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Insight review on solar still application

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Abstract

Access to drinkable water is essential for life, and solar energy offers a sustainable method for water purification. Solar stills, which use solar energy to distill water, have been widely studied to improve efficiency. However, challenges such as low productivity and reliance on sunlight remain. This study reviews advancements in solar still technology, focusing on enhancements using nanoparticles, phase change materials (PCM), and design modifications. Due to their high surface area and thermal conductivity, Nanoparticles improve heat transfer when applied to the glass surface of solar stills. However, their effectiveness depends on factors such as type, size, shape, and concentration. PCM is incorporated to address the limitation of solar availability by storing energy and enabling water production during cloudy conditions and nighttime. Additionally, various solar still designs have been explored to enhance efficiency. This review critically examines these techniques, highlighting their benefits and limitations. The findings provide valuable insights for optimizing solar still performance, contributing to the development of more efficient and reliable solar water purification systems.

Keywords: Distillations, review; nanoparticles; phase change; solar still.

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1. INTRODUCTION

Water scarcity is on the increase worldwide as we have an exponential population increase, increase in pollution, and economic crisis (El Hafid & Abderafi 2024; Baccour et al., 2024; Liu et al., 2024). Distillation of water by the most sustainable approach which is solar still has become a technology to adapt worldwide (Bellila et al., 2024).

Balachandran et al., (2020) conducted a study to improve the absorbent of the solar still. They used nanotechnology to improve thermal diffusivity to produce distilled water each hour/day. This study includes the effect of Fe_2O_3 nanoparticles on the desalination. The study examined the effects of nanoparticles at a concentration of 0.1 weight percent. Data collection occurred over 48 hours. During the initial 24 hours, the water level measured 0.5 cm, while in the subsequent 24 hours, it rose to 1 cm. The mean thickness of the absorbent layer was 3.23 kg/m², while the mean thickness of the nano-absorbent layer was 4.39 kg/m².

Sahota & Tiwari (2016) provided a comparative study for System A and System B. System A contains a photovoltaic-solar collector combined with dual tilt solar-still with no functional heat exchanger. System B presents a new technique to thermal production and it includes a photovoltaic solar collector integrates with dual tilt solar-still and functional spiral wound heat exchanger. The effect of different types of nanoparticles has been considered such as copper oxide, titanium dioxide, and aluminum oxide. In both systems A and B, it was found that copper oxide has higher performance improvements than others. Additionally, nanofluid in system A shows higher efficiency than nanofluid in system B.

Moreover, a parabolic trough solar collector with dimensions of 0.7m width and 2m height was fabricated and built by Kasaeian et al., (2015). Several experiments were conducted using receiver tubes of different designs. Nanofluid flows in the receiver pipe. It concludes that the efficiency of the vacuum pipe was 11% higher than other vacuum tubes. The use of nanofluid was determined to enhance thermal efficiency and augment the performance of PTC across numerous studies.

A further investigation on parabolic trough collectors was carried out by Subhedar et al., (2020). The researchers examined the efficacy of a single slope solar still integrated with a parabolic trough collector. The maximum productivity obtained was 1741 mL for a 1 m basin area with a saline water depth of 2.5 cm for the entire day. Al2O3-nanofluid combined with the solar still system shows an increase in productivity has been recorded at all times of the day.

Zanganeh et al., (2020), and Chorghe et al., (2024) concentrated on improving the performance of solar stills by modifying surface wettability using nanoparticles. The study emphasized the condensation surface in energy transfer during the condensation process, which directly affects freshwater production. The surface was coated by various nanomaterials, that is, titanium dioxide and silica nanoparticles. It was found that nanocoated surfaces significantly improved solar still productivity, with silicone coatings increasing efficiency by 20% for glass covers; as Abdel-Aziz et al., (2024) in their research also emphasized the benefit of having nanoparticle coatings to enhance solar distillers' performances.

Nazari et al., (2019) completed an experimental investigation on a monoracial solar still system by thermo-electric cooling tubes and copper oxide (CuO) as nanoparticles. An addition of 0.08% CuO in solar still loaded by thermo-electric coolers channels resulted in an 81% rise in the generation of freshwater and an 80.6% enhancement in energy performance.

The different shapes of solar are still considered by Sharshir et al., (2019). In this study, an experiment focused on pyramid solar still enhanced by evacuated tubes and nanoparticles, specifically copper oxide mixed with carbon black at a 1.5% weight content. Three types of stills were tested: conventional, modified with evacuated tubes, and modified with nanoparticles. The research results indicated that the modified stills generated 4.77% to 26.6% more quantities of fresh water compared to the conventional design. The copper oxide modification resulted in yield improvements of 27.85% and 54.85%, whereas the carbon black modification achieved increases of 33.59% and 57.098%. The daily efficiency of the modified stills reached 50%, improving to 61% using CuO, and 64.5% using black carbon.

Sathyamurthy et al., (2020) studied experimentally tiered solar-powered still waterfalls utilizing silica nanoparticles in dark-hued paint. The nanoparticle concentration ranges from 10% to 40%. At 10% concentrations of nanoparticles, an increment of 27.2% was observed in comparison to standard black paint. Similarly, the output for 20%, 30%, and 40% of the concentration of nanoparticles was increased by 34.2%, 18.3 %, and 18.4 %, respectively.

Panchal et al., (2019) examine the yearly performance of stepped solar stills utilizing MgO and TiO2 nanofluids. The concentrations of nanoparticles were 0.1% and 0.2%. It was indicated that MgO nanofluid significantly enhances distillate production by 45.8% and 33.33% at the specified concentrations, whilst TiO2 nanofluid shows increases of 20.4% and 4.1%. The improved performance of MgO is attributed to its higher thermal diffusivity. The period of energy payback for solar stills with a 0.2% nanofluid concentration is established at only three months. The research highlights the capability of nanofluids to develop the efficiency of solar stills.

Modi et al., (2019) researched a single-sided double-tank solar still that utilized Al_2O_3 nanoparticles. The total weight of Al_2O_3 nanoparticles was adjusted during the trials at 0.01%, 0.05%, 0.10%, and 0.20%. Compared to the distillation system without nanoparticles, the distillation result of 0.01% weight concentrations of Al2O3 was 17.6%, while 0.05%, 0.10%, and 0.20% Al2O3 were 12.3%, 7.2% and 2.6%, in respective.

Kabeel et al., (2014) investigate challenges of water scarcity highlighting solar stills as a sustainable solution, particularly in arid environments. It analyzes many studies aimed at enhancing solar still efficiency by considering factors such as environmental conditions and design modifications. Significant developments encompass the incorporation of external condensers and the utilization of nanofluids, which markedly enhance evaporation rates and overall efficiency. Kabeel et al., (2014) conducted research indicating that the integration of vacuum conditions with nanofluids can enhance water output by more than 116%. The study also determines the ideal amounts of cuprous and aluminum oxide nanoparticles to enhance productivity.

Elango et al., (2015) considered the comparative effectiveness of single solar-powered basins using 3 different nanofluids. The effect of nanoparticle types was studied using aluminum oxide, zinc oxide, and tin oxide. More productivity was achieved when aluminum oxide was employed compared to pure water. Similarly, using Tin oxide and Zinc oxide showed an improvement of 18.63% and 12.67% in comparison to water, respectively.

Sahota & Tiwari (2016) studied experimentally the effect of nanoparticle load on the performance of double-slope solar still. Al_2O_3 nanoparticles are used with different volume concentrations. It was shown that 0.12 Vol. % of Al_2O_3 improves the performance of solar still by 12.2% for 35 kg of water and 8.4% for 80 kg of water, compared to the control without nanoparticles.

2. METHODS AND MATERIALS

This study employs a comprehensive literature review methodology to analyze advancements in solar still technology for water purification. Relevant research articles, experimental studies, and review papers were systematically collected from reputable scientific databases. The selection criteria focused on studies exploring the effects of nanoparticles, phase change materials (PCM), and solar still design modifications on water production efficiency. Key parameters such as nanoparticle type, size, shape, concentration, thermal conductivity, and PCM energy storage capacity were critically examined.

Comparative analysis was conducted to evaluate the effectiveness of different enhancement techniques in improving heat transfer, evaporation rates, and overall water yield. Additionally, the study assesses the limitations and challenges associated with these techniques, such as material costs, long-term sustainability, and dependence on solar availability. By synthesizing findings from multiple sources, this review provides a structured understanding of current advancements and potential future improvements in solar still technology.

3. RESULTS

3.1. Storage medium inside solar still:

In order to ensure a continuous production of distilled water using solar energy a storage medium must be integrated into the solar still. The material used to store energy is the phase change material (PCM) which is studied by many researchers.

According to Saeed et al., (2024), nanoparticles are used to improve the heat transfer ability of paraffin wax (PCM). PCM is considered the most frequently utilized wax, augmented with Al_2O_3 nanoparticles. The findings indicated that utilizing Al_2O_3-PCM enhances the performance of solar still. The main use of PCM/nano-PCM during the night or cloudy weather is to ensure a continuous working of solar still.

Furthermore, Murali et al., (2024) explore the effects of PCM and nano-PCM on the effectiveness of solar stills. Conducted in Vaddeswaram, India, the research involved various configurations of copper pipes filled by PCM and nano-PCM, including different nanoparticle concentrations. Results indicated that NPCM significantly enhanced thermal properties, leading to 60.37% increments in production and 68.29% enhancement in efficiency compared to conventional setups.

On the other hand, Rufus et al., (2017) apply the techniques of storage energy using PCM (paraffin wax) using copper oxide nanoparticles. The results found dispersing nanoparticles into PCM increased thermal diffusivity and improved the storage system of the solar distillation system.

Another study for solar storage in the solar still systems has been considered by Elfasakhany (2016). The experiments considered CuO-PCM in a single tank. He conducted experiments on three different cases. In case 1, the system was solar and still without PCM. In case 2, the system was solar still with PCM. Case 3 was solar still with PCM and CuO nanoparticles. The results showed efficiency using case 3 outperformed case 1 and case 2 by 125% and 106%, respectively. The working hours of solar still increased by 5 to 6 hours using nano-PCM.

Elavarasi et al., (2018) conducted experiments on two different solar stills of the same size. The first one still used paraffin wax, while the second one used a mixture of silicone oil and CuO nanoparticles. By using CuO-silicone oil, performance was improved by 25%.

Behura & Gupta (2021) conducted experimental research on a solar-powered still using nano-PCM. The experimental rig comprises a corrugated plate with PCM or nano-PCM. They studied the effect of different weight concentrations such as 0.1 wt.%, 0.2 wt.%, and 0.3 wt.%. The volume of the output was 440 ml/0.25 m^2/day for 0.1 wt.% nano-PCM. Similarly, when the weight concentration of 0.2% and 0.3% is considered, the productions are equal to 455ml/0.25m^2/day and 510 ml/0.25m^2/day. The results clarify that nano-PCM improves the output by 62.74% in comparison to the conventional solar still.

Rufus et al., (2021) studied numerically nano-PCM. The type of PCM is paraffin wax. Paraffin wax is considered a stable material in comparison to lauric acid, stearic acid, and so on. The effect of dispersing TiO2 nanoparticles on the PCM was conducted. In this study, different thermophysical properties were tested such as thermal conductivity, latent heat, melting, and solidification properties. The measured thermophysical properties are inserted in the numerical model. The total cumulative production rise to 6.6 L/m2/day for TiO2-PCM compared to PCM.

Somanchi et al., (2015) conducted an experimental study on PCM- solar still. There were two different types of the storage medium. PCM1 was Magnesium Sulphate Heptahydrate and PCM2 was Sodium Sulphate. To improve the thermophysical properties of PCM, the addition of Titanium Oxide (TiO2) to PCM was studied experimentally. Nano-PCM1 has higher efficiency in comparison to nano-PCM2. This clarifies the effect of PCM type on the performance of solar still.

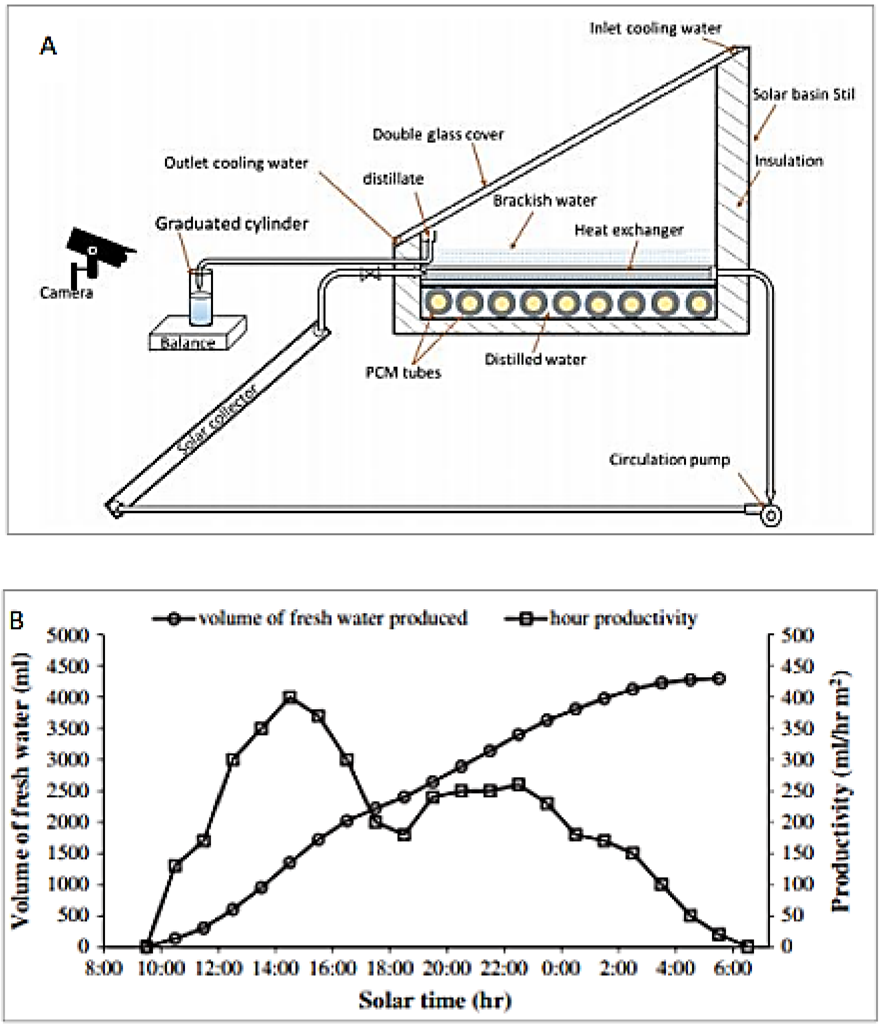
Rajasekhar & Eswaramoorthy (2015) investigate PCM and nano-PCM in single basin solar still. Al2O3 nanoparticles dispersed into the PCM. The overall yield was determined to be 2800 mL per day. The usage of

PCM and nano-PCM resulted in daily efficiencies that were 44.40% and 60%, respectively. Productivity rose by 49.82% with the inclusion of PCM and by 72.85% with nano-PCM.

Shafieian et al., (2020) delivered an experimental study on thermal solar still utilizing aluminum oxide nanoparticles. Utilizing nanoparticles in both hot and cold climates resulted in an 18% & 22% increase in freshwater output, respectively. Enhancing the performance and efficiency of static PCMs can be accomplished by including nanoparticles, which store latent heat and hence augment thermal conductivity. There are other studies about the PCM and nano-PCM to store solar energy (Awad, 2018; Awad et al., 2021; Awad & Muayad 2023; Hussein et al., 2024; Awad & Hussein 2024; Hussein & awad 2024). Figure (1) shows a diagram for an experimental study by Al-harahsheh et al., (2018). They found that distilled water directly proportional to the temperature of the environment.

Figure 1

The experimental diagram with the volume of freshwater vs time



Source: Al-harassed et al., (2018).

3.2. Other techniques used to improve solar still

Abdullah (2013) studied the effect of combined system. The combined system consists of a staged solar still and an air solar heater. Their study produces a comparison between the conventional solar still and the combined system. Furthermore, the area of the solar collector equals 0.5 square meters. In this study, the heat was stored by a storage medium. This storage is located behind the absorber plate. The main aim of the storage medium is to ensure stable production of distilled water during night or cloudy weather. It was found that the combined system outperforms the conventional one by 112%. Moreover, a further enhancement was found when they used aluminum fillers.

On the other hand, Pancha (2016) conducted a study on the effect of transmittance of the glass thickness. The study was conducted over 6 months for three different thicknesses, that is 4 mm, 5 mm, and 6 mm. It was found that 4mm and 5mm outperform 6mm by 27%, and 12%, respectively.

Aljubouri (2017) provided a study on the inclination of glass covers of the 5 single-sided solar stills was changed to 20°, 31°, 45°, and 50°. The amount of freshwater produced per day increased when the slope was reduced from 50° to 20° and water depth in the tank minimized from 7cm to 1cm. At a 20° inclination angle with a 1cm depth and a water depth of 1 cm, the maximum total daily volume of the solar still system equals 495 mL (2 L/m^2/day).

Kabeel, et al., (2019) conducted a conductive study using a different design such as solar parabolic, 2-conical trough, single solar still, and 4-photovoltaic similar modules. The use of the dish collector type can produce distilled water by 8.8 kg/day, and 5.45 kg/day for 10mm, and 20mm water depth respectively. Combined solar dishes and solar systems can raise the production to 13.63kg/day and 7.69 kg/day for 10mm, and 20mm, respectively. According to Jaafar et al., (2020), two enhancement techniques were then proposed. The first one was using solar still to produce distilled water where the productivity increased by 48.83%. The second technique was the use of iron wicks of two different sizes in a single-slope solar still system. The iron wick increases the area of solar absorption and improves production by 86.65% and 72.53%, respectively for the two sizes.

Amiri et al., (2021) developed and tested a new standalone desalination system combining a parabolic trough solar collector with a solar still. A transient numerical model was created to analyze the system's performance across different parameters, yielding results that closely matched experimental data. The study revealed that in Kerman's climate, the production equals 0.961 L of freshwater daily in summer, a 55% increase compared to winter, integrating a track system achieving 1.266 L/day. Hassan et al., (2020) provide a study investigates the developments of two different designs. The first design was a conventional solar still with a glass condenser (CSS) and the other design was a solar still with a plated finned heat sink condenser (HSC). It was found that incorporating wire mesh, sand, and HSC significantly enhances fresh-water production and effectiveness. In summer, the highest freshwater increases by 67% with PTC, 7.3% with HSC, and 6% with sand compared to CSS. Additionally, HSC improves performance up to 11.6% in summer with 8% in winter relative to CSS. The combination of MSS, sand, and PTC produces the lowest freshwater cost, with efficiencies of 41.95% in summer and 31.96% in winter, representing a 25.2% reduction compared to CSS.

Kumar et al., (2020) conducted an experimentation study to analyze energy performance for single slope solar still linked to a parabolic trough collector, focusing on three depths: 5 cm, 10 cm, and 15 cm. It was indicated that water decreased with increasing depth, yielding 4.1 L/m^2 at 5 cm, 3.645 L/m^2 at 10 cm, and 3.2 L/m^2 at 15 cm. Additionally, the output energy, charging time, and CO_2 diminishment were negatively impacted by deeper water levels. Notably, reducing the water level from 15cm to 5cm caused a 22% increase in daily energy yield.

Lalitha & Ramachandra (2019) used flat panel solar collector FPCs (the area of each collector is 2^{2}m^2 with a monoclinic solar still, the base area is 1^{2}m) in India. In the summer, they obtained that increasing the size of the solar collector would increase the output of distilled water. However, the efficiency of solar still decreased.

4. CONCLUSION

In this paper, a summary of literature studies is presented on the application of solar still. There were different methods used to produce distilled water, that is, nanoparticles, phase change materials, different designs of solar still, and so on. The main findings of this study can be summarized as follows: The production of distilled water is essential, with a particular emphasis on utilizing renewable energy sources such as solar energy. Among available technologies, solar stills have been identified as the most cost-effective solution for producing drinkable water using sunlight due to their simple design and ease of manufacturing.

Recent research has focused on enhancing the efficiency of solar stills through the incorporation of nanoparticles. The daily output of distilled water is directly influenced by the weight concentration of nanoparticles; however, at higher concentrations, agglomeration effects reduce efficiency improvements. Nanoparticles possess higher thermal conductivity compared to the base fluid, and their increased surface area facilitates better heat transfer, thereby improving overall performance.

Another widely adopted technique involves energy storage using phase change materials (PCM), which ensures continuous operation of solar stills during nighttime or cloudy weather. However, the low thermal conductivity of PCM presents a challenge, which can be mitigated by incorporating nanoparticles to enhance heat transfer properties. Among various nanoparticles studied, alumina nanoparticles have been identified as the most suitable for improving the efficiency of solar stills in distilled water production.

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