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Mohammed Alktranee

University of Miskolc, Faculty of Mechanical Engineering and Informatics, Department of Fluid and Hea Engineering, Miskolc, Hungary

Southern Technical University, Technical Institute of Basra, Mechanical department, Basrah, Iraq

Péter Bencs

University of Miskolc, Faculty of Mechanical Engineering and Informatics, Department of Fluid and Hea Engineering, Miskolc, Hungary

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APPLICATIONS OF NANOTECHNOLOGY WITH HYBRID PHOTOVOLTAIC/THERMAL SYSTEMS: A REVIEW

Mohammed Alktranee[1,2], Péter Bencs[1]*

[1]University of Miskolc, Faculty of Mechanical Engineering and Informatics, Department of Fluid and Hea Engineering, Miskolc, Hungary

[2]Southern Technical University, Technical Institute of Basra, Mechanical department, Basrah, Iraq

This paper appears potential of use nanofluids as a working fluid with the photovoltaic/thermal (PV/T) systems as an alternative of the conventional liquids in improves the efficiency of the hybrid PV/T system. The review highlights the impact of some parameters (base fluid, volume fraction, the concentration of nanoparticles, surfactants, shape, and size of nanoparticles) on nanofluids' thermophysical properties and their effect on the PV/T system's efficiencies. Hence, it discusses the PV/T behavior, which uses different nanofluids based on previous experimental, analytical, and numerical studies. The review concluded that using nanofluid as a cooling fluid or spectral filter contributes by enhancing the performance and increasing the PV/T system's efficiency. Thus, each type of nanofluids has certain features that contribute to removing the PV cells' excess heat by cooling it, contributing to its work's stability, and increasing its productivity. Nanofluids thermophysical properties play an intrinsic role by enhancing nanofluids' performance, thus positively reflecting on the PV/T system's performance. Despite the variation in the values of thermal and electrical efficiency, Most of the studies that used nanofluids have achieved encouraging results that appeared by improving the performance of PV/T systems.

Key words: nanofluid, hybrid PV/T system, thermophysical properties, efficiencies

INTRODUCTION

Increased energy demand with greater reliance on conventional energy sources raises concern about the sustainability of conventional energy sources and the possibility of meeting the increase of global energy demand [1]. On the other hand, environmental protection with reducing pollution represents the essential matters for countries and decision-makers [2]. Adopting alternative energy sources, such as solar energy, is an appropriate solution that provides clean energy that contributes to environmental protection, reducing dependence on conventional energy sources. Thus, exploitation of the sunlight and heat that resulted from the sun and converted it to electric and thermal energy [3]. Most of the solar radiation received by photovoltaic (PV) panels not converted to electrical energy. Where 15–20% converts to electricity by PV panels, and the rest of the solar radiation negatively affects the PV cell's performance as heat [4]. Therefore, raising the PV cell operating temperature will robustly affect the PV panel's performance and the energy produced [5]. Thus overheating leads to full damage of the PV panel [6]. The PV system's low efficiency at rising temperatures is still the main obstacle for adopting sustainable systems [7]. Sustaining the PV panel's operation effective requires maintaining the PV cells' temperature at a suitable range.

Using a cooling technique for the PV panels is a successful method for reducing the PV cells' high temperature and enhancing electrical efficiency [8]. The hybrid PV/T system is the most effective technology for converting sunlight to heat and electricity [9]. Hybrid photovoltaic/thermal (PV/T) system is a new system that combined photovoltaic panels with a solar collector in one system, which produces electrical and thermal energy simultaneously [10]. THE hybrid PV/T system consists of the PV solar panel to produce the electricity with an absorber plate behind the PV that extracts the heat and transfer it by the circulating fluid passing through pipes. Thus, it contributes to decreasing the PV's temperature and enhancing their efficiency; Figure 1 shows the schematic diagram of the PV/T system [11], [12]. Circulating the water or air in the back of the PV contributes to reducing the PV module's high temperatures. Thus maintaining the electrical efficiency and the heated fluid produce use for other applications [13]- [15]. Many studies have conducted air and water use as a cooling medium for the PV/T to reduce the temperature and raise the system efficiency [16], [17], with better performance than the PV alone [18]. However, the PV/T systems are relatively suffering from low efficiency due to the conventional heat transfer fluids [19].

Recently, significantly researchers used nanofluids in the PV/T system because of its positive impact on the PV/T system's performance as a cooling fluid or optical filter [20]. Due to their high thermal properties, it was used as an alternative to conventional fluids [21]. Nanofluids have an appropriate property for heat transfer and absorption [22]. The authors [23]- [26] have investigated the influence of using nanofluids as a cooling fluid for the PV panel and apply in the solar systems. The nanofluid's high thermal conductivity has increased its uses as a heat transfer factor with the PV/T systems and the

*mohammed84alktranee@gmail.com

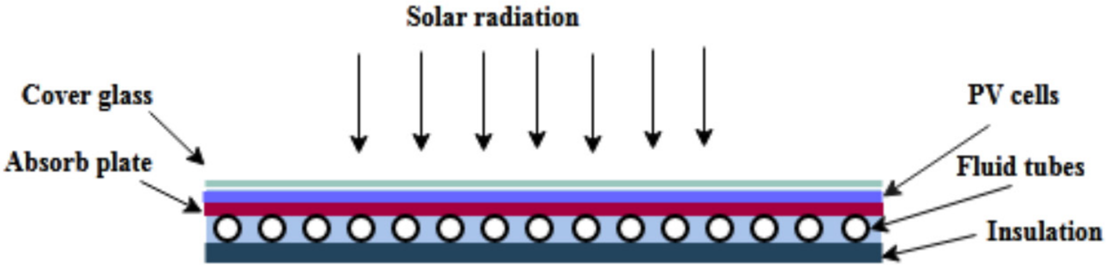

Figure 1: Schematic diagram of the hybrid PV/T system

heat exchangers [27]. Conventional fluids like water or oil used as heat transfer fluids have a lower thermal conductivity, which influences all sorts of heat exchangers' efficiency [28]. Therefore, using fluids with high thermal conductivity became important in thermal applications, which encouraged researchers to use nanofluids as an alternative to conventional fluid [29]. Other researchers studied the effect of using different types of nanoparticles on solar systems' performance that produce thermal and electrical energy or a hybrid PV/T system. Nevertheless, various researchers have achieved advanced results, using nanofluid as a working fluid that contributes to cooling the solar cells by extracting the excess heat and using it in thermal applications [30]. Thus, enhancement of the overall efficiency and increasing the performance of solar systems.

NANOTECHNOLOGY

Nanotechnology has a significant role in different fields, such as heat transfer processes and energy applications, where it has achieved remarkable progress. Nanotechnology's positive role can be exploited by using it as a working fluid to replace conventional fluids that remove the solar system's excess heat [31]. This review focuses on nanofluids' vital role in improving solar systems' efficiencies by increasing the thermal conductivity and heat transfer coefficient.

Nanofluid

Nanofluids are the term given for the stable dispersion of the nanometer-sized materials into base fluids [32]. In 1993 the concept of suspending nanoparticles with different fluids was adopted to improve heat transfer fluids. In 1995 the term nanofluid was applied as colloidal suspensions. Several theoretical and experimental studies on nanofluids' use found that the nanofluid has better heat transfer characteristics than other fluids [20]. Therefore, different definitions were found for the nanofluid in the literature. Still, most researchers agree to define the nanofluid as mixing nanoparticles with a diameter between 1 to 100 nm dispersed in the base fluid [8], [33]. Mixing the nanoparticles by the base fluid to produce nanofluid that is considered a new working fluid has distinctive properties that extract excess heat, especially from solar systems [34]. Enhance the heat transfer coefficient is an essential feature of nanofluid that leads to an increase in the thermal conductivity of the working fluid [35].

Therefore, to achieve significant performance using nanofluid, it requires preparation of nanoparticles with high stability and suspension within the base [36]. The most popular methods used to prepared nanoparticles are a single-step method that depends on the physical or chemical means to prepare. The two-step method is the second method to make nanoparticles mixed with the base fluid using either the high shear or ultrasound methods. Hence, direct or indirect ultrasonication has been used with the two-step method to ensure nanoparticles' stability inside the base fluid [37]. On the other hand, the hybrid nanofluids are produced during two methods; the first method is to add two different nanoparticle types into the basic fluid. The second one is the manufacture of nanocomposites and then dispersed in a basic fluid. The second method is complex and requires the different nanoparticles' stability to ensure its dispersion into the base fluid [38]. Wherever advantages have been founding, the disadvantages it noticed as well. The authors [34], [33] found that nanofluids' preparation has a high cost and observed nanofluids' unstable behavior at high temperatures. Thus, the agglomerate of nanoparticles leads to clogging of the fluid flow channel and the erosion of the system's metallic configurations.

Type of nanoparticles

Mixing the base fluid with low thermal conductivity with solid nanoparticles with high thermal conductivity leads to producing a new fluid and has high transfer characteristics higher than the base fluid [39], [40]. The nanoparticles are the essential factor of the nanofluid, which contributes after mixing with the base fluid to produce the nanofluids. Its improved thermal properties have wide use in various applications as cooling fluid. Different types of nanoparticles used metallic such as copper, silver, etc. and nonmetallic such as copper oxide, aluminum oxide, etc. Other types of carbon and nanocomposites, figure 2, show the different types of nanoparticles [36], [41]. Each type of nanoparticles has unique thermo-physical properties represented by thermal conductivity and thermal diffusivity in addition to viscosity [42]. Thus, the author [43] referred to enhancing absorption and increasing conversion efficiencies according to particle concentrations into pure water after mixing nanoparticles in the base fluid.

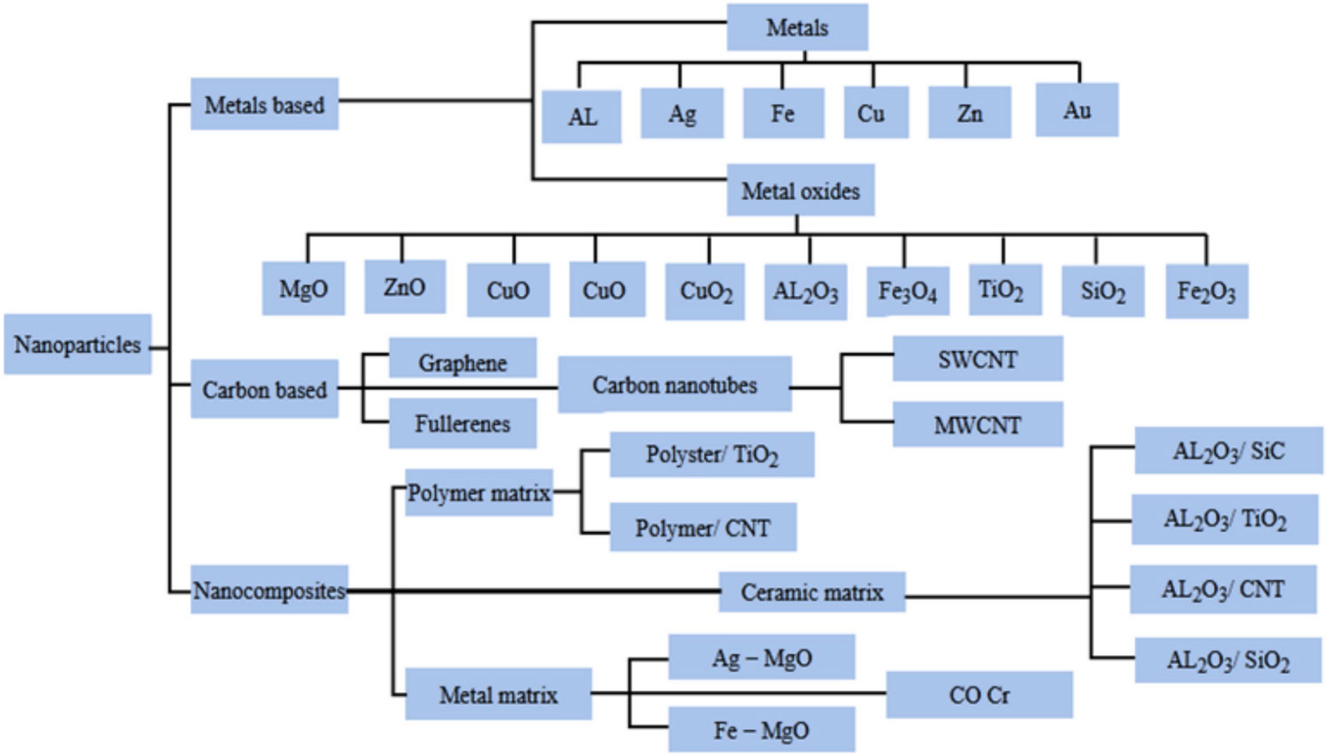

Figure 2: Type of nanoparticles

Thermophysical properties of nanofluid

The nanofluids' thermophysical properties represent the significant factors contributing to enhancing its properties and positively reflect on its performance. Several studies have investigated the influence of nanofluid's thermophysical characteristics on its performance. The effects of some parameters on the nanofluids thermophysical, such as temperature, base fluid, volume fraction, the nanoparticles concentration, etc. Nanofluid density is an essential property that significantly affects the system's sustainability and achieves a suitable extent of nanofluid stability [44], [45]. Therefore, an increase in nanofluids' density causes a robust effect on the pumping capacity [46]. Adding a surfactant contributes to a limited increase by the density of nanofluid [47]. The viscosity of nanofluid affects nanofluids' behavior and the capacity of the pumping power of the circulating of fluids [48], in addition to heat transfer characteristics [49]. Increasing the viscosity of nanofluid is linked with increasing surfactant concentrations [50], [51]. Based on the author [52], the volume concentration and temperature would control the viscosity, while the base fluid is the most important factor determining the nanofluid viscosity. The author [27] studied the effects of temperatures on nanofluids' density and found that rising temperatures led to nanofluid density reduction. Whereas the specific heat plays a vital role in providing the energy that transmits from a body to another [22]. In nanofluid, specific heat is different depending on the kind of nanomaterials used and their concentration in the base fluid in addition to the type of base fluids [24]. The specific heat increases with the rising temperature, while the size of nanoparticles with its concentration and base fluids have a negative impact on the specific heat [53], [54]. Increasing the value of nanofluid's thermal conductivity is required to enhance the heat transfer nanofluid applications [55]. A review of both [49], [56] proven the increase in the temperature with nanoparticle concentration contributes by increasing nanofluid's thermal conductivity. According to a study conducted on nanofluids' thermal behavior, increasing the thermal conductivity is mainly associated with the nanoparticles' size and the type of nanoparticle material with its concentration in the base fluid [57]. Hence, adding the surface modifiers has a limited influence on nanofluid's thermal conductivity [58].

APPLICATIONS OF NANOFLUIDS IN THE HYBRID PV/T SYSTEMS

Recently, applying nanofluids in the hybrid PV/T systems has attracted many researchers to improve the system's performance. The lower efficiency of the PV/T systems resulting from using conventional fluids has encouraged nanofluids to improve heat transfer properties. Adding nanoparticles to conventional fluids has improving its thermal properties, which leads to enhancing efficiency [19], [21]. Using nanofluids contributes to the extraction excess of the PV system's heat and use it in other applications. Thus cooling the PV system by the nanofluid will increasing electricity generation of the PV system [59]. Numerous researchers have use nanofluids with the PV/T systems in two ways, for coolant of the PV/T system and as a spectral filter, or combine both of them, as shown in figure 3 [18]. An experiment conducted by

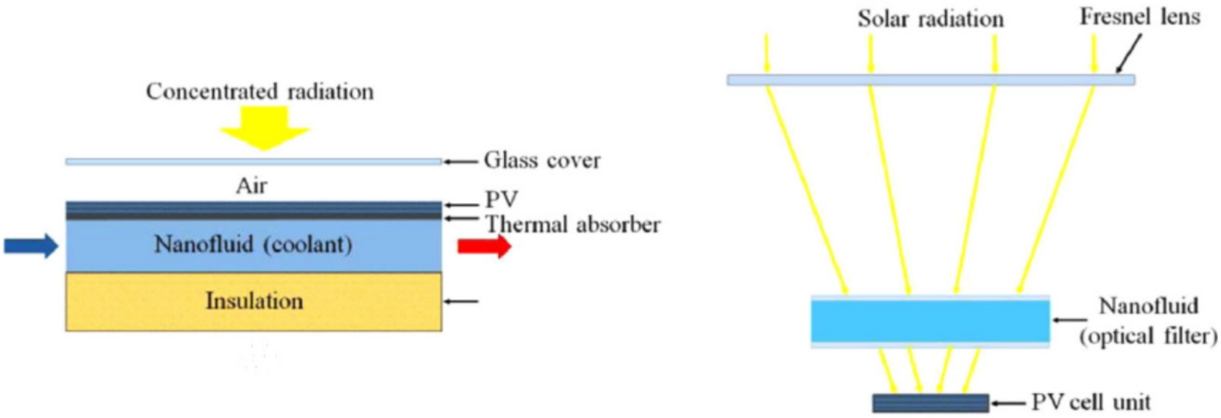

Figure 3: Schematic of the PV/T system with nanofluid as a coolant and spectral [60]

[61] that used nanofluid with a PV/T system with a certain percentage of nanoparticles leads to an increase the electrical efficiency higher than the PV system alone. Thermal efficiency has increased compared with cooling water, thus increasing the system's overall efficiency.

A new technique has used mirrors to concentrate the sunlight on the PV system, as shown in figure 4, using nanofluids to increase the electrical and thermal efficiencies of the concentrated PV/T system (CPV/T). Both authors [62], [63] indicate that using nanofluid as a cooling fluid and optical filter had a noticeable effect on the CPV/T system's overall efficiencies. Many researchers have concentrated on uses different sorts of nanoparticles, such as (metal, metal oxide, etc.), to improve the PV/T system.

Various studies were conducted on improving the PV/T performance using different types of nanofluids, base fluids with different designs of PV/T systems, as shown in Table 1, to increase the system's electrical and thermal efficiency.

Use metal-based nanoparticles as a working fluid in the PV/T system

Recently, many studies and researchers used metal-based nanoparticles that mix with the base fluids to enhance the PV/T system's performance. Glazed and unglazed hybrid PV/T systems have been designing with a direct copper absorber plate to the PV cells to study the system's efficiency, where use Cu/water as a nanofluid that flows in one rectangular channel. The results refer to enhancing the thermal efficiency with used Cu/water, while electrical efficiency has decreased along with glazing [65]. A study conducted on the effects of dispersing different sorts of nanoparticles during various conventional base fluids has proven added Cu nanoparticles to water leads to an increase in the PV/T system's efficiency more than use ethylene glycol [66]. The analysis was conducted with CFD on the PV/T system with the use of Ag-water and AL-water as nanofluids to recognize the system's behavior. The results appeared to increase the heat transfer coefficient and efficiency by increasing the volume of a fraction of the nanofluid. Increasing the volume of a fraction (Ø) at 5% leads to an increase in the AL-water nanofluids' heat transfer coefficient about 2% and the inlet velocity. At the same time, Ag-water had exhibited a higher increase in the heat transfer coefficient [10]. A study done by [67] used nanofluids to reduce the PV panel's temperatures and enhance the system's efficiency. Ag and Cu nanoparticles have been using, where Ag nanoparticles had a better effect than Cu nanoparticles. Whereas Ag-water nanofluid using on the system has a greater influence on performance than Cu/water use. An experiment has used Ag and Au nanoparticles for cooling and optical purposes with the PV/T systems. The finding revealed that select Ag nanoparticles have

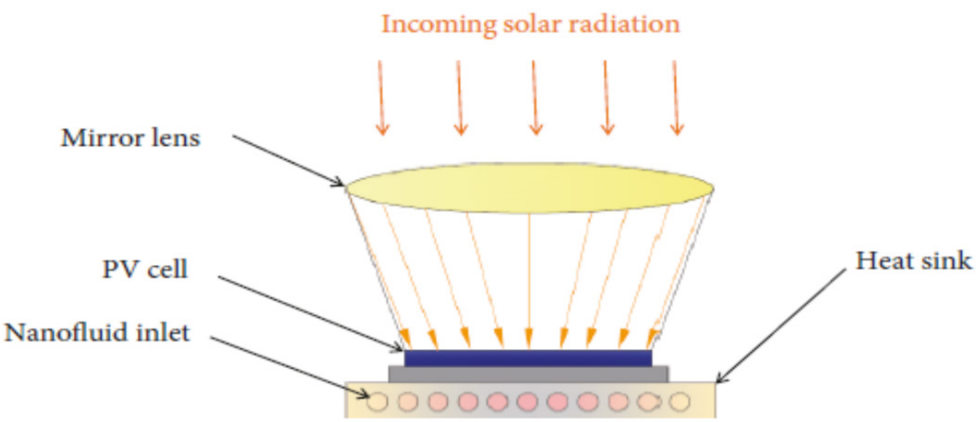

Figure 4: Schematic diagram of the CPV/T system work on nanofluid [64]

Table 1: Some studies related to the usage of nanofluids with PV/T applications

Ref.	Type nanoparticles	Base fluid	Application	Outcomes
[20]	Metal oxide-based nanoparticles	Water, ethylene glycol-water	PV/T	The use of nanofluids with hybrid PV/T systems applications improves the system's performance, whether with the laminar or turbulent regime. Nanoparticles with a larger diameter positively influence overall energy efficiency in the laminar regime, while opposite that with the turbulent regime. Moreover, it observed that aluminum oxide/water has higher system performance than titanium oxide. Nanofluid that adopting water as a base fluid contributes to increased energy and exergy efficiency more than ethylene glycol used as a base fluid.
[22]	Metal-based, oxide-based nanoparticles and carbon-based nanoparticles	Different type of base fluids	PV/T	The use of nanofluids helps enhance the PV/T system's performance. It raises the total solar energy yield and increases the system's thermal energy compared with conventional fluids. However, nanofluids have contributed to enhanced heat transfer as a base fluid in the PV/T system, thus increasing electrical and thermal efficiencies.
[18]	Metal-based, oxide-based nanoparticles and carbon-based nanoparticles	Water, ethylene glycol	PV/T, CPV/T	According to various types of PV/T systems that used nanofluids or other fluids, the studies concluded that used nanofluids have improved thermal conductivity, which positively impacts the performance. Thus, the possibility for used nanofluid as an optical filter or for cooling in the PV/T systems because of nanofluids' high thermal properties, which appeared higher efficiency in the PV/T system than other fluids.
[8]	Metal-based, oxide-based nanoparticles	Water, ethylene glycol	PV/T, CPV/T	Use nanofluid as an alternative for the conventional liquids as work fluid or optical filtration as a cooling for the PV/T system leads to high enhancement in the system's performance. Also, using some modifications in the system's design, like using honeycomb in the backside of the PV panel instead of the channel's cross-section, has contributed to enhancing the thermal load distribution.
[71]	Oxide-based nanoparticles	Water	PV	A study was conducted on the PV module's performance using cotton wick structures that fixed at the back of the PV module using nanofluids as cooling fluid. The results refer to increasing the PV module temperature up 65 °C without cooling. Using water with the cotton wick as a cooling contributes to lowering PV's temperature up 45 °C. While using both CuO/water and Al_2O_3/water as nanofluids reduce the temperature of the PV module about 59 °C and 54 °C, that is lower than using water as cooling with cotton wick structures and that because of the adherence of nanoparticles by the wick fibers, which natively influence in wick structures.

the best effect on conventional fluids used in PV/T systems. Therefore, for cooling and optical filtering, using Ag/water nanofluid has achieved higher thermal and overall efficiency than Au-water and Cu-water [68]. Using Ag-water nanofluid as a coolant in separate channels in PV/T was better than the double-pass channel. Increasing volume fraction leads to rising the overall efficiencies of the PV/T system [69].

A comparison has conducted by [70] between Cu and AL nanofluids to recognize the thermal conductivity enhancement at 1% volume fraction, and nanoparticle size was 80 nm. The results revealed Cu nanofluid has higher thermal conductivity than AL nanofluids [71], as shown in figure 5 (A). To improve nanofluids' thermal conductivity, ethylene glycol-based Fe nanofluids have prepared using sonication at high powered pulses. Compared with Cu nanofluids, it observed nonlinear function with volume fraction, increasing the thermal conductivity as reaching 18%, as shown in figure 5 (B). Thus, Fe nanofluids' conductivity is improved more than Cu nanofluids because Fe nanofluids are efficient in thermal transport [72]. An active cooling technique had used by [73] to enhance the performance of the PV panels, Zn-water nanofluid used as a work fluid passing during small heat exchanger placed in the back of the PV panels, with different concentration ratios Zn have used. The results appear to reduce the PV panels' temperature by increasing the electrical efficiency with a concentration ratio of 0.3%.

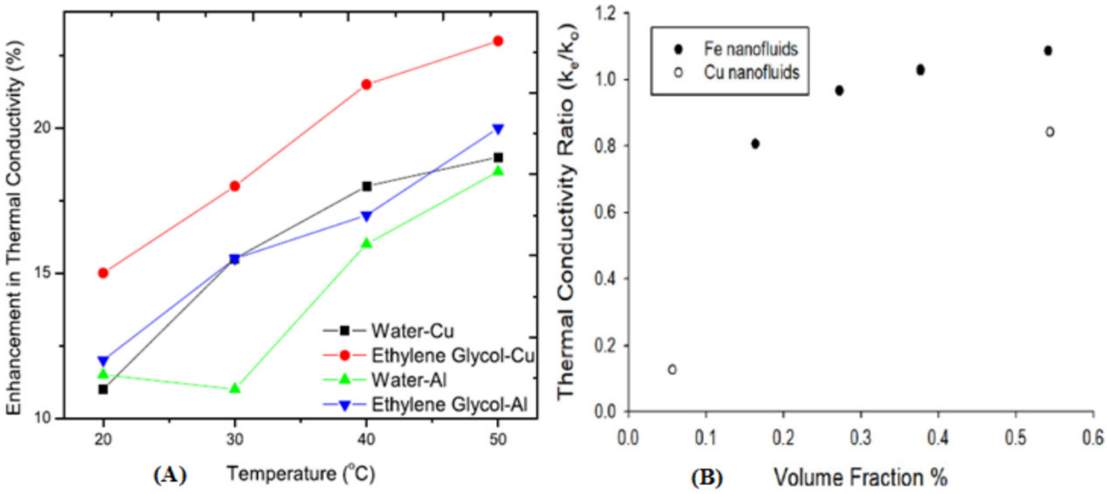

Figure 5: (A) The relationship between Cu and Al with different base fluids and enhancement in thermal energy, (B) The relationship between volume fraction and the thermal conductivity of Fe and Cu nanofluids [74]

Use metal oxide-based nanoparticles in the PV/T system

Other experimental and numerical studies have been conducting on the use of metal oxide-based nanoparticles mixed with various sorts of base fluid to recognize nanofluids' effect on the PV/T system's efficiencies.

Aluminum oxide (AL_2O_3)

Several researchers adopted metal oxide of nanoparticles after mixing with the base fluids as a nanofluid. The author [75] has investigated the use of AL_2O_3-water with the PV/T system to study the influence AL_2O_3 -water with various concentrations began (0.1, 0.2, 0.3, 0.4, and 0.5%). The investigation results show reducing temperature to 42.2 °C with an increase the electrical efficiency to 12.1% at 0.3% of AL_2O_3 concentration. A higher than 0.3% concentration ratio leads to a rising temperature with lower electrical efficiency again. A simulation study of the PV/T system for the one-way channel placed behind the PV/T system, AL_2O_3/water used as a working fluid with the volume of a fraction Ø (0% to 10%). The results show a lower Reynolds number to 5 has contributed to enhancing the heat transfer rate to 27% at Ø =10 % volume of a fraction [76]. Study the impact of using different concentrations of nanoparticles (1 wt.%, 1.5 wt.%, and 2 wt. %) of AL_2O_3 as a nanofluid with the PV/T system. Thus, both thermal and electrical efficiencies have increased by 27.3% and 1.1% at used 1.5 wt.% nanoparticle concentration, which was considered optimum values, with a 50% filling ratio [77]. Author [78] indicates using 1.2 wt.% nanoparticle concentration of AL_2O_3 nanofluid and 40 L/H mass flow rate has increased the thermal efficiency by 58%, electrical efficiency by, 45% the overall efficiency by 13%, respectively.

Furthermore, Using AL_2O_3/water as a nanofluid that passes during the rectangular channel in the PV/T system causes an increased heat transfer rate with a dropped PV temperature [76]. Hence, enhancing both the electrical and overall efficiencies while there is no significantly varying thermal efficiency [79], [80]. Another study used AL_2O_3/water as a nanofluid that flows over the PV cells instead of water, increases thermal and overall efficiency. Increment visible light that was absorbed by nanofluids has caused a decrease the electrical efficiency [81]. An experimental study by [82] used AL_2O_3-water as a cooling fluid with forced convection. Nanofluid concentrations used were (0.1, 0.2, 0.3, 0.4, and 0.5); when the water used, the PV temperature was 79.1 ˚C. The temperature dropped with used variable concentrations of AL_2O_3-water, where it reached 42.2 ˚C at a 0.3% concentration ratio.

Silicon oxide (SiO_2)

To avoid the rising of the PV/T system temperature, SiO_2/water was used as a coolant and maintaining the system's efficiency, with used 1 and 3% by weight of mass fractions. The study refers to an increased thermal and energetic efficiency of about 12.8, 24.31% at 3 wt. %, while overall efficiency increased 3.6, 7.9% with used 1 and 3% by weight of mass fractions [83]. The PV/T system's performance has been studying with different types of nanofluids [84]. The results indicate that using SiO_2 as working fluids has achieved better performance with enhancing the thermal and electrical efficiencies than other nanofluid or water [85]. It was used different

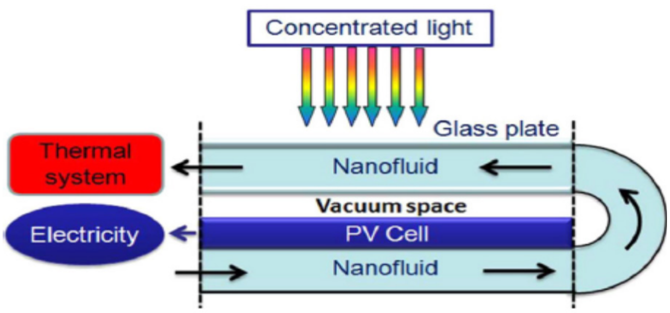

Figure 6: Decoupled PV/T system use nanofluid as a working fluid

sizes of SiO_2 nanoparticles from 11-14nm with 1, 3 wt. % concentration mixed with water as nanofluids for cooling the PV/T system. The experimental results revealed improving the exergy efficiency and energy of the PV/T system [86].

The decoupled PV/T system has designed using SiO_2 nanoparticles as a sol-gel method, as shown in figure 6. Another experimental study was conducted to use SiO_2/water nanofluids as a coolant and spectral filter the system; a 2% volume concentration adopted with used a variety of sizes between 5 nm to 50 nm. Therefore, used 0.015 L/s of flow rate, 5 nm particle size, and 2 % volume concentration, the system's energetic efficiency has increased 7% compared to water [59]. The percentage proportion of nanoparticles weight uses have notably on the efficiencies of the PV/T systems. An investigation was conducted on the influence of SiO_2-nanofluid by the PV/T system as a coolant to enhance the system's efficiencies, where different proportions of 1% wt.% and 3%wt% have tested. Using 1 wt.% from the silica-water nanofluid has increased the system's overall efficiency to 3.6% with a thermal efficiency of 7.6%, which is more effective than pure water. Thus using 3 wt.% of silica-water nanofluids has increased the overall efficiency to 7.9% while thermal efficiency12.8% [83]. An experimental study was conducted by [87] on using SiO_2-water nanofluid for coolant the CPV/T system. The experimental reported increase in the efficiency of the system even with high irradiance.

Iron oxide (Fe_3O_4)

Lowering the PV panel temperature is the main purpose that many studies focus on; various types of nanofluids were used to achieve a suitable level of efficiency. A study used two proportions, 1 and 3 wt% of mass concentrations of Fe_3O_4 − water under two values of solar radiation 600 and 1100 W/m^2 of solar radiation. The results revealed rising the electrical, thermal efficiency to 4.93%, and 46.29%, respectively. Thus, the overall efficiency until 76% at 3 wt.% compared with distilled water [88]. Other experiments used Fe_3O_4/water nanofluid as a coolant in sheet and tube of the PV/T system; the concentration was 1, 3 wt. %, with size 45 nm, the testing had done with a constant and alternating magnetic field. The results show improving the energy and exergy efficiency of the PV/T system by using ferrofluid with alternating magnetic field better than other conditions [59]. Another proposal by [89] used Fe_3O_4 nanoparticles as an optical filter in the PV/T system, as shown in figure 7, where the nanoparticles of magnetic Fe_3O_4 has dispersed with a 50% water /50% ethylene glycol and adding either methylene blue or copper sulfate. The test outcomes refer to good stability with the electrolyte nanofluid's better efficiency at used magnetic, optical filter compared to the conventional filters with smaller thickness. Thus, nanofluid's magnetic electrolyte leads to higher thermal conductivity at a limited range of temperatures.

Titanium oxide (TiO_2)

A study was accomplished by [90] using TiO_2/water as a working fluid on the concentrated photovoltaic receiver. It has studied the influence of increasing the volume fraction and type of flow regime, concentration ratio, and pipe length. The nanofluids' thermal conductivity and viscosity have increased with decreasing the Reynolds number at a steady mass flow rate. Thus the temperature of the PV has dropped. Furthermore, there is a high increase in thermal, electrical efficiency, and overall efficiency compared to the laminar-turbulent flow, whereas using TiO_2 nanoparticles cause enhancing the thermal performance, overall energy, and exergy efficiency of the system [91]. The author [20] studies the impact of volume fraction, the diameter of nanoparticles, and nanofluid outlet temperature in the PV system. TiO_2/water was used as nanofluid with diameters (21 and 100) nm at constant mass flow rates for both laminar and turbulent regime. The results show the PV's reduced temperature at added nanoparticles to the base fluid at laminar flow, an opposite observed with the turbulent regime.

Copper oxide (CuO)

Maintaining the PV system's efficiency at a specific lev-

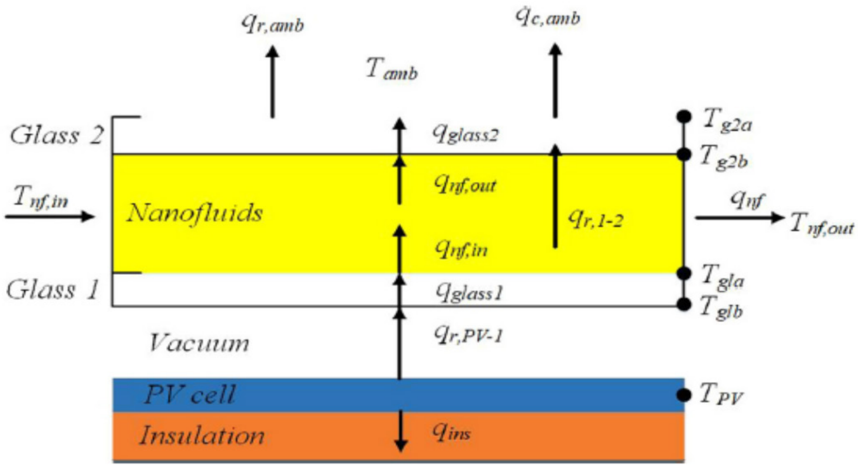

Figure 7: Schematic diagram of using optical filtration nanofluid for the PV/T system

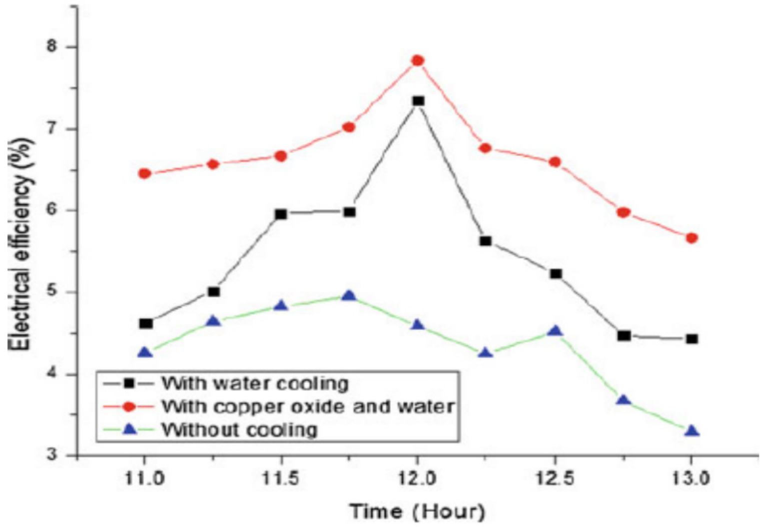

Figure 8: The behavior of the electrical efficiency with and without cooling

el that allows produces an adequate return is the focus of attention for many researchers. A study conducted by [92] on using copper oxide- water as a cooling fluid of the PV panel exposed to high-temperature reaches 55.5 °C. The results show reducing the temperature of the PV to 41 °C when used copper oxide-water. The maximum electrical efficiency was 7.8%, while the electrical efficiency was 7.3% at used pure water as a cooling fluid; figure 8 shows the PV panel's electrical efficiency with water cooling and without cooling and copper oxide-water for cooling. Thus used copper oxide-water leads to increase exergy efficiency to 57.78% compared to water. A numerical and experimental study was conducted using CuO/water to cool the PV/T system with a laminar flow regime. It observed decreased the PV panel temperature by 14.5 °C using CuO/water nanofluid, with a 0.5% increase in electrical efficiency while the exergy was 57.78% [64].

Solidworks flow simulation was used to study the influence of using CuO/Syltherm 800 to improve the CPV/T system's performance with a parabolic trough concentrator. The study has considered the effect of temperature range from 25 to 200 with 300 to 720 L/hr of nanofluid flow rate on the thermophysical properties. The results revealed to enhancing all the system efficiencies, at 540 L/hr, there was a small improvement in thermal efficiency. The higher efficiency for both the thermal, electrical efficiency as well as the overall efficiency was at 100°C in the inlet with 540 L/hr flow rate, the values of efficiencies were 46 84, 6.60%, and 2.08%, that was bigger than values which achieved when used pure oil only [92]. Another experimental study conducted by [93] replaced the Tedlar layer of the silicon cell with a thin copper sheet; Cuo/water nanofluid has been used for cooling to boost the system's performance; the volume fraction used was 0.05% with the use of glazing and without. The results indicate to increase in thermal efficiency to 45% when used glazing with nanofluid, while the electrical efficiency has dropped about 3%.

Zinc oxide (ZnO)

An investigation conducted used two types of working fluids (ZnO/water and pure water) on the efficiency of the

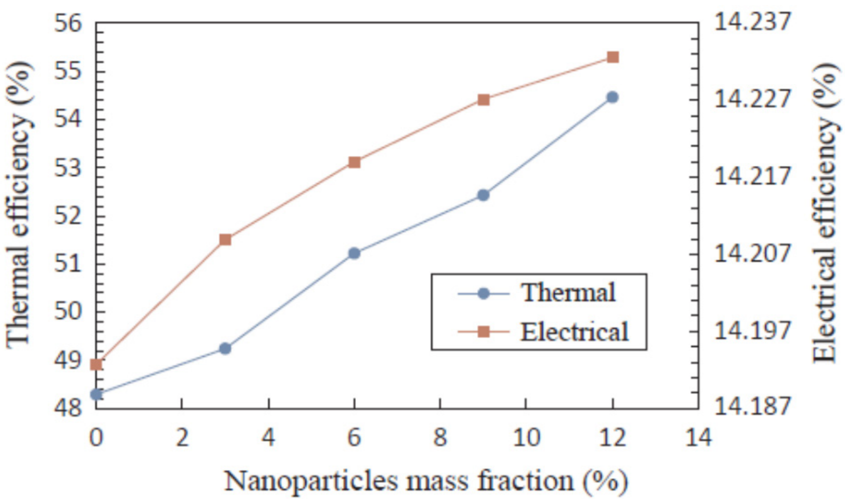

Figure 9: The effect of nanoparticles mass fraction on the efficiency of the PV/T system

hybrid PV/T system using the Taguchi method to define the PV/T system's performance. ANSYS Fluent software was used to compare with the numerical results of the 3D numerical model. The result shows that using ZnO/water, the PV/T system's thermal efficiency has relatively enhanced compared with pure water. Thus a slight increasing the thermal efficiency by 1.97%, 6.07%, 8.57%, and 12.78% with using 3 wt%, 6 wt%, 9 wt%, and 12 wt% of nanoparticle mass fractions, as shown in figure 9, with limited improvement in the electrical efficiency [94]. According to different nanofluid types used to improve the PV/T system's performance, using ZnO/water nanofluid gives better performance. Another possible effect on the PV/T system's electrical efficiency has been studying by [91] the influence of adding mass fraction between 0.05 to 10%wt of the ZnO/water. The study refers to increase the thermal efficiency four times while dropping both temperatures, the electrical efficiency 2%, and 0.02%.

Magnesium oxide (MgO)

A study conducted using MgO-Water nanofluid by the PV/T system, where the nanofluid is flowing over the solar cells, the nanoparticle's size was around 10 nm with different concentrations. In contrast, the mass fractions used were (0.02, 0.06, 0.1)%wt. and film thickness of 10 mm. The study indicates decreasing the transmittance of nanofluids with both the mass fraction and the film thickness. Increasing the mass fractions reduces the output power of the PV/T systems [95].

Use combined metal and metal oxide nanoparticles in the PV/T system

Recently several studies and researches using different sorts of metal oxide nanoparticles with varying fluids as nanofluids that flow by the pipes that were placed behind the PV/T system. A study was conducted by [91] on using a collection of metal oxide nanoparticles represented by TiO_2, AL_2O_3, and ZnO with the impact of adding mass fraction. The study concluded that both TiO_2 and ZnO have a good ability to enhance electrical efficiency than AL_2O_3. The thermal efficiency has a big value when used ZnO compared with AL_2O_3 and TiO_2. Therefore, the temperature dropped by 2% and 0.02% of the electrical efficiency, while thermal efficiency increased four times when the addition mass fraction from 0.05wt to 10%wt of ZnO. The author [71] developed a simple passive cooling for the PV panel by cotton wick structures, as shown in figure 10, using both CuO/water and AL_2O_3/water nanofluid with a concentration of CuO/water, and AL_2O_3/water was 0.1 wt.%). The finding indicates the PV panel's efficiency was 10.4% with wick structures in and water, while the efficiency was 9% without cooling. Using AL_2O_3/water and CuO/ water with wick structures, the efficiency was 9.7% and 9.5%.

Furthermore, an experimental investigation using two types of SiO_2-water and Fe_3O_4-water nanofluids for cool-

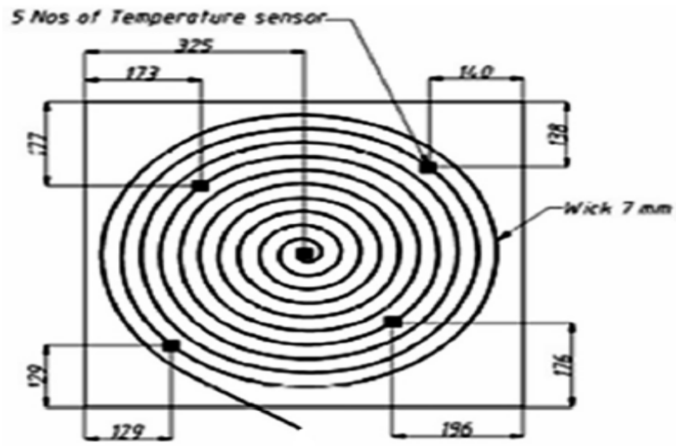

Figure 10: Cotton wick structures fixed in the back of the PV

ing the hybrid PV/T system. The results show a good influence by the thermal and electrical efficiency more than using water only. Thus, using SiO_2-water nanofluid gives better efficiency than Fe_3O_4-water by 3%–4% [96]. Using AL_2O_3/water and CuO/water nanofluids as a working fluid contributed to increased thermal efficiency by 21.30% and the electrical efficiency by 0.07% at using CuO/water compared with water only [97]. An experiment on the PV/T systems' performance was conducted by [98] using nanofluids in turbulent and laminar flow regimes. Al_2O_3/water and TiO_2/water have tested at volume fractions from (0-4%), with a diameter of particles between (21and 100) nm. It found enhancing the system's performance using nanofluids and noticed that AL_2O_3 nanoparticles have good thermal characteristics more than TiO_2. The mathematical models have been simulating by [99] used ANSYS FLUENT® software, CFD, and MATLAB® to select the better nanofluid for the PV/T system. The nanoparticles SiO_2, AL_2O_3, and CuO that used dispersed in the water with different concentrations. The results indicate that CuO nanofluid has higher thermal conductivity with better thermal stability than SiO_2 and AL_2O_3. Also, use CuO nanofluid with both air and water leads to efficiency reach 90.3% and 79.8%. In contrast, the author [100] studies the impact of using AL_2O_3/water, ZnO/water, and TiO_2/water nanofluids on the energy and exergy of the PV/T system. The results show that used ZnO and TiO_2 in the PV/T system have better total energy efficiency and exergy efficiency than others.

Use carbon-based nanoparticles in the PV/T system

Several researchers have used carbon-based nanoparticles of both types of single-wall carbon nanotubes (SWCNT) multi walls carbon nanotubes (MWCNT) in different solar energy applications. water-MWCNT has been using with the PV/T system as a heat absorption and heat storage with the influence of volume concentration ratio (0% to 0.3%) at a constant flow rate of 1.2 l/min. [101] The experimental results indicate enhancing the thermal and electrical efficiency of the PV/T system due to used 0.075% V from MWCNTs, which leads to a drop in the temperature of the PV panel to 12 °C. Hence, the overall efficiency was 83.26%; the average temperature drops during daytime reached 10.3 °C and the total efficiency of around 61.23%. To improving the PV/T system's performance, a water/MWCNT nanofluid has been using as active cooling. COMSOL Software Multiphysics used 3D numerical simulation with different solar radiation values from 200-1000 W/m^2, the mass flow rate constant at 0.5 L/min, inlet temperature 32 °C, and weight fraction (0 to 1%). The numerical and experimental results refer to the PV/T system's overall efficiency were 89.2 and 87.65% with nanofluid use at 1000 W/m^2. It found the PV performance was 9.2% when using water as the cooling system, while the thermal performance was higher, about 4 and 3.67% in both numerical and experimental studies [102]. Another numerically and experimental investigation conducted by [103] using COMSOL software to check the results obtained from an indoor experimental uses MWCNT–water to improve the PV panel's efficiency. Fixed the value of solar radiation at 1000 W/m^2 and different mass flow rates between 30 to 120 l/h. PV's electrical efficiency has improved by about 12.25% at 120 L/h of mass flow rate with nanofluid concentration MWCNT–water by 0.75%wt. The PV panel temperature decreased to 0.72 °C, with a rising volume flow rate to 10 l/h, which leads to improving the thermal storage to 6.89 W.

CRITICAL ANALYSIS

The hybrid PV/T system is widely employed by producing thermal and electrical energy, but these systems still need to develop to improve its performance. Several researchers have used different nanofluids as a working fluid to enhance the PV cells' performance and thermal energy. Using nanoparticles with base fluids as nanofluids achieved encouraging results by a remarkable increase in the PV/T system's overall efficiency. During the review, there is some hiatuses have noticed can summarize as follows:

- Regarding types of nanoparticles, many researchers used various nanoparticles with base fluids as nanofluids, but not all the types. It found very limited use of some types of nanoparticles, for instance, (Au, MgO, and SWCNT) nanoparticles, and other types can barely mention their use, such as (Fe_2O_3, CuO).
- The contrasts have been founding regarding improved thermophysical properties of nanofluids, which affect the system efficiency. The control by some parameters as (concentration, disperse, volume fraction, size, addition surfactants, shape) of nanoparticles, etc., leads to enhancing the properties of nanofluids and, at the same time, reducing other properties. Therefore, resulted increase the thermal efficiency, with slightly improved electrical efficiency.
- Regarding operational conditions, many of the experiments and studies conducted under the climates considered somewhat moderate in terms of weather conditions. The experiments must conduct in the hot regions when the temperature reaches 50 °C and solar radiation more than 1000W/m^2 to recognize nanofluids' behavior as a cooling fluid use with the PV/T system.

CONCLUSIONS

This review appears the potential of using nanofluids as a working fluid with the PV/T systems instead of the conventional liquids improves the hybrid PV/T system's efficiency. Several studies and researchers have used different nanofluids with different PV/T systems designs to improve performance. Most of the studies that used nanofluids have achieved encouraging results by enhancing the PV/T systems' performance. Therefore, using nanofluids as a cooling fluid will contribute to an increase in the electrical and thermal energy of the PV/T system by removing excess heat of the PV cells by cooling it, which contributes to the stability of its work and increase its productivity. Furthermore, nanofluids' thermophysical properties play an intrinsic role by enhancing nanofluids' performance, thus positively reflecting on the PV/T system performance. Other conclusions can be drawn from the review as follows:

- Rising temperatures have a significant effect on nanofluids' thermophysical properties, where both the density and viscosity of nanofluids are reduced with increasing temperature and increase with added surfactant. On the other side, nanofluids' specific heat increases with temperature increase, while the volume fraction causes a decrease in nanofluids' specific heat. Adding the surfactant quantity has a slight reduction in the thermal conductivity of nanofluid. Increase both temperature and nanoparticle concentrations lead to improve the thermal conductivity of nanofluids.
- Most of the applications have used nanofluids in the PV/T systems in two ways, either for coolant of the PV/T system and as a spectral filter or combine both. Using a certain proportion of nanoparticles leads to an increase the electrical efficiency higher than the PV system alone.
- Using metal nanoparticles with base fluids as a nanofluid leads to enhancing the PV/T system's performance in varying proportions. Some of the nanoparticles improve the PV/T system's thermal efficiency, while electrical efficiency has decreased. On the other hand, used another type of metal nanoparticles has improved both thermal and electrical efficiency. Other researchers found a better performance of the PV/T system with used metal oxide nanoparticles by control in the parameters such (volume fraction, the concentration of nanoparticles, disperse of nanoparticles, size of nanoparticles, the shape of nanoparticles, addition surfactants, etc.).
- Using combined metal and metal oxide nanoparti-

cles mixed with base fluid produces new nanofluids that have good features that enhance thermal conductivity and reduce PV cells' temperatures. Hence, improving the overall efficiency and exergy energy of the PV/T system. Moreover, use carbon-based nanoparticles mixed with a base fluid to boost the thermal and electrical efficiency of the PV/T system. Thus, it contributes by absorbing the PV's high temperature and improving the PV/T system's thermal storage.

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