Current and Future Challenges of Nanomaterials in Solar Energy Desalination Systems in Last Decade

***Trupti S. Gajbhiye*[1], *Sagar D. Shelare*[2*], *and Kapil R. Aglawe*[3]**

[1]Electrical Engineering Department, G H Raisoni Institute of Engineering and Technology, Nagpur, Maharashtra– 440028, India.

[2]Mechanical Engineering Department, Priyadarshini College of Engineering, Nagpur, Maharashtra-440019, India

[3]Mechanical Engineering Department, Priyadarshini College of Engineering, Nagpur, Maharashtra-440019, India.

[*]Sagar D. Shelare; sagmech24@gmail.com

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Renewable energy plays key role in developing any nation. Freshwater is sometimes hard to get to in places far aside or poor. Because of this, it is essential to have a cheap and effective desalination system that helps these communities grow and helps society as a whole. For example, the development of nanotechnology could help solve water problems by making it easier to get rid of viruses, bacteria, and other contaminants and lowering the cost of purification processes. Desalination is a process that uses a lot of energy and is responsible for most of the costs of running the plant. Also, a lot of the power comes from greenhouse gas emissions and traditional fossil-fuel-fired power plants, which pose a severe danger to the ecosystem. In the last few years, many studies have been done on the use of nanotechnology in desalination, the treatment of brine, and the role of renewable energy in desalination. The main goal of this paper is to look at the most important new developments in desalination nanotechnology with respect to energy. Some conclusions and suggestions for future research are made based on the progress and problems that still need to be solved.

Keywords: Water productivity; Nanoparticles; Nanofluids; Solar distillation systems Performance; Solar energy.

1 Introduction

Energy is one of the primary foundations supporting evolutionary changes [1]. Increases in both developed and developing nation's economies have led to higher living standards and, in turn, greater demand for energy during the past few decades. An ever-increasing global population and the ever-increasing energy demands of contemporary society have boosted the demand for alternative power sources [2]. Conventional

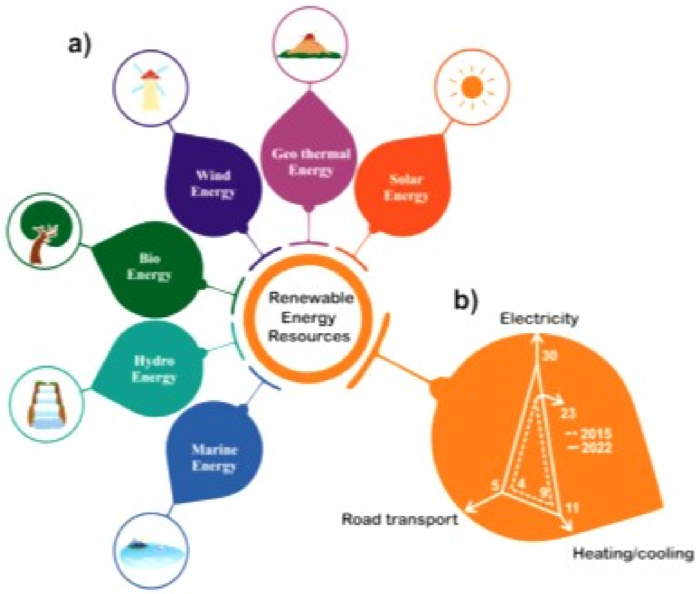

Figure 1: *(a) Multiple renewable energy sources (b) significance of renewable sources of energy to road transport, heating/cooling, and electricity generation.*

primary energy generating techniques (such as burning fossil fuels) must be replaced with low-emission alternatives if the Paris Agreement 2°C global warming target is to be fulfilled. Fig. 1(a) depicts the relationship between electricity, heating/cooling, transportation energy use, and the use of renewable energy sources. Solar energy, wind energy, geothermal energy, marine energy, hydro energy, and bioenergy are the six main types of renewable energy [3]. Global power consumption dropped significantly as a result of the Covid-19 crisis as a result of restrictions on freedom of travel, shutdowns, and economic slowdown. Renewable energy sources such as geothermal, hydropower, sun, wind, and biomass can provide sustainable energy services based on the usage of indigenous, habitually accessible resources [4]. As the cost of renewable energy sources decreases and oil and natural gas prices continue to vary, a transition to renewable energy sources becomes highly probable [5]. For reasons such as energy security, access to cheap energy supplies, power greenhouse gas emissions, etc., it is relevant to evaluate the potential worldwide contribution of renewables to long-term energy demand [6]. In the past three decades, fossil fuel and renewable energy prices, as well as environmental and social costs, have been trending in different directions, and the political and financial mechanisms required to sustain the widely dissemination of and sustainable marketplaces for renewable energies are continually developing [7]. In April 2020, the United States saw a decrease of 5% in its electricity usage from April 2019, while Germany saw a decrease of 12%, Spain saw a decrease of 18%, and India saw a decrease of 23%. As can be seen in Fig. 1 (b), it is predicted that by 2022, the share of electrical energy supplied by renewable sources would rise to as much as 30%. In addition, by 2025, renewable energy sources will have contributed to 95 percent of the net expansion in global power capacity [8].

The advent of produced materials at the nanoscale scale is largely attributable to the development of cutting-edge scientific methods. Nanoparticles has played a significant role in the development of superior heat exchange fluids for a variety of industrial applications because of their exceptional properties. Argonne National Laboratory (ANL) in the United States introduces the concept of a "Nanofluid" [9]. Water, engine oil, ethylene glycol, and refrigerants are all examples of common base liquids that may be used to create nanofluids with the addition of nanoscaled solid particle auxiliaries. Because it allows for more efficient heating and cooling processes, this extraordinary breakthrough in nanoscale research is a tool for improving heat transfer in fluids. Indeed, many studies, some of which will be discussed here, have shown

Table 1: Organization of overall desalination technologies.

Desalination Process	Energy utilized	Phase	Technologies
	Electrical and Thermal	Phase Change	Formation and Freezing of Hydrates (Solid/Liquid)
Evaporation	Mechanical	Phase Change	Mechanical Vapour Compression (MVC) (Gas/Liquid)
Evaporation	Electrical and Thermal	Phase Change	Solar distillation, Ocean Thermal Energy Conversion (OTEC), Thermal Vapour Compression (TVC), Multi-Effect Distillation (MED), Multi-Stage Flash (MSF) (Gas/Liquid)
Evaporation and filtration	Electrical and Thermal	Phase Change	Membrane Distillation (MD)
Exchange	Chemical	Single Phase	Extraction and Ion Exchange (IX) (Electrochemical separation)
Filtration	Mechanical	Single Phase	Nanofiltration and Reverse Osmosis
Selective filtration	Electrical	Single Phase	Electro Dialysis (ED)

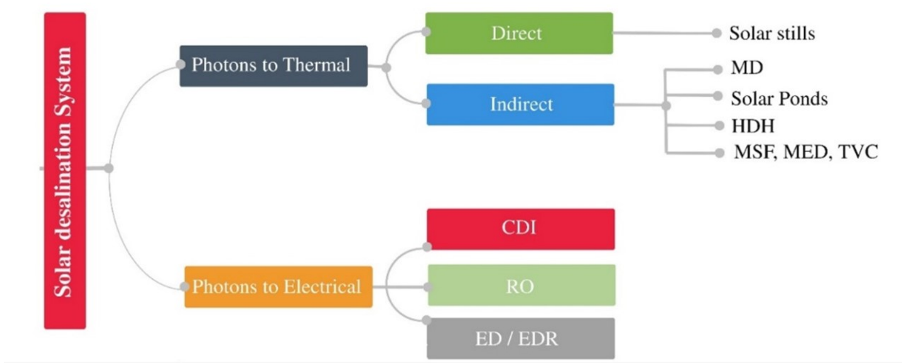

Figure 2: *Organization of solar water desalination methods.*

convincingly that the presence of nanofluids may plainly contribute to reducing the system size, design flexibility, and compact size [10].

Single-phase and phase change procedures are the two main types of desalination technologies [11]. Techniques that include a phase transition—from solid to gas, liquid to gas, or liquid to solid—are grouped below the umbrella term "phase change," as the name suggests. The latest desalination methods are categorized in Table 1 according to the separation mechanisms and energy utilization procedures that they employ. Desalination techniques that rely on evaporation or crystallisation experience a phase change.

Decentralized freshwater needs are met by solar distillation units, which are commonly divided into direct and indirect processes (Figure 2).

In places far from civilization where regular sources of energy, such as running water, are scarce, solar desalination systems have become increasingly popular. The most significant drawbacks of solar desalination systems are their bulkiness and inability to be moved easily. Unfortunately, the absorber and glass cover sizes often seen in domestic solar desalination systems are too tiny to maximize freshwater output or plant efficiency. The pace at which water is produced from the sun in a solar distillation unit depends mostly on the strength of the sun's rays. Using solar desalination systems can help make up for

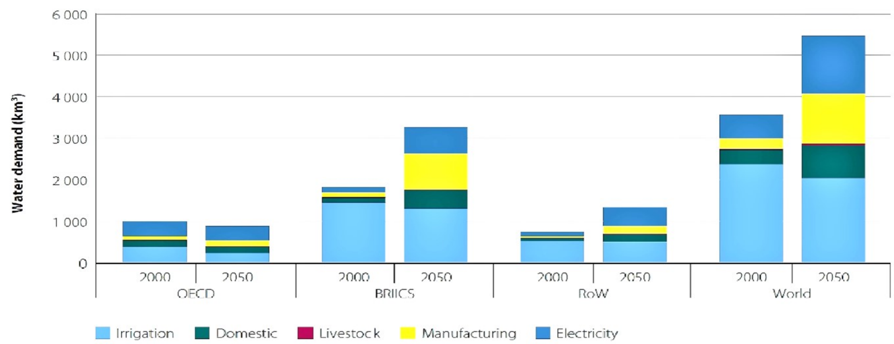

Figure 3: *Demand of freshwater worldwide: baseline scenario, 2000 and 2050 [16]. (BRIICS: Brazil, Russia, India, China and South Africa; ROW: Rest of the World; OECD: Organization for Economic Co-operation and Development).*

the shortage of freshwater in arid places with high sun intensity and high temperatures, such as South Africa, Saudi Arabia, and the Middle East [12]. The effectiveness of solar desalination systems relies upon the evaporation of water and moisture via glass top cover [13]. Increased output may result from the large temperature difference between condensation and evaporation zones. Multiple factors, including solar desalination system water geometry, absorber material, water depth, and insulation thickness and material, might impact the water production rate [14]. Additionally, the water temperature can be raised by using nanoparticles, thermoelectric heating, Photovoltaic/Thermal, a solar collector or a phase change material; additionally, the condensation rate can be enhanced by utilizing thermoelectric cooling, water/air glass cooling, or an external condenser [15].

The goal of providing drinkable water to every person on Earth requires a significant increase in seawater desalination capacity. Figure 3 depicts this increase by comparing freshwater demand across industries from the years 2000 to 2050. Physical water shortage may be separated from the more economical forms of water scarcity. When it becomes too expensive to draw clean water from current sources, we have a situation known as economic water scarcity. Calculations of water stress for a number of nations suggest that it is worst in Northern Africa (at 112.2%), next in Central Asia (79%), and finally Melanesia, Micronesia, and Polynesia (together, 0.1%).

Nanofluids, a novel class through enhanced thermophysical characteristics introduced by Choi and Eastman have opened up opportunities to boost the thermal performance of various systems. Numerous studies have looked at multiple aspects of nanofluids, including their manufacturing techniques, dynamic viscosity, thermal conductivity, machine learning applications for forecasting thermophysical parameters, and heat transfer performance. Many review articles have been written to describe the developments in this emerging topic [17]–[19]. Heat transfer rates in many types of energy systems can be improved by using nanomaterials. Solar desalination systems have also made use of a variety of nanoparticles to boost efficiency [20].

To speed up the water-making process, some researchers have tried mixing nanoparticles with pure fluid. Through modifications to the fluid's physical characteristics, nanoparticles can combine with the pure fluid and accelerate evaporation heat transfer in the solar desalination system. Alternate nanoparticle application strategies that boost condensation and evaporation include incorporating nanoparticles into a coating of a glass cover and mixing nanoparticles with absorber paint. Evaporation is increased when nano-coating is combined with absorber paint, and condensation is improved when nano-coating is applied to a glass cover. Other nano-techniques have improved water production in the face of low solar intensity by increasing a heat transfer rate by the addition of nanoparticles to phase changer material. Researchers have evaluated nanofluids in a solar desalination system, researched their effects in a solar desalination system, and found that utilizing them increases mass transfer and heat [21].

This manuscript aims to examine the development of nanofluids for water desalination with solar energy during the past decade. This evaluation fills in a blank left by other studies by focusing on the relationship between NP characteristics and performance. The mechanism of energy transmission between NPs is the central focus of this discussion. The function of NFs as heat carriers and its impact on desalination system efficiency will then be the primary topic of the following discussion. The NF's composition will also be investigated in order to investigate its bearing on desalination system efficiency. After discussing the relevant NFs and design adjustments, we will move on to the obstacles and research problem.

2 Various Nanomaterials in Solar Energy Desalination System

The efficiency of a solar distillation unit for producing water may be improved with the use of various nanoparticles. Solar desalination system nanomaterials are depicted in Figure 4.

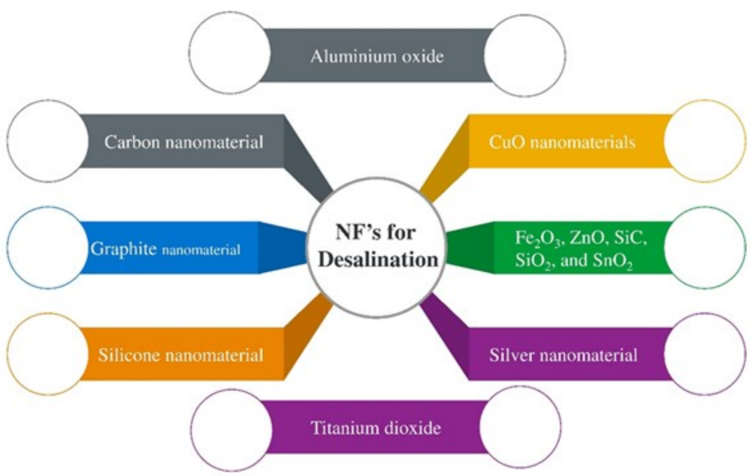

Figure 4: *Various nanomaterials used in the solar energy desalination system.*

2.1 Al_2O_3 in Solar Desalination System

Kabeel et al. investigated the effects of Al_2O_3-water nanofluids on single-slope solar performance and the role of an external condenser [22]. Rates of Production Water 76% and 116% were reported while employing nanofluid with and without an external condenser, respectively. Muraleedharan et al. looked at improved solar desalination unit that included a heat exchanger, an evacuated tube, and a Frensel lens concentrator [23]. Therminol-55 has 0.1% Al_2O_3 added to it in order to rise its heat transfer efficiency in the heat exchanger loop. Outcomes of experiments suggest that the water production rate of the modified solar desalination system is approximately 3.5 times higher than that of traditional distillation units. Karthikeyan et al. studied the efficiency of nine distinct solar desalination system designs, each of which made use of a unique combination of absorber materials [24]. As absorber material, the solar desalination system made use of a glass ball. Al_2O_3 nanoparticles, in comparison to other absorber materials, had the highest productivity. Al_2O_3 nanoparticles and gravels, respectively, increased freshwater output by around three and two and a half times additional compared to the material absorber.

When compared to a solar desalination system without Al_2O_3 nanoparticles and PCM, authors found that the efficiency of water of FWCW and CW absorber materials utilizing these additives increased by 56.7% and 79.3%, respectively. The impact of incorporating Al_2O_3 nanoparticles into the black paint and solar distillation units base fluid was investigated [25]. The water temperature and rate of evaporation rose with both approaches. Al_2O_3 nano-coated and nano-fluid increased solar desalination system water production by around 24.3%, as shown by the output data. The efficiency of a mixture of Al_2O_3 nanoparticles and PCM in a single slope solar distillation unit was evaluated by the authors. Through the use of Al_2O_3 nanoparticles-PCM, they demonstrated the efficiency of solar desalination systems equivalent to 45%. Using nano-coated and nanofluid techniques together can have a significant effect on water evaporation and productivity.

2.2 Carbon Nanomaterial in Solar Desalination System

Arora et al., analyzed the efficiency of different photovoltaic/thermal systems that used SWCNT and MWCNT nanoparticles in water [26]. At a 1% concentration of nanoparticles, the component temperatures, heat transfer coefficient, and Nusselt number were studied in a modified solar desalination system. Water was heated using a PV/T-CPC system connected to a helically coiled heat exchanger. The sun desalination system produced 65.7% and 28.1% more water, respectively, as shown by the results. Sharshir et al. improved water output of a stepped double solar still. Findings revealed that using CBN nanoparticles and LW increased solar desalination system freshwater output by approximately 110.5%, and 80.57% respectively [27]. The thermo-physical effects of Al2O3-water and MWCNT-water nanofluids in a double-slope conventional solar distillation unit were studied by Sahota. In order to maximize the efficiency of the solar desalination system, the suggested thermal model was used to generate optimal concentrations of nanofluids of 0.12%, 0.08%, and 0.04%. Specifically, they discovered that the water productivity increased by 58.1% and 52.1%.

2.3 CuO Nanomaterials in Solar Energy Desalination System

Nazari et al. found that the CuO-water nanofluid affects the water temperature and cooling water, resulting in a lower temperature of glass cover in the solar desalination system [28]. The glass is cooled by a fan and a channel that is connected to the thermoelectric cold side. The output findings demonstrate that compared to traditional ones, the exergy, productivity, and energy were enhanced by 112.5%, 81%, and 80.6%, respectively. Bahiraei et al. forecasted water production using ANN Tool from a single-slope solar desalination system using thermoelectric cooling and CuO-water nanofluid [29]. Abdullah increased water output in another study. The solar desalination system's water temperature is greater than before while a water depth is decreased. Once again, the trials were carried out in the climate of Saudi Arabia. Based on the data, it was determined that the freshwater production was maximized at 0.1 rpm drum speed, an increase of 4.49 times above the yield of traditional solar distillation units.

Abdullah et al. investigated the efficacy of a solar desalination system. The results showed that the total solar distillation unit yield of water trays increased by 57.14%, 70.7%, and 108% [30]. The study of nighttime water production was also conducted. According to the findings, the freshwater yield of SSSS-CuO-NCAP was approximately 2.9 L/m2, SSSS-PVA about 1.9 L/m2, SSSS-SCB about 2.8 L/m2, and SSSS-pebbles about 2.6 L/m2. When used together, nanoparticles and phase change materials (PCM) drastically alter the time it takes to absorb and release heat from PCM. Behura and Gupta studied the use of a single-slope solar desalination system to distill a colorless solid mixture (wax) at varying concentrations of CuO nanoparticles [31]. The results have shown that increasing the concentration of CuO nanoparticles in PCM from 0.1 to 0.2 to 0.3% increased solar water production.

2.4 Graphite Nanomaterial in Solar Desalination System

Sharshir et al. studied the influence of water depth on water productivity rate as a result of employing flake graphite nanoparticles (FGN), phase change nanomaterial, and water film cooling in the solar desalination system. Sharshir investigated the performance of a single-slope solar distillation unit after introducing copper oxide and graphite nanoparticles [32]. Graphite nanoparticles and Copper oxide were shown to increase water production by 41.18%, and 32.35% respectively, associated to conservative methods.

Kabeel et al. looked at the efficiency of three different solar desalination system designs using graphene oxide nanoparticles and PCM in a tubular solar distillation unit. Experiments were conducted using a standard solar distillation unit, a solar distillation unit including PCM, and a solar desalination system containing graphene oxide nanoparticles. Adding graphene oxide to PCM allowed for higher solar desalination system water yields. The results show that both the solar distillation unit with PCM and the solar desalination system with graphene oxide are more productive than a traditional solar desalination system by a factor of 29.3 and 216.9, respectively. By incorporating nanoparticles of GO, CuO, and TiO2 into PCM at 0.3%, concentrations, improved water production in a solar distillation unit. The paraffin PCM lines both sides of the solar distillation unit wall [33]. Results demonstrate that daily water productivity from solar distillation unit using CuO, TiO2, and GO nanofluids ranged from around 3.66 L/ m2 /day to 5.28 L/ m2 /day. Wax, a colorless solid combination, was utilized as a PCM in solar desalination systems' washbasins. As shown by the data, the productivity of solar distillation unit freshwater systems using PCM and mixed nanoparticles in PCM is much higher than that of conventional systems by 39.5% and 83.7%, respectively.

2.5 Fe_2O_3, ZnO, SiC, SiO_2, and SnO_2 Nanomaterial in Solar Desalination System

The effectiveness of a single slope solar distillation unit was evaluated by Elango et al. after nanoparticles of Al_2O_3, ZnO, and SnO_2 were added to water [34]. The first findings indicate that the nanofluid had a significant effect on amount of water that was made by the solar distillation unit. In comparison to a solar desalination system that did not use nanofluids, the generation of water using SnO_2-water, Al_2O_3-water, and ZnO-water nanofluids were enhanced by 18.63%, 29.95%, and 12.67%, respectively. Chen et al. evaluated the effect of SiC nanoparticles in the solar still at varying concentrations of thermal conductivity. Based on the findings, it appears that the addition of SiC nanofluid resulted in a 5.2% increase in thermal conductivity. Saleh et al. investigated the influence of the hydrothermal synthesis technique on generated ZnO nanoparticles in a solar desalination system [35]. They used a variety of solvents to do their research. Nanoparticles in the form of nanorods and nanospheres were investigated. It was discovered that the water productivity and thermal efficiency improved by 30% and 38%, respectively. Experiments were carried out with a volume fraction concentration of 10% and at two distinct water depths. They discovered that the water productivity of the absorber coated with $Fe2O_3$ nanoparticles was increased by 35.9% when compared to the water productivity of the absorber coated with microparticles.

2.6 SiC Nanomaterial in Solar Desalination System

Using an experimental approach, Chen et al. analyzed the characteristics of SiC nanoparticles. The study's overarching goals included examining the thermal conductivity, stability, and optical features of SiC/water nanofluid [36]. According to the findings, there is an obvious problem with the salts in the water-base fluid. The thermal conductivity of the water base fluid was significantly improved by the use of nanoparticles. Zanganeh et al. were successful in determining the influence of employing silicone nano-coating on the single-slope solar distillation unit water systems productivity [37]. The findings suggest that the incorporation of silicon nanoparticles into a coated glass cover results in an approximately 20.3% improvement in productivity when compared to a regular glass cover. For a PV/T system, Al-Waeli performed experiments to look into using SiC nanofluid as the base fluid [38]. When compared to only using the PV system, adding 3% SiC nanofluid by weight was shown to boost electrical efficiency by 24.1%. Zanganeh et al. examined influence of titanium dioxide and silicon nanoparticles on the glass cover surface of a solar distillation unit [39]. The nanoparticles that are on the surface of the condensation have varying degrees of wetting characteristics. When compared to a solar desalination system that did not have a nano-coating, the results show that silicon nanocoating contributed to an increase in water production that was roughly 20% higher. In another work, the author employed a nano-coating approach to adjust the glass cover wettability in order to boost water production. This research was conducted in another study. To condense the surface, a nano-silicon solution was utilized, and a hot water bath tank with an immersed electrical heater combined with a heat exchanger was placed within the solar desalination system water. At a glass inclination angle of 50 degrees, they discovered that adding a nano-silicon solution to a solar desalination system produced a freshwater output that was 23 percent higher than before. Experimental research by Sardarabadi et al. examined the impact of nanofluid on the thermal and electrical efficiency of a PV/T system [40]. Overall energy efficiency was found to be enhanced by 3.6% and 7.9%, respectively, for the instances with a silica/water nanofluid of 1 wt% and 3 wt%, compared to the case with pure water, in that study.

2.7 Silver Nanomaterial in Solar Desalination System

Parsa et al. accompanied an examination upon the efficiency of three distinct kinds of solar distillation unit [41]. In the first design of the solar distillation unit, the basin was linked to the thermoelectrically hot side of the system. In the second experiment, a silver-water nanofluid was employed in conjunction with the thermoelectric hot side. The thermoelectric cold side, glass cooling water, and an external condenser were used for increasing the rate of condensation. According to the findings, the thermal efficiency and solar water production of the solar desalination system coupled with the condenser/nanofluid were enhanced by 26.7%, and 100.5% respectively. This was accomplished by increasing the temperature of the nanofluid. According to the findings of other studies, the contribution of thermoelectric cooling and water cooling to the overall water production was around 26.3%. In a different piece of research, Parsa was observed utilizing a nanofluid consisting of silver and water at a concentration of 0.04% in a solar desalination system. When compared to a traditional solar desalination system, exergy and energy outputs of solar desalination systems utilizing silver nanofluid showed significant increases of 106 and 196%, respectively, when analyzed using.

2.8 TiO_2 Nanomaterial in Solar Desalination System

Researchers Shanmugan et al. evaluated the effectiveness of solar distillation units by applying a coating of TiO_2 nanoparticles to the basin liner that was combined with Cr2O_3 [42]. According to the findings, the production of a solar desalination system was 7.89 liters during the summer months and 5.39 liters during the winter months. Experimental research on improved solar desalination system water productivity was carried out by Sahota and colleagues utilizing a variety of solar photovoltaic and thermal techniques. The dimensions of the system were 2 square meters. In order to improve the performance of the solar desalination system, nanofluids including Al_2O_3-water, CuO-water, and TiO_2-water were heated using thermal and photovoltaic techniques. Both of these increases were seen in the solar desalination system. Kabeel et. al., carried out research that involved doing an exploratory evaluation of a pyramid solar distillation unit containing TiO2 nanoparticles combined with a variety of black paint in order to boost the rate of heat transmission [43]. The findings suggest that the incorporation of TiO_2 nanomaterial inside the black color coating of the pyramid solar distillation unit resulted in an increase of 6.1% in the amount of water produced.

3 Application of Nanofluids for Thermal Desalination

Desalinating seawater with heat is conceptually similar to how rain forms. Thermal distillation removes heavy metals and other contaminants from saltwater. The water that is generated is as pure as rainfall. Solar thermal technologies are one example of the many possible sources of thermal energy. Since nanofluids are capable of effective heat transmission, they have also been investigated for use in thermal desalination processes, in addition to studies aimed at improving the thermal characteristics of nanofluids for use in concentrated solar power production. In order to enhance the efficiency of solar desalination systems, Sharshir et al. conducted experiments with three distinct designs and used nanofluids [44]. Basin depths varied from 0.25 to 5 cm, while the micro flakes percentage in nanofluids varied from 2% to 0.125%. Micro-flakes of copper oxide and graphite had an average particle size of 1 micrometer, and 1.2-1.3 micrometers respectively. Productivity for solar desalination systems was increased by 44.91%, and 53.95% respectively, when copper oxide and graphite microparticles were used in conjunction with glass-cooling.

For desalination purposes, a greater thermal conductivity means more solar radiation may be absorbed and used as heat. Dispersing Fe3O4-modified MWCNTs nanoparticles in salt water, Chen et al. created nanofluids of varying concentrations. Based on the research, we modified MWCNTs with a diameter of 8-15 nm and a purity of 95% to impart magnetic characteristics. Using a two-stage procedure, we could create nanofluids with 0 to 0.04 wt% concentrations. Furthermore, zeta-potential measurements were used to assess the stability of nanofluids, with results showing that the solutions exhibited outstanding stability in pure water but decreased when exposed to salt. The zeta potential value was deficient with a salt concentration of 5000 PPM in water. When placed in salt water, nanofluids are only somewhat stable thanks to the employment of certain surfactants. Furthermore, an investigation into the optical characteristics of magnetic MWCNTs was conducted, resulting in greater heat energy for the evaporation of salt water. When the fluid's thickness was more than 1 cm, the author found that it absorbed solar energy at a rate of 100%. With a nanofluid concentration of 0.04 wt%, we could see this absorption. In addition, it was discovered that a higher concentration of nanofluid resulted in greater evaporation efficiency. An experimental study of seawater-based silicon carbide nanofluids for solar distillation was also conducted by Chen et al. [36]. According to the results of the experiment, the thermal conductivity of the nanofluid based on seawater was increased by 5.2%. Since the concentration of salt in water has a detrimental impact on the thermal conductivity and stability of nanofluid, finding the optimal concentration is essential. The group found that concentrations above 5000 PPM reduced thermal conductivity. In addition, when concentration was increased, the samples were much less stable, as measured by their zeta potential values. At 10 degrees Celsius with a concentration of 50,000 parts per million, the thermal conductivity is 6% lower than it would be at zero parts per million. The study found that SiC nanofluids had superior stability and increased thermal conductivity at reduced salt concentrations of TDS of the seawater, proving the nanofluid's viability for solar desalination. The evaporation efficiency was found to be 24.91% at 0% wt% and 76.65% at 0.04 wt%. The model was put through its paces in a wide range of scenarios, from varying functional parameters to climate extremes, and the results were well documented. Modeling the system using copper nanoparticles revealed that it was extremely efficient but not economically viable due to the tiny scale of the unit employed in the study. Suggestions for lowering the overall price tag included things like increasing the collection area and utilizing the right volume fractions of nanoparticles. Using the created equations, it was concluded that a collecting area of a solar water heater is an important component in lowering water production costs. In addition, as the collecting area of a solar water heater expands, the cost per unit of generated water decreases. Increased freshwater generation at a lower cost is possible when nanoparticles make up a larger portion of the working fluid in solar collectors. The production of solar desalination systems initially rises with the particle concentration in the nanofluid, as shown in a study of their performance by Kumar et al. [45]. When there are more particles in the system, however, the viscosity rises and the pressure drop increases, worsening the system's performance. In this article, we looked at how nanofluidics may be employed in desalination processes. Enhanced thermal characteristics of nanofluids are explored, highlighting its potential as a foundation for creating effective desalination systems. Using eco-friendly technologies to power desalination systems is crucial because the process requires a lot of energy. Nanofluids have been dubbed "NegaWatt" because they can help reduce energy use right off the get. By definition, a NegaWatt is a fictitious measurement of power that is spared as a result of increased efficiency or reduced energy consumption. Table 2 provides a quick summary of the many uses of nanofluids in solar desalination systems.

4 Challenges in Nanofluids for Solar Energy

Human exposure to nanoparticles is associated with unknown adverse health consequences. This is because different nanoparticles can have wildly varying chemical compositions and, in certain cases, sizes. As a result of their larger surface areas, nanoparticles are more likely to do harm to both humans and the

Table 2. Overview of various nanofluids in solar desalination system.

Nanofluid	**Base Fluid**	**(%) Concentration**	**Thermal Conductivity (W/mk)**	**Outcome**	**Reference**
Al_2O_3	Water	0.04, 0.08, 0.12	46	Productivity enhanced by 16.83% for 0.12% Concentration	[46]
Al_2O_3	Mix with black paint	-------	46	Productivity enhanced by 38.09%	[47]
CuO	Water	0.12	17.6	Productivity enhanced by 22.5%	[48]
CuO	Water	0.125–2	17.6	Productivity enhanced by 44.91%	[48]
CuO_2	Mix with black paint	10–40	76.5	Productivity enhanced by 25%	[22]
Fe_2O_3	Water	0.05–0.1	6	-------	[28]
Graphite Flakes	Water	0.125–2	129	Productivity enhanced by 53.95%	[28]
SnO_2	Water	0.05–0.1	1.34–1.38	Productivity enhanced by 18.63%	[28]
ZnO	Water	0.05–0.1	29	Productivity enhanced by 12.67%	[28]

natural world than bulk materials. They also noted that particles were taken into cells in vitro via diffusion or adhesion contacts, allowing them direct access to the cell's DNA, proteins, and organelles.

The high superconductive qualities of copper oxide nanoparticles (CuO) make them appealing in a wide variety of applications, including batteries, electronics, solar panels, and many others. As of 2014, the United States produced more than 300 metric tonnes of CuO nanoparticles. Considering the toxicological impacts of Cu ions and CuO nanoparticles on aquatic species and earthworms, to a greater extent than usual, copper materials must be protected from the dangers of environmental contamination. Nanoparticles made of copper oxide frequently release copper ions into liquids, which may contribute to their toxicity.

The higher price of producing nanoparticles, the agglomerating and instability of nanoparticles, and the pressure loss and pumping power are all potential obstacles to the uses of nanofluids. As a result, nanotechnology relies on extremely clean environments with very few defects. The developed procedure must be trustworthy in order to exert precise control over nanoparticles' properties, which drives up the price of producing nanoparticles. Experimental research: Another issue with our solar systems is the instability and aggregation of nanoparticles. Experimental measurements of pumping power were made by Routbort et al. for nanofluids moving through a whole system of straight tubing, elbows, and expansions [49]. As expected, the addition of nanoparticles to a base fluid increased the pumping power. The high price of using nanoparticles in heat exchangers was discussed by Lee and Mudawar [50]. Adding nanoparticles to a fluid raises its viscosity, which in turn raises the pressure drop and, by extension, the pumping power required to move the fluid. At high temperatures, and especially when subjected to natural circulation, the agglomeration of nanoparticles is a major problem. Nanoparticle selection is becoming increasingly important in high-temperature applications.

5 Conclusions

In the decades, a new class of fluids called nanofluids has evolved. These fluids are advanced because they include particles on the nanoscale. Inexpensive heat transfer methods will be greatly aided by cutting-edge integrated systems based on nanofluids. Key findings from this review are discussed and recommendations for further research. Nanofluids in the energy industry face a number of significant issues, the most significant of which are the improvement of efficiency, reliability, and safety, as well as the decrease in the cost of nanoparticles. When the percentage of nanoparticles that are solid grows, so does daily productivity. Frictional and thermal irreversibilities are highest at the solar desalination system's bottom and top walls and lowest in the desalination system's center. Because of their low luminosity, low cost, and high thermal and mechanical durability, Silicon carbide nanoparticles are encouraged for use in solar desalination units.

Solar desalination systems can increase their productivity by combining the nanoparticle process with additional passive and active methods. Using nanofluids improves the quantity of carbon dioxide reduction.

Since the creation of solar desalination systems has direct human applications, certain recommendations are provided for further research. The study of nanofluids requires the development of methodologies for the synthesis of nanoparticles at a cheap cost. As such, prior to its implementation, nanoparticles' potential risks to people's well-being must be evaluated. The device's complexities need to be resolved. Stability in operations over the long term and life cycle evaluation are important considerations. Future studies in this area ought to take these things into account. In order to collect more complete information regarding this method, it is necessary to analyze the effects of nanoparticles on production in various climatic zones. Most studies in this area focus on single as well as double solar desalination systems because these are the most common kind of solar desalination systems used for research. Therefore, nanotechnology has tremendous promise for addressing the challenges faced by the desalination industry, as it will facilitate the creation of environmentally friendly desalination processes and the harnessing of solar thermal energy. More research is required into other sorts of solar desalination systems, such as the sun tracing, pyramid, semi-sphere, and cascade varieties.

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About the Authors

Prof. (Mrs.) Trupti S. Gajbhiye (Shelare) is presently working as an Assistant Professor in the Department of Electrical Engineering at G H Raisoni Institute of Engineering and Technology, Polytechnic, Nagpur, Maharashtra, India. She has completed her M.Tech. in Industrial Drives & Control from the Department of Electrical Engineering, Priyadarshini College of Engineering, Rastrasant Tukdoji Maharaj Nagpur University Nagpur, Maharashtra, India. She has published more than 5 research articles throughout the several SCI / Scopus indexed journal, including International / National level conferences. During her academic career, she has authored a book of international publishers. Also, she has patents in her credentials.

Dr. Sagar D. Shelare is presently working as an Assistant Professor in the Department of Mechanical Engineering at Priyadarshini College of Engineering, Nagpur, Maharashtra, India. He has received a Doctor of Philosophy (Ph.D.) degree in the area of Mechanical Engineering, from the School of Mechanical Engineering, Lovely Professional University, Punjab, India. He has published more than 30 research articles throughout the several SCI / Scopus indexed journal, including International / National level conferences. He is also academically engaged as the reviewer with several SCI/ Scopus indexed Journals from the last 5 years. He has delivered several Expert Talks/Lectures at different levels of the platform throughout the country. He has received a Global Teacher award for his contribution to research and development. He is a lifetime member of more than eight reputed professional societies at the National and International levels. During his academic career, he has authored five books by international publishers. Also, he has five patents in his credentials in the field of Agricultural Mechanisation.

Prof. Kapil R. Aglawe is presently working as an Assistant Professor in the Department of Mechanical Engineering at Priyadarshini College of Engineering, Nagpur, Maharashtra, India. He is pursuing his the Doctor of Philosophy (PhD) degree in the area of Mechanical Engineering, from the Mechanical Engineering, National Institute of Technology, Raipur, India. He has published more than 15 research articles throughout the several SCI / Scopus indexed journal, including International / National level conferences. He is also academically engaged as the reviewer with several SCI/ Scopus indexed Journals from the last 2 years. He is a lifetime member of several reputed professional societies at National and International level. Also, he has a patent in his credentials in the field of Mechanical Engineering.