to improve heat transfer in flat-plate solar collectors, several research gaps still exist that hinder optimal adoption and generalization. The most notable of these gaps is the lack of standardization in experimental protocols for measuring thermal and rheological properties, and the paucity of studies evaluating long-term stability under variable thermal cycles and realistic dynamic operating conditions. In addition, there are few systematic comparisons between them and hybrid nanofluids, which may offer different synergies or complexities. Furthermore, the trade-off between improved heat transfer and pumping costs resulting from increased viscosity, as well as the effects of continuous use on collector materials (such as corrosion or optical changes), has not been adequately studied. Finally, there is a lack of comprehensive assessments that include the environmental and economic aspects of using these fluids in actual solar energy applications.

2. Methodology

A systematic and comprehensive methodology was followed to prepare this review on the performance of mono nanofluids in flat plate solar collectors. The research preparation steps were as follows:

main objective: The main objective of the study was defined as a systematic review of previous research on the use of single nanofluids (such as Al_2O_3, CuO, MWCNT, TiO_2, etc.) with the aim of analyzing their thermal and physical performance, highlighting the differences in efficiency, thermal conductivity, and fluid stability.

Scope of study: The study was restricted to flat plate solar collectors, excluding other applications such as evacuated tubes or concentrators. The review also focused on laboratory experiments and numerical simulations published at last six years ago (90%).

Data collection: The following scientific databases were used Scopus, Web of Science, ScienceDirect, SpringerLink, Google Scholar

Keywords such as:

"Flat plate solar collector + Water heating + Nanotechnology + Nanofluids + Enhancement heat transfer" were used.

Inclusion and exclusion criteria: Studies with clear quantitative data (thermal efficiency, Nusselt number, heat transfer coefficient) were included. Studies that did not focus on flat plate solar collectors were excluded. The quality of studies was assessed according to criteria such as data clarity, experimental methodology, and analysis of results.

Analysis and comparison: Studies were categorized by nanofluid type, volumetric concentration, mass flow rate, and operating temperature. General trends in thermal performance were then analyzed, and tables and graphs were used to compare differences.

Verification and interpretation: The results are reviewed and analyzed from a physical perspective that considers thermal and dynamic effects, including effective thermal conductivity, viscosity, nanoscale effect, and particle stability in the fluid.

Figure 1 shows the flowchart of this study.

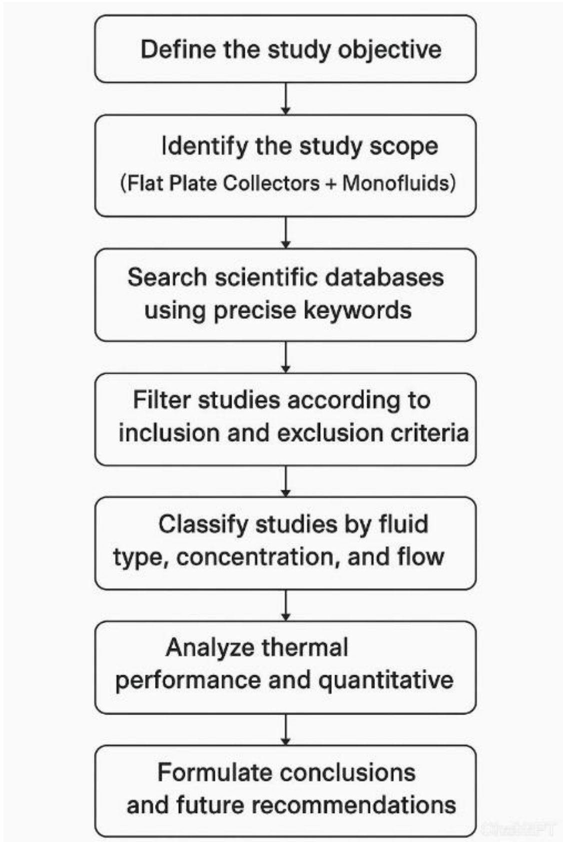

Figure 1. flowchart of this study

3. Nanofluid and Their Role in Solar Energy Systems

Nanofluids are created by nanoparticles that are suspended in a base fluid. Nanoparticles are widely used metals such as aluminium, copper and silver as well as their oxides, as well as carbonaceous materials such as graphene and carbon tubes. These nanoparticles significantly increase the thermal properties of the working fluid, which is very important to increase thermal performance in solar thermal systems [47], [48].

Nanofluids are mainly used as heat transfer fluids (HTFs) in solar thermal systems that absorb solar radiation in solar collectors such as flat plate solar collectors (FPSCs), which transfer heat to storage or conversion systems [49]. By increasing the thermal conductivity of nanofluids, the heat transfer capabilities within the solar collectors improve, allowing for an increase and speed in heating and reducing waste heat, resulting in improved overall efficiency of the system [50]. One of the advantages of using nanofluids is the possibility of reducing the size of the system with high performance and thus reducing the size of heat exchangers, tubes and other parts of the system. Therefore, this will reflect positively on the cost of the system [51].

4. Method of Preparation of Nanofluid

The preparation of nanofluids is not just a simple process of mixing the nanoparticles into the base fluid. To get nanofluids with homogeneously dispersed nanoparticles, stabilization and proper mixing are required under certain environment conditions [52]. There are many methods used for the preparation of nanofluids, which can be further classified into two primary classes one step method and two step method [53]. [54] employing two-step techniques in which water and TiO_2 were electrically mixed to create a nanofluid for the two-step, which ensured the dispersion of water nanoparticles. [36] Using an electric mixer, mechanical mixing was used to create the nanofluid (CuO/water). This procedure made sure that the nanoparticles' dispersion and suspension in the aqueous medium. [55] studied using one step method, deionized water is used as the basis fluid for the synthesis of the nanofluid, and dry powdered CuO and TiO_2 nanoparticles with an average size of 20–60 nm and 99.9% purity are acquired from nano technology to create the water-based nanofluids, CuO and TiO_2 nanoparticles were chosen. [56] the nanoparticle of Al_2O_3 is dispersed in water as a base fluid to prepare nanofluid by using one step method. [57] used two step method to preparation (Al_2O_3 and SiO_2) with water as nanofluid Initially, the base fluid was mechanically infused with nanoparticles. Second, the nanofluid was homogeneously dispersed using an electronic mixing technique for 90 minutes. For ninety minutes, ultrasonic has been utilized to guarantee a well-dis perse nanofluid. Figure 2. Shown nanofluid preparation methods, while Figure 3. And Figure 4. Shown one step method and two step method, respectively.

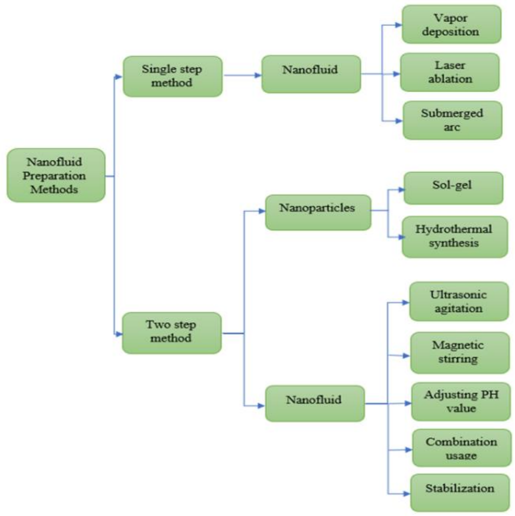

Figure 2. Nanofluid preparation methods

Figure 3. Schematic diagram of one-step process to prepare the nanofluids [58]

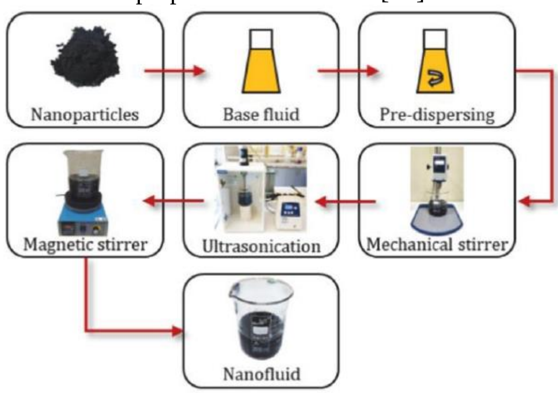

Figure 4. Schematic diagram of two-step process to prepare the nanofluids methods [59]

5. Thermophysical Properties of Nanofluid

Improving the thermophysical characteristics of nanofluids is one of the objectives of employing nanoparticles. Among these properties, thermal conductivity, viscosity, density, and specific heat are the most significant. We'll talk about a number of variables that affect these characteristics, including the kind and size of the material, the form of the nanoparticles, the temperature, and the particle size concentration [60].

5.1 Thermal conductivity

Achieving high thermal conductivity raises thermal efficiency and improves system performance. The kind of base fluid, the working temperature, and the concentration of the nanoparticles all have a significant impact on the thermal conductivity of nanofluids [61]. To enhance the heat conductivity, some researchers have employed experimental data and thermal conductivity measuring tools like the KD2 Pro and thermal characteristics analyzer [62].

$$k_{hn} = \left[\frac{k_p + 2k_f + 2\phi_p\left(k_p - k_f\right)}{k_p + 2k_f - 2\phi_p\left(k_p - k_f\right)}\right] k_f \qquad (1)$$

5.2 Viscosity

An essential component for fluid-based thermal applications is viscosity. Numerous parameters, including pressure drop, pumping energy, and the convectional heat transfer coefficient, are impacted by the fluid's viscosity [63], so this property is very influential [64]. Before taking into consideration Nanofluids for usage in solar thermal applications, their viscosity in comparison to base fluids needs to be carefully investigated and assessed [65].

$$\mu_{nf} = \frac{\mu_f}{\left(1 - \phi_p\right)^{2.5}} \qquad (2)$$

5.3 Specific heat and Density

One important characteristic of nanofluids is specific heat; as solids usually have lower specific temperatures than fluids, adding nanoparticles to the base fluid causes the specific heat of the nanofluids to fall [66]. Another crucial characteristic of nanofluids is density, which rises with increasing nanoparticles concentration and falls with rising temperature. The settling of the particles in the base fluid is caused by this important factor [67].

$$\rho_{nf} = (\rho\phi)_p + \rho_f(1 - \phi) \qquad (3)$$

$$(C_p\rho)_{nf} = \left(C_p\rho\phi\right)_p + (C_p\rho)_f(1 - \phi) \qquad (4)$$

6. Advantages of Nanofluids for Flat Plat Solar Collector in Iraq

Iraq's climate is known for very high temperatures, especially in the summer, when the temperature approaches 50 degrees Celsius. Nanoparticles help improve heat transfer and reduce heat loss in solar thermal systems [68].

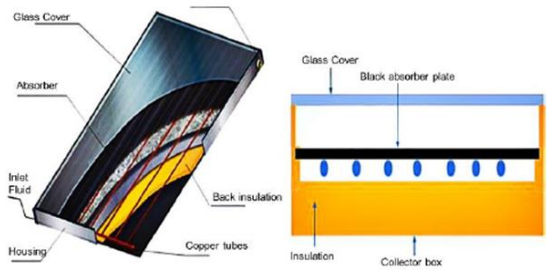

Figure 5. Flat plate solar collector schematic [6]

6.1 Enhanced Thermal Conductivity

One of the main advantages of using nanofluids is their ability to increase thermal conductivity compared to base fluids. The addition of nanoparticles has the potential to increase thermal conductivity by up to 50% compared to water from commonly used nanoparticles Al_2O_3, CuO and MWCNT. The use of nanofluids in flat plate solar collector improves heat transfer and improves the rate of heat absorption from solar radiation, which enhances the performance of the system [69], [70].

6.2 Increased Efficiency

The use of nanofluids enhances the overall efficiency of solar energy systems by increasing the ability to absorb heat and thus the speed of heating, thereby absorbing greater energy. In Iraq, the using of nanofluids can help increase the efficiency of flat plate solar collector due to the abundance of solar radiation. With increased heat transfer capacity. Solar collectors using nanofluids can increase the absorption and transfer of heat from solar energy to the storage system, resulting in the production of large amounts of energy in all seasons of the year [71], [72], [73].

6.3 Reduced Size and Cost of System Components

Nanofluids help solar systems operate more efficiently through improved thermal properties with smaller components. The size of the components of the solar system can be reduced by reducing the size of heat exchangers, tubes and pumps thus leading to a more efficient design and also reducing costs [74], [75].

6.4 Better Performance at High Temperature

In the hot climate and high temperatures in Iraq, nanofluids show greater stability compared to base fluids, leading to better solar system performance [76]. Nanoparticles such as Al_2O_3, CuO and MWCNT have high thermal stability and can maintain their high temperature performance without decomposing. These advantages of nanoparticles lead to the longevity and efficiency of solar heating systems under high temperatures [70].

Figure 7. Schematic flow diagram illustrating the key thermal enhancement mechanisms of nanofluids. The nanofluid consists of a base fluid with uniformly dispersed nanoparticles. The main mechanisms contributing to improved heat transfer include enhanced thermal conductivity of the fluid due to high-conductivity nanoparticles, increased convective heat transfer driven by nanoparticle-induced micro-mixing, improved fluid dynamic properties such as viscosity and density changes, and multi-scale effects at both micro and macro levels. Collectively, these mechanisms result in a significant enhancement of the overall thermal performance of the system.

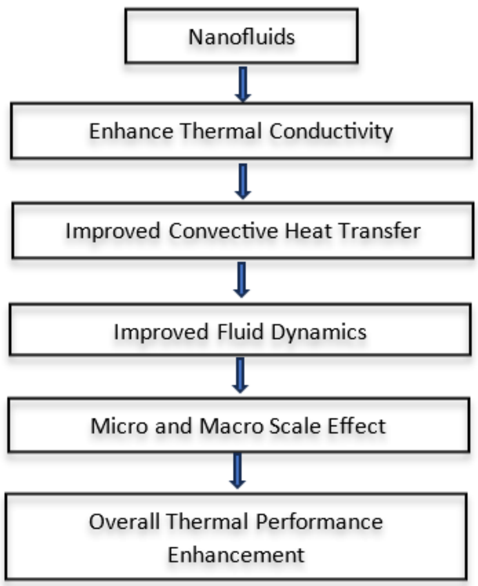

Figure 6. schematic flow of thermal enhancement mechanisms using nanofluids

7. Performance Analysis

For an investigation of FPSC's steady state performance, which features a cylindrical absorber tube bonded beneath the absorber plate. The efficiency of heat [77].

$$\eta = \frac{Q_u}{GA_c} \tag{5}$$

where the collector's efficiency, irradiance, and collector area are denoted by η, G, and A_C. Eq. (7) can be used to determine the convective heat transfer between the tube and the heat transfer fluid (HTF) [78].

$$Q_u = \dot{m}\, C_P(T_O - T_i) \tag{6}$$

Where Qu, m, Cp, T_o, and T_i, and stand for useful energy, HTF mass, specific heat, outlet temperature, and inlet temperature, respectively.
Eq. (8) provides the heat flux at the copper tube wall [79].

$$q_w = \frac{Q_u}{\pi L D_h} \tag{7}$$

Here, hydraulic diameter is calculated by Eq. (9), and heat flux is represented by D_h and q_w [80].

$$D_h = \frac{4A_C}{P} \tag{8}$$

P and L stand for the tube's length and perimeter, respectively.
Eq. (10) expresses the useful heat gain to the water by taking into account the heat losses [81].

$$Q_u = A_P S - q_1 \tag{9}$$

where q_1 is the rate of heat loss via the top, bottom, and side, A_p is the area of the absorber plate, and S is the absorber's absorption of incident solar radiation.
According to Eq. (11), the overall heat loss coefficient can be used to determine the rate of surrounding heat loss [82].

$$q_1 = U_1 A_P(T_{pm} - T_a) \tag{10}$$

where the overall heat transfer coefficient is U_1 [82].

$$U_1 = U_t + U_b + U_e \tag{11}$$

The following formula can be used to determine the heat loss coefficients (Eq. 13-16) [82].

$$U_t = \frac{1}{\frac{1}{h_w + h_{r,c2-a}} + \frac{1}{h_{r,c1-c2} + h_{c,c1-c2}} + \frac{1}{h_{r,p-c1} + h_{c,p-c1}}} \quad (12)$$

$$h_{r,p-c1} = \frac{\sigma(T_{c1} + T_{c2})(T_{c1}^2 + T_{c2}^2)}{\frac{1}{\epsilon_p} + \frac{1}{\epsilon_c} - 1} \quad (13)$$

$$h_{r,c1-c2} = \frac{\sigma(T_p + T_{c1})(T_p^2 + T_{c1}^2)}{\frac{1}{\epsilon_{c1}} + \frac{1}{\epsilon_{c2}} - 1} \quad (14)$$

$$h_{r,c2-a} = \frac{\sigma\epsilon_{c2}(T_{c2} + T_{sky})(T_{c2}^2 + T_{sky}^2)(T_{c2} - T_{sky})}{(T_{c2} - T_a)} \quad (15)$$

where Eq. (17) can be used to determine the sky temperature [83].

$$T_{sky} = 0.0552 T_a^{1.5} \quad (16)$$

Numerical calculation can be used to determine the coefficient of convective heat transfer (Eq. 18) [82].

$$Nu = 1 + 1.44\left[1 - \frac{1708(sin1.8\theta)^{1.6}}{Ra.cos\theta}\right]\left[1 - \frac{1708}{Ra.cos\theta}\right] + \left[\left(\frac{Ra.cos\theta}{5830}\right)^{\frac{1}{3}} - 1\right] \quad (17)$$

$$U_b = \frac{k}{L} \quad (18)$$

$$U_b = \frac{(UA)_{edge}}{A_C} \quad (19)$$

$$f = (1 + 0.089h_w - 0.1166h_w\varepsilon_p)(1 + 0.07866N) \quad (20)$$

$$C = 520(1 - 0.000061\theta^2) \quad (21)$$

$$e = 0.430\left(1 - \frac{100}{T_{pm}}\right) \quad (22)$$

Where θ tilt angle of collector.

Heat losses should be kept to a minimum and the collector temperature should be kept at the incoming fluid temperature for optimal collector efficiency [84], [85].

$$Q_u = A_C F_R(S - U_L(T_i - T_a)) \quad (23)$$

$$F_R = \frac{\dot{m}C_P}{A_C U_L}\left[1 - \exp\left(\frac{A_C U_L F'}{\dot{m}C_P}\right)\right] \quad (24)$$

where the collector efficiency factor is denoted by F'. (Eq.26) provided the instantaneous energy efficiency.

$$\eta = F_R(\tau_C\alpha_p) - \frac{F_R U_L(T_{fi} - T_a)}{G} = \frac{\dot{m}C_f(T_{fo} - T_{fi})}{\dot{m}C_P} \quad (25)$$

(Eq. 27-30). provide the equation for Reynolds number, Grashof number, Rayleigh number, and Richardson number [79].

$$Re = \frac{\rho V D_h}{\mu} \quad (26)$$

$$Gr = \frac{\rho\beta D_h^3(T_w - T_{f,b})}{\nu^2} \quad (27)$$

$$Ra = \frac{\rho g\beta D_h^3(T_w - T_{f,b})}{K_f\nu^2} \quad (28)$$

$$Ri = \frac{\rho\beta D_h(T_w - T_{f,b})}{V^2} \quad (29)$$

Viscosity, thermal conductivity, tube wall temperature, bulk heat transfer temperature, characteristic velocity, and coefficient of thermal expansion are represented by the variables μ, k, T_w, T_f, V, and β.

8. Selection of Nanofluid for Solar Collector in Iraq

The selection of nanoparticles is critical to the performance of nanofluids. Commonly used nanoparticles used in thermal applications include the following [86].

Copper oxide (CuO): These nanoparticles have high thermal conductivity and good dispersion stability, which makes these nanoparticles enhance thermal properties when added to base fluids. CuO-based nanofluids are widely used in solar energy applications due to their high efficiency in thermal performance as well as their cost [87].

Aluminum oxide (Al_2O_3): These nanoparticles are commonly used as they are widely used in solar collectors. These nanoparticles provide between cost, stability and thermal conductivity and this makes them suitable for use in various solar applications [88], [89].

Graphene and carbon nanotubes (CNTs): These particles have very high thermal properties as they have the highest thermal conductivity compared to other nanoparticles, but these particles have a very high cost and are difficult to disperse in basic fluids, this thing limits their widespread use in solar thermal applications. These particles are frequently used in hybrid nanofluids, where a small percentage of these particles are added with other nanoparticles [54], [90].

Water-based nanofluids: Water is the most commonly used base fluid in solar energy applications due to its high specific thermal capacity; good thermal conductivity compared to other basic fluids and very low cost. Water-based nanofluids, especially those containing Al_2O_3, CuO and MWCNT particles, are a good choice in flat plate solar collector applications in Iraq's climate [91], [92], [93].

Oil-based nanofluids: Oil-based nanofluids are used in thermal applications that require higher temperature stability. These fluids can maintain their thermal properties at higher temperatures than water-based fluids, making them suitable for high-temperature solar applications such as flat plate solar collector (FPSC) systems [94].
Table 1 shows several numerical, theoretical and experimental studies of the use of nanofluids in FPSC.

Table 1. An overview of analysed some theoretical, numerical, and experimental papers of using nanofluids in FPSCs

Inves.	Bf & Np	Result	Ref.
Num & Exp.	(H_2O) Al_2O_3	It is possible to overlook the modest increase in friction factor when 3% solid nanoparticles are added to water, as this results in a 54% improvement in heat transmission.	[56]
Num & Exp.	(H_2O) diamond	With 1% ND/water nanofluid, the highest collector thermal efficiency is 68.90%, which is a 12.2% improvement over pure water. A change in physical characteristics and an increase in thermal conductivity make 1% nanofluid more efficient than other concentrations.	[95]
Exp.	(H_2O) Al_2O_3 SiO_2	The findings showed that the type of nanoparticles had a substantial impact on the collector's efficiency. Nanofluid 1 was 4.8% ahead of nanofluid 2 at 1 p.m. in February. This result emphasizes the importance of nanoparticle materials in improving solar collector efficiency.	[57]
Exp.	(H_2O) TiO_2	Result showed that solar radiation increased thermal efficiency until midday, reaching 48.48% for water and 51.23% for the nanofluid. With increasing mass flow rates from 0.0045 kg/s to 0.02 kg/s , thermal efficiency improved from 16.26% to 47.37% for water and from 20.65% to 48.76% for the nanofluid.	[54]
Exp.	(H_2O) CuO	At a mass flow rate of 0.015Ls−1, the practical efficiency of a 0.25% nanofluid (CuO) reaches its maximum. Heat transmission in tubes filled with fluid is improved by higher mass flow rates. At this flow rate, the collector efficiency varies from 31.66% in January to 44.44% in April.	[36]
Exp.	(H_2O) TiO_2& CuO	Maximum outlet-inlet temperature differences at (0.5 vol.%) nanofluid are 16.2 0C for Al2O3/water, 15.5 0C for CuO/water, and 10.2 0C for pure water, according	[75]

		to the results. Additionally, Al2O3 exhibits higher heat transfer than CuO, which enhances the solar fat-plate collector's performance.	
Num & Exp.	(H_2O) Al_2O_3	The results of the simulation match the experimental data extremely well. The strong consistency of these results is underscored by thorough confirmation versus earlier research. A volume fraction of 3% stands out as being especially significant in the effort to increase heat transmission, producing an astounding 54% improvement. Even though they exist, slight increases in the friction factor have been shown to be acceptable and can be safely ignored.	[96]
Exp.	(H_2O) ZnO	Experiments show that at a mass flow velocity of 0.03 kg/s, a ZnO/water nanofluid's energy efficiency increases by 31% at a particle volume concentration of 0.35%. The increase in energy and exergy efficiency highlights improved system performance in terms of efficiently converting the available energy into useful functions. At 0.35%, ZnO/water has the largest gain in collector energy efficiency, followed by 0.25 and 0.15%, respectively .	[97]

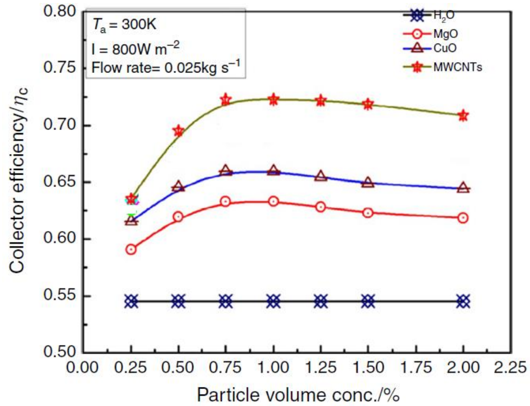

Figure 7. Efficiency of FPSC vs volume concentration of tested nanofluids [98]

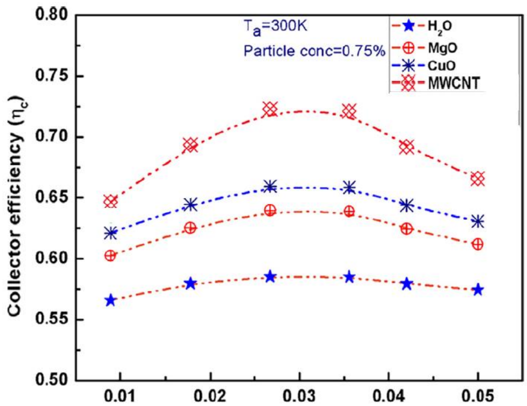

Figure 8. Collector efficiency vs mass rate [98]

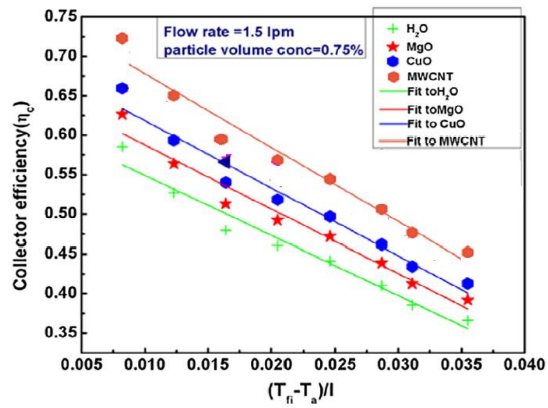

Figure 9. Collector efficiency vs reduced temperature parameter [98]

9. Challenges and Considerations in the Applications of Nanofluids

Despite their advantages, there are several challenges associated with the use of nanofluids in solar collectors, particularly in regions like Iraq [99]:

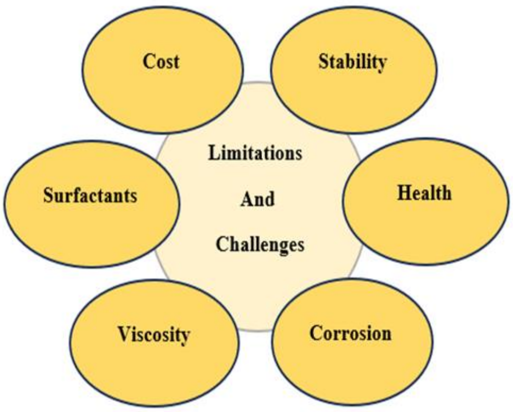

Figure 10. Limitations and challenges of nanofluids

9.1 Cost of Nanofluids

The production of nanofluids can be expensive due to the cost of nanoparticles and the processes involved in their dispersion and stabilization [100]. While some nanoparticles, such as CuO and Al_2O_3, are relatively inexpensive, more advanced nanoparticles like graphene and CNTs can significantly increase the cost of nanofluids [101].

9.2 Nanoparticles Stability

One of the major challenges of using nanofluids in solar energy systems is maintaining the stability of the nanoparticles in the base fluid [102]. Agglomeration of nanoparticles can reduce the effectiveness of the nanofluid, and settling or sedimentation of particles can cause clogging and damage to the system components. Advanced stabilization techniques, such as using surfactants or surface-modified nanoparticles, are necessary to address this issue [103], [104].

9.3 Environmental and Health Concerns

The use of nanofluids requires special treatment and management of the use of these particles in particular to avoid their negative impact on the environment, so the use of this technology is considered worrying because it poses risks to human health and the systems used [105]. We need a lot of research to focus on the long-term environmental and health impacts of nanofluidic use [106], [107].

9.4 Durability and Corrosion

Over time the interaction of nanoparticles with metal components in the solar system can lead to corrosion. This will affect the durability and lifespan of solar thermal systems [108]. Therefore, it requires studying and evaluating the impact of the use of these nanoparticles on the longevity and components of the solar system, especially in light of the hot and humid climate inside Iraq [109], [110].

9.5 Viscosity

The use of nanofluids in flat plate solar collectors increases their efficiency by improving heat transfer properties by increasing thermal conductivity but increasing the viscosity of nanofluids, which can have negative effects by increasing the energy required for pumping [111]. It is crucial to choose the optimal concentration and size of these particles within the base fluid as well as working conditions to achieve the required balance between improved heat transfer and reduced energy costs [112], [113].

9.6 Surfactants

Surfactants are substances that reduce the surface tension between two fluids. These materials during their use in the context of nanofluids can lead to many problems:

Effect on heat transfer: The heat transfer efficiency within the nanofluid may be affected when using surface materials, which negatively affects the efficiency of the solar system [114].

Nanofluid stability: The using of surface materials may lead to undesirable stability of nanoparticles, which is reflected in the distribution of these particles within the base fluid and thus reduces the thermal efficiency of the solar system [115], [116].

Foam formation: The use of surface materials may lead to the formation of foam, which may increase the pressure inside the system, which negatively affects the thermal performance in solar systems [117], [118].

In general, these phenomena are a challenge to consider when using nanofluids in solar energy applications [119], [120], [121].

Table 2. shown limitations and challenges for most nanoparticles usen in this study

Np	Limitations and Challenges
MWCNT	Stability / Agglomeration High-Viscosity/Increased Pumping Power Non-uniform dispersion over time Surface-functionalization requirement Potential erosion / abrasion Health & safety concerns
Al_2O_3	Sedimentation and long-term stability. Viscosity increase / pumping cost. Fouling / deposition on surfaces. Agglomeration at elevated temperature. Compatibility with base fluid chemistry.
Cu	Oxidation / chemical transformation. Stability and aggregation. Increased viscosity / pumping penalty.
CuO	Sedimentation / Gravitational settling. Increased viscosity. Corrosion potential. Thermal-optical trade-offs. Temperature-dependent stability. Particle aggregation.
TiO_2	Agglomeration and sedimentation / long-term stability. Viscosity increase and pumping penalty. Preparation sensitivity. Optical trade-offs (scattering). Thermal cycling instability.
ZnO	Sedimentation and dispersion stability. Photocatalytic side effects. Viscosity increase / hydrodynamic cost. pH sensitivity / possible dissolution. Thermal cycling-induced agglomeration
SiC	Dispersion difficulty / stability. Increased viscosity and complex rheology. Fouling / deposition on collector surfaces. Scale-up reproducibility. Cost and preparation complexity.
Fe_2O_3	Magnetic-induced aggregation. Sedimentation / gravitational settling. Viscosity elevation / non-Newtonian effects. Chemical compatibility / corrosion influence. Thermal cycling destabilization.

10. Future Trends

With the continuous advancement in solar energy technologies, mono nanofluids are expected to undergo significant developments in terms of composition and physical optimization to meet the high thermal performance requirements of flat plate solar collectors [33]. One of the most prominent future trends is the design of smart nanofluids with adjustable thermal properties depending on operating conditions such as solar radiation intensity and surface temperature, using thermally or magnetically responsive nanomaterials [122]. Also, developing accurate thermal models that take into account nonlinear effects such as unsteady heat transfer and local changes in viscosity and thermal conductivity is an important path to improving heat exchange efficiency [123]. This research is expected to focus on controlling the deposition of nanoparticles inside tubes, a phenomenon that negatively affects heat transfer over time, by improving the stability of nanosuspensions through new techniques such as surface treatment or the addition of surfactants [124].

One of the most significant challenges that remain is the high cost of producing nanofluids in commercial quantities while maintaining their homogeneity and stability over long operational periods [125]. Long-term experimental data is also urgently needed to understand the behavior of these fluids under real-world operating conditions, especially in regions experiencing extreme climate fluctuations. Furthermore, Multiphysics simulation techniques are expected to play a key role in predicting the performance of these fluids within complex solar systems, paving the way for more efficient and sustainable thermal designs [126]. Ultimately, integrating mono nanofluids with smart energy concepts and hybrid systems could represent a paradigm shift toward achieving highly efficient solar collectors with a low carbon footprint.

11. Economic and Environmental aspects

Nanofluids represent an important development in improving the thermal performance of flat plate solar collectors, but their widespread adoption requires careful evaluation of economic and environmental aspects to ensure their sustainability and cost justification [127].

Although the cost of producing nanofluids is relatively higher than conventional fluids, due to the cost of manufacturing and distributing nanoparticles, dispersion, and stabilization processes, this cost can be offset in the long run by improved thermal efficiency [128]. Increasing heat transfer reduces the required solar collector area or increases the amount of energy collected without changing the area, which reduces installation and maintenance costs and increases the overall economic return of the system [129].

Furthermore, the optimal use of nanofluids may contribute to reducing the consumption of electric pumps, due to improved thermodynamic properties, thus reducing auxiliary energy consumption, enhancing long-term economic viability [76]. With the continued development of low-cost manufacturing methods such as green synthesis, the cost of producing these fluids is expected to gradually decrease, increasing the possibility of their commercial adoption [44].

Environmentally, nanofluids offer promising potential for reducing dependence on fossil energy sources by improving solar energy efficiency, thereby reducing greenhouse gas emissions [46]. However, the most significant challenge lies in managing the life cycle of nanoparticles, from manufacturing to final disposal, as some nanomaterials can cause environmental or health hazards if not properly treated or stored [62]. Therefore, there is a need to develop environmentally friendly, biodegradable, or recyclable nanomaterials, as well as to impose regulations requiring safe and sustainable practices in the production and use of these fluids. Furthermore, improving the stability of nanofluids reduces the need for frequent replacement, reducing industrial waste and improving the overall environmental performance of the solar system [130].

In short, the power of nanofluids lies in their ability to achieve a balance between high thermal performance and reduced environmental impact, provided the technical, economic, and environmental challenges are managed in an integrated manner.

12. Conclusion

In flat plate solar collectors, the use of nanofluids is a promising innovation for improving performance, especially in regions such as Iraq that benefit from the abundance of solar radiation. The enhanced thermal properties as well as the high heat transfer capabilities of nanofluids enhance the efficiency of the solar system, reduce the size of the system and give better performance under high temperature conditions. However, the use of nanofluids has many challenges that must be addressed, the most important of which are stability, cost, environmental impact and robustness of the system in order to be an ideal application of these nanofluids in solar thermal systems. Continued research and development in nanofluid technology are crucial to realizing its full potential in solar energy applications, particularly in Iraq's challenging climate. The tests' findings demonstrated:

- The efficient absorption of sunlight and the improvement of solar collector efficiency depend on achieving the proper dispersion of nanoparticles and guaranteeing long-term stability.
- At first, it was found that as the volume fraction rose, so did the collector efficiency. However, as the volume fraction increased further, the efficiency dropped because the heat transfer rate slowed and viscous forces increased.
- The substantial increase in heat conductivity brought about by the use of nanofluid was the main factor contributing to the improvement in collector efficiency. The precise cause of this phenomenon is still unknown, though.
- The use of carbon nanotubes MWCNT produced the highest level of collector efficiency arrived up on 80%, while CuO, TiO_2 and Al_2O_3 achieve less efficiency (60-70%) but better than base fluid.
- At higher temperatures, it was shown that using nanofluid improved a solar collector's performance more than using water.
- It was discovered that the effects of adding surfactant varied depending on the literature.

13. Recommendations

The recommendations for improving hybrid nanofluids in flat plate solar collectors include:

- Investigating how various elements affect the stability of nanofluids, as stability is crucial for their application.
- Researching thermal conductivity behavior at high temperatures, relevant for solar collector operation.
- Exploring new types of mono and hybrids nanofluids to enhance thermal performance in solar collectors.
- Considering the economic implications of using nanofluids in solar thermal technologies due to their high costs.
- Enhancing techniques like turbulator and porous media to further improve thermal performance.
- Implementing mono and hybrid secondary fluids in real-world systems on a large scale to monitor efficiency improvements.

Nomenclature

Symbol	*Quantity*
Ag	*Silver*
Al	*Aluminum*
Al_2O_3	*Alumina*
CeO_2	*Cerium oxide*
CNT	*Carbon Nanotube*
CO_2	*Carbon dioxide*
Cp	*Specific heat*
Cu	*Copper*
CuO	*Copper oxide*
Dh	*Hydraulic Diameter*
EG	*Ethylene Glycol*
Fe	*Iron*
Fe_3O_4	*Iron ɪɪɪ oxide*
FPSC	*Flat Plate Solar Collector*
FPSWH	*Flat Plate Solar Water Heating*
h	*Heat transfer coefficient*
k	*Thermal Conuctivity*
$\dot{m}$	*Mass flowrate*
MCV	*Mixed Convection Validation Model*
MgO	*Magnesium oxide*
MWCNT	*Multi Wall Carbon Nanotube*
NCV	*Natural Convection Validation Model*
ND	*Nanodiamond*
Q	*Useful Heat*
SiC	*Silicon carbide*
SWCNT	*Single Wall Carbon Nanotube*
T	*Temperature*
TiO_2	*Titanium dioxide*
u	*Fluid velocity*
Vwind	*Wind Speed*
WO_3	*Tungsten trioxide*
ZnO	*Zinc oxide*
Symbols of Greek	
ρ	*Density*
μ	*Dynamics Viscosity*
Φ	*Volumetric-Concentration Ratio*
η	*Thermal-Efficiency*
θ	*Collector Tilt Angle*
β	*Thermal-Expansion Coefficient*
Optical parameters	
α	*Absorptivity*
ε	*Emissivity*
σ	*Stefan–Boltzmann Constant*
τ	*Transmissivity*
ρ	*Reflectivity*
Subscripts	
abs	*Absorber*
avr	*Average*
ext	*External*
gc	*Glass Cover*
hnf	*Hybrid Nanofluid*
f	*Fluid*
in	*Inlet*
nf	*Nanofluid*
np	*Nanoparticle*
out	*Outlet*
Dimensionless numbers	
Nu	*Nusselt Number*
Pr	*Prandtl Number*
Re	*Reynolds Number*

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