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Using Of Phase Change Material, Nano-Fluids To Improve The Solar Water Heater Performance: Review

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Abstract: Due to its economic appeal and technological feasibility, solar water heating is the most popular application of solar energy. However, the utilization of solar water heaters (SWHs) is limited by the sporadic nature of solar energy and the absence of energy storage. Phase change materials (PCMs) efficiently use the thermal energy from the sun. By integrating PCMs with SWHs, the restriction of restricted usage during the day is removed, and the system becomes more effective and user-friendly. The working fluid's thermal conductivity must be raised in order to enhance its heat extraction properties. One of the main materials with greater thermal conductivity is nanoparticles. Thus, the total thermal conductivity of the working fluid is increased when the nanoparticles are added to the base fluid. An overview of the main technics and enhancement methods of utilization of solar water heaters are presented in this work. This study is generally divided onto three main sections. First, an outline of the types of solar water heaters and the mechanical method to improve the performance. Second section focused on the use of phase change materials to enhance the solar water heater performance. Finally, the third section introduces the use of Nano-Fluids in solar water heater.

Keywords: Solar water heater, flat plate collector, evacuated tube collector, Phase change material, Nano-fluid.

1. Introduction

Hot water is essential for many aspects of daily life, including industrial, medical, and other applications. Homes, factories, hotels, hospitals, and other establishments all use hot water. Due to the conventional water heating process's reliance on electrical energy, expenses and fuel

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consumption will rise. Innovations in technology promote the use of sustainable and clean energy sources. With the right equipment, solar radiation may be utilized to provide significant thermal energy, which is readily available. The utilization of solar radiation for water heating is made possible by the solar water heater. Which results in the production of hot water without the need for harmful or thermal gas pollution, utilizing solar energy that is freely accessible, and eliminating the need for electrical energy [1].

1 The main component of solar water collector

The most common configuration for solar water heaters consists of a solar collector, a water storage tank, pumps or other fluid circulation devices, a heat exchanger (in most systems), water or other fluid-filled pipelines, an efficient and safe control system, and a backup heating element. The most crucial part of solar domestic hot water (SDWH) systems is the solar collector, whose effectiveness has significant effects on how well these water heaters work. Figure 1 shows a schematic illustration of a typical solar system [2].

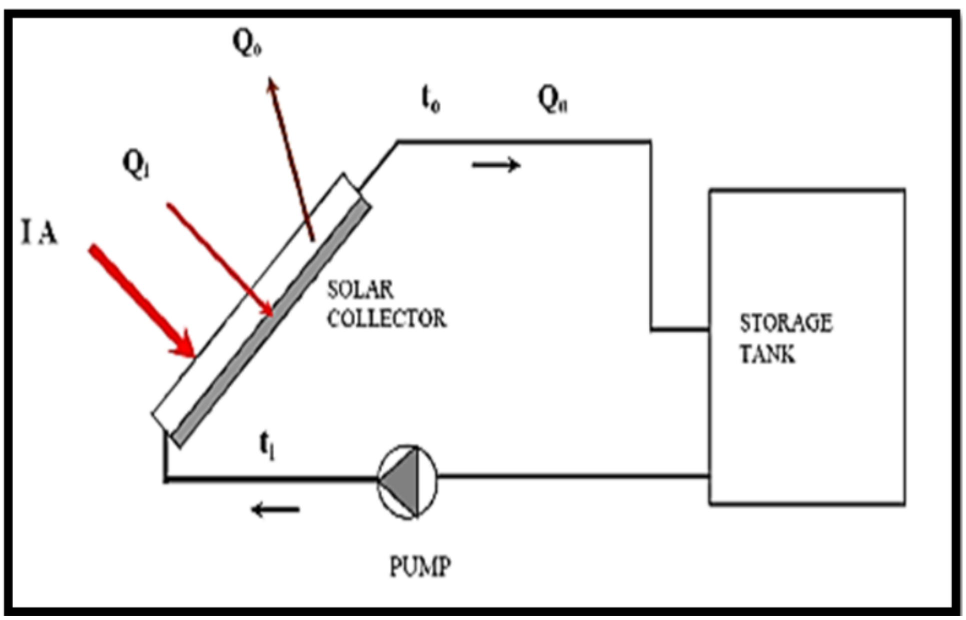

Figure 1 Scheme of the main parts of solar water heater[3].

2 Classifications of solar water heating systems

Sunlight radiation is converted into thermal energy by solar thermal collectors, which is a useful energy-saving method for heating a heat-transfer fluid. The collection technology determines both the temperature and the quantity of this conversion. Typically, the degree of concentration determines whether a solar thermal collector is non-concentrating or concentrating. A non-concentrating direct absorption collector (DAC) directly absorbs all or a substantial portion of the sun's energy. Flat plate collectors are the most popular type of collectors are used. For solar space heating applications as well as home solar water heating, FPCs are the most popular type of collectors in use worldwide. They employ solar energy in both beam and diffuse forms, don't need to be tracked by the sun, low maintenance cost, efficient and long-lasting. There are two types of concentrating collector technology: high concentration (like paraboloidal collectors) and medium concentration (like parabolic cylinders). A parabolic reflector is employed by a concentrating collector to direct and focus solar energy to the center or focal line at which the absorber is located. For optimal solar collection and efficient operation, a concentrating collector can be built as a stationary object or with revolving reflectors to be able to continuously track the sun's location in the sky.

Another type, evacuated tube solar collector made of several glass tubes. In order to minimize heat loss by conduction and convection, a vacuum is produced inside the glass tubes during the production process. Inside a vacuum-sealed solar tube, a copper heat pipe connected to an absorber plate makes up heat pipe ETCs[4] . Some of these categories and different designs are discussed below:

2.1 Water based Flat plate solar collector.

In a flat plate solar collector, the absorber plate, absorber tubes, and related manifold are housed in a casing. To reduce heat loss, a layer or layers of glass sheets are covered with insulation and glazing. Because it lets short-range radiation through while blocking long-range radiation, glazing is crucial to preventing radiation-induced loss. The FBC have a benefit over other varieties in that they effectively shed rain and snow when installed [5].

2.2 Water based Evacuated tube solar collector.

Another type, evacuated tube solar water heaters are widely used for capturing the sunlight. The selective surface coating and vacuum insulation of the evacuated tube solar collector (ETSC) result in reduced heat loss and a higher fluid output temperature [6].

3 Classification of SWH based on integration of PCM

Solar water heaters are a great way to utilize renewable energy for hot water needs. However, a traditional solar water heater's usefulness is limited because it can only provide hot water when the sun is shining. This is where Phase Change Materials (PCMs) come in and enhance the system. A PCM is a special material that can store and release thermal energy by changing its state (usually solid to liquid and vice versa). During this phase change, the PCM absorbs or releases a significant amount of heat without a significant change in temperature[7].

Overall, solar water heaters with PCM offer a promising technology for maximizing the use of solar energy for hot water needs. To a deeper understanding of the effect of PCM on the performance of SWH, below is a summary of some previous studies that studied, mentioning the most prominent results that were reached.

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3.1 Flat plate collector integrated with PCM

To examine the impact of two differently constructed PCM storage units on the temperature distributions in water tanks, Tarhan, S. et al. [8] studied trapezoidal built-in solar water heaters (BSSWH) without a PCM storage unit. They added myristic acid to a PCM storage tank, which doubled as an absorbing plate. Lauric acid was used as a thermal obstacle against heat loss during the night, and the PCM's thermal properties and packing arrangement controlled water temperature during the day and night. The performance and thermal behavior of a solar latent heat storage unit (LHSU), which consists of many identical tubes embedded in phase change material (PCM), were predicted by, El Qarnia, H. [9] conducted numerical simulations for three types of PCM (n-octadecane, paraffin wax, and stearic acid) in Marrakech to determine the best design for a specific summer climate. Results showed n-octadecane was not advantageous due to hot water temperature fluctuations, while paraffin wax retained some PCM liquidity.

Zeng, R. et al. [10], designed and investigated an innovative integrated water pipe floor heating system's structure through experimentation, utilizing shape-stabilized phase change materials (SSPCM) for thermal energy storage. The thermal characteristics of the floors with and without the SSPCM were tested under intermittent heating conditions. The SSPCM floor's Energy Storage Ratio (ESR) is substantially greater than the non-SSPCM floor's., according to the data; this indicates that the SSPCM floor heating system can maintain a steady heat flux and avoid a significant reduction in the floor surface temperature. Additionally, under testing settings, the SSPCM floor heating system raises the lowest interior air temperature by 2-3°C and reduces the indoor temperature variation by around 50%. It is possible for the SSPCM floor heating system to effectively use solar energy during the day to heat at night. In the same context, Huang, K. et al. [11] developed a new PCM floor with capillary plaits and a macro-packaged PCM layer. The floor can release 37677.6 kJ of heat for 16 hours, accounting for 47.7% of solar water energy. The latent heat storage from capric acid is more practical than concrete. The design can achieve large-span intermittent heating and reduce thermal conductivity, regulating floor surface temperature.

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Shabtay, Y.L. and Black, J.R. [12],examined two methods to increase wax's heat conductivity by over 100. The first involves inserting a modified copper tube/aluminum fin heat exchanger into a wax-based container, while the second involves adding copper tube circuits to a high-conductivity graphite-wax composite. The prototype graphite-wax composite TES system offers better design flexibility and leak-free operation. The study also explores the use of thermoelectric storage systems (TES) in heat pump and solar thermal water heaters, resulting in faster charging times, constant output temperature, higher efficiency, and longer operation periods. Chaabane, M. et al. [13], conducted numerical simulations on the performance enhancement of solar water heaters with collector storage using PCM. They found that myristic acid as PCM led to better latent heat storage units (LHSU) during the day and night, allowing to reduce the thermal energy losses and enhanced heat preservation.

Liang, F. et al. [14] Found that The heat exchange temperature variations between water and PCMs results in a non-uniform phase transition degree and temperature distribution due to the limited thermal conductivity of the PCMs. Both the volumetric heat storage capacity and efficiency may be increased by raising the energy storage water tank's heat storage density. Allouhi, A. et al. [15] studied a modified ICSSWH (Integrated Collector Storage Solar Water Heater) for its affordability, ease of use, and small size. The system aims to increase thermal energy at night by integrating a latent storage system with phase change materials (PCM). The performance of the system was evaluated using hourly weather data from ER-RACHIDIA and PCM melting and solidification processes. Prakash, J. et al. [16] Prakash et al. developed a solar thermal water heating system using a latent heat storage tank filled with phase-change materials like stearic acid/palmitic acid eutectic combination, paraffin wax, and puretemp68. The system integrated solar thermal collector, photovoltaic modules, operational controller, circulation pumps, battery, and data logger. Results showed that stearic acid/palmitic acid performed better than paraffin wax and puretemp68 in terms of water charging efficiency and store energy density.

Naghibi, Z. et al. [17] used Transient System Simulation (TRNSYS) software to assess the benefits of adding phase change materials (PCM) to a solar heating system's water tank. Four configurations were tested, showing a 10%-14% increase in energy performance. The payback period was determined by PCM price, natural gas cost, and carbon tax. Guerraiche, D. et al. [18] studied the performance of a small-scale parabolic trough solar concentrator with a thermal energy storage device. They used a novel receiver design with phase-change material, which stored thermal energy. The absorber tube was filled with a binary salt, transforming heat from the sun into phase change material as shown in figure (3). The receiver's daily thermal efficiency increased by 6.56% and 8.32 for both days. Neri, M. et al. [19] conducted an experimental study on a hybrid latent-sensible heat storage system that combines phase transition materials with macro-encapsulated commercial hot water tanks. The study created three numerical models, including a model replicating the charge and discharge of a PCM storage unit, a model describing a water storage tank without PCM, and a final model combining the three.

A study by Abdelsalam, M.Y. et al. [20] developed a numerical model to simulate hybrid and sensible energy storage in a solar domestic hot water system. They investigated two designs using submerged heat exchangers and found that direct heat exchange storage systems use 18-23% more solar than immersed coil heat exchangers. They suggested adding PCM modules to reduce storage volume. Shareef, A.S. et al. [21] conducted a CFD simulation using ANSYS Fluent to study thermal heat storage in a water heating system. They found that phase change materials (PCM) can meet residential water heating needs by maintaining higher water temperatures. The simulation showed a 21.46% increase in water temperature, with the PCM case reaching 8.5°C higher. Eng. Zahraa A. Abdalaali. et al. [22] , reported an Experimental and Numerical study to evaluate the performance of solar heating system with a PCM capsules impeded in the storage tank. As per the study, the optimal performance may be achieved by utilizing the maximum flow rate of 15lit/min and the largest amount of PCM (10kg), respectively.

Awani, S. et al. [23] conducted an experimental and numerical analysis of a novel thermosyphon design for solar water heating. They investigated the effectiveness of adding phase-change materials to a cylindrical storage tank to increase solar energy use. The study found that

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the new design kept water temperature constant during night, but twice as high during summer and winter. The system had a payback period of 7.39 years and a net present value of $4265 over its lifetime. Energy savings in Tunisian zones ranged from 60 to 75 percent.

Rahmadhani, M.A. et al. [24] examines the thermal performance of a solar water heater (SWH) using phase change material (PCM) paraffin wax. The study uses numerical simulation to investigate four variations of the model, including standard flat plate (SFP), SFP+PCM 10mm, SFP+PCM 7mm, and SFP+PCM 4mm as shown in Figure 2. The results show that the collector with PCM storage performs well, with models with a 7mm PCM or SFP+PCM 7mm having the highest efficiency. Al-Zurfi, H.A. et al. [25] studied the use of phase change materials (PCMs) in solar water heaters to enhance efficiency. The study aimed to identify the optimal PCM composition, arrangement, and qualities for optimizing heat transport and storage. Experimentation validated the approach, revealing that adding the right PCMs significantly improves heat retention and efficiency. A. Hussein et al. [26] studied the use of PCMs like paraffin wax to enhance the thermal performance of solar water heaters. They used an innovative technique, combining a solar collector and heat storage tank. The results showed that adding metallic strips and fins to the wax increased heat energy release by 47% and 304%, respectively. This suggests that adding fins or metallic strips can improve water heater performance.

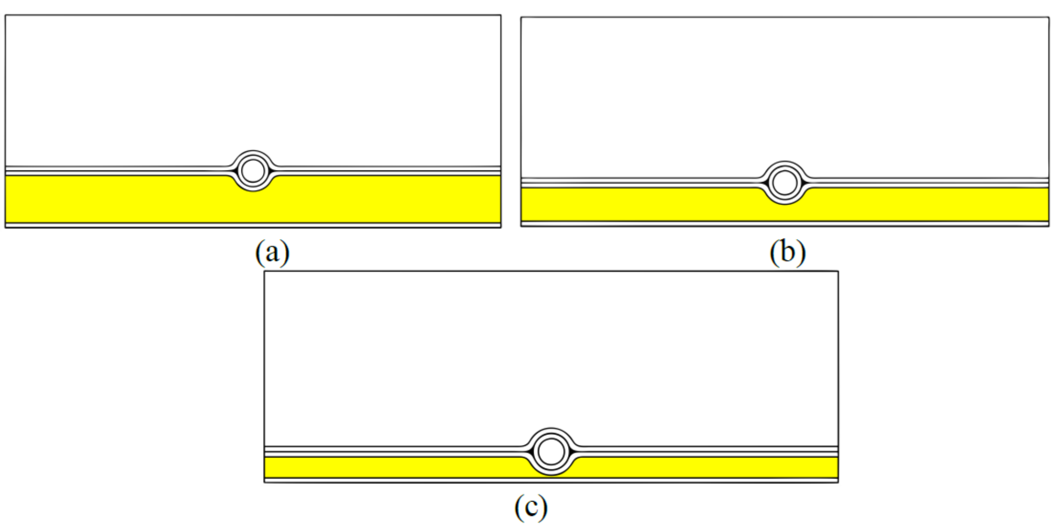

Figure 3 Schematic models of different PCM thicknesses a)10mm b)7mm c)4mm.

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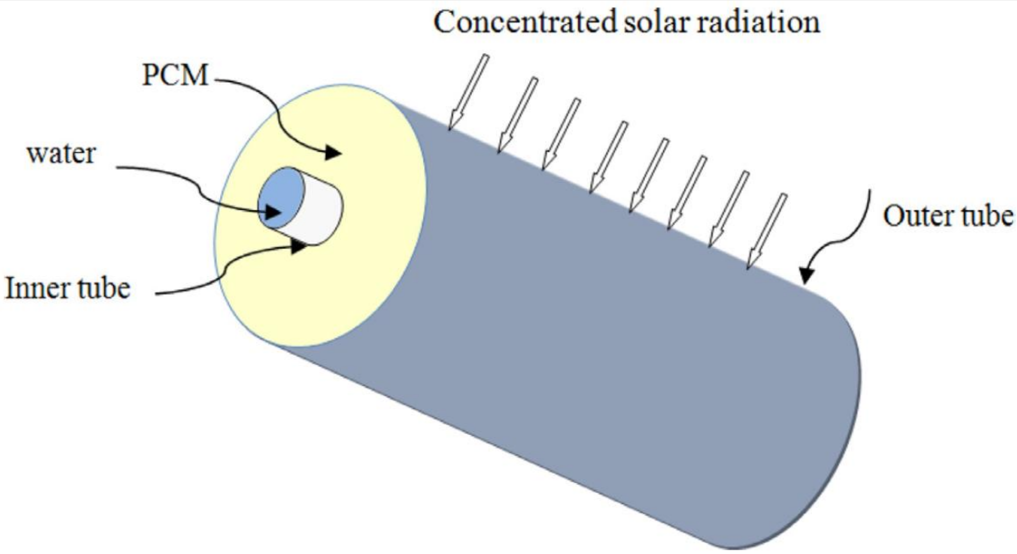

Figure 4 Model scheme of the parabolic trough solar collector with PCM.

3.2 Evacuated tube collector (ETC) integrated with PCM

On the other hand, PCM can also improves the performance of evacuated tube solar water heaters. In the context, Naghavi, M.S. et al. [27] presents a model for integrating phase change material (PCM) with a heat pipe solar water heater system (HPSWH) to limit water heating during the day and increase the system's operating duration. The PCM is placed beneath the heat pipe and solar absorber plate to store and absorb additional thermal energy.

The thermal behavior and annual energy production of the basic and enhanced systems are evaluated using real meteorological data from a Malaysian station. The study suggests that integrating PCM can enhance the HPSWH system's overall performance. The study also highlights the impact of filling the latent heat thermal energy storage tank on the system's performance. Naghavi, M.S. et al. [28] evaluates the performance of a LHTES tank with a finned heat exchanger pipe, revealing superior thermal performance compared to a comparable system without latent heat storage. The system's efficiency is less susceptible to water flowrate draw off, making it suitable for generating hot water during nighttime or poor radiation conditions. Sweidan, A. et al. [29] improved the installation of a PCM thermal storage water tank and heat pipe photovoltaic-thermal panel for a housing office. The system's performance was predicted using a mathematical model,

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and the optimal system cost was optimized. The best system for year-round electric power was 4 kW with 20 PV panels and a 37 l PCM storage tank per panel.

Papadimitratos, A. et al. [30] developed a new technique for incorporating phase change materials into solar water heater evacuated tubes. They used Tritriacontane and Erythritol, two different phase change materials, with melting temperatures of 72°C and 118°C respectively. The study found a 26% increase in efficiency during normal operation and a 66% increase during stagnation mode. Abokersh, M.H. et al. [31], Experimentally evaluated the performance of a novel evacuated tube solar collector (ETC) for energy storage that is small and combined with paraffin wax is called Alex WAX 600. With an average melting temperature of 60 degrees Celsius and a thermal conductivity of 0.21 W/m, the ALEX WAX 600 is a phase change material (PCM) based on organic chemicals. Using an active solar water heating system (ASWHS) under the same operating and meteorological circumstances, the created system is examined in two configurations: an un-finned and a finned U-pipe evacuated tube solar collector side by side. Overall, the findings demonstrate that the incorporation of PCM for heat transfer and energy storage in U-pipe ETC performs better than a normal ASWHS in both simultaneous operation and actual water usage profile operating.

The following table summarizes the most prominent previous studies, the basic variables they relied on, the type of phase change material used, and the most important findings they reached. Note; the symbols E and N refer to the abbreviation of the words Experimental and Numerical respectively.

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Table 1: Solar water heaters studies with PCM				
Ref.	Method	Type of PCM	Parameters	Outcomes
[8]	E	myristic acid	Temperatures	8.8% increment of dip temperatures
[9]	E and N	n-octadecane, paraffin wax, and stearic acid	Temperature, Water flow rate, Mass, number of tubes	selection of Phase change material has to be done carefully.
[10]	E	graphite	Room temperature	About 50% enhancement of indoor temperature
[11]	E and N	capric acid	Room Temperatures	Enhancement of thermal performance by 47.7%
[12]	N	graphite-wax	Temperature and pressure drop	Enhancement of thermal efficiency
[12]	N	myristic acid and RT42-graphite	Temperature	Enhancement of thermal performance
[13]	E	paraffin	Temperature of storage tank	Enhancement of thermal performance
[15]	N	N-eicosane	Thickness of PCM	Enhancement of thermal performance
[16]	E	stearic acid/palmitic acid, paraffin wax and, puretemp68	Temperature	55 % efficiency with stearic acid/palmitic acid. 20 % efficiency with paraffin wax. 45 % efficiency with puretemp68.

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[17]	N	Methyl eicosanate	Concentration of PCM	10% to 14% Enhancement of thermal performance
[18]	E and N	60% NaNO3 and 40% KNO3.	Temperature	Enhancement of thermal efficiency by 6.56% and 8.32, respectively when PCM used
[19]	E and N	macro-encapsulated PCM	Temperature	Enhancement of 92.10% to 99.80% for the physical parameters (temperatures and thermal powers)
[20]	E and N	Capric acid	storage volume on the solar fraction	Adding 50% volume fraction of PCM leads to 40% potential reduction in the storage volume
[21]	N	Paraffin wax	Temperature	21.46% Temperature Enhancement
[22]	E and N	Paraffin wax	Temperature	Thermal and hydrodynamics enhancement
[23]	E and N	Paraffin wax	Temperature	60 to 75 % energy savings
[24]	N	Paraffin wax	Thickness of PCM	7mm thickness of PCM have the highest thermal efficiency as 64%
[24]	E and N	Flat plat solar water heater with PCM	Temperature	Enhancement of thermal efficiency
[26]	E	Paraffin wax	Temperature	improve the thermal performance of solar water heaters
[27]	N	Paraffin (Code no. C_{16}-C_{28})	Temperature amount of supply water, thickness of PCM	Enhancement of thermal performance

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[28]	N	Paraffin wax	Temperature amount of supply water	Enhancement of thermal performance
[29]	N	Hypothetical PCM	Electrical and thermal parameters	The performance of PV/T system improved by combining with PCM.
[30]	E	Paraffin wax	T_w, T_f	26% Enhancement of thermal efficiency
[31]	E	Paraffin wax (ALEX WAX 600)	Temperature	The total annual efficiency for the finned, un-finned, and FSWHS systems is 85.7%, 71.8%, and 40.5%, respectively

4 Nano-Fluid based solar water heater

The use of nano-fluids is one efficient way to improve the thermal performance of solar water collectors. The impact of zinc oxide (ZnO) nanofluids on solar water heaters featuring Helical Twisted Tape (DTHTT) and Dimple Tube surfaces is investigated by M. Arun et al. [32] . According to the findings, the PTSWH's thermal efficiency increased by 39.25% when twisted helical tapes were used. Additionally, compared to baseline operation using a simple tube with base fluid, ZnO nanofluids at 3.0 kg/min of mass flow rate boosted the thermal efficiency by 13.25%. Thermal exchange and nanofluid mixing are enhanced by the helical twisted tape design's increased turbulence. Furthermore, I. Harrabi et al. [33] Numerically investigate the use of copper oxide/multiwalled oxide–carbon nanotube nanofluid-based nanoparticles, titanium oxide, and magnesium. The collector performances increased when the considered nanofluids were used, according to the results. Specifically, when 0.2 v% and 0.6 v% TiO2 homogeneously distributed in water were used instead of the water reference instance the auxiliary energy was lowered by up to 47.6 and 60.9%, respectively.

B. Saleh et al. [34] used a hybrid nanofluid flows consisting of multi walled carbon nanotubes and Fe_3O_4 for experimental investigation. Different concentrations ranging from 0.05% to 0.3% and volume flow rates between 0.1 and 0.75 L/min are carried out. The collector attained greater thermal efficiency as a result of the hybrid nanofluids' enhanced thermophysical characteristics. M. Mirzaei [35] conducted an experiments to determine the impact of CuO-water nanofluid as a working fluid on a flat plate solar collector's (FPSC) efficiency. The size of the nanoparticles was 40 nm, and their volume percentage was 0.1%. The energy efficiency was found to be increased by 15.2%, 17.1%, and 55.1%, respectively. Verma, et. al [36] evaluated the performance of FPSC experimentally in terms of energy and exergy efficiencies. Several parameters were analyzed by using different types of nanofluids (SiO2/water, TiO2/water, Al2O3/water, CuO/water, Graphene/water, and Multiwalled carbon nanotube per water MWCNTs/water) and by changing the flow rates. The results showed that for a particle volume concentration of 0.75% at a mass flow rate of 0.025 kg/s, exergy efficiency for MWCNTs/water was increased by 29.32%. Also, MWCNTs/water was the highest increase in the energy efficiency of a solar collector at 23.47%.

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M. Reza [37] Saffarian et al. suggested the flow direction of a flat plate solar collector change to improve convective heat transfer coefficient, in addition to using nano-fluid. Three-dimensional and steady-state, Nano fluids containing Al2O3/water and CuO/water are utilized at 1% and 4% volume fractions, respectively. Using wavy and spiral pipes dramatically improves heat transfer coefficient and Nusselt number. Additionally, it is observed that the pressure drop had its highest value for the wavy pipes. R, Nasrin, et. al [38] used four different Nano fluid such as water based cu Nano fluid , water Ag Nano fluid ,Water –CuO Nano fluid were used as the operation fluid inside the solar collector and study of thermal behavior of N fluid in solar collector like temperature ,velocity distribution, convective heat transfer and radiative the result water based Ag Nano fluid (highest Nano particle volume fraction) was batter performed of heat transfer inside the collector.

A.E. Kabeel et, al [39] experimentally investigated the impact of the concentration of Nano-Particles on the solar water heater. The collector efficiency and water outlet temperature, are increased with the increasing of concentration of Nano-particle by 11%, 5.46%, respectively. K. Modi et al. [40] used two types of nanofluids, Aluminum oxide and Chitosan to analyze the performance of solar water heater. The outcomes indicate that using of Chitosan gives higher efficiency. In order to determine the exergy factor , energy and exergy efficiency for the same solar intensity with water and SiC + water, a concentrated solar dish reflector and cavity receiver collector system is constructed and tested by D.Rajendran et al. [41].

K. Farhana et al. [42] Performed a study to assess the stability of the thermophysical properties such as thermal conductivity of Al2O3 and CNC nanofluids, measured at four numerous temperatures, while specific heat and viscosity has been determined at constant temperature ranges by viscometer and differential scanning calorimetry, respectively, both qualitative and quantitative methods were employed in multiple phases, namely characterization and stabilization. Chaw Sint et al.[43] theoretically used MATLAB code to analyze and optimize the flat plate collector. CuO-water nanofluid used as a working fluid in order to improve the flat plate solar collector efficiency.

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In the same context, Omer A. Alawi et al. [44] used MATLAB code to verifying the experimental observations of flat plate collector. Different mass flow rates, inlet fluid temperature and, solar radiation intensity is experimentally conducted. Syam L. et al. [45] experimentally study the impact of using nanofluid to improve the thermal conductivity of the solar water heater. different flow rates 0.033, 0.05, 0.066 and 0.083 kg/s are examined. The following table summarizes the most prominent previous studies, the basic variables they relied on, the type of Nano fluid used, and the most important findings they reached. Note; the symbols E and N refer to the abbreviation of the words Experimental and Numerical respectively.

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Table 2: Solar water heaters studies with Nano fluid

Ref.	Method	Type of Nano-fluid	Parameters	Outcomes
[32]	N and E	ZnO	mass flow rate	39.25% Enhancement of thermal efficiency
[33]	N	TiO2, MgO, CuO	Percentages of nanoparticles	47.6 and 60.9% Enhancement of auxiliary energy
[34]	E	fe3o4	friction factor, volume flow rates	28.09% Enhancement of thermal efficiency
[35]	E	CuO	mass flow rates of the nanofluid	The energy efficiency enhancement by 15.2%, 17.1%, and 55.1% for the flow rate of 1, 2, and4 L/min,
[36]	E	TiO2, CuO, Al_2O_3	Temperature, Nano fluids flow rate, Mass, particle volume concentration	Enhancement in exergetic and consequently energetic efficiency of MWCNTs is the highest at 29.32% and23.47%, respectively
[37]	N	CuO	Nusselt number, heat transfer coefficient, and pressure drop	increasing the heat transfer coefficient by using the Nano fluids, in all cases except for CuO 4%, the Nusselt number decreases.
[38]	N	Cu, Al2O3, CuO, Ag	Nusselt number, Reynold number Prandtl number and heat transfer coefficient	Enhancement of collector efficiency by 85% for water-Cu

[39]	E	Al_2O_3	Concentration of Nano-fluid	4.25% enhancement of H.X. effectiveness
[40]	E	Chitosan and Al_2O_3	Type of Nano-fluid	33.60% and 26.10% improvement of the efficiency of system
[41]	E	SiC	flow rates	Enhancement of energy efficiency by 12.74% at 0.2L/min, and 29.14% at 0.6L/min
[42]	E	Al_2O_3 and CNC	Viscosity, thermal conductivity, specific heat	Enhancement of solar collector efficiency of 2.48% with 0.5% Al2O3 And 8.46 % with 0.5% CNC
[43]	N	CuO	volume concentration of CuO	2% Enhancement of solar collector efficiency.
[44]	N and E	Pentaethylene Glycol	Concentrations of Nano-particles	The flat plate collector efficiency improved by 10.7%, 11.1%, and 13.3% for 0.00833, 0.01667, and 0.025 kg/s.
[45]	E	Al_2O_3	volume concentration of nanofluid	21% Enhancement of heat transfer for 0.3% volume concentration.

5. Conclusions

Using of PCM has a direct influence to the performance improvement of solar water heater. PCM can be integrated directly within the collector, or in the storage tank, so as a film covering the tube of solar trough collector. So as to, choosing the proper PCM corresponding to the operating conditions plays a key role of solar collector efficiency. Using passive heat transfer improvement strategies can increase the thermal efficiency of solar water heaters. Increasing the working fluid's thermal conductivity and flow turbulence are two of the best passive heat transfer augmentation strategies.

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Using Of Phase Change Material, Nano-Fluids To Improve The Solar Water Heater Performance: Review

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Abstract: Due to its economic appeal and technological feasibility, solar water heating is the most popular application of solar energy. However, the utilization of solar water heaters (SWHs) is limited by the sporadic nature of solar energy and the absence of energy storage. Phase change materials (PCMs) efficiently use the thermal energy from the sun. By integrating PCMs with SWHs, the restriction of restricted usage during the day is removed, and the system becomes more effective and user-friendly. The working fluid's thermal conductivity must be raised in order to enhance its heat extraction properties. One of the main materials with greater thermal conductivity is nanoparticles. Thus, the total thermal conductivity of the working fluid is increased when the nanoparticles are added to the base fluid. An overview of the main technics and enhancement methods of utilization of solar water heaters are presented in this work. This study is generally divided onto three main sections. First, an outline of the types of solar water heaters and the mechanical method to improve the performance. Second section focused on the use of phase change materials to enhance the solar water heater performance. Finally, the third section introduces the use of Nano-Fluids in solar water heater.

Keywords: Solar water heater, flat plate collector, evacuated tube collector, Phase change material, Nano-fluid.