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Review Article

A review on enhancement of solar photovoltaic (PV) system performance with water-based nano-fluid cooling systems

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ABSTRACT

Photovoltaic cooling systems are emerging as an interesting research area globally with the increasing demand for solar photovoltaic power generation. As the operating temperature of solar photovoltaic modules negatively impacts the efficiency of solar panels, the demand for efficient PV cooling technologies is increasing. As a result, researchers are focused on developing efficient PV solar photovoltaic cooling technologies by utilizing nanotechnology, especially using water-based nanofluids as an enhanced heat transfer fluid for solar PV cooling systems. In this review, initially, a comparative analysis of electrical efficiency enhancement was conducted between nanofluid-based PV cooling systems and other PV cooling technologies such as water spray, nanofluid cooling, floating solar systems, heat pipe type cooling systems, forced air, etc. Also, the enhancement of thermo-physical properties of water-based nanofluids was reviewed to study the applicability of different water-based nanofluids for solar photovoltaic cooling applications. This study focuses on the challenges of using nanofluids for solar photovoltaic cooling systems, such as nanofluid's stability, pressure drop, and friction factor, which are considerable obstacles when using nanofluids as the heat transfer fluid in commercial solar photovoltaic cooling systems. This study reveals the potential of nanofluid-based cooling systems to fulfill the increasing demand for high-performance cooling solutions for PV panels.

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INTRODUCTION

The recent data released by the International Energy Agency (IEA) reveals that Solar Photovoltaic (PV) power generation reached almost 1300 TWh in 2022, with a 26% increase, which is the highest generation growth among all the other renewable power generation technologies [1]. The Renewables 2022 [2], a global renewable energy status

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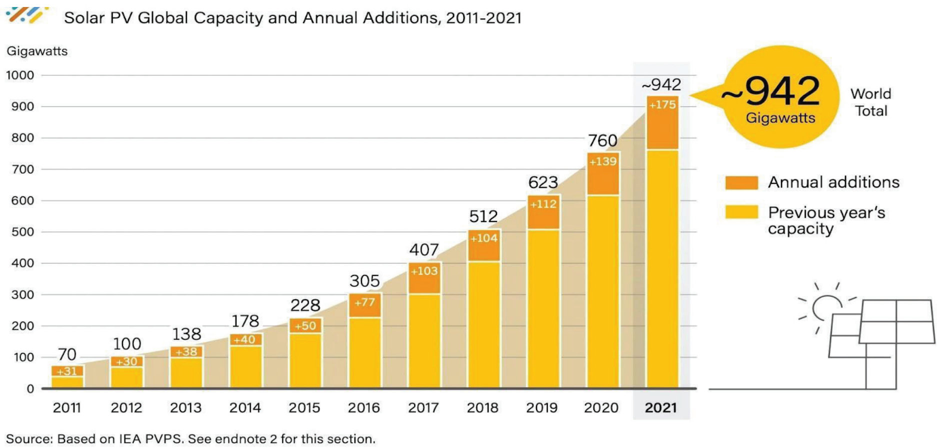

Figure 1. Solar PV annual additions [From Renewables 2022 report [2] with permission from REN21].

report, reveals that the annual additions of solar PV to the global capacity from 2011 have increased each year by a considerable percentage, as demonstrated in Figure 1.

Even though the solar PV market has maintained record-breaking growth in terms of PV global capacity each year, it accounts for less than 5% of global electricity demand. One of the main reasons for this less power generation compared to installed capacity due to the low efficiency of solar PV technology, which is a huge challenge that needs to be overcome. According to Figure 1, the total installed solar PV capacity in 2021 is 942 GW. However, as the efficiency of commercially used solar panels is lower than 20%, the impact of Solar PV electricity generation is not highlighted compared to the total global solar PV installation [3][4]. The power output of a solar system mainly depends on the solar irradiance and the solar cell operating temperature [5]. There are many environmental and installation technique-dependent factors affecting the solar cell temperature and the solar irradiance received by the panel, as illustrated in Figure 2. When considering the different types of losses associated with solar power systems, losses due to solar cell temperature account for around 36% of total losses, which is one of the major factors for low efficiency in solar PV systems [3]. An increase of 1 °C in solar panel operating temperature leads to a decrease in output power ranging from 0.4% - 0.5% [5]. As a result, solar PV cooling systems emerged as a significant requirement for solar PV systems, and numerous research studies have been conducted to control the operating temperature of PV panels.

There are several technologies used to control the temperature of solar PV panels, such as water-based cooling systems, air-based cooling systems, heat sinks, nanofluid-based

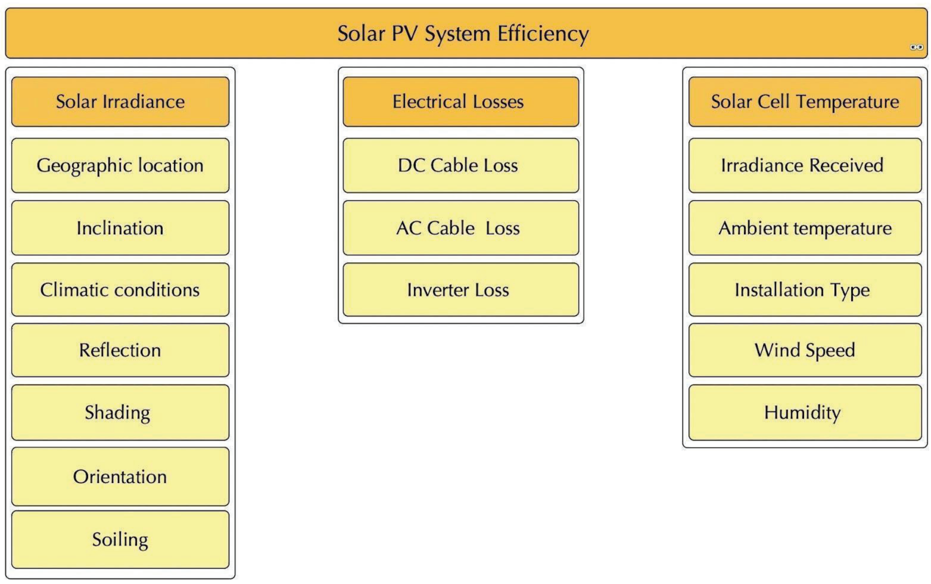

Figure 2. Factors affecting the efficiency of a solar PV system.

cooling systems, heat pipes with various heat transfer fluids, refrigerant-based cooling, evaporative cooling, etc. [6]-[8]. From these technologies, nanofluid-based cooling systems are emerging as a promising solution due to the superior thermal properties of nanofluids. In this review, the latest experimental findings of nanofluid-based solar PV technologies will be evaluated, and a comparative analysis between the existing solar PV cooling technologies and nanofluid-based solar PV cooling will be presented.

SOLAR PV PANEL COOLING TECHNOLOGIES

The temperature of the solar PV panel is one of the major deciding factors of the power output as the efficiency of the solar panel considerably decreases with the increase of operating temperature [9]-[11]. As a result, several researches have been conducted to control the operating temperature of solar PV panels. Most of these solar PV cooling systems are under research level and not commercially used due to several practical limitations such as higher capital cost, requirement of external power source, complexity in installation, etc. Several studies have been conducted on each of the solar PV cooling technologies under different experimental conditions. Apart from the cooling methods discussed in Table 01, there are several other methods, such as heat sinks-based cooling, phase change materials-based cooling, thermo-electric cooling, etc. It was observed that the majority of these cooling technologies are water-based cooling systems.

Table 1. Advantages and Disadvantages of solar PV cooling technologies

No	Solar PV cooling Technology	Advantages	Disadvantage
1.	Forced air solar type PV panel Cooling Systems. [12-15]	• Economical. • Comparatively more efficient than passive air cooling. • The cooling system design is not complex. • Hot air output can be used for HVAC systems in the buildings.	• A customized design for the cooling system is required, depending on the installation parameters. • Lower efficiency compared to other technologies. • Limited temperature control range and higher initial, operating, and maintenance costs.
2.	Water spray/ flow type solar PV panel cooling systems. [16-20]	• Cooling system design is not complex • Efficient compared to other cooling technologies • The operating and maintenance process is simple. • Reduce the soiling effect.	• A customized design for the cool system is required, depending on the installation parameters. • Waste of Water. • Difficult to utilize absorbed heat. • Increase corrosion effect on infrastructure.
3	Heat pipe/ water type solar PV panel cooling systems. [21-24]	• Simple to integrate and ability to develop as a commercial product. • High design flexibility and flow rate control. • Ability to utilize hot water for HVAC applications.	• Complex manufacturing process. • Sensitive to orientation • Expensive compared to other cooling technologies.
4.	Water immersion type PV panel cooling systems. [24-26]	• The heat is removed from both sides of the panel. • More efficient compared to other cooling technologies • Important in specific underwater applications.	• A limited number of possible applications. • Energy loss due to the reflection of light depends on the submersion depth. • Difficult to utilize absorbed heat.
5.	Floating type solar PV systems. [27-30]	• Comparatively more efficient than ground-mounted or rooftop solar PV systems. • Reduces the water evaporation. • No requirement for land for installation.	• Higher installation cost compared to ground-mounted or rooftop solar PV systems. • Financially feasible only for large-scale applications • Negatively affect the underwater plants and algae.
6.	Nanofluid based PV cooling systems [31-34]	• Efficient compared to heat pipe/ water type solar PV panel cooling systems. • Ability to adjust the properties of heat transfer fluid by varying the nanoparticle concentration, type, shape, size, etc.	• High power requirement for pumping nanofluid-based heat transfer fluids due to higher viscosity. • High cost of nanoparticles. • Possible clogging in flow channels

Table 2. Increase in power output of different PV cooling technologies

No	PV Cooling Technology	Increase in power output %	Reference
1	Forced Air	2.1 %	[13]
		2.6 %	[15]
2	Water Spray	9.5 %	[17]
		9.0 %	[18]
		18.6 %	[19]
3	Heat pipe / Water	19.45 %	[21]
		14.0 %	[22]
		18.0 %	[23]
4	Water Immersion	9.1 %	[25]
		18.7 %	[24]
		21.6 %	[26]
5	Floating Solar	4.0 %	[27]
		4.52 %	[28]
		2.59 %	[29]
		2.33%	[30]
6	Nanofluid Cooling	15.5 %	[31]
		13.0 %	[32]
		11.7 %	[33]
		12.66 %	[34]

The increase in power output of each of the technologies discussed above in Table 2 is summarized in Figure 3 below.

These technologies have clearly shown an increase in the power output of solar PV systems according to the experimental results. However, it can be observed in Figure 3 that it's not possible to come to a conclusion on the most effective cooling technology as these experiments were conducted under different conditions. And it must be noted that cooling technologies like water immersion type and forced air cooling type can only be used in special-purpose applications. There are several practical limitations and financial concerns in using many of these technologies in large-scale commercial PV systems installation methods such as ground-mounted type or rooftop type. However, it's important to characterize the performance of these technologies to develop an optimum cooling solution for solar PV panels. When observing the latest experimental results, apart from water immersion and water spray type cooling technologies, heat pipe/water type solar PV panel cooling systems are showing a higher increase in power output. A number of CFD (Computational Fluid Dynamics) studies have been conducted to study the characteristics of fluid flow through pipes [35,36]. This technology is significant because of its ability to be developed as a commercial product. With the development of nanotechnology, the efficiency of heat pipe/water-type solar PV panel cooling systems can be enhanced by replacing water with water-based nanofluids, which show better thermal properties than water.

Water Based Nano-Fluids as Heat Transfer Fluids

Enhancing the thermo-physical properties of heat transfer fluids with nanoparticles is the latest research area that is increasing in popularity. Modern cooling systems designed for advanced technological applications require efficient heat transfer mechanisms to remove the heat generated during the operation. Modern high-tech applications demand more efficient and compact cooling systems in several different industries, such as aerospace, automobile, manufacturing, power generation, manufacturing, HVAC (Heating, Ventilation, Air conditioning), medical, etc. It's important to study improving the efficiency of

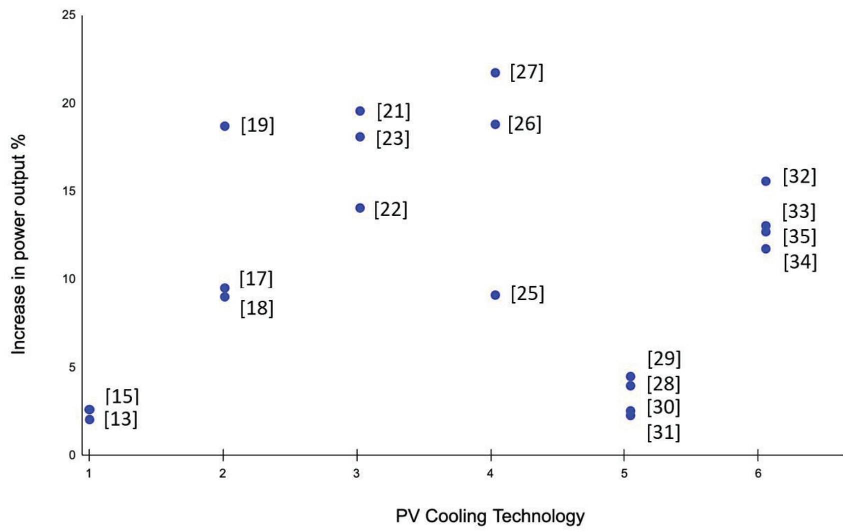

Figure 3. Increase in power output of different PV cooling technologies.

water-based cooling systems as water is the most preferred heat transfer fluid due to higher thermal conductivity and specific heat capacity. With the demand for efficient and compact thermal management systems from the industry, nanofluid-based cooling systems have gained popularity in recent years. When considering the latest research on water-based nanofluids, metal-oxide nanoparticles are most commonly used [34-42]. Also, there are recent studies on the thermo-physical properties of water-based nanofluids with carbon, metallic, polymer, ceramic, silica, and many other different types of nanoparticles [43-47]. Most of these researches have proven the ability of nanoparticles to enhance the thermo-physical properties of water, which carving the path to develop a water-based heat transfer fluid with superior thermo-physical properties.

Thermal conductivity of water-based nanofluids

The ability of water-based nanofluids to perform better thermal conductivity compared to its base fluid, water, has gained attention in several industrial heat transfer applications. The thermal conductivity of water-based nanofluids depends on a number of parameters when considering the summary of experimental results presented in Table 3, such as nanomaterial type, nanoparticle concentration in the base fluid, size and shape of the nanoparticle, nanofluid preparation techniques, nanofluid stabilization techniques, surfactant type used and concentration, temperature, etc. [37-43]. The primary objective of these research studies, summarized in Table 03, is to observe the heat transfer enhancement of water with dispersed nanoparticles. All the metal oxide/water-based nanofluids have shown an enhancement in thermal conductivity compared to water. It's observed that, even though the above studies have used water as the base fluid, they are processed differently, such as distilled water, bi-distilled water, deionized water, etc. It's difficult to come to a comparative conclusion based on these results as these experiments were done under different experimental conditions and methodologies such as nanoparticle concentrations, nanofluid preparation techniques, nanofluids stability enhancement techniques, measured temperature range, etc. But it's obvious that for all TiO_2/Water, Al_2O_3/ Water, and Fe_2O_3/Water nanofluids, the thermal conductivity has increased with the increasing volumetric concentration of the nanoparticle and with the decreasing nanoparticle size, as illustrated in Figure 04 and Figure 05 based on results from [35][42]. It can also be concluded from the experimental results that nanoparticle type and temperature have a direct relationship with the thermal conductivity of the nanofluid.

Viscosity of water-based nanofluids

Among the properties of nanofluids, viscosity stands out as a key indicator of the fluid's resistance to flow. The viscosity of nanofluids increases with the amount of volume or mass fraction of nanoparticles and decreases with the temperature increases [43]. Temperature and nanoparticle concentration are two major parameters that impact the viscosity of nanofluids [44]. For a particular requirement, there are specific and optimistic values of viscosity. Therefore, optimizing the design of a nanofluid requires a comprehensive understanding of how nanoparticles interact with the carrier fluid, including the proper selection of surfactants, stabilizers, particle size, concentration, and shape, all of which can greatly enhance the viscosity of the

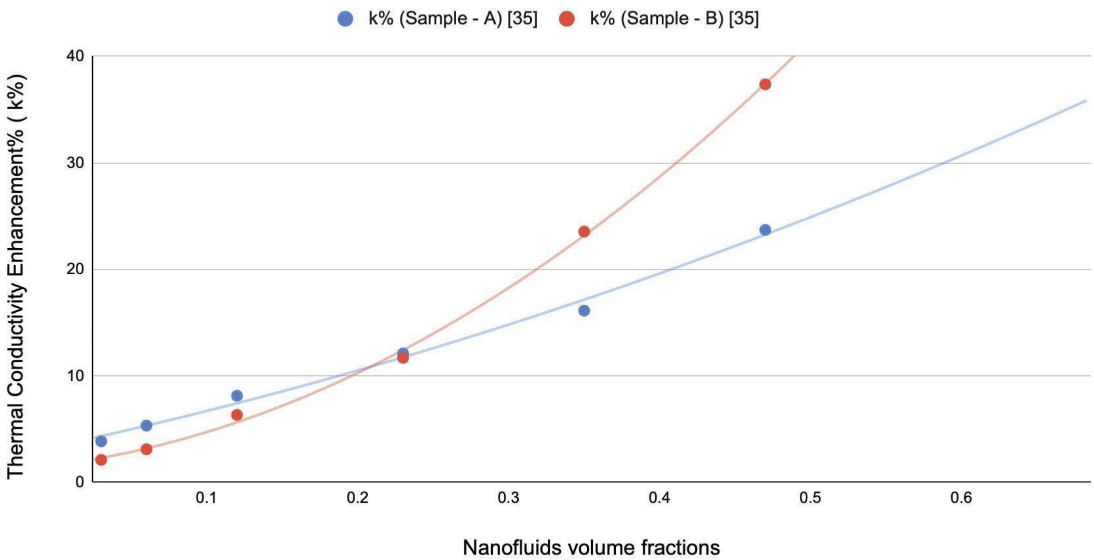

Figure 4. Thermal conductivity enhancement of nano-TiO_2/Water samples in two different temperature levels (samples A - 10 ºC, sample B - 90 ºC) (created by author).

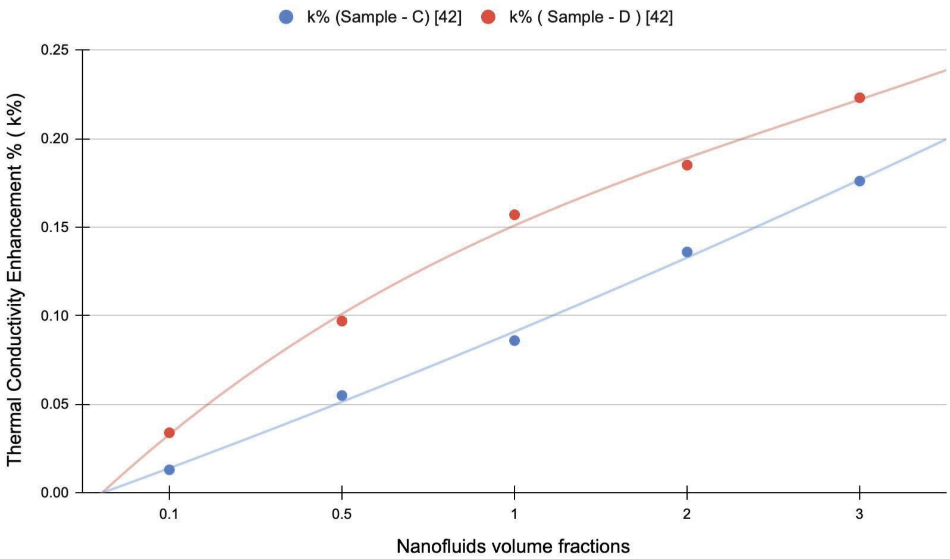

Figure 5. Thermal conductivity enhancement of nano-Al_2O_3/Water samples in two different nanoparticle sizes (sample C - 15nm, sample D - 60 nm) (created by author).

fluid. To the best of our knowledge, there are only a few recent experimental research works on the viscosity of water-based nanofluids available, and Table 4 represents the viscosity variations of water-based nanofluids, which were recently published by researchers.

Performance Enhancement of Solar PV Systems with Water-Based Nanofluids

The incorporation of nanofluids in cooling systems has become a turning point in research related to solar PV cooling applications in recent years. As a result, several studies have been conducted to control the operating temperature of PV panels using water-based nanofluids, and they have shown promising results, with considerable electrical efficiency enhancements in solar PV modules [55-61]. Some of the latest studies are summarized in Table 04. These studies are conducted under different experimental conditions where the type of solar module, geographical location, cooling method, flow rate, nanofluid type, nanoparticle volume concentration, nanoparticle size, and measuring techniques differ in each study.

Recent research studies on PV module cooling with water-based nanofluids with heat exchangers

There are several different technologies used in recent studies to use nanofluids for PV module cooling, such as tube-type heat exchanges, nano-spray, fins with nano-spray, etc. The tube-type heat exchangers arranged in the rear side of the solar PV panel were the technology used in the majority of the studies [55-58]. When observing the results of recent studies, it can be concluded that tube-type heat exchanger systems with water-based nanofluid coolants have increased the electrical efficacy of solar PV systems, and nanofluids have performed better than water as a heat transfer fluid.

Challenges to use Nanofluids for PV Cooling Applications

There are several drawbacks that we can identify within the nanofluids while applying them in solar PV applications, such as instability, pressure drop, and the changing of rheological properties.

Nanofluid instability

The instability is the main challenge that can be identified for nanofluids in solar photovoltaic cooling applications. This challenge is limited to not only solar photovoltaic applications but also a challenge for all sorts of nanofluid-based heat transfer applications. The common methods used to address this instability are a longer ultrasonication period, adding surfactants, and adjusting the pH value [62-69]. The most widely used methods to evaluate the stability are zeta-potential measurement, UV spectroscopy analysis, and sedimentation analysis. Table 06 summarizes the outcome of some research that recently analyzed the stability of water-based nanofluids. It's very important to consider this challenge as it will be a major obstacle to using water-based nanofluids in solar PV cooling systems. It can be observed that the water-based nanofluid preparation method and the use of surfactants have a great influence on the stability of the nanofluid. Most of the research has used zeta potential analysis and visual inspection to measure the stability of nanofluids [68,69].

Nanofluid pressure drop

The use of coolant or water has to maintain a considerable level of pressure for the cooling process of the solar PV systems. However, the use of nanoparticles might cause a

Table 3. A summary of recent studies on thermal conductivity of metal oxide/water nanofluids

Researcher & Reference	Nanoparticle and volume concentration	Nanoparticle Characterization technique	Size of nanoparticles	Preparation and Stability enhancement techniques	Method of measurement	Thermal Conductivity Enhancement %
Salem Abdel-Samad et al. [34]	$Ti0_2$ / Water 0.03 *vol%*, 0.06 *vol%*, 0.12 *vol%*, 0.23 *vol%*, 0.35 *vol%* and 0.4 *vol%*	Transmission electron microscopy (TEM) X-ray Powder Diffraction (XRD)	12 nm (mean)	Nano $Ti0_2$ Synthesized by Sol-gel Technique (20 min) Sonication by ultrasonic bath at 50 ^{0}C (120 minutes)	A modified transient hot-wire method	A maximum of 37.35 % thermal conductivity enhancement was observed at 90°C for a volume fraction of 0.47%
Dong-sheng Wen et al. [37]	$Ti0_2$ / Distilled Water 0.29 *vol%*, 0.41*vol%*, 0.53 *vol%*, 0.68 *vol%*	Scanning electron microscope (SEM)	34 nm (mean)	No surfactant was used. Mixing is done using a high-shear homogenizer at 24000 rpm.	Transient hot-wire method	A maximum thermal conductivity enhancement of 6.3 % was observed for 0.68 *vol%*.
Laura Colla et al. [38]	Fe_2O_3 / Bi-distilled Water 0.99 *vol%*, 2.08 *vol%*, 4.55 *vol%*	Dynamic light scattering (DLS)	67 nm (mean)	Sonication by ultrasonic bath (60 min)	Hot-disk technique	A maximum of 15 % thermal conductivity enhancement was observed at 70°C for a volume fraction of 4.55 *vol%*.
Zoulia N.I et al. [39]	Fe_2O_3 / deionized Water 0.01 *vol%*, 0.02 *vol%* 0.05 *vol%*, 0.09 *vol%*	X-ray Powder Diffraction (XRD)	20 - 40 nm	Prepared using the two-step method. Mixing is done using a digital homogenizer at 5000 rpm (45 min)	Transient hot-wire method	A maximum of 23 % thermal conductivity enhancement was observed for a volume fraction of 0.09%
Yogesh Kokate et al. [41]	Al_2O_3/ Distilled Water 0.1 *vol%*, 0.5 *vol%*1.0 *vol%*, 2.0 *vol%*,3.0 *vol%*	-	15 nm(mean)	Prepared using the two-step method. Sonication by ultrasonic vibrator.	Transient hot-wire method	The thermal conductivity enhancements of 3.4%, 9.7%, 15.7%, 18.5%,22.3% were observed for 0.1 *vol%*, 0.5 *vol%*,1.0 *vol%*, 2.0 *vol%*, 3.0 *vol%*.
Yogesh Kokate et al. [41]	Al_2O_3/ Distilled Water 0.1 *vol%*, 0.5 *vol%* ,1.0 *vol%*, 2.0 *vol%*, 3.0 *vol%*	-	60 nm(mean)	Prepared using the two-step method. Sonication by ultrasonic vibrator.	Transient hot-wire method	Thermal conductivity enhancements of 1.31%, 5.5%, 8.6%,13.6%, 17.6%, were observed for 0.1 *vol%*, 0.5 *vol%* ,1.0 *vol%*, 2.0 *vol%*, 3.0 *vol%*.
Mohammed Saad Kamel et al. [42]	Al_2O_3 / deionized Water 0.01 - 0.5 *vol%*	-	20 nm	Prepared using the two-step method. Stirring (1 hour) Sonication by ultrasonic vibrator for 45 minutes.	Transient plane heat source sensor (SKZ1061)	The maximum thermal conductivity enhancement of 5.34% was observed in 0.5 *vol% sample* at 50 °C.

Table 4. A summary of recent studies on the viscosity of water-based nanofluids

Researcher & Reference	Nanoparticle and volume concentration	Nanoparticle Characterization technique	Size of nanoparticles	Preparation and Stability enhancement techniques	Method of measurement	Viscosity variation
Ali Vakilinejad et al. [50]	Al_2O_3 & TiO2 0.01% - 0.04% wt.% 298-338 K	XRD, SEM Nano dynamic light scattering (DLS) particle size analyzer	50 nm & 80-120 nm	Two-step method: Stirred for 1 hour and sonicated 40 mins and again stirred and sonicated three times at 15 15-minute intervals	capillary viscometer size 50	The viscosity ratio decreased when increasing the mass fraction, and the viscosity ratio increased as the temperature increased for the same mass fraction.
Ali Vakilinejad et al. [50]	Graphene 0.05, 0.25, 0.5, 0.75, 1 wt.% 298-338 K	XRD SEM Nano dynamic light scattering (DLS) particle size analyzer	900 nm	Two-step method: Stir for 1 hour and sonicate for 40 mins. Again, stir and sonicate three times at 15-minute intervals.	Capillary viscometer size 50	The viscosity ratio increased when increasing the mass fraction, and the viscosity ratio decreased as the temperature increased for the same mass fraction.
K. S. Pavithra et al. [51]	ZnO 0.5-3 % vol.%	UV, FESEM, TEM, XRD, FTIR, NMR, TGA	70—100 nm	Two-step method. Dispersants were used to increase the stability	Brookfield Viscometer	Viscosity increases with an increase in volume fraction and decreases as the shear rate increases for the same volume fraction.
Solomon O. Giwa et al. [52]	MWCNT-Fe_2O_3 (80:20) 0.1-1.5 vol.%	TEM	MWCNT : length: 10-30μm, outer diameter: 10-20 nm, inner diameter: 3-5 nm Fe_2O_3 :20-30 nm	Two-step method. The pH and electrical conductivity of the formulated MWCNT-Fe_2O_3/DIW nanofluids were monitored while SDS amounts. Sonication time of 120 min using a dispersion fraction of 0.5.	Vibro—viscometer (SV-10; A&D, Tokyo, Japan; with ±3% accuracy)	35.7% increased
A. N. Payzullaev et al. [53]	SiO_2 0.5 and 3 wt.% At 304 K	spectral analysis, electron microscopy, dynamic scattering of light, and visual observation	12 nm	Two-step method. ζ-potential analysis, used ultrasonic disperser operating at 100 W and 22 kHz for 20 min	Relative technique in an instrument calibrated using a liquid of known viscosity	3 wt.% added nanofluids viscosity 39% increased relatively to the 0.5 wt.% added nanofluid
S. Ramesh Krishnan et al. [54]	Al_2O_3 and CuO	—	—	One-step method Surfactants were used to enhance the stability	Modular compact rheometer	Viscosity increases with an increase in volume fraction and decreases as the temperature increases for the same volume fraction.

Table 5. Summary of recent research studies conducted on water-based nanofluid cooling for PV modules

Researcher & Reference	Solar PV module / Experimental setup details	Location	Cooling Method / Flow rate	Nanoparticle type, size, and volume concentration of water-based nanofluid	Method of measurement	Electrical efficiency of the PV system % / Results
SK. Fakruddin Babavali et al. [55]	Two identical setups with 300 W solar PV panels. Nanofluid circulation through heat tubes on the rear side of one setup.	GPS coordinates: *16° 30' 54.3564" N and 80° 37' 55.5420" E*	A tube heat exchanger system is arranged on the rear side of the PV panel. Flow rate: 0.05 L/s	MgO nanoparticles with 50 nm particle size, 0.5 vol% concentration	Thermocouples Solar intensity sensors Multimeter	Electrical efficiency enhancement of 16.9 %with nanofluid cooling.
Talib K. Murtadha [56]	Three monocrystalline 50W solar photovoltaic (PV) modules were used, south faced with a 30^0 tilt angle.	GPS coordinates: *31.09262°' 33" N and 35.71708° 35° 43' 2"E*	Tube heat exchanger system arranged on the rear side of the PV panel Flow rate: 0.5-3L/min	Al_2O_3 / TiO_2 hybrid nanofluid with Al_2O_3 - 55 nm and TiO_2 - 28 nm particle sizes with 2 wt.% concentration (Al_2O_3 50%: TiO_2 50%)	Thermocouples Flowmeter TM - 206 Solar power meter Mini Anemometer DT-90	Without cooling: 17.54 % Water cooling: 17.97 % Nanofluid cooling: 19.23%
Ismail Hossain et al. [57]	Two monocrystalline 50W solar photovoltaic (PV) modules were used.	-	Tube heat exchanger system arranged on the rear side of the PV panel Flow rate: 2L/min	TiO_2 nanoparticles with 0.2 wt. % concentration.	TES-132 solar power meter DS18-B20 thermal sensors	Nanofluid cooling: 6.12%
Talib Murtadha [58]	Five monocrystalline 50W solar photovoltaic (PV) modules were used, with a 30^0-tilt angle.	GPS coordinates: *31.09262° ' 33" N and 35.71708° 35° 43' 2"E*	Tube heat exchanger system arranged on the rear side of the PV panel with a copper plate Flow rate:0.8-1.6 L/min	Al_2O_3 nanoparticles with 55 nm particle size, 1 wt. %, 2 wt. %, and 3 wt. % concentrations	Thermocouples Flowmeter TM - 206 Solar power meter Mini Anemometer DT-90	Without cooling: 18.5 % Nanofluid cooling: 20.2 %
Mohammad Javidan et al. [59]	A 10W polycrystalline silicon solar panel is arranged in an indoor setting under the light of metal halide lamps.	Indoor setup	A jet collision system is used to strike fluid to the rear part of the module. Flow rate: 0.14 kg/s	SiC nanoparticles with 45 - 60 nm particle size,0.25, 0.5, 0.75, 1, and 1.1 wt.% concentrations	Thermocouples Lutron, BTM-4208SD - Thermometer Pyranometer - Tes1333R	The surface temperature of the panel decreased by 7.3^0C

Table 6. Summary of recent research studies conducted on water-based nanofluid stability.

Researcher & Reference	Nanofluid (Surfactant)	Concentration	Stability Analysis Method	Methodology	Results
Asadi A et al. [62]	MWCNT-Water	0.1, 0.3, 0.5 vol. %	Visual inspection Zeta Potential	The stability was measured on days 1, 5, 10, and 30 for different ultrasonication times from 10 to 60 minutes.	No considerable effect from the ultrasonication time.
Choudhary S et al. [63]	MgO-Water (CTAB)	0.08, 0.2, 0.4 vol.%	Zeta Potential UV-visible absorption	The zeta potential has been measured for up to 15 days.	-
Adam, S. A et al. [64]	SiO_2-Water	0.0011 to 0.0367 vol. %	UV-Visible spectroscopy	Sonication was done at 25 and 50 °C. Higher stability was obtained at 25 °C.	Prepared nanofluids were stable at higher temperatures.
Sharaf, O. Z. et al. [65]	Citrate and Polyethylene coated glycol coated gold particles–gold nanoparticles with deionized water	0.0358 to 0.3580 mg/ mL^{-1}	UV-Visible spectroscopy STEM micrograph	-	The chemical and collide stability of the nanofluid samples was verified for 16 months.
Choi, T. J et al. [66]	MWCNT with Di-ionized water (SDBS, CTAB SDS, TX-100)	0.0005 - 0.002 vol. %	TEM UV-Visible spectroscopy	The stability measurements were carried out for 3 different parameters: i) Short time (3h), ii) Long time (one month), iii) Higher temperature (85 °C), Low temperature (10 °C)	i) SDBS, CTAB, and TX-100 show better stability ii) SDBS and the TX-100 show the best stability iii) The SDBS, CTAB, and SDS nanofluids were not affected by the higher temperature, and TX-100 stability decreased rapidly with the higher temperature. iv) CTAB and SDS show precipitation.
Abdelrazik, A. S et al. [67]	rGO decorated Ag with Water (SDBS)	0.0005 - 0.05 wt%	Visual inspection UV-Visible spectroscopy UV-Visible transmittance	The visual inspection was conducted for 14 days, UV-visible was measured for 7 days, and Spectral transmission measurement was measured for 7 days.	High stability is observed for one complete day, and a slow rate of stability degradation with time has been observed through the visual aspect.
Abdelrazik, A. S. et al. [68]	MXene (Ti_3C_2)-Water (CTAB, SDBS)	0.0005–0.05 wt. %	Visual inspection Zeta Potential UV-Visible spectroscopy Spectral transmittance	The visual inspection, UV-visible analysis, and the Spectral transmittance were conducted over 7 days.	Nanofluid samples prepared using the CTAB surfactant are more stable at higher concentrations. At lower concentrations, the samples prepared using the SDBS were more stable.
Murtadha, T. K. et al. [69]	MXene (Ti_3C_2)-Water	0.05 – 0.2 wt. %	Zeta Potential	Zeta potential analyses were conducted for three different temperatures (25, 45, 60 °C)	The nanofluid samples exhibit better stability at higher temperatures.

Table 7. Summary of recent research studies conducted on the pressure drop of water-based nanofluid.

Researcher & Reference	Nanofluid	Concentration	Remarks	Maximum Pressure Drop
Karaaslan, I. et al. [70]	CuO + Fe / Water CuO/Water	CuO + Fe (1 wt.% + 1 wt. %) CuO (2 wt.%)	The pressure drop was measured from 0.02 m/s to 0.08 m/s fluid velocity	Base fluid – 162.08 Pa CuO Nanofluid – 172.2 Pa CuO + Fe Nanofluid – 214.78 Pa
Motamedi, M et al. [71]	Ag-SiO_2/Water	0.026 wt. %	The experiment was conducted using a micro channel system. The pressure drop was obtained by using the Poiseuille number versus Reynolds number graph, from 20 to 60 Reynolds value.	Water-17 % Nanofluid-19% (All the values are given compared to a smooth surface)
Bianco, V. et al. [72]	Al_2O_3/Water	0 – 6 vol. %	The analysis was carried out for two different nanoparticle diameters, 20 nm and 40 nm. Also, for two different temperatures, 293.15 K and 323 K, with 250, 500, and 1000 Reynolds numbers.	The highest pressure drop was observed for 20 nm diameter, 293.15 K at 250 Reynolds number.
Sarafraz, M et al. [73]	Graphene Nanoplatelet /Water	0 – 0.1 wt. %	The pressure drop was measured for the 250 to 1400 Reynolds number at the 303 K temperature.	18.3% at the highest concentration and the highest Reynolds number
Adun, H et al. [74]	Al_2O_3-ZnO /Water CuO-MgO-TiO_2/ Water	0.001 & 0.01 v/v %	The pressure drop was measured from 0.005 to 0.01 v/v% and 0.005 to 0.01 kg/s fluid flow rate. The pressure drop shows a linear relation with the fluid flow rate.	Al_2O_3-ZnO-Water (0.01 v/v %): 8.6 Pa CuO-MgO-TiO_2-Water (0.01 v/v %): 6.7 Pa Approximately at 0.01 kg/s flow rate.
Hozien, O et al. [75]	Ag/Water ZnO/Water TiO_2/Water	(0.25v/v%)	A customized experimental setup was used to measure and control the nanofluid's pressure drop. Pressure drops for each nanofluid were measured for different coil pitches (2cm, 4cm, 6 cm, 8cm, and 10cm) and different inlet temperatures.	Ag/water, ZnO/water, and TiO2/water nanofluids resulted in an increase in pressure drop (average), respectively, 25.4%, 23.5%, and 28.5%.

Table 8. Summary of recent research studies conducted on the friction factor of water-based nanofluid.

Researcher & Reference	Nanoparticle	Nanoparticle concentration	Methodology	Results
Ebaid, Munzer. S. Y. et al. [76]	TiO_2/Water Al_2O_3/Water	0.01 wt.% 0.05 wt.% 0.1 wt.%	The friction factor was plotted with respect to the Reynolds number at different flow rates for TiO_2 and Al_2O_3 nanofluids for 0.1 wt. %, 0.01 wt. %, 0.05 wt. % concentration.	The variation of friction factor with respect to the Reynolds number for all water, TiO2/Water, and Al_2O_3/Water nanofluids looks similar.
Hormozi Moghaddam [77]	MWCNT/ Water Ag/MgO/Water (Hybrid nanofluid)	0.0 to 2.0 v/v %	The friction factor was measured for different volume fractions and channel heights for both nanofluid samples.	Water: 5.28, MWCNT/Water: 13.84, Ag/MgO/Water: 6.51 at 2 v/v %. At a flow rate of 8L/h with a channel height of 10 mm, the friction factor of CNT/Water nanofluids is 62% higher than that of water and 53% higher than that of hybrid nanofluids.
Bhattacharyya, S [78]	Fe_3O_4 - TiO_2/ Water (Hybrid nanofluid)	1.0 v/v %	The friction factor was observed with Reynolds number with different magnet field strengths.	The variation of friction factor of the nanofluid presented with different magnetic field strengths.

drop in the pressure level of the cooling system. The pressure drop depends on several factors of the nanofluid samples, such as other important thermo-physical properties. To overcome this problem, the cooling system must provide additional power to the fluid flow through pumps. This will increase the manufacturing cost and the operating cost of the nanofluid-based cooling system. There are a number of recent studies conducted related to pressure drops following an experimental procedure that have identified several parameters that affect the pressure drops of water-based nanofluids, which are summarized in Table 7 [70-75]. It has been identified that pressure drop has a linear relationship with the nanofluids flow rate, and pressure drop varies with nanoparticle size and temperature [72-74].

Nanofluid friction factor

The friction factor of nanofluids is a dimensionless quantity that represents the resistance to fluid flow. It is an important parameter in the study of nanofluids; this parameter changes with the nanofluid type due to the interaction between the nanoparticle type and fluid type. The increment of the friction factor causes an increase in the pumping power requirement of the nanofluid-based cooling system. It's a very important parameter when designing cooling systems that use water-based nanofluids as heat transfer fluid for solar PV cooling applications. There are several researchers who have studied the friction factor of nanofluids in solar PV system applications [76]-[78].

CONCLUSION

This study reviewed different types of solar PV cooling technologies considering the electrical efficiency based on the results obtained in the most recent research. Among these technologies, nanofluid-based closed-loop cooling systems can be identified as promising PV panel cooling system technology that shows a higher increase in power output and has comparatively fewer practical obstacles for installation. Also, this study reviewed the possibility of using water-based nanofluids as a coolant liquid for PV cooling systems, reviewing different thermo-physical properties of different water-based nanofluids. The following conclusions can be made from the above study,

- Water-based active cooling systems for PV modules, such as water spraying, heat pipe/water type, and heat pipe/nanofluid type cooling systems, show comparatively higher efficiencies and fewer practical obstacles when applied to industrial PV power plants.
- Water-based nanofluids can be used as an improved alternative to water in heat pipe/water-type PV cooling systems, as water-based nanofluids have better thermo-physical properties than water.
- The majority of research for water-based nanofluids is conducted on metal oxides, which shows a considerable thermal conductivity increase with the volumetric concentration of the nanoparticle and nanoparticle type, and the operating temperature has a direct relationship with the thermal conductivity of the water-based nanofluid.
- The viscosity of water-based nanofluids increases with the volumetric concentration of the nanoparticle, which is an obstacle that has to be overcome when using water-based nanofluids as the heat transfer fluid in PV cooling systems as the power requirement of the cooling system operation will be increased.
- The water-based nanofluids demonstrated better stability with surfactants and at high-temperature levels.
- The water-based nanofluids show an increased pressure drop and an increased friction factor, which is a considerable drawback for solar PV systems that use nanofluids as heat transfer fluid.

Water-based nanofluids can be considered a successful solution for the higher demand for more efficient cooling systems for various applications with the development of science and technology. These research studies will develop the most optimized water-based heat transfer fluid with modern nanotechnology.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

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