Journal of Solar Energy Research (JSER)

Journal homepage: www.jser.ut.ac.ir

Advancements in Solar Still Water Desalination: A Comprehensive Review of Design Enhancements and Performance Optimization

Sabbir Ahmed Udoy[a,*], Khaled Mohammad Shifullah Bhuiya[a], Pronob Das[a], A M Almas Shahriyar Azad[b], Md. Ariful Haque[b], Zarin Tasnim Oishi[b], Md. Sohel Rana[a], Marowa Jahan[c]

[a]*Department of Mechanical Engineering, Rajshahi University of Engineering & Technology, Rajshahi, Bangladesh.*
[b]*Department of Industrial & Production Engineering, Rajshahi University of Engineering & Technology, Rajshahi, Bangladesh.*
[c]*Department of Computer Science & Engineering, American International University - Bangladesh (AIUB), Dhaka, Bangladesh.*

ARTICLE INFO

Article Type:

Review Article

Received:13.09.2024
Accepted:13.01.2025

Keywords:
Solar still;
Desalination;
PCM;
Nanofluids;
Reflectors;
Photovoltaic

A B S T R A C T

Freshwater scarcity affects over 40% of the global population, demanding sustainable solutions. Solar stills (SS) present an eco-friendly desalination method, utilizing solar energy for freshwater production. This comprehensive review critically examines design enhancements and operational strategies to optimize SS performance. Notable advancements include the integration of phase change materials (PCMs), nanofluids, and photovoltaic (PV) panels, alongside innovations in fin designs, wick materials, and reflectors. Key findings reveal that incorporating PCMs like paraffin wax can enhance productivity by up to 87.4%, while CuO nanofluids and rotating wick systems achieve a remarkable 350% improvement in freshwater yield. Moreover, PV-integrated SS systems amplify water and electricity generation, with efficiency gains up to sixfold compared to conventional designs. Novel configurations, such as pin-finned absorbers paired with condensers, demonstrate a 76.5% boost in output, while optimal water depths (0.5 cm) yield 4.5 L/m² daily. The study highlights the dual benefits of integrating renewable technologies, balancing sustainability and scalability. It also addresses challenges like cost-effectiveness and environmental impacts, proposing multidisciplinary approaches involving IoT and advanced computational tools. By identifying actionable strategies, this work establishes a pathway for advancing SS technology as a global cornerstone for sustainable freshwater production.

*Corresponding Author Email: udoy2000@gmail.com

Cite this article: Udoy, S. A. , Bhuiya, K. M. S. , Das, P. , Azad, A. M. A. S. , Haque, M. A. , Oishi, Z. T. , Rana, M. S. and Jahan, M. (2024). Advancements in Solar Still Water Desalination: A Comprehensive Review of Design Enhancements and Performance Optimization. Journal of Solar Energy Research, 9(4), 2025-2061. doi: 10.22059/jser.2025.382301.1464

DOI: 10.22059/jser.2025.382301.1464

1. Introduction

Freshwater is one of the basic needs of human beings. However, there is a severe scarcity of clean water across many parts of the world. Over the last few decades, population growth and pollution of natural water sources have intensified the problem. As a result, freshwater scarcity has reached critical levels [1]. Approximately 40% of the world's population currently lacks access to clean drinking water, and by 2025, this scarcity is projected to increase by more than 60% [2]. The primary causes of this crisis include rapid population growth, increasing economic development, and changing lifestyles. Furthermore, water-related disasters and health issues result in 6-8 million deaths annually worldwide [3]. Various scenarios and models are available to assess current and future water stress.

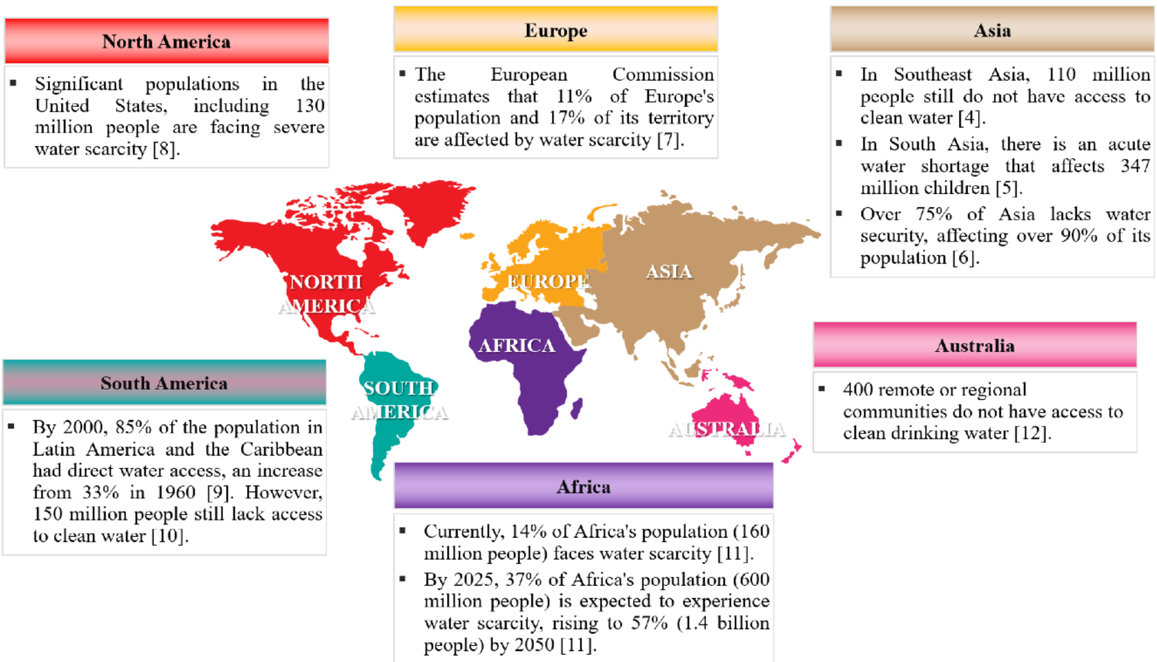

Figure 1: Water scarcity conditions in each region worldwide

Figure 1 depicts the global water scarcity conditions, with North America and Europe facing significant shortages, Southeast and South Asia struggling with severe water insecurity that affects millions, particularly children, Australia dealing with limited access to clean drinking water in remote communities, South America showing progress but still leaving many without reliable sources, and Africa being the most vulnerable region, projected to experience worsening scarcity in the coming decades, highlighting the urgent need for sustainable water management solutions to ensure equitable access to clean water worldwide [4-12].

The demand for freshwater in developed countries is increasing. In the coming years, regions like Asia, Central and South America, and Eastern Europe are anticipated to face the challenges of water scarcity [13]. Conventional water distillation methods that rely on fossil fuels consume significant amounts of energy, leading to environmental harm [14]. At present, fossil fuels account for 87% of global energy production, releasing large quantities of CO_2 that severely disrupt the ecological system [15]. As a result, scientists are endeavoring to establish new and sustainable sources of safe drinking water by harnessing renewable energies, as the rapidly expanding population and depletion of non-renewable energy sources worsen the already acute energy constraint [16]. Desalination of water is one of civilization's earliest known approaches to water treatment and has emerged as one of the greenest alternatives to producing fresh water [17]. Desalination is the method of transforming saltwater into freshwater so that it may be utilized by individuals [18]. As shown in **figure 2**, there are several types of desalination processes that provide fresh water to places in need and satisfy potable water standards.

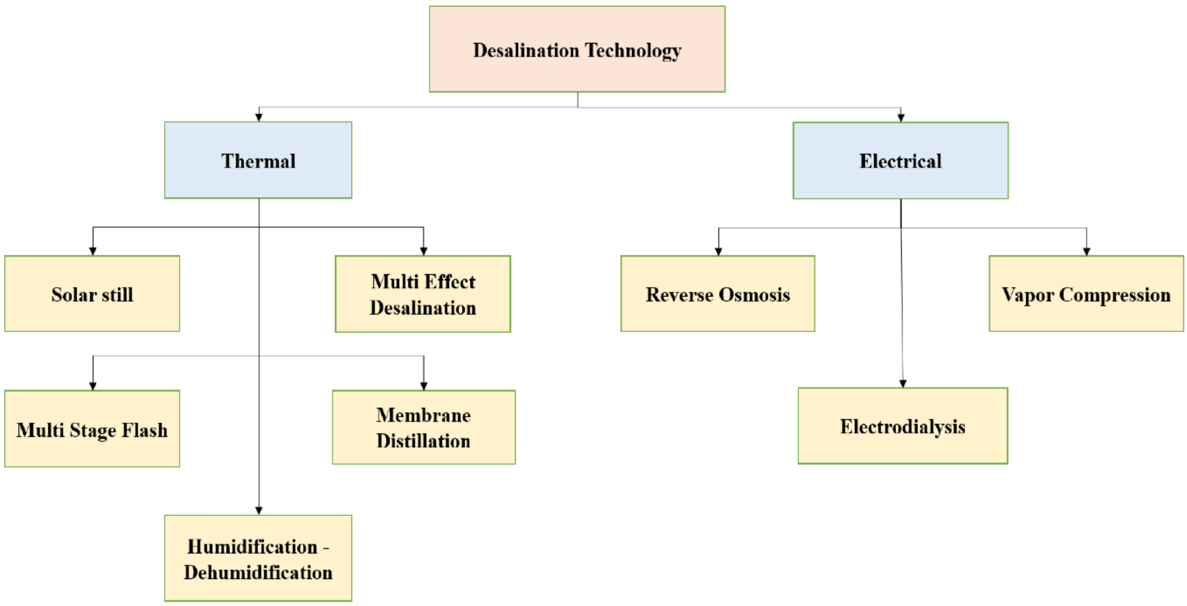

Figure 2: Classification of desalination methods [19]

Among the different types of desalination processes, Electrodialysis (ED) and Reverse Osmosis (RO) are the two most common methods. These techniques, however, are costly, intricate, and require professional labor for their upkeep. Additionally, their usage is limited in rural areas due to their lack of portability. In contrast, solar desalination, powered by renewable energy, offers a more affordable and promising alternative.

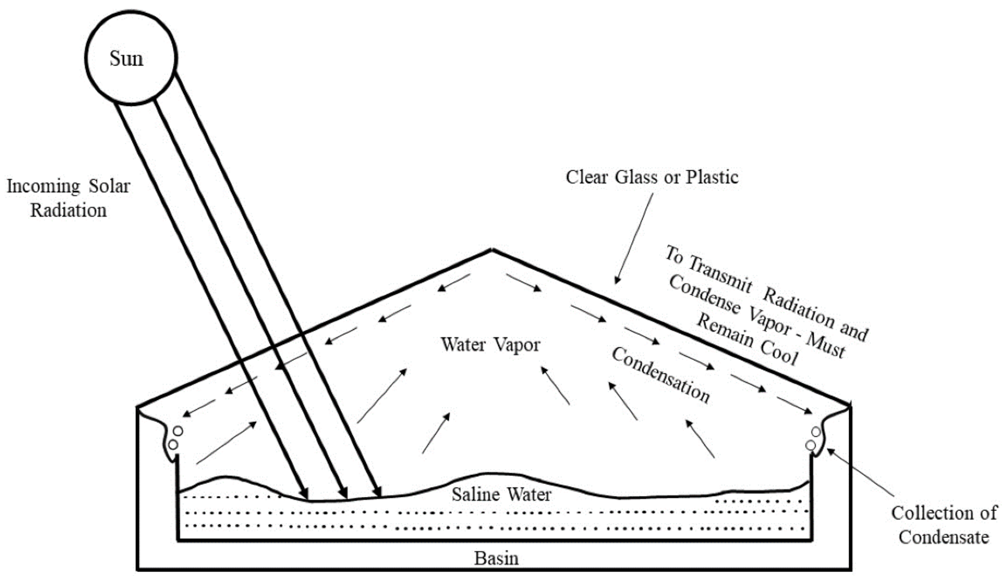

Figure 3: Schematic of a solar still desalination system [20]

Recent advancements in renewable energy systems, combining solar and biomass energy, have shown significant improvements in energy efficiency and sustainability, highlighting the potential of renewable sources for desalination [21]. Solar stills harness direct solar energy from the sun to desalinate salty water through the evaporation and condensation process [22]. In regions with abundant solar energy, solar stills offer a cost-effective, environmentally friendly solution for water purification. Compared to other desalination systems, solar stills are particularly beneficial as they rely on green energy for water purification [23]. The simplest solar still desalination process is shown in **figure 3**. Solar stills exhibit low efficiency and productivity, which limits their widespread use.

This paper distinguishes itself by introducing a holistic framework for advancing SS technology, integrating design and operational enhancements with cutting-edge renewable solutions. Unlike conventional studies focusing on isolated parameters, this work explores the interplay between innovative elements such as phase change materials, nanofluids, and photovoltaic integration, uncovering their potential for synergistic performance gains. A standout feature is the detailed quantification of improvements, such as the 87.4% productivity boost with paraffin wax-based PCMs and the transformative sixfold yield increase enabled by PV-integrated systems. Additionally, the paper delves into novel configurations, including pin-finned absorbers with condensers and advanced reflector designs, offering new benchmarks for efficiency. By addressing overlooked aspects like economic viability, environmental sustainability, and scalability, this study transcends a mere review to serve as a practical guide for the future of desalination technology. Its multidisciplinary approach, incorporating IoT and computational tools, redefines the boundaries of SS innovation, paving the way for its adoption as a sustainable solution to the global freshwater crisis.

1.1. Research gap

Even though solar still technology for desalination has made great strides, there remains a critical need to address several underexplored areas. This review aims to outline those areas. There have yet to be any studies regarding the findings of optimized parameters. The goal here is to ascertain which enhancements - such as fin designs, wick materials, and nanoparticle integration - work best together to increase freshwater production. The effort made in this research to identify the precise optimum characteristics that yield the greatest outcomes for freshwater production makes it unique. Nonetheless, there is a significant lack of comprehensive study on the economic evaluation and scalability of these advancements. More research is needed to evaluate their economic feasibility and practical applicability on a larger scale. Furthermore, although strategies like hybrid energy systems and phase change materials show promise in reducing the intermittent character of solar energy, their efficiency and sustainability in a range of climatic circumstances have yet to be sufficiently investigated. This review highlights these gaps and calls for an in-depth examination of the environmental impacts of advanced solar still designs, and the integration of emerging technologies such as artificial intelligence and advanced materials, which could significantly improve the efficiency and sustainability of solar still systems. Bridging these gaps will make it possible to create solar still systems that are more robust and efficient, which is essential for solving the alarming global water shortage.

1.2. Aims with specific objectives

The primary objective of this review is to analyze advancements in solar still technology, focusing on design and operational enhancements that improve efficiency and productivity. Key areas include evaluating innovations such as fin integration, phase change materials, optimal water depth, and novel materials like nanofluids and wick materials. The study also examines the integration of renewable energy solutions, particularly photovoltaic systems, and addresses these designs' economic viability, scalability, and environmental impacts. This work aims to guide future research and promote sustainable freshwater production, addressing global water scarcity challenges by offering actionable insights.

2. Research Methodology

This section outlines the systematic approach employed to conduct a comprehensive review of advancements in solar still water desalination. The following steps, shown in **figure 4** for a quick overview, were meticulously undertaken to ensure that the review was thorough, and accurate, and provided meaningful insights into the design enhancements and performance optimizations of solar still systems.

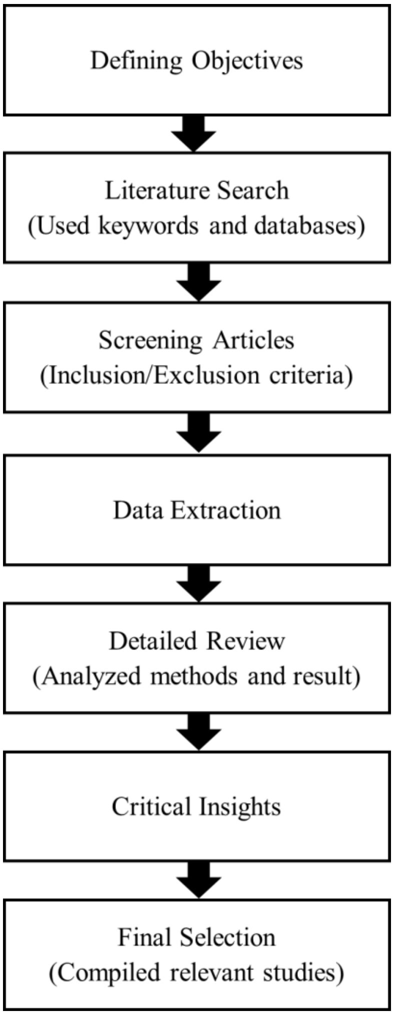

Figure 4: Steps involved in the systematic review of solar still technology advancements

2.1. Defining objectives

This step established the foundation of the review. The primary objective was to explore advancements in solar still technology, which included setting specific relevance criteria, such as focusing on design enhancements, operational strategies, and performance optimizations. By defining clear objectives, the process ensured that only pertinent studies were included.

2.2. Literature search

A comprehensive search of relevant academic databases, including Google Scholar, Scopus, ScienceDirect, and other peer-reviewed journals, was conducted to identify articles pertaining to solar stills and water desalination technologies. The search was guided by keywords such as "solar still," "desalination," "phase change materials," "nanofluids," "photovoltaic systems," and "efficiency enhancement," ensuring that the review captured the most current advancements in the field. By focusing on recent publications, this approach allowed for the inclusion of the latest studies that explore innovative materials, design enhancements, and operational strategies aimed at improving the efficiency and productivity of solar stills for water desalination.

2.3. Screening and selection criteria

The screening and selection criteria for this review were carefully defined to ensure the inclusion of only relevant and credible studies. The inclusion criteria focused on articles that discussed advancements in the design and performance of solar stills, including studies that proposed or tested new materials such as phase change materials (PCMs), nanofluids, and novel wick materials, as well as energy-enhancing technologies like photovoltaic systems and hybrid energy solutions. Only peer-reviewed papers published within the last decade were considered to capture the most recent trends and innovations in the field. Studies were excluded if they did not directly relate to solar stills or desalination, if they focused solely on theoretical concepts without experimental validation, or if they were non-peer-reviewed or poorly documented, in order to maintain the credibility and rigor of the review.

2.4. Data extraction

Key data were extracted from the selected articles, including experimental setups, methodologies used, materials tested (e.g., different types of PCM, nanofluids, fin designs), and performance results. The extracted data were then organized systematically to facilitate a comparative analysis of various solar still designs and their efficiency improvements.

2.5. Detailed review

The selected papers were analyzed in detail, evaluating their methodologies, experimental setups, and results. This process ensured that only studies with robust methodologies and significant findings were included. Attention was given to productivity metrics and innovative technologies mentioned in these studies, ensuring that the review highlighted advancements that contributed meaningfully to the field of solar stills and desalination.

2.6. Critical insights

This section included summarizing the critical parameters studied in the reviewed articles. Key insights were extracted regarding technologies such as PCM integration and the use of nanoparticles. Research gaps were identified, particularly concerning the economic feasibility and scalability of these technologies for large-scale applications, highlighting opportunities for future investigation.

2.7. Final selection

This section included compiling a refined list of articles that met all the criteria and contributed valuable insights into solar still technology. This ensured that the review was comprehensive and focused on advancements.

3. Investigation of the Factors Affecting the Productivity of Solar Still

Understanding the productivity of a solar still isn't just about its design but also the intricate factors that play pivotal roles in its efficiency. This section aims to shed light on these critical determinants, offering a comprehensive look into what makes solar still more effective in its operation.

3.1. Solar still with fins

Fins are well recognized for having a major impact on solar still production. To increase the rate of evaporation, pin fins were found to be more effective [24]. In an experimental study, applying pin-finned wick was shown to boost the system's productivity by more than 23 percent [25]. Another experimental investigation found that a solar still equipped with a pin-finned absorber and connected to a condenser produced around 42% more cumulative water compared to a conventional solar still (CSS) [26]. Abdelgaied et al. [24] examined a modified tubular solar still featuring vertical pin fins and another variant with inclined pin fins. Their findings revealed improvements of 18% and 27.6% with the use of vertical and inclined pin fins, respectively, compared to the conventional tubular solar still (CTSS). In a separate investigation, Mohaisen et al. [27] experimentally observed a passive single-slope solar distillation system that included a condenser and found that the system's hourly cumulative productivity increased by 76.5% and 68.3% with and without fins, respectively. Alawee et al. [28]investigated solar still productivity in Iraqi climatic conditions and observed an increase in performance of the finned still by 16%-54% when it was incorporated with an inclined perforated rectangular fin. According to Sathyamurthy et al. [29], tubular solar still's efficiency was 13.76% without a fin and 23.39% when one. In another experiment, Abdelgaied et al. [30] found that hollow round fins increased tubular solar still's production by 47.2%, while hollow square fins enhanced productivity by 33%. Suraparaju et al. [31] designed a single-basin solar still incorporating a solid staggered pin-finned absorber positioned within a paraffin wax bed and discovered that this developed system was highly effective in producing fresh drinking water. Panchal & Sathyamurthi [32] carried out an experimental investigation on a single-basin solar still featuring fins made of porous material and observed a 42.3% increment in productivity.

3.1.1. Deduced critical insights about fins

Out of all the fin-enhanced solar still designs studied, the combination of a pin-finned absorber with a condenser distinctly outperformed, providing a superior increase of up to 42% in water production compared to other designs. This configuration leveraged the synergistic effects of increased surface area for evaporation and effective condensation, ensuring optimal water output. While certain designs, like those with hollow or staggered fins, showed promising results, they generally resulted in smaller productivity gains and did not capitalize on both evaporation and condensation processes as effectively. Thus, the pin-finned absorber with a condenser not only sets a benchmark for efficiency but also offers an effective way to produce freshwater sustainably, particularly in arid regions with abundant sunlight. This design's clear advantage in balancing evaporation enhancement and condensation efficiency positions it as the most promising for future advancements in solar still technology.

3.2. Effects of the depth of water in solar still

The effect of water depth in different types of solar stills has been the subject of several investigations. It turns out that the rate of evaporation in a solar still is inversely related to the basin's water depth [33]. Examining the impact of water depth on tubular solar stills, Kabeel et al. [34] conducted experiments at different depths (0.5 cm, 1 cm, 2 cm, and 3 cm) with varied cooling water rates. They found that a water depth of 0.5 cm, coupled with a cooling water flow rate of 2 L/h, resulted in the highest efficiency of 54.9%. The productivity for the 0.5 cm water depth was 4.5 L/m^2, while the productivity decreased to 3 L/m^2 at the highest water depth of 3 cm. In an experiment, Manokar et al. [35] varied the water depth in an acrylic pyramid solar still from 1 to 3.5 cm, both with and without insulation. At a depth of 1 cm, water production remained the same for both insulated and uninsulated conditions, but productivity decreased as the depth increased. In another study, Kumar et al. [36] conducted experiments with both a triangular pyramid solar still and a triangular pyramid solar still incorporated into an inclined solar still at different water depths of 0.02 m, 0.04 m, 0.06 m, and 0.08 m. The research consistently indicated that the least water depth resulted in the greatest water production.

3.2.1. Deduced critical insights about water depth

The most significant finding from various research on water depth in solar stills is that a minimal depth of 0.5 cm achieved the highest efficiency and productivity, making it the most impactful. This shallow depth substantially enhanced evaporation rates, resulting in a productivity of 4.5 L/m^2 compared to lower outputs at greater depths. This research highlights a clear, actionable insight: reducing water depth in solar stills can markedly improve performance. This principle is particularly valuable for designing solar stills to generate freshwater as effectively as possible, making it an essential consideration for advancements in solar desalination technology.

3.3. Effects of phase change materials

One of the major issues with solar stills is their inability to produce fresh water in the absence of sunlight. However, this limitation can be addressed by integrating a heat storage unit into the solar still. Such a unit can store heat, which can later be used to produce fresh water when solar radiation is unavailable. Furthermore, the incorporation of sensible or latent heat storage is crucial when integrating heat storage with solar stills. A latent heat storage system offers a higher energy storage density and can function within a narrower temperature range [37]. In this regard, phase change materials (PCM) can be utilized as latent heat storage to enhance the overall productivity of solar stills. Various types of PCMs are used in solar stills. **Figure 5** illustrates the classification of PCM.

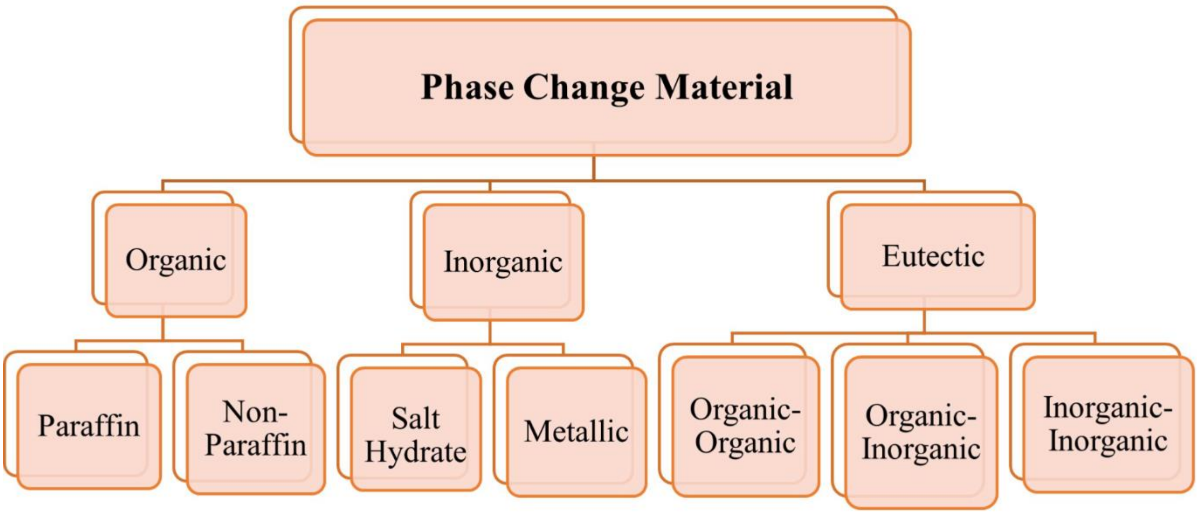

Figure 5: Classification of PCM [38]

Several research studies have explored the impacts of PCM integration in different solar still models. **Table 1** provides a comprehensive overview of the influence of PCM.

Table 1: Summary of the impact of PCM on the productivity of solar still

Types of Solar Still	**Study Area**	**Tilt Angle**	**Type of Study**	**PCM**	**Enhancement in Productivity**	**Ref.**
Single slope	Egypt	30.47^0	Experimental	Paraffin	67.18%	[39]
Single slope	Tehran	35^0	Experimental	Salt hydrate low-temperature PCM	30.3% for using 6 kg PCM	[37]
Single slope	India	11^0	Experimental	Paraffin, Paraffin-SiO_2	51.22% and 67.07%, respectively	[40]
Single slope	India	13^0	Experimental	Paraffin, paraffin-TiO_2, paraffin-CuO, paraffin-Graphene Oxide	23.0%, 39.3%, 43.2%, and 18.0% respectively.	[41]
Modified pyramid	Egypt	30.47^0	Experimental	Paraffin wax	87.4%	[42]
Modified single slope	China	30^0	Experimental	Paraffin wax	73.8%	[43]
Single slope	-	30^0	Experimental	Paraffin, Paraffin-Al_2O_3	10.38% and 60.53% respectively	[44]
Pyramid	China	32^0	Experimental and Theoretical	Shape-stabilized paraffin wax	43.3% (Experimental) and 42% to 53% (Simulation)	[45]
Single slope	Egypt	-	Experimental	Paraffin wax	9.5%	[46]
Single slope	-	11^0	Experimental	Crude wax	50.24%	[47]
Single slope	Iran		Experimental	Paraffin-CuO and Paraffin-Al_2O_3	55.8% and 49.5% respectively	[48]
Modified hemispherical	Algeria		Experimental and Theoretical	Paraffin wax	29.17%	[49]

3.3.1. Deduced critical insights on PCM

Extensive research on the integration of phase change materials into solar stills highlights the standout performance of the modified pyramid solar still with paraffin wax. This design demonstrated an impressive 87.4% increase in productivity, making it the most effective option. The significant productivity boost is attributed to the excellent energy storage capacity of paraffin wax, which enables the solar still to operate effectively even during periods without sunlight. Paraffin wax consistently outperformed other tested PCMs, providing a strong rationale for its use in modified pyramid structures. This finding offers an exceptionally effective solution for the consistent generation of freshwater, particularly in regions with intermittent sunlight.

3.4. Effect of nanofluids in solar still

Nanofluids are fluids composed of nanoparticles that exhibit high thermal conductivity and are extremely effective at absorbing more solar radiation than water. By raising the temperature differential between the glass and the water, nanofluids increase the output of solar stills. Two types of solar stills are commonly used: active solar stills and passive solar stills. Studies have found that using nanofluids can improve the economic, environmental, and energy performance of both active and passive distillers [50]. Over the past few decades, researchers have increasingly focused on nanofluid-based solar stills due to their ability to significantly boost productivity. Among the various properties of nanofluids, thermal conductivity is the most critical, as nanoparticles with high thermal conductivity can store and absorb larger amounts of heat. **Figure 6** displays the thermal conductivities of different nanoparticles.

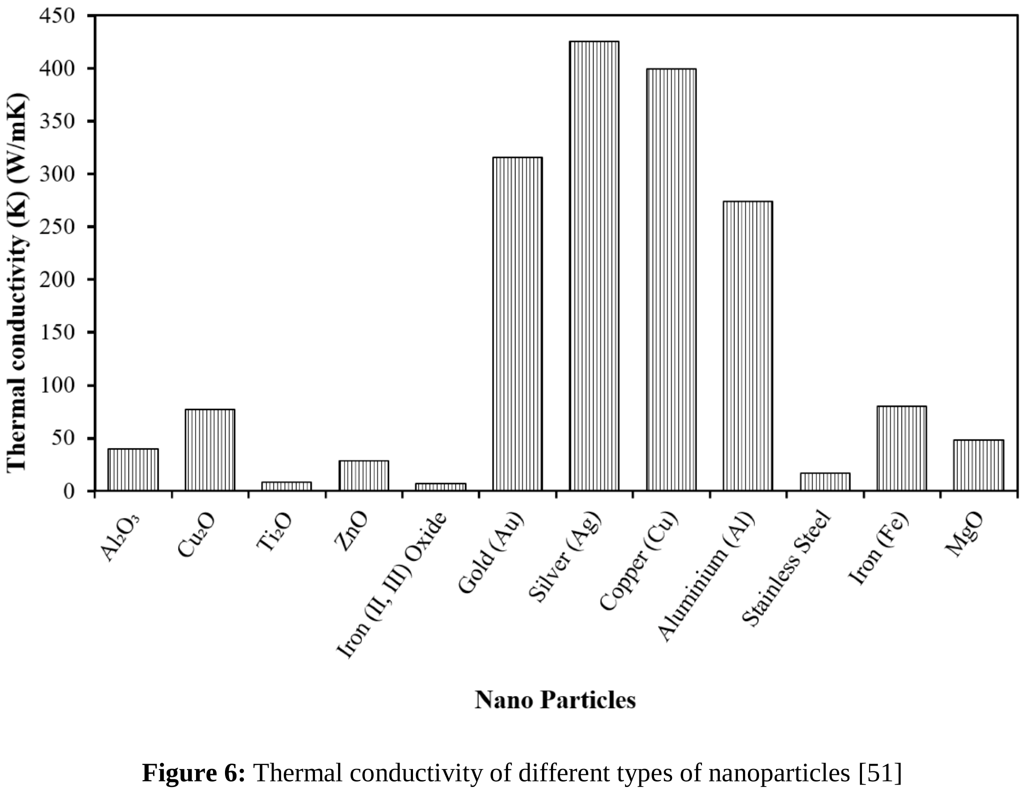

Figure 6: Thermal conductivity of different types of nanoparticles [51]

Researchers have experimented with various nanoparticles in an effort to increase solar still efficiency. In this regard, Thakur et al. [52] conducted an experiment introducing a blend of ZnO and CuO nanoparticles into the basin water of a solar still. They observed a 41.60% increase in productivity with CuO nanofluids and an 11.11% increase with ZnO nanofluids compared to the productivity of the solar still without nanofluids. Katekar et al. [53] demonstrated that blackboard paint, combined with aluminium oxide nanoparticles (30%), improves the performance of solar absorbers by enhancing solar absorption. Elango et al. [54] examined and assessed the effectiveness of three distinct nanoparticles, namely Al_2O_3, SnO_2, and ZnO. The experiment revealed that Al_2O_3 demonstrated the highest productivity among the three, as depicted in **figure 7**.

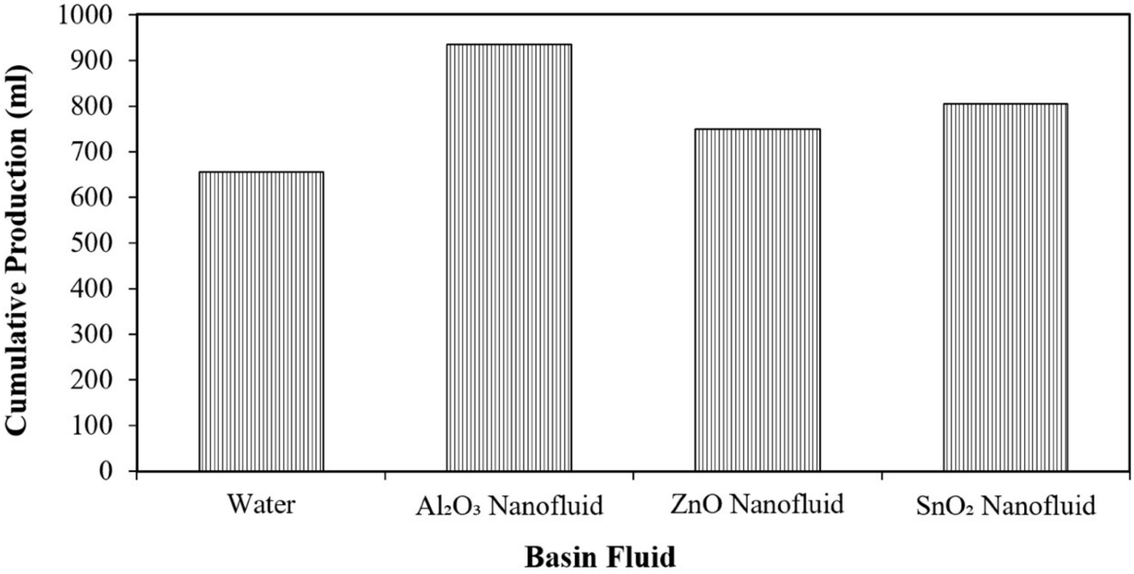

Figure 7: Cumulative production (ml) for different fluids [54]

In another study, Sharshir et al. [55] performed an experiment on a single basin solar still using graphite and CuO micro-flake nanoparticles with various combinations of film cooling flow rates, as shown in **figure 8**. The findings indicated a rise in net yield of approximately 47.80% and 57.60% when utilizing graphite and copper oxide particles, respectively, with water flowing over the glass cover.

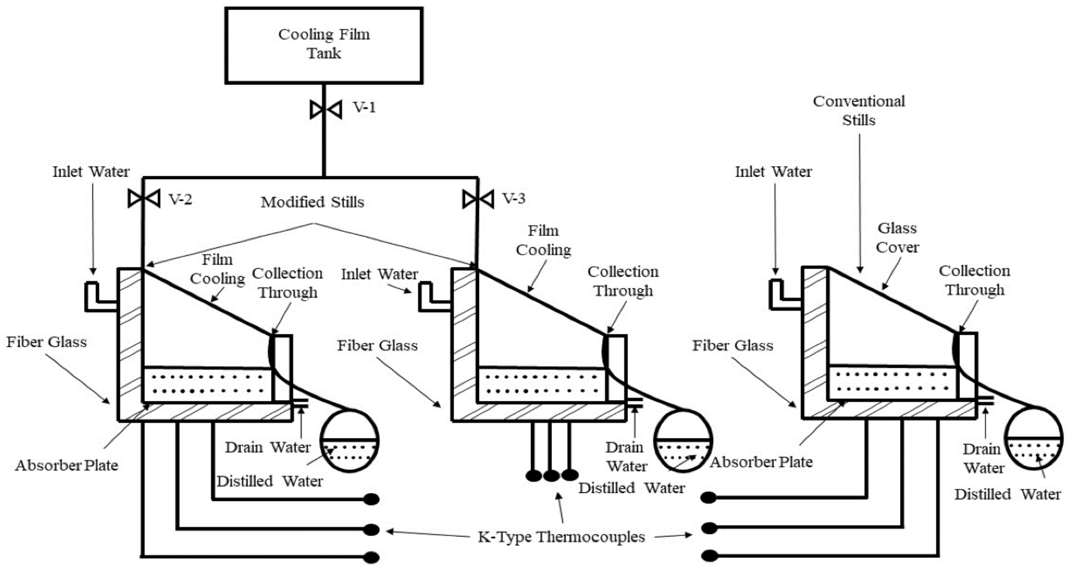

Figure 8: Illustration of the film-cooled single-slope solar still incorporating nanofluid (graphite and CuO micro-flakes) [55]

Additionally, researchers have investigated several nanofluids, including MnO_2, SiO_2, TiO_2, Fe_3O_4, etc. **Table 2** provides a summary of a thorough assessment of nanofluid-based solar distillation systems.

Table 2: Synopsis of nanoparticle-based (nanofluid) solar distillation units

Ref.	SS Type	Types of Study	Nanoparticles	Concentration/ Particle Size	Effects
Shoeibi et al. [56]	Double slope	Numerical	Hybrid nanofluid (Al_20_3-TiO_2)	0.4%	Yield increased by 11.09%, and energy efficiency by 28.21%.
Rabbi and Sahin [57]	Single slope	Experimental	Hybrid nanofluid (Water-Al_2O_3-SiO_2)	0.1% Al_2O_3 and 0.1% SiO_2	Compared to CSS, pure desalinated water production increased by 298.3%.
Bellila et al. [58]	Modified hemispherical	Experimental	Al_2O_3-water nanofluid	0.1%, 0.2%, and 0.3%	The modified distiller's yield enhanced by 41.8%, 50.9%, and 61.3%, respectively, compared to CSS.
Jathar and Ganesan et al. [59]	Concave type stepped	Experimental	Utilization of MgO, Al_2O_3, and TiO_2 nanofluids	At 0.1% and 0.2%	Using MgO nanofluid with a 0.2% concentration increased productivity by 41.35%.
Ghandourah et al. [60]	Double slope	Experimental	$LaCoO_3$	20.0 wt%	An increase of 40.26% in the freshwater production.
Faridani & Ameri [61]	Single slope	Experimental	γ-Al_2O_3	0.1, 0.2, 0.3 mass % of γ-Al_2O_3	Distillate production increased by 60.03% with 0.3 mass percent of γ-Al_2O_3.
Modi et al. [62]	Single basin dual slope	Experimental	Al_2O_3	0.1% mass	At water depths of 30 mm, 20 mm, and 10 mm, distilled output increased by 19.40%, 28.53%, and 26.59%, respectively, compared to a nanoparticle-free still.
Benoudina et al. [63]	Modified	Experimental	Al_2O_3	0.1%, 0.2% and 0.3%	Yield increased by 62.25%, 81.12%, and 102.64%, respectively.
Nazari et al. [64]	Single slope	Experimental	Cu_2O	0.08% volume fraction	Productivity increased by about 81%.
Abdullah et al. [65]	Rotated drum type	Experimental	CuO	10–14 nm	Utilizing an external condenser, a water heater, and a CuO nanofluid, productivity increased by 350%.

Chen et al. [66]	Single basin	Experimental	Carbon nanotubes prepared by dispersing Fe_3O_4	0.04 wt%	With the increase of concentration from 0 wt% to 0.04 wt%, evaporation efficiency increased from 24.91% to 76.65%.
Kabeel et al. [67]	Modified	Numerical	Al_2O_3 & Cu_2O	0.02–0.3%	The improved still's daily efficiency was 84.16% and 73.85%, respectively.
Attia et al. [68]	Modified	Experimental	CuO	0.1%	In winter, produces a daily yield that is 26.34% higher.
Sahota and Tiwari [69]	Passive double slope	Numerical	Al_2O_3	0.04%, 0.08%, and 0.12%	The increase in daily yield was 8.9%, 10%, and 12.2% for the three varied concentrations, respectively.
Modi et al. [70]	Single slope	Experimental	Al_2O_3	0.01%, 0.05%, 0.10%, and 0.20%	Distilled output rose by 17.6% at 0.01% concentration but decreased with higher concentrations.

3.4.1. Deduced critical insights about nanofluids

Amongst the many studies on the impact of nanofluids in solar stills, the use of CuO nanoparticles, which resulted in a 350% increase in productivity in a rotated drum-type solar still, is particularly noteworthy. The significant improvement in heat transfer characteristics observed with CuO nanoparticles highlights their potential impact. These characteristics greatly enhanced the rate of evaporation, outperforming the results achieved with other nanoparticles. The practical application of CuO in this particular solar still design exemplifies a breakthrough in leveraging nanotechnology to overcome the limitations of traditional solar stills, especially in enhancing operational efficiency during less ideal circumstances. This make CuO nanoparticles an exceptional candidate for further research and broader implementation in solar desalination technology, with the potential to revolutionize solar still performance and scalability.

3.5. The tilt angle’s impact on solar still

Solar stills are surrounded by materials with high transmissivity, with a transparent glass plate positioned on top where condensation occurs. The tilt angle of the glass cover is typically adjusted according to the latitude of the location to optimize solar radiation absorption. Six identical solar stills with angles of 10, 15, 20, 30, 35, and 45 degrees were used in an experiment by Cherraye et al. [71] at the University Kasdi Merbah Ouargla's LENREZA facility, located at 31.95° N latitude. According to the results of that experiment, the optimal inclination was found to be 20° during the spring and summer & 30° during the winter and fall. They also observed that the solar still's output might rise by up to 80% when the tilt angle was raised, and this was partially because the still's operating temperature increased. Panchal et al. [72] did an experiment using a solar still inclined at a 30° angle in Mehsana, Gujarat, wherein the latitudinal inclination was 23.6° and observed a 26.77% enhancement in productivity. Dhivagar & Mohanraj [73] carried out an experiment of single slope solar still at Coimbatore city in India with an inclination angle of 12°, whereas the city’s latitude angle is also 12° and found a 19.6% enhancement in productivity. Tuly et al. [74] analyzed the effectiveness of an active double slope modified solar still in Rajshahi, Bangladesh. The still had an angle of 25°, while Rajshahi, Bangladesh, has a latitude angle of 24.3636° N, and there was an improvement of 22.33% greater than the conventional one. Consequently, a latitude-equivalent angle of ± 10° was consistently maintained by numerous researchers. Additionally, it has been discovered via multiple experiments that the tilt angle fluctuates with the season and has an impact on productivity. Nafey et al. [75] carried out an experiment in Suez City during the winter and summer of 1998 (January and May, respectively), as shown in **figure 9**, which illustrates that the production enhanced if the tilt angle increased during the winter months, whereas the output increased when the tilt angle decreased during the summer.

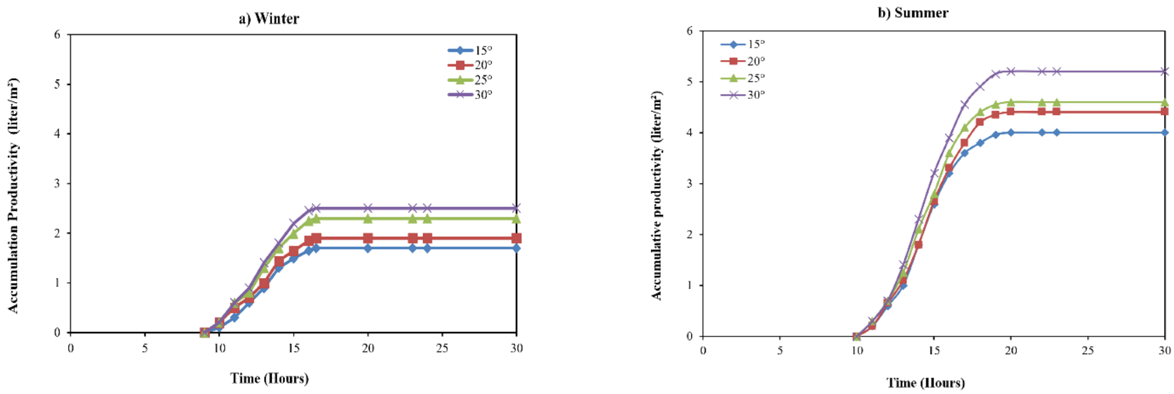

Figure 9: Experimental transformation of the still yield concerning the angle of glass tilt during a) Winter and b) Summer [75]

3.5.1. Deduced critical insights about tilt angle

From the studies reviewed, it's evident that there is a seasonal variance in the most suitable tilt angle for solar stills. However, setting the tilt angle at 30° has proven to be the most effective choice for consistently optimizing efficiency and maximizing clean water output throughout the year. This angle ensures optimum performance by efficiently balancing solar exposure across seasonal changes.

3.6. Effect of reflectors in solar still

Reflectors are affordable and highly effective in boosting the output of a solar still. They are positioned in SS to focus sunlight conveniently on the desired area. As a result, the targeted area receives more heat flux. Reflectors also play a significant role in reducing wasted heat energy from solar stills [76]. Researchers have incorporated both internal and external reflectors in their experiments to assess their impact on solar stills. These reflectors are especially beneficial when solar intensity is low.

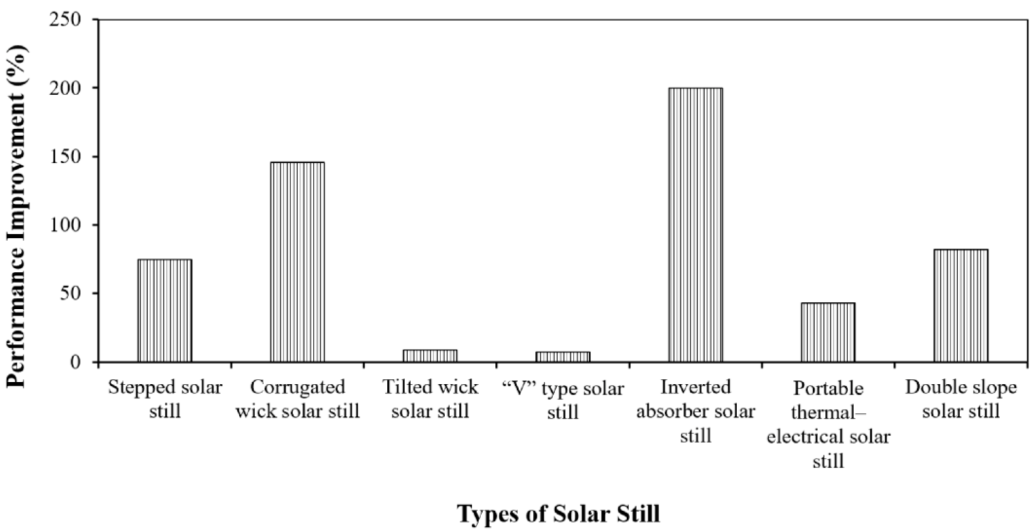

Figure 10: Productivity improvement of several solar still types utilizing reflectors [76]

Gnanaraj and Velmurugan [77] investigated solar still with external reflectors and found that the reflector-equipped still produced 93.39% more distillate than the traditional still. Essa et al. [78]

utilized both external and internal reflectors in tray solar still and observed that reflectors increased efficiency by 51% compared to a traditional distiller, which achieved only 34.5%. In a study by Younis et al. [79], it was found that the hemispherical solar still with internal reflective mirrors and El-Oued sand grains achieved a 98% improvement in daily yield and a 96% increase in thermal efficiency, demonstrating significant performance gains in solar still design. Abdullah et al. [80] carried out an experiment using reflectors on a rotating wick solar still (RWSS) and reported that its freshwater production was 300% greater than that of the conventional solar still (CSS). El-Samodany et al. [81] investigated a stepped solar still with internal and external reflectors and a 165% boost in distilled water output compared to a conventional solar still. Tanaka [82] designed a basin still with an external reflector, a glass cover, and internal reflectors and observed that utilizing reflectors on cold days enhanced daily production by 70% to 100%, as additional solar energy was directed into the still. **Figure 10** illustrates how reflectors affect the increase in production of several solar still types.

A summary of thorough assessment of reflectors-based solar distillation systems is summarized in **table 3.**

Table 3: Summary of solar distillation units using reflectors

Ref.	SS Type	Types of Study	Location	Types of Reflectors	Effects
[83]	Single slope	Experimental and numerical	Jordan	Internal reflectors with fins together	Using internal reflectors and fins to traditional solar still, especially with a high-tilt factor in winter, significantly boosted solar still productivity.
[84]	Trays	Experimental	Saudi Arabia	Internal flat reflector	Total freshwater yield increased by 57%.
[85]	Stepped	Experimental	Egypt	Internal reflectors	Using PCM and internal reflectors with an evacuated tube collector (first case) to one with graphite and PCM (second case), the latter improved daily efficiency by 21.56%.
[86]	Single slope	Experimental	India	Internal reflector	The highest efficiency of 33.6% was achieved by using the internal reflector with a heat exchanger and condenser.
[87]	Modified pyramid	Experimental	Egypt	Reflector with glass cooling, hanging wick, and nano-TiO_2 particles.	An enhancement of 127.27 % in yield was achieved compared to a traditional solar still.
[88]	Single slope	Theoretical and experimental	Iran	Internal reflectors	Enhanced the efficiency by 18%.
[89]	Double basin	Experimental	India	External Reflector	The productivity was 105.8% higher.
[90]	Basin	Theoretical and experimental	Iran	External Reflector	Attained efficient utilization of solar energy with external reflectors, as their incorporation resulted in a 20% increase in radiation.

3.6.1. Deduced critical insights about reflectors

Among the various research efforts exploring the use of reflectors in solar stills, the study involving rotating wick solar stills equipped with reflectors stands out significantly. This configuration achieved a 300% increase in potable water production. The considerable enhancement was primarily due to the effective combination of the rotating wick mechanism, which expands the surface area for evaporation, and the strategic use of reflectors that concentrate more solar energy directly onto the still. This approach excelled in employing reflective and motion technologies efficiently to maximize heat absorption and water production, making it an outstanding model for attaining high efficiency in solar distillation systems.

3.7. Effects of wick materials in solar still

The efficiency of a solar still is remarkably impacted by the wick material, which influences the speed at which water is transported from the heated surface to the condensate surface. Omara et al. [91] described that adding wick material to solar stills expands the surface area for vaporization, reduces the water layer thickness, and diminishes heat retained within the solar still. Consequently, the quantity of freshwater produced is increased. In an experiment, Essa et al. [92] discovered that adding a black jute wick belt that rotates inside the solar still, combined with graphene quantum dots nanofluid, considerably improved thermal energy efficiency and clean water distillation. Hansen et al. [93] conducted an experiment on an inclined-type solar still and discovered that water coral fleece combined with a stepped wire mesh absorber significantly outperformed flat and stepped absorbers in freshwater production. Alaian et al. [25] looked into how well a solar still performed when it was supplemented with a pin-finned wick evaporation surface and discovered an output gain 23% higher than that of a conventional system. Omara et al. [94] performed an experiment and noticed that adding a wick to the corrugated base of a solar still increased daily efficiency to 49.3% and enhanced water production by over 90% compared to the traditional stills. Abdelaziz et al. [95] carried out an experiment on a tubular solar still and noted that incorporating wick material into the aluminum v-corrugated surface improved clean water productivity, energy efficiency, and thermal effectiveness by 42.77%, 103.01%, and 52.22%, respectively. Murugavel and Srithar [96] carried out an experiment with several wick materials in the basin, including sponge sheet, light cotton cloth, coir mate, and waste cotton pieces, finding that light black cotton cloth yielded the best outcomes. Sharshir et al. [97] compared the productivity of cotton towel, cotton cloth, and jute cloth and concluded that cotton cloth wicks performed best due to their superior capillary action. Manikandan et al. [98] studied multiple designs of wick-type solar stills, including basin wick type, wick basin-type, floating wick type, multi-wick type, floating cum tilted wick-type, tilted wick-type with a flat plate reflector, ‘‘V’’ type solar still with charcoal absorber, and clothes moving wick type. Among these, the floating wick type achieved the highest output. **Figure 11** shows a schematic illustration of the wick-type solar still.

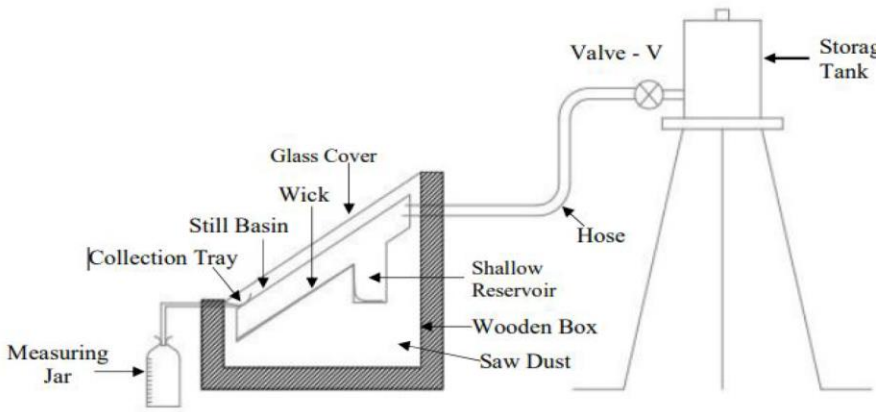

Figure 11: Diagrammatic illustration of the solar still using wicks [99]

In **table 4**, a comprehensive summary of research outcomes highlighting the influence of wick materials on the performance of solar stills by juxtaposing findings with relevant studies from the past has been provided.

Table 4: Summary of outcomes utilizing wick materials in solar stills from previous research

Ref.	Solar Still Type	Description of Materials	Effects
Essa et al. [100]	Convex tubular	Jute cloth and cotton wick	* Improvement in productivity using jute cloth was 92.5% (without nanocomposites) and 114% (with nanocomposites). * Improvement in productivity using cotton wick was 88% (without nanocomposites) and 107% (with nanocomposites).
Alawee et al. [101]	Cords wick	Jute wick and cotton wick (at 25 wick cords)	The increase in productivity was 122% and 118% when using jute and cotton wicks, respectively.
Mahdi et al. [102]	Tilted wick	Charcoal cloth	The still's average daily efficiency was around 53% on clear summer days.
Abdullah et al. [80]	Rotating wick solar still	Wick belt of black jute cloth	The increase in productivity was 300% and 260% with and without reflectors, respectively.
Younes et al. [103]	Tilted wick	Flat absorber wick solar still, corrugated absorber wick solar still, half barrel absorber wick solar still	The productivity of flat wick solar stills, half barrel wick solar stills, and corrugated wick solar stills was 75%, 93%, and 100% larger than that of conventional solar stills, respectively.

3.7.1. Deduced critical insights about wick materials

Of all the wick materials investigated for enhancing solar still production, black jute cloth has proven to be the most productive. This material can boost production by up to 300% when combined with reflectors, especially in rotating wick solar stills. Black jute's strong capillarity and coarse texture promote surface evaporation rates and water flow. Throughout its operational time span, the wick's rotation continuously exposes fresh surfaces, maximizing solar energy absorption and evaporation. This notable enhancement in output makes black jute cloth an excellent choice for solar still applications, offering a highly efficient and sustainable method for water distillation.

3.8. Effects of the porous materials in solar still

In a solar still, porous materials can be employed as the material for the condensation surface, and they can affect the efficiency of the still. Porous materials contain small pores that can trap water vapor and provide a large surface area for condensation, which increases the quantity of water produced. Mohamed et al. [104] conducted an experiment to test the hypothesis that the thermodynamic performance of a solar still can be improved by employing porous absorbers to enhance mass and heat transfer. The experimental outcomes were reasonably encouraging. Peng et al. [105] explained that the efficient localization of heat on the evaporation surface makes porous materials useful for accelerating the solar evaporation process.

Table 5 encapsulates a comprehensive summary of the impact of porous materials on solar still productivity, drawing insights from various studies. The juxtaposition of findings with relevant research allows for a nuanced understanding of the multifaceted effects of porous materials in this context.

Table 5: Summary of porous materials' effects on solar still productivity

Ref.	Solar still type	Description of Materials	Effects
Rashidi et al. [106]	Single slope	Black sponge rubber was employed to form the reticular porous insert	Productivity improvement was about 17.5%.
Mohamed et al. [104]	Solar still with black fine stones	Employing a porous bed with a range of porosities according to the size of the stone	The solar still cavity's interior had an average Nusselt and Sherwood number improvement of roughly 115% and 51.95%, respectively.
Arunkumar et al. [107]	Single slope	Using a porous absorber (carbon-impregnated foam) with bubble-wrap insulation	Cost just went up 5%, while output went up 22%.
Mohamed et al. [108]	Modified solar still with fine stones	An exquisite natural stone (black basalt)	The daily productivity increased by roughly 19.81%, 27.86%, and 33.37% for stones that were 1 cm, 1.5 cm, and 2 cm in size, respectively.
Hassan et al. [109]	Single slope	Modified solar still with a basin filled with sand and forced-water cooling	* Energy and exergy effectiveness increased to their highest levels by 39% and 33%, respectively. * The highest average still efficiency was determined to be 46.46% in the summer and 38.84% in the winter.
Abdallah et al. [110]	Single slope	Coated and uncoated metallic wiry sponges, black rocks	Black rocks provided about 60% gain without any corrosion issues, while coated and uncoated metallic wiry sponges improved the water collecting yield, which was assessed to be roughly 28% and 43%, respectively.

3.8.1. Deduced critical insights about porous materials

The utilization of black basalt stones within solar stills has proven to be especially effective in enhancing productivity. This approach maximizes the evaporation and condensation processes by leveraging the natural heat absorption and retention capabilities of basalt, coupled with its porous structure. The material is a preferable option among the numerous porous materials examined because of its potential to considerably enhance the performance of the solar still, as evidenced by the noticeable rise in daily production observed with different sizes of stone.

3.9. Effects of the additional basin in the solar still

Adding a basin in a solar still can increase its efficiency by improving heat transmission and expanding the surface area suitable for evaporation. The additional basin can be used to preheat the water before it enters the main still, which may accelerate the pace at which water is produced and increase the temperature differential between the evaporation and condensation surfaces. Rajaseenivasan et al. [111] conducted an experiment and observed that incorporating more basins slightly raised the overall cost but significantly boosted the distillate. The same basin condition resulted in an 85% increase in production, and when compared to the single basin's lowest output condition, the increase in production was 169%. Rajaseenivasan et al. [112] observed that the distillate yield for double basin still was 20% greater than for single basin still when employing shards of mild steel. In another study, Rajaseenivasan and Murugavel [113] observed that, given the same basin condition, the output of a double basin still was 85% higher than that of a single basin still.

In light of these findings, it is evident that employing additional basins in solar still designs can significantly enhance water production capacity without the need for complex or expensive technologies. This approach not only makes the solar distillation process more efficient but also more adaptable to larger-scale applications where increased water demand aligns with the need for more efficient water production systems.

3.10. Wind speed's impact on solar stills

Wind speed is a fundamental factor that influences the output and effectiveness of solar stills. The performance of a solar still can be affected by the wind speed in a plethora of ways. High wind speed can increase evaporation and reduce the efficiency of the still, while low wind speed may cause the still to be less effective in removing contaminants and producing fresh water. Additionally, high wind speed can cause instability in the still and disrupt the difference required for condensation to occur. A moderate wind speed can help to promote the flow of air and improve the overall effectiveness of a solar still. Zurigat and Abu-Arabi [114], Elsherbiny and Fath [115], Elsafty et al. [116] identified these enhancement characteristics through their thorough experimental analysis. El-Sebaii [117] found that as wind speed increased, the daily output of active basin type, wick-type, and vertical solar stills improved up to a typical velocity above which the increment in daily productivity became pretty trivial. Larger water masses offered greater wind effectiveness, and the smallest mass of water yielded the highest daily output [118].

Figure 12 illustrates how the daily productivity of a single slope single basin still changes with different wind speeds and varying masses of basin water, and in **figure 13**, the impact of wind speed on the overall productivity of solar stills is depicted.

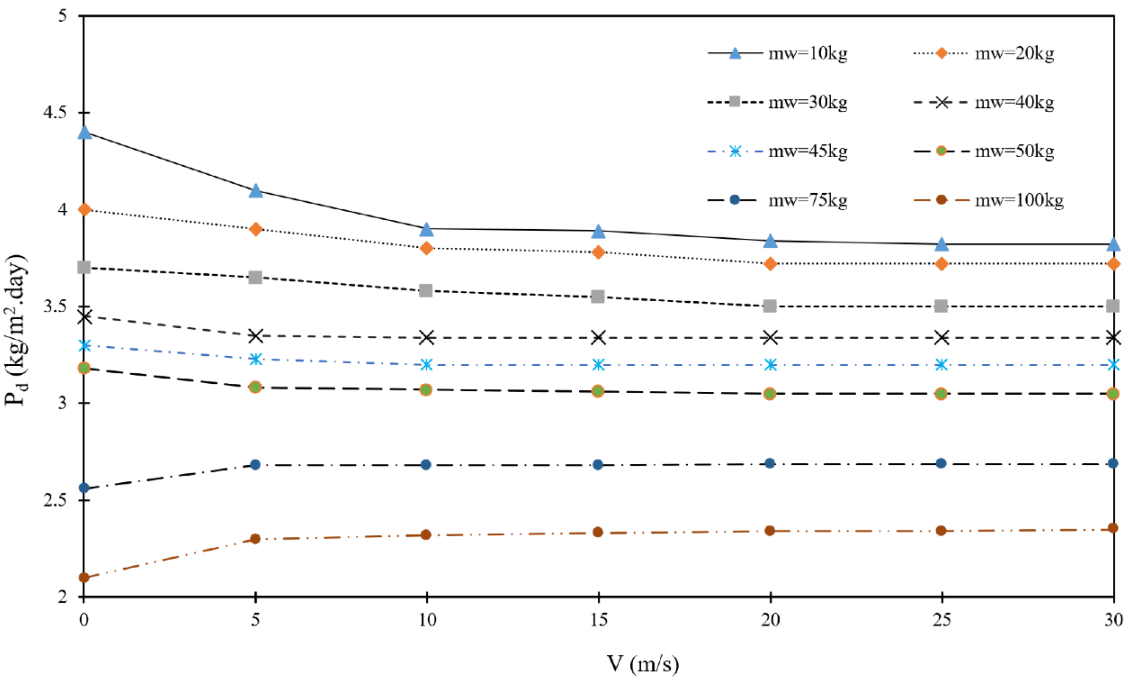

Figure **12:** Changes in daily productivity (P_d) of the single slope single basin still with varying wind speed (V) for various masses of basin water (m_w) [119]

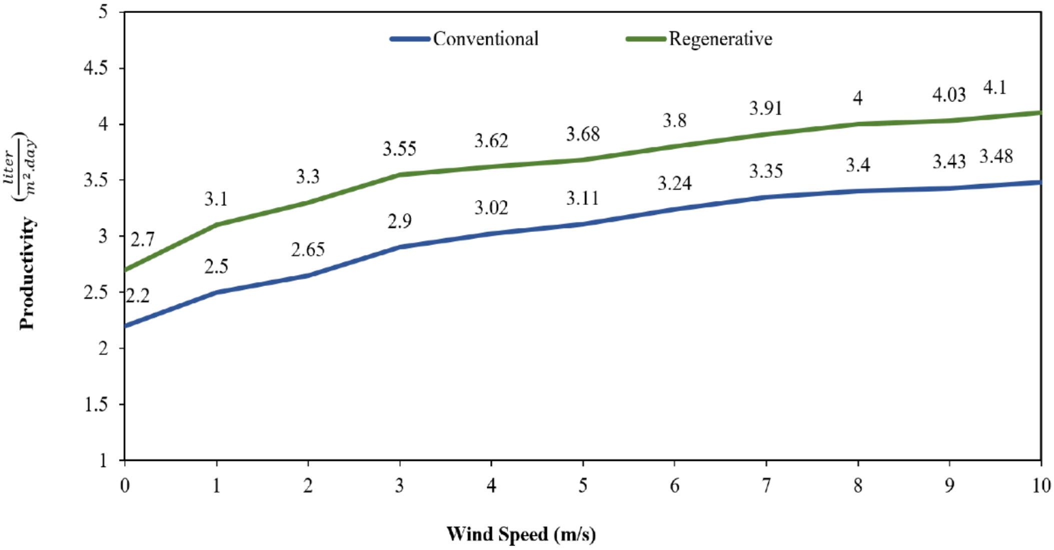

Figure 13: Impact of wind speed on solar stills' productivity [114]

3.11. Effect of the number of stages on solar stills

The number of stages in a solar still affects its productivity. However, the optimal number of stages may vary based on the climate, the still's size, and the desired output. In multi-effect still, the next effect heats the water using the heat from condensation from the preceding effect [120]. Estahbanati et al. [121] carried out an experiment and observed that adding stages increased the surface area available for evaporation, which enhanced the production of purified water.

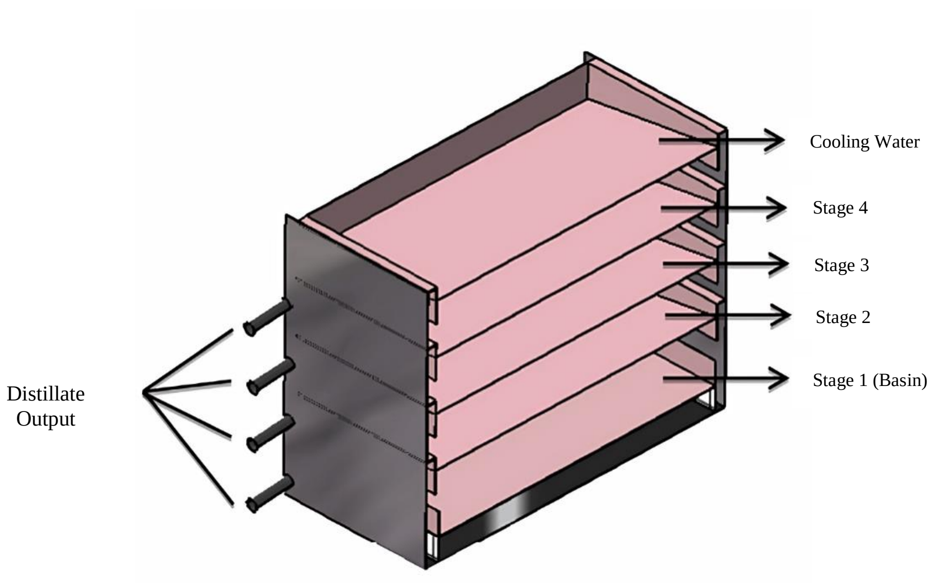

Figure 14: A Schematic of Multi-Stage Solar Still [121]

Shanazari and Kalbasi [122] conducted an experiment and found that by incorporating extra basins up to four, the yield was linearly enhanced; when there were more basins, however, the yield trend slowed down, and the results indicated that productivity increased only a little beyond the first 7 basins. In **figure 14,** a schematic of multi-stage solar still has been shown, and **figure 15** depicts the variations in daily output in accordance with the number of effects.

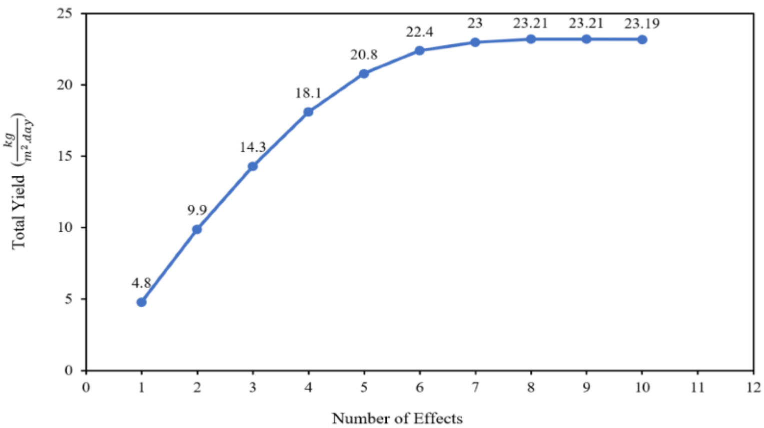

Figure 15: Variations in daily productivity accordance with the number of effects [122]

Xiong et al. [123] performed an experiment on a three-stage active solar still and noticed that 40% of the freshwater generation took place. Alshammari et al. [124] developed a theoretical model of tubular solar still and evaluated that the yield would increase by 60.5%, 97.8%, and 122.4% for double, triple, and quadruple effects, respectively.

3.12. Effect of heat pump on solar still

The integration of heat pump technology with solar stills has emerged as a promising strategy to enhance the desalination process's efficiency and reliability. By introducing controlled heating to the solar still, heat pumps elevate the brine's temperature, accelerating evaporation rates and increasing freshwater production. A schematic of heat pump-assisted regenerative solar still is shown in **figure 16**.

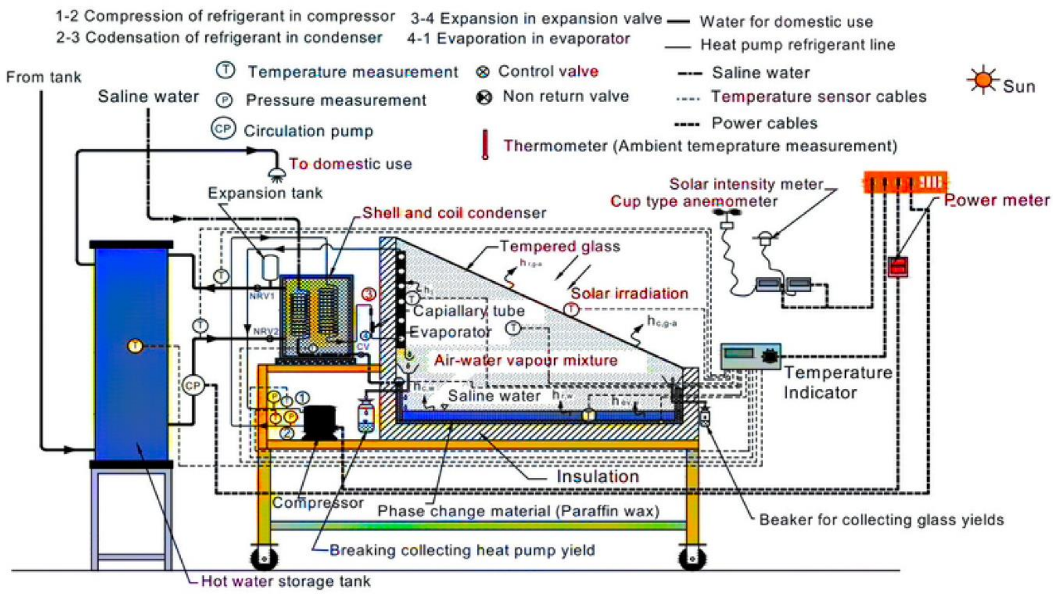

Figure 16: Schematic representation of heat pump-assisted regenerative solar still [125]

Ongoing research seeks to optimize this integration, emphasizing its potential to address freshwater scarcity challenges in solar-rich regions. **Table 6** provides a comprehensive summary of the effects observed in solar still performance with the integration of heat pumps. It details the impact on various key parameters, offering insights into the enhanced efficiency and productivity achieved through this integration.

Table 6: Summary of the impact of heat pump integration on solar still performance

Ref.	Solar Still Type	Type of Study	Effects
Dhivagar et al. [126]	Regenerative	Experimental	A Heat pump water-assisted regenerative solar still enhanced productivity by 85.1% compared to CSS.
Hidouri et al. [127]	Simple	Experimental	The hybrid system of a solar still connected to a heat pump raised average efficiency from 20% to 80%.
Halima et al. [128]	Simple	Numerical	Productivity was enhanced by 75% when simple solar still was coupled to a compression heat pump.
Shakir et al. [129]	Regenerative	Numerical	The enhancement in productivity was 75% for a heat pump water-assisted regenerative solar still.
Hidouri and Mohanraj [130]	Active	Experimental	The active solar still, with the assistance of a heat pump, increased the yield by approximately 84.5%.

3.12.1. Deduced critical insights about heat pump

The integration of heat pump technology in regenerative solar stills has been demonstrated to be an extremely effective way to improve desalination processes over conventional approaches. The difficulties of freshwater shortfall may be effectively addressed by utilizing this technology, which stands out as especially promising for boosting freshwater production in areas that have abundant solar energy.

3.13. Effect of natural circulation loop on solar still performance

The integration of a natural circulation loop within a solar still system has garnered significant attention due to its potential to enhance the overall efficiency and productivity of the desalination process. A natural circulation loop, typically consisting of pipes or channels, facilitates the circulation of the heated brine from the solar collector to the distillation unit and back, driven solely by buoyancy forces.

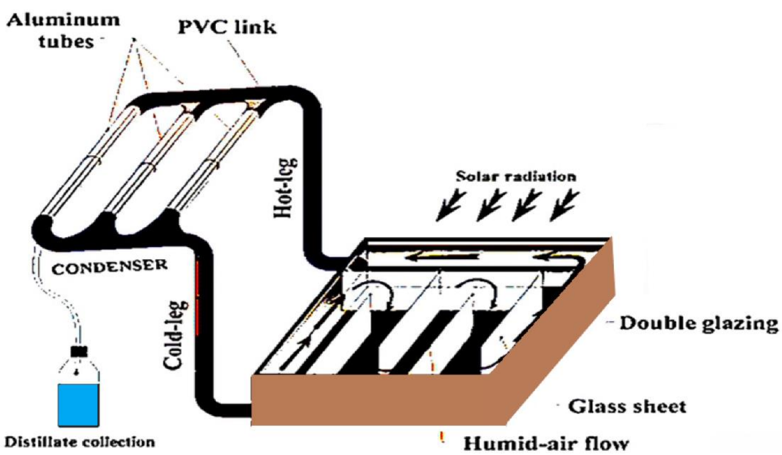

Figure 17: Schematic representation of the Natural Circulation Loop Solar Still [131]

In an experiment, Rahmani et al. [132] found that integrating a natural circulation loop enhanced productivity by 45.15%. In another experiment, it was found that a novel open natural circulation loop-based parabolic trough collector demonstrated stable dual-mode operation (hot water and low enthalpy steam generation) under varying climatic conditions, exhibiting consistent efficiency of 68% throughout the day and suitability for agricultural and small-scale industries [133]. In harsh climates like Baghdad, managing high glass cover temperatures is critical for solar still productivity. A study showed that water cooling after 4 PM increased productivity by up to 403%, emphasizing the importance of temperature management - a key factor also addressed by natural circulation loop systems, offering complementary benefits in solar still design [134]. A schematic illustration of the natural circulation loop solar still has been shown in **figure 17**.

3.14. Effect of geothermal energy for enhancing the performance of solar still

Geothermal energy, derived from the earth's natural heat reservoirs, offers a sustainable and reliable source of power. When integrated with solar stills for water desalination, it enhances productivity and efficiency. By preheating feedwater with geothermal heat, the temperature gradient between feedwater and the condensing surface is increased, improving distillation rates. Danish et al. [135] investigated a solar still's performance enhancement through the integration of a geothermal cooling system and a vacuum pump, achieving a substantial 305% increase in daily water productivity. Incorporating a coaxial borehole exchanger with a single basin solar still enhanced productivity by approximately 126%, showcasing the potential of geothermal energy extraction via a ground exchanger for solar desalination [136]. In another study, it was found that incorporating geothermal and solar energy with desalination and combined cooling, heating, and power for a hotel's water, heating, cooling, and electricity needs significantly reduced costs and environmental impact, improving the objective function by 14.38% for solar, 54.61% for geothermal, and 59.78% for combined modes compared to the traditional mode [137].

3.15. Effect of photovoltaic panel integrated systems on solar still

The integration of photovoltaic (PV) systems with solar stills holds immense potential to enhance water desalination efficiency. By providing a continuous and reliable source of electrical energy, PV integration ensures stable operation even in low-solar radiation conditions. This results in increased water temperatures within the solar still, boosting evaporation rates and overall productivity. In **figure 18**, a schematic of the PV integrated solar still has been demonstrated.

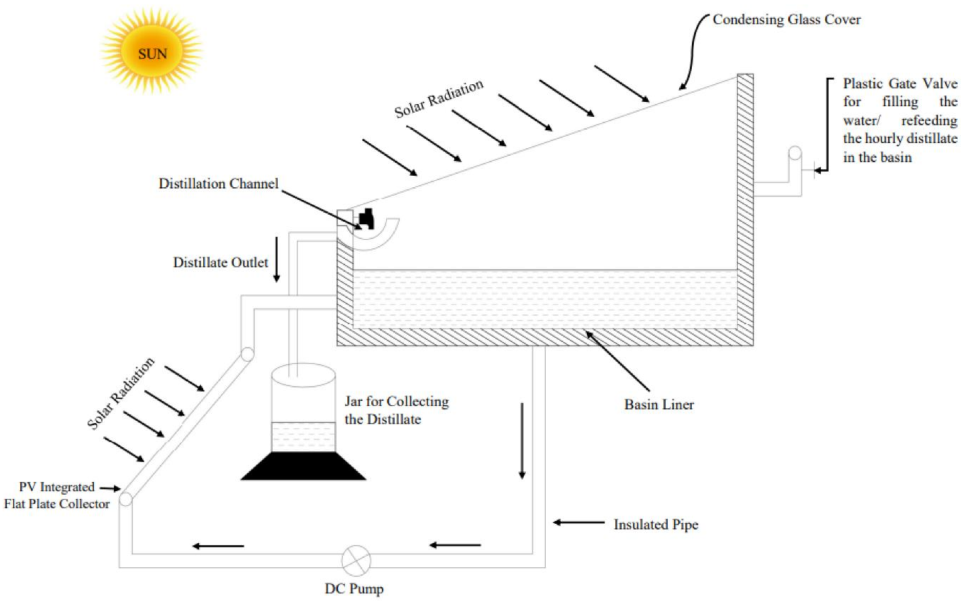

Figure 18: Schematic representation of the PV-integrated solar still [138]

In an experimental study, fully opened cover cooling in an inclined solar panel basin solar still significantly enhanced distilled water production by reducing glass temperature and increasing condensation rates, thereby improving hourly instantaneous efficiency [139]. In another experiment, Singh et al. [140] investigated a partially covered hybrid photovoltaic thermal (PVT) flat plate collector (FPC) solar still and found that the system achieved annual productivity in the range of 120.29% to 883.55% and showcased self-sufficiency in meeting both potable water and electricity needs. In **table 7**, a comprehensive summary of the influence of integrating PV panels on the performance of solar stills, elucidating the varied effects observed in different studies and their implications for overall efficiency and productivity has been provided.

Table 7: Summary of the impact of PV panel integration on solar still performance

Ref.	**Solar Still Type**	**Type of Study**	**Effects**
Elbar et al. [141]	Single acting	Experimental	Integration of a PV module, coupled with phase change material and forced air cooling, enhanced productivity by up to 19.4%.
Manokar et al. [142]	Inclined solar panel basin	Experimental	Incorporating sidewall and bottom insulation significantly enhanced daily efficiency by 51.54%.
Kumar et al. [143]	Active	Experimental	Integrating a hybrid photovoltaic/thermal (PV/T) system into a solar still significantly enhanced overall thermal and electrical efficiency, achieving a remarkable 25% increase.
Riahi et al. [144]	Double slope	Experimental	Solar still with a PV-heater system enhanced productivity by about six times compared to the conventional one.
Al-Nimr et al. [145]	Single slope	Numerical	PV integration with an external finned condenser enhanced the performance, yielding 6.8 kg/day at 56.5% efficiency, surpassing the conventional solar still at 4.07 kg/day and 28.6% efficiency.

3.15.1. Deduced critical insights about the photovoltaic panel

The integration of a photovoltaic heater system in a double-slope solar still has proven to be revolutionary, increasing production by around six times above that of conventional solar stills. The system's capacity to sustain constant high temperatures is responsible for this remarkable improvement in efficiency, greatly enhancing evaporation processes. Such a system not only dramatically increases water output but also utilizes solar energy more efficiently, marking it as an exemplary advancement in solar still technology for enhancing both efficiency and sustainability.

4. Discussion & Summary of the Optimum Parameters

When figuring out the best parameters to increase the productivity and efficiency of solar stills, we must consider the innovation, accessibility, affordability, and degree of improvement provided by each parameter. Every aspect that has been addressed has a distinct benefit in a certain situation, ranging from adding fins and changing the depth of the water to integrating advanced substances like PCM and nanofluids. The main objective of a thorough evaluation, however, is to identify a parameter that greatly increases production while being adaptable to many environmental circumstances and scalable for broad implementation.

Fins, especially pin-finned absorbers combined with condensers, provide a significant boost in productivity by accelerating the process of evaporation and condensation. However, their manufacturing complexity and costs may pose challenges in low-resource settings. Comparably, altering the still's water depth offers a somewhat inexpensive but very efficient way to boost evaporation rates, although its effects are limited by the operational adjustments and physical restrictions it requires. Utilizing PCM, such as paraffin wax in modified pyramid solar stills, showcases a substantial productivity increase by utilizing latent heat storage to maintain efficiency during non-sunlight hours. While there is promise for this technology, especially in areas with intermittent sunshine, the cost and feasibility of incorporating and sustaining PCM in solar stills may be prohibitive.

On the other hand, the integration of nanotechnology, specifically CuO nanoparticles, into solar still designs dramatically increases productivity. This substantial improvement is facilitated through enhanced heat transfer properties, which significantly boost the evaporation rate. However, the technological sophistication and potential costs of producing and integrating these nanoparticles into existing systems could limit their widespread application. Reflectors and additional basins both serve to increase the surface area for evaporation and maximize solar energy capture. While these methods are effective, they can lead to increased complexity in solar still design and a corresponding rise in costs and maintenance requirements. Wind speed management and the number of stages in solar stills also provide significant enhancements in productivity, but their effectiveness can be highly variable and dependent on local climatic conditions. Among the advanced energy integration strategies, the use of heat pumps in regenerative solar stills stands out due to its ability to maintain high temperatures consistently, thereby ensuring high productivity even in less ideal solar conditions. This approach not only maximizes water output but also enhances the solar still's efficiency across various environmental settings.

Considering all these parameters, the integration of photovoltaic (PV) panels emerges as the most transformative. The experimental results demonstrate an increase in productivity by approximately six times with the use of PV-integrated systems, which highlights not only the potential for substantial efficiency gains but also the dual benefit of producing both potable water and electricity. This dual functionality is particularly advantageous as it addresses two critical needs in many regions - energy and fresh water simultaneously. The ability of PV systems to maintain consistently high temperatures optimizes evaporation processes significantly, making this system not only highly effective but also a sustainable solution that leverages renewable energy. Therefore, the integration of photovoltaic panel systems into solar still designs is identified as the optimum parameter. It not only offers a significant increase in productivity and efficiency but also provides a sustainable and scalable solution that can be implemented across diverse geographic and climatic conditions. This technology represents a convergence of energy and water production processes, making it an ideal choice for future advancements in solar still technology and a pivotal step towards addressing global water scarcity challenges.

Existing research in solar still technology has primarily explored isolated parameters or configurations. For instance, studies on PCMs like paraffin wax have shown promising productivity enhancements of up to 87.4% in single-slope designs. However, such findings are often presented without exploring their scalability or integration with other advanced components. This study expands on these insights by evaluating PCMs in combination with reflectors and hybrid energy systems, uncovering synergistic effects that further enhance desalination efficiency.

Similarly, while using nanofluids such as CuO has been reported to boost productivity by up to 350%, previous works lack a comprehensive evaluation of their environmental and economic implications. This review addresses this gap by examining the practical feasibility of nanofluid integration, considering factors such as material availability, lifecycle costs, and maintenance requirements.

Photovoltaic integration represents another area where this study advances the field. Existing studies have highlighted PV systems' potential to sustain SS operations during low sunlight hours, achieving water yield increases of sixfold. This work confirms these findings and provides a comparative analysis of various PV-integrated configurations, such as hybrid photovoltaic-thermal systems, to identify the most effective designs.

5. Future Scope and Recommendations

In this section, we outline potential avenues for future research and development in solar still water desalination. By identifying key areas for improvement and innovation, we aim to guide researchers and practitioners in addressing critical challenges and maximizing the potential of solar still technology.

5.1. Integration with renewable energy systems

Future research efforts should focus on integrating solar stills with other renewable energy technologies, such as wind and geothermal energy, to create hybrid systems. These hybrid models have the potential to enhance energy efficiency, improve freshwater production rates, and ensure reliable operation under varying environmental conditions. However, integrating these technologies introduces challenges, including the technical complexity of merging different energy systems and the high initial costs. Additionally, the variability of renewable energy sources can impact the consistent operation of solar stills, necessitating robust energy storage solutions. Addressing these issues is crucial for ensuring the practicality and environmental sustainability of hybrid solar still systems.

5.2. Scaling up to large-scale implementations

While much of the existing research focuses on small-scale prototypes, there is a pressing need to transition towards large-scale implementations of solar still systems. However, this transition faces significant challenges, including the high cost of scaling, which may be prohibitive for widespread deployment. Additionally, large-scale implementations can encounter efficiency losses and require extensive infrastructure changes, which can complicate integration with existing water supply networks. Regulatory and land acquisition issues also pose barriers, necessitating careful planning and cooperation between various stakeholders to ensure successful scaling while minimizing environmental impacts. So, future studies should explore the scalability of solar still technology and evaluate its feasibility for addressing freshwater scarcity on a broader scale, particularly in regions facing severe water shortages.

5.3. Economic viability and cost analysis

Further research is warranted to conduct comprehensive cost analyses and economic assessments of solar still systems. Conducting comprehensive economic assessments of solar still systems is crucial to understand their financial feasibility. However, accurately assessing the economic viability poses challenges, including variability in costs associated with different geographical locations and scales of implementation. Additionally, the upfront investment for advanced technologies in solar stills can be substantial, potentially deterring adoption. There is also a need to consider long-term operational and maintenance costs, which can impact the overall cost-effectiveness. Effective economic evaluations must therefore encompass a broad range of factors to provide a realistic view of the potential for widespread deployment of solar still technologies. By quantifying the initial investments, operational costs, and long-term benefits, researchers can provide valuable insights into the economic viability of solar still technology and its potential for widespread adoption in water-scarce regions.

5.4. Environmental sustainability

Future studies should investigate the environmental implications of solar still technology, including its carbon footprint, energy consumption, and ecological impact. It involves challenges such as quantifying the full lifecycle impact, from manufacturing to disposal. There is often a lack of comprehensive data on the environmental footprint of materials and processes involved, which can hinder accurate assessments. Additionally, the potential ecological impacts of large-scale deployments, such as land use changes and habitat disruption, must be carefully evaluated. Addressing these challenges requires detailed environmental assessments and sustainable design practices to ensure that solar stills contribute positively to water solutions and by adopting a lifecycle perspective, researchers can assess the sustainability of solar still systems and identify strategies for minimizing environmental degradation while maximizing freshwater production.

5.5. Advanced materials and design optimization

Continued research efforts are needed to explore advanced materials and design strategies for optimizing solar still performance. Exploring advanced materials and design optimization for solar stills presents challenges, such as the availability and cost of cutting-edge materials, which can be prohibitive. Integrating new materials into existing designs requires extensive testing to ensure compatibility and durability under operational conditions. Addressing these issues involves continuous research and development, coupled with rigorous field testing, to validate the performance improvements offered by new materials and design changes. Novel materials with enhanced thermal conductivity, light absorption, and durability can improve evaporation rates and overall efficiency. Additionally, optimizing the design parameters, such as basin geometry and condensation surface morphology, can further enhance productivity and reliability.

5.6. Smart monitoring and control systems

The integration of smart monitoring and control systems, including IoT-enabled sensors and automated feedback mechanisms, can enhance the operational efficiency and performance of solar stills. It involves technical challenges, including the complexity of designing and maintaining such systems. Ensuring compatibility between different components and achieving real-time data accuracy can be difficult. Moreover, the initial costs for implementing advanced sensors and IoT technologies can be high, potentially limiting their adoption in cost-sensitive areas. These systems require reliable internet connectivity, which might not be available in remote or underdeveloped regions. Overcoming these obstacles is essential to improve operational effectiveness in a variety of environments via automation and accurate control. Future research should focus on developing intelligent control strategies to optimize energy utilization, minimize water loss, and adapt to changing environmental conditions in real time.

5.7. Exploration of emerging technologies

Researchers should explore emerging technologies, such as 3D printing, nanotechnology, and machine learning, to advance solar still water desalination. These include the high costs of cutting-edge technology, potential scalability issues, and the need for specialized expertise to develop and maintain these advanced systems. Besides, it may be difficult to integrate new technologies into solar still frameworks that already exist; thorough testing is necessary to make sure the innovations improve efficiency without jeopardizing the integrity of the system. These technologies offer promising opportunities for enhancing thermal management, improving material properties, and optimizing system operation, thereby unlocking new avenues for innovation in the field. Moreover, from our study, it can be seen that the authors in the literature were unable to detect optimal design parameters. It would be better if we could take the unsolved issues of the problem and come up with a solution by developing a method using computational fluid dynamics (CFD).

In light of these recommendations, the future of solar still technology looks promising. Embracing continuous innovation and research will undoubtedly elevate this technology, positioning it as a cornerstone for sustainable freshwater solutions globally.

6. Conclusions

Solar stills stand out as an innovative and eco-friendly solution to global water scarcity, utilizing abundant solar energy to produce freshwater. This review has extensively analyzed key advancements and optimum parameters for improving solar still performance. The following summarizes the critical insights and achievements:

- PV systems significantly enhance solar still performance, increasing productivity by sixfold while generating electricity. It is the most optimal parameter for advancing solar still efficiency, offering a transformative, dual-purpose solution to address water and energy scarcity.
- Pin-finned absorbers combined with condensers increased productivity by up to 76.5%, while reducing water depth to 0.5 cm maximized efficiency with 4.5 L/m² daily output. Optimizing the tilt angle to 30° ensured consistent performance throughout the year.
- PCMs, such as paraffin wax, increased productivity by 87.4% in modified pyramid designs by utilizing latent heat storage for non-sunlight hours, while CuO nanofluids enhanced freshwater yield by up to 350% through superior heat transfer properties.
- Reflectors, additional basins, and stages improved evaporation and energy capture, with gains ranging from 18% to 300%.
- Other factors, including wick materials like black jute, enhanced productivity by up to 300%, while porous materials like black basalt stones improved evaporation and condensation. Geothermal energy integration boosted daily output by 305%, and natural circulation loops facilitated efficient heat transfer. Wind speed optimization, and heat pumps further ensured consistent temperatures and higher efficiency across varying conditions.

While these advancements mark significant progress, several challenges remain, including:

- Ensuring economic feasibility and scalability of advanced materials and designs to make them accessible on a larger scale.
- Conducting lifecycle assessments to evaluate environmental impacts and promote sustainable solutions.
- Exploring hybrid systems that combine renewable energy sources or integrate improved

energy storage solutions to address solar intermittency.

- Incorporating emerging technologies such as IoT-enabled monitoring, machine learning, and 3D printing to enhance adaptability and performance.
- Customizing solar still designs to suit specific climatic conditions and water quality needs for broader global applicability.

In conclusion, the integration of photovoltaic systems into solar still designs remains the most promising pathway for future progress. This approach not only addresses freshwater and energy needs simultaneously but also demonstrates sustainability, scalability, and adaptability across diverse environments. By leveraging advanced materials, hybrid systems, and intelligent technologies, solar stills can transform into a cornerstone of sustainable water and energy resource management. These innovations offer a practical and impactful path in addressing global water and energy challenges, paving the way for a future where clean water is accessible to all.

Nomenclature

°C	Degree Celsius
Al_2O_3	Aluminum oxide
CFD	Computational Fluid Dynamics
CSS	Conventional solar still
CTSS	Conventional tubular solar still
CuO	Copper oxide
ED	Electrodialysis
FPC	Flat plate collector
IoT	Internet of Things
L/h	Liters per hour
L/m^2	Liters per square meter
PCM	Phase change materials
PV	Photovoltaic
PV/T	Photovoltaic Thermal
RO	Reverse Osmosis
RWSS	Rotating wick solar still
SS	Solar still
TiO_2	Titanium dioxide
ZnO	Zinc oxide

References

1. Shannon, M.A., P.W. Bohn, M. Elimelech, J.G. Georgiadis, B.J. Mariñas, and A.M. Mayes. (2008). *Science and technology for water purification in the coming decades.* Nature, **452**(7185), 301-310. DOI: https://doi.org/10.1038/nature06599
2. El-Dessouky, H.T., & Ettouney, H. M. (2002). *Introduction.* In *Fundamentals of Salt Water Desalination*. (p. 1-17). Elsevier. DOI: https://doi.org/10.1016/B978-044450810-2/50003-8
3. Essa, F.A., A. Abdullah, H.S. Majdi, A. Basem, H.A. Dhahad, Z.M. Omara, S.A. Mohammed, W.H. Alawee, A.A. Ezzi, and T. Yusaf. (2022). *Parameters affecting the efficiency of solar stills—recent review.* Sustainability, **14**(17), 10668. DOI: https://doi.org/10.3390/su141710668
4. Tech, G.W. (2024). *Addressing Water Insecurity in Southeast Asia: Causes & Solutions*. Retrieved May 19, 2024, from: https://genesiswatertech.com/blog-post/addressing-water-insecurity-in-southeast-asia-causes-and-solutions/.
5. UNICEF. (2023). *South Asia has highest number of children exposed to severe water scarcity - UNICEF*. Retrieved May 19, 2024, from: https://www.unicef.org/rosa/press-releases/south-asia-has-highest-number-children-exposed-severe-water-scarcity-unicef.
6. Bank, A.D. (2015). *Water: 12 Things to Know*. Retrieved May 19, 2024, from: https://www.adb.org/news/features/12-things-know-about-water#:~:text=Over%2075%25%20of%20Asia%20is,facing%20an%20imminent%20water%20crisis.&text=The%20gap%20between%20water%20demand,population%20faces%20a%20water%20crisis.
7. Agency, E.E. (2009). *Water resources across Europe — confronting water scarcity and drought*. Retrieved May 19, 2024, from: https://www.eea.europa.eu/publications/water-resources-across-europe/at_download/file.
8. Mekonnen, M.M. and A.Y. Hoekstra. (2016). *Four billion people facing severe water scarcity*. Science advances, **2**(2),

e1500323. DOI: https://doi.org/10.1126/sciadv.1500323

9. Council, W.W. (2004). *Water Problems in Latin America*. Retrieved May 19, 2024, from: https://www.worldwatercouncil.org/fileadmin/wwc/News/WWC_News/water_problems_22.03.04.pdf.

10. MAKINO, A.W.M. (2022). *The Latin American climate crisis is also a water crisis. How do we move forward?* Retrieved May 19, 2024, from: https://blogs.worldbank.org/en/latinamerica/latin-american-climate-crisis-also-water-crisis-how-do-we-move-forward.

11. Hasan, E., A. Tarhule, Y. Hong, and B. Moore III. (2019). *Assessment of physical water scarcity in Africa using GRACE and TRMM satellite data.* Remote Sensing, **11**(8), 904. DOI: https://doi.org/10.3390/rs11080904

12. University, A.N. (2022). *Remote Australians lack access to quality drinking water*. Retrieved May 22, 2024, from: https://www.anu.edu.au/news/all-news/remote-australians-lack-access-to-quality-drinking-water#:~:text=Australians%20in%20more%20than%20400,Australian%20National%20University%20(ANU).

13. Kucera, J. (2014). *Introduction to Desalination.* In *Desalination: water from water*. (p. 1-37). John Wiley & Sons. DOI: https://doi.org/10.1002/9781118904855.ch1

14. Chaichan, M.T., H.A. Kazem, A.H. Al-Waeli, W.H. Elawee, M.A. Fayad, and K. Sopian. (2024). *Advanced techniques for enhancing solar distiller productivity: a review.* Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, **46**(1), 736-772. DOI: https://doi.org/10.1080/15567036.2023.2289559

15. Bhuiya, K.M.S., M.M.R. Rony, S. Ahmed, S.B. Udoy, N.I. Masuk, A.C. Diganta, M.H. Hasan, M. Islam, M.A. Islam, and A. Shariar. (2022, December). *A Case Study on Hybrid Power Systems Using HOMER Pro: Design, Optimization and Comparison of Different Configurations and Proposing the Best Configuration for a University Campus*. (Paper presented at the *5th International Conference on Mechanical, Industrial and Materials Engineering*, Rajshahi, Bangladesh)

16. Azad, A.A.S., Z.T. Oishi, M.A. Haque, P. Das, S.A. Udoy, and K.M.S. Bhuiya. (2024). *An integrated framework for assessing renewable-energy supply chains using multicriteria decision-making: a study on Bangladesh.* Clean Energy, **8**(3), 1-19. DOI: https://doi.org/10.1093/ce/zkae019

17. Shatat, M., M. Worall, and S. Riffat. (2013). *Opportunities for solar water desalination worldwide.* Sustainable cities and society, **9**, 67-80. DOI: https://doi.org/10.1016/j.scs.2013.03.004

18. Omara, A.A., A.A. Abuelnuor, H.A. Mohammed, and M. Khiadani. (2020). *Phase change materials (PCMs) for improving solar still productivity: a review.* Journal of Thermal Analysis and Calorimetry, **139**(3), 1585-1617. DOI: https://doi.org/10.1007/s10973-019-08645-3

19. Kabeel, A., M.H. Hamed, Z. Omara, and S. Sharshir. (2013). *Water desalination using a humidification-dehumidification technique—a detailed review.* DOI: http://dx.doi.org/10.4236/nr.2013.43036

20. Buros, O.K. (2000). *The ABCs of Desalting*. (Denver: International Desalination Association)

21. Hashemian, N. and A. Noorpoor. (2019). *Assessment and multi-criteria optimization of a solar and biomass-based multi-generation system: Thermodynamic, exergoeconomic and exergoenvironmental aspects.* Energy Conversion and Management, **195**, 788-797. DOI: https://doi.org/10.1016/j.enconman.2019.05.039

22. Sakthivadivel, D., K. Balaji, D.D.W. Rufuss, S. Iniyan, and L. Suganthi. (2021). *Solar energy technologies: principles and applications*. In *Renewable-energy-driven future*. (p. 3-42). Elsevier. DOI: https://doi.org/10.1016/B978-0-12-820539-6.00001-7

23. Asadi, R.Z., F. Suja, and M.H. Ruslan. (2013). *The application of a solar still in domestic and industrial wastewater treatment.* Solar energy, **93**, 63-71. DOI: https://doi.org/10.1016/j.solener.2013.03.024

24. Abdelgaied, M., K. Harby, and A. Eisa. (2021). *Performance improvement of modified tubular solar still by employing vertical and inclined pin fins and external condenser: an experimental study*. Environmental Science and Pollution Research, **28**, 13504-13514. DOI: https://doi.org/10.1007/s11356-020-11585-3
25. Alaian, W., E. Elnegiry, and A.M. Hamed. (2016). *Experimental investigation on the performance of solar still augmented with pin-finned wick.* Desalination, **379**, 10-15. DOI: https://doi.org/10.1016/j.desal.2015.10.010
26. Rabhi, K., R. Nciri, F. Nasri, C. Ali, and H.B. Bacha. (2017). *Experimental performance analysis of a modified single-basin single-slope solar still with pin fins absorber and condenser.* Desalination, **416**, 86-93. DOI: https://doi.org/10.1016/j.desal.2017.04.023
27. Mohaisen, H., J. Esfahani, and M.B. Ayani. (2021). *Improvement in the performance and cost of passive solar stills using a finned-wall/built-in condenser: An experimental study*. Renewable Energy, **168**, 170-180. DOI: https://doi.org/10.1016/j.renene.2020.12.056
28. Alawee, W.H., H.A. Dhahad, and T.A. Mohammad. (2021). *Enhancement of solar still productivity using absorber plate with inclined perforated rectangular fins: experimental study with economic analysis.* Desalination and Water Treatment, **213**, 53-63. DOI: https://doi.org/10.5004/dwt.2021.26730
29. Sathyamurthy, R., A.E. Kabeel, A. Chamkha, H.A. Kumar, H. Venkateswaran, A.M. Manokar, R. Bharathwaaj, and S. Vasanthaseelan. (2022). *Exergy and energy analysis of a tubular solar still with and without fins: a comparative theoretical and experimental approach.* Environmental Science and Pollution Research, **29**(5), 6612-6621. DOI: https://doi.org/10.1007/s11356-021-16065-w
30. Abdelgaied, M., Y. Zakaria, A. Kabeel, and F.A. Essa. (2021). *Improving the tubular solar still performance using square and circular hollow fins with phase change materials.* Journal of Energy Storage, **38**, 102564. DOI: https://doi.org/10.1016/j.est.2021.102564
31. Suraparaju, S.K. and S.K. Natarajan. (2021). *Experimental investigation of single-basin solar still using solid staggered fins inserted in paraffin wax PCM bed for enhancing productivity*. Environmental Science and Pollution Research, **28**(16), 20330-20343. DOI: https://doi.org/10.1007/s11356-020-11980-w
32. Panchal, H. and R. Sathyamurthy. (2020). *Experimental analysis of single-basin solar still with porous fins.* International Journal of Ambient Energy, **41**(5), 563-569. DOI: https://doi.org/10.1080/01430750.2017.1360206
33. Taghvaei, H., H. Taghvaei, K. Jafarpur, M.K. Estahbanati, M. Feilizadeh, M. Feilizadeh, and A.S. Ardekani. (2014). *A thorough investigation of the effects of water depth on the performance of active solar stills.* Desalination, **347**, 77-85. DOI: https://doi.org/10.1016/j.desal.2014.05.038
34. Kabeel, A., S.W. Sharshir, G.B. Abdelaziz, M. Halim, and A. Swidan. (2019). *Improving performance of tubular solar still by controlling the water depth and cover cooling.* Journal of cleaner production, **233**, 848-856. DOI: https://doi.org/10.1016/j.jclepro.2019.06.104
35. Manokar, A.M., Y. Taamneh, D.P. Winston, P. Vijayabalan, D. Balaji, R. Sathyamurthy, S.P. Sundar, and D. Mageshbabu. (2020). *Effect of water depth and insulation on the productivity of an acrylic pyramid solar still–An experimental study.* Groundwater for Sustainable Development, **10**, 100319. DOI: https://doi.org/10.1016/j.gsd.2019.100319
36. Kumar, P.N., A.M. Manokar, B. Madhu, A. Kabeel, T. Arunkumar, H. Panchal, and R. Sathyamurthy. (2017). *Experimental investigation on the effect of water mass in triangular pyramid solar still integrated to inclined solar still.* Groundwater for Sustainable Development, **5**, 229-234. DOI: https://doi.org/10.1016/j.gsd.2017.08.003
37. Jahanpanah, M., S.J. Sadatinejad, A. Kasaeian, M.H. Jahangir, and H. Sarrafha. (2021). *Experimental investigation of the effects of low-temperature phase change*

material on single-slope solar still. Desalination, **499**, 114799. DOI: https://doi.org/10.1016/j.desal.2020.114799

38. Katekar, V.P. and S.S. Deshmukh. (2020). *A review of the use of phase change materials on performance of solar stills.* Journal of Energy Storage, **30**, 101398. DOI: https://doi.org/10.1016/j.est.2020.101398
39. Kabeel, A. and M. Abdelgaied. (2016). *Improving the performance of solar still by using PCM as a thermal storage medium under Egyptian conditions.* Desalination, **383**, 22-28. DOI: https://doi.org/10.1016/j.desal.2016.01.006
40. Kumar, P.M., D. Sudarvizhi, K. Prakash, A. Anupradeepa, S.B. Raj, S. Shanmathi, K. Sumithra, and S. Surya. (2021). *Investigating a single slope solar still with a nano-phase change material.* Materials Today: Proceedings, **45**, 7922-7925. DOI: https://doi.org/10.1016/j.matpr.2020.12.804
41. Rufuss, D.D.W., L. Suganthi, S. Iniyan, and P. Davies. (2018). *Effects of nanoparticle-enhanced phase change material (NPCM) on solar still productivity.* Journal of Cleaner Production, **192**, 9-29. DOI: https://doi.org/10.1016/j.jclepro.2018.04.201
42. Kabeel, A., M.A. Teamah, M. Abdelgaied, and G.B.A. Aziz. (2017). *Modified pyramid solar still with v-corrugated absorber plate and PCM as a thermal storage medium.* Journal of Cleaner Production, **161**, 881-887. DOI: https://doi.org/10.1016/j.jclepro.2017.05.195
43. Sharshir, S., G. Peng, L. Wu, F. Essa, A. Kabeel, and N. Yang. (2017). *The effects of flake graphite nanoparticles, phase change material, and film cooling on the solar still performance.* Applied energy, **191**, 358-366. DOI: https://doi.org/10.1016/j.apenergy.2017.01.067
44. Chaichan, M.T. and H.A. Kazem. (2018). *Single slope solar distillator productivity improvement using phase change material and Al2O3 nanoparticle.* Solar Energy, **164**, 370-381. DOI: https://doi.org/10.1016/j.solener.2018.02.049
45. Cheng, W.-L., Y.-K. Huo, and Y.-L. Nian. (2019). *Performance of solar still using shape-stabilized PCM: Experimental and theoretical investigation.* Desalination, **455**, 89-99. DOI: https://doi.org/10.1016/j.desal.2019.01.007
46. Yousef, M.S. and H. Hassan. (2019). *Energetic and exergetic performance assessment of the inclusion of phase change materials (PCM) in a solar distillation system.* Energy conversion and management, **179**, 349-361. DOI: https://doi.org/10.1016/j.enconman.2018.10.078
47. Kumar, P.M., P. Chauhan, A.K. Sharma, M.L. Rinawa, A. Rahul, M. Srinivas, and A. Tamilarasan. (2022). *Performance study on solar still using nano disbanded phase change material (NDPCM).* Materials Today: Proceedings, **62**, 1894-1897. DOI: https://doi.org/10.1016/j.matpr.2022.01.050
48. Shoeibi, S., H. Kargarsharifabad, and N. Rahbar. (2021). *Effects of nano-enhanced phase change material and nano-coated on the performance of solar stills.* Journal of Energy Storage, **42**, 103061. DOI: https://doi.org/10.1016/j.est.2021.103061
49. Abdelgaied, M., M.E.H. Attia, A. Kabeel, and M.E. Zayed. (2022). *Improving the thermo-economic performance of hemispherical solar distiller using copper oxide nanofluids and phase change materials: Experimental and theoretical investigation.* Solar Energy Materials and Solar Cells, **238**, 111596. DOI: https://doi.org/10.1016/j.solmat.2022.111596
50. Iqbal, A., M.S. Mahmoud, E.T. Sayed, K. Elsaid, M.A. Abdelkareem, H. Alawadhi, and A. Olabi. (2021). *Evaluation of the nanofluid-assisted desalination through solar stills in the last decade.* Journal of Environmental Management, **277**, 111415. DOI: https://doi.org/10.1016/j.jenvman.2020.111415
51. Nagaraju, V., G. Murali, M. Sankeerthana, and M. Murugan. (2021). *A review on recent developments of solar stills to enhance productivity using nanoparticles and nano-PCM.* International Journal of Green Energy, **1956935**. DOI: https://doi.org/10.1080/15435075.2021.1956935
52. Thakur, V.K., M. Gaur, A. Dhamneya, and M. Sagar. (2021). *Performance analysis of*

passive solar still with and without nanoparticles. Materials Today: Proceedings, **47**, 6309-6316. DOI: https://doi.org/10.1016/j.matpr.2021.05.539

53. Katekar, V.P., A.B. Rao, and V.R. Sardeshpande. (2024). *Performance enhancement of solar distillation system with hemispherical projections and low-cost coating on absorber plate.* Proceedings of the Institution of Mechanical Engineers, Part N: Journal of Nanomaterials, Nanoengineering and Nanosystems, 23977914241259114. DOI: https://doi.org/10.1177/23977914241259114

54. Elango, T., A. Kannan, and K.K. Murugavel. (2015). *Performance study on single basin single slope solar still with different water nanofluids.* Desalination, **360**, 45-51. DOI: https://doi.org/10.1016/j.desal.2015.01.004

55. Sharshir, S.W., G. Peng, L. Wu, N. Yang, F. Essa, A. Elsheikh, S.I. Mohamed, and A. Kabeel. (2017). *Enhancing the solar still performance using nanofluids and glass cover cooling: experimental study.* Applied thermal engineering, **113**, 684-693. DOI: https://doi.org/10.1016/j.applthermaleng.2016.11.085

56. Shoeibi, S., H. Kargarsharifabad, N. Rahbar, G. Ahmadi, and M.R. Safaei. (2022). *Performance evaluation of a solar still using hybrid nanofluid glass cooling-CFD simulation and environmental analysis.* Sustainable Energy Technologies and Assessments, **49**, 101728. DOI: https://doi.org/10.1016/j.seta.2021.101728

57. Rabbi, H.M.F. and A.Z. Sahin. (2021). *Performance improvement of solar still by using hybrid nanofluids.* Journal of Thermal Analysis and Calorimetry, **143**(2), 1345-1360. DOI: https://doi.org/10.1007/s10973-020-10155-6

58. Bellila, A., M.E.H. Attia, A. Kabeel, M. Abdelgaied, K. Harby, and J. Soli. (2021). *Productivity enhancement of hemispherical solar still using Al2O3-water-based nanofluid and cooling the glass cover.* Applied Nanoscience, **11**(4), 1127-1139. DOI: https://doi.org/10.1007/s13204-021-01677-y

59. Jathar, L.D. and S. Ganesan. (2021). *Assessing the performance of concave type stepped solar still with nanoparticles and condensing cover cooling arrangement: an experimental approach.* Groundwater for Sustainable Development, **12**, 100539. DOI: https://doi.org/10.1016/j.gsd.2020.100539

60. Ghandourah, E.I., A. Sangeetha, S. Shanmugan, M.E. Zayed, E.B. Moustafa, A. Tounsi, and A.H. Elsheikh. (2022). *Performance assessment of a novel solar distiller with a double slope basin covered by coated wick with lanthanum cobalt oxide nanoparticles.* Case Studies in Thermal Engineering, **32**, 101859. DOI: https://doi.org/10.1016/j.csite.2022.101859

61. Hasanianpour Faridani, Z. and A. Ameri. (2022). *Performance enhancement of a basin solar still using γ-Al 2 O 3 nanoparticles and a mixer: an experimental approach.* Journal of Thermal Analysis and Calorimetry, 1-13. DOI: https://doi.org/10.1007/s10973-021-10564-1

62. Modi, K.V., H.K. Jani, and I.D. Gamit. (2021). *Impact of orientation and water depth on productivity of single-basin dual-slope solar still with Al2O3 and CuO nanoparticles.* Journal of Thermal Analysis and Calorimetry, **143**(2), 899-913. DOI: https://doi.org/10.1007/s10973-020-09351-1

63. Benoudina, B., M.E.H. Attia, Z. Driss, A. Afzal, A.M. Manokar, and R. Sathyamurthy. (2021). *Enhancing the solar still output using micro/nano-particles of aluminum oxide at different concentrations: an experimental study, energy, exergy and economic analysis.* Sustainable Materials and Technologies, **29**, e00291. DOI: https://doi.org/10.1016/j.susmat.2021.e00291

64. Nazari, S., H. Safarzadeh, and M. Bahiraei. (2019). *Performance improvement of a single slope solar still by employing thermoelectric cooling channel and copper oxide nanofluid: an experimental study.* Journal of cleaner production, **208**, 1041-1052. DOI: https://doi.org/10.1016/j.jclepro.2018.10.194

65. Abdullah, A., F. Essa, Z. Omara, Y. Rashid, L. Hadj-Taieb, G.B. Abdelaziz, and A. Kabeel. (2019). *Rotating-drum solar still with enhanced evaporation and*

condensation techniques: comprehensive study. Energy Conversion and Management, **199**, 112024. DOI: https://doi.org/10.1016/j.enconman.2019.112024
66. Chen, W., C. Zou, X. Li, and H. Liang. (2019). *Application of recoverable carbon nanotube nanofluids in solar desalination system: An experimental investigation.* Desalination, **451**, 92-101. DOI: https://doi.org/10.1016/j.desal.2017.09.025
67. Kabeel, A.E., Z. Omara, and F. Essa. (2017). *Numerical investigation of modified solar still using nanofluids and external condenser.* Journal of the Taiwan Institute of Chemical Engineers, **75**, 77-86. DOI: https://doi.org/10.1016/j.jtice.2017.01.017
68. Attia, M.E.H., A. Karthick, A.M. Manokar, Z. Driss, A.E. Kabeel, R. Sathyamurthy, and M. Sharifpur. (2021). *Sustainable potable water production from conventional solar still during the winter season at Algerian dry areas: energy and exergy analysis.* Journal of Thermal Analysis and Calorimetry, **145**, 1215-1225. DOI: https://doi.org/10.1007/s10973-020-10277-x
69. Sahota, L. and G. Tiwari. (2016). *Effect of Al2O3 nanoparticles on the performance of passive double slope solar still.* Solar Energy, **130**, 260-272. DOI: https://doi.org/10.1016/j.solener.2016.02.018
70. Modi, K.V., D.L. Shukla, and D.B. Ankoliya. (2019). *A comparative performance study of double basin single slope solar still with and without using nanoparticles.* Journal of Solar Energy Engineering, **141**(3), 031008. DOI: https://doi.org/10.1115/1.4041838
71. Cherraye, R., B. Bouchekima, D. Bechki, H. Bouguettaia, and A. Khechekhouche. (2022). *The effect of tilt angle on solar still productivity at different seasons in arid conditions (south Algeria).* International Journal of Ambient Energy, **43**(1), 1847-1853. DOI: https://doi.org/10.1080/01430750.2020.1723689
72. Panchal, H., D. Mevada, K.K. Sadasivuni, F. Essa, S. Shanmugan, and M. Khalid. (2020). *Experimental and water quality analysis of solar stills with vertical and inclined fins.* Groundwater for Sustainable Development, **11**, 100410. DOI: https://doi.org/10.1016/j.gsd.2020.100410
73. Dhivagar, R. and M. Mohanraj. (2021). *Performance improvements of single slope solar still using graphite plate fins and magnets.* Environmental Science and Pollution Research, **28**, 20499-20516. DOI: https://doi.org/10.1007/s11356-020-11737-5
74. Tuly, S., M. Rahman, M. Sarker, and R. Beg. (2021). *Combined influence of fin, phase change material, wick, and external condenser on the thermal performance of a double slope solar still.* Journal of Cleaner Production, **287**, 125458. DOI: https://doi.org/10.1016/j.jclepro.2020.125458
75. Nafey, A.S., M. Abdelkader, A. Abdelmotalip, A.J.E.c. Mabrouk, and management. (2000). *Parameters affecting solar still productivity.* **41**(16), 1797-1809.
76. Omara, Z., A. Kabeel, and A. Abdullah. (2017). *A review of solar still performance with reflectors.* Renewable and Sustainable Energy Reviews, **68**, 638-649. DOI: https://doi.org/10.1016/j.rser.2016.10.031
77. Gnanaraj, S.J.P. and V. Velmurugan. (2019). *An experimental study on the efficacy of modifications in enhancing the performance of single basin double slope solar still.* Desalination, **467**, 12-28. DOI: https://doi.org/10.1016/j.desal.2019.05.015
78. Essa, F., A. Abdullah, Z. Omara, A. Kabeel, and Y. Gamiel. (2021). *Experimental study on the performance of trays solar still with cracks and reflectors.* Applied Thermal Engineering, **188**, 116652. DOI: https://doi.org/10.1016/j.applthermaleng.2021.116652
79. Younis, O., A.K. Hussein, M.E.H. Attia, F.L. Rashid, L. Kolsi, U. Biswal, A. Abderrahmane, A. Mourad, and A. Alazzam. (2022). *Hemispherical solar still: Recent advances and development.* Energy Reports, **8**, 8236-8258. DOI: https://doi.org/10.1016/j.egyr.2022.06.037
80. Abdullah, A., Z. Omara, F. Essa, A. Alarjani, I.B. Mansir, and M. Amro. (2021). *Enhancing the solar still performance using reflectors and sliding-wick belt.* Solar Energy, **214**, 268-279. DOI:

https://doi.org/10.1016/j.solener.2020.11.016

81. El-Samadony, Y., A. Abdullah, and Z. Omara. (2015). *Experimental study of stepped solar still integrated with reflectors and external condenser.* Experimental heat transfer, **28**(4), 392-404. DOI: https://doi.org/10.1080/08916152.2014.890964
82. Tanaka, H. (2009). *Experimental study of a basin type solar still with internal and external reflectors in winter.* Desalination, **249**(1), 130-134. DOI: https://doi.org/10.1016/j.desal.2009.02.057
83. Bataineh, K.M. and M.A. Abbas. (2020). *Performance analysis of solar still integrated with internal reflectors and fins.* Solar Energy, **205**, 22-36. DOI: https://doi.org/10.1016/j.solener.2020.04.059
84. Abdullah, A., F.A. Essa, H.B. Bacha, and Z. Omara. (2020). *Improving the trays solar still performance using reflectors and phase change material with nanoparticles.* Journal of Energy Storage, **31**, 101744. DOI: https://doi.org/10.1016/j.est.2020.101744
85. Kabeel, A., M.M. Khairat Dawood, T. Nabil, and B.E. Alonafal. (2020). *Improving the performance of stepped solar still using a graphite and PCM as hybrid store materials with internal reflectors coupled with evacuated tube solar collector.* Heat and Mass Transfer, **56**, 891-899. DOI: https://doi.org/10.1007/s00231-019-02741-8
86. Bhargva, M. and A. Yadav. (2024). *Productivity augmentation of single-slope solar still using evacuated tubes, heat exchanger, internal reflectors and external condenser.* Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, **46**(1), 2646-2666. DOI: https://doi.org/10.1080/15567036.2019.1691291
87. Sharshir, S.W., M. Rozza, M. Elsharkawy, M. Youns, F. Abou-Taleb, and A. Kabeel. (2022). *Performance evaluation of a modified pyramid solar still employing wick, reflectors, glass cooling and TiO2 nanomaterial.* Desalination, **539**, 115939. DOI: https://doi.org/10.1016/j.desal.2022.115939
88. Estahbanati, M.K., A. Ahsan, M. Feilizadeh, K. Jafarpur, S.-S. Ashrafmansouri, and M. Feilizadeh. (2016). *Theoretical and experimental investigation on internal reflectors in a single-slope solar still.* Applied energy, **165**, 537-547. DOI: https://doi.org/10.1016/j.apenergy.2015.12.047
89. Gnanaraj, S.J.P., S. Ramachandran, and D.S. Christopher. (2017). *Enhancing the design to optimize the performance of double basin solar still.* Desalination, **411**, 112-123. DOI: https://doi.org/10.1016/j.desal.2017.02.011
90. Afrand, M., R. Kalbasi, A. Karimipour, and S. Wongwises. (2016). *Experimental investigation on a thermal model for a basin solar still with an external reflector.* Energies, **10**(1), 18. DOI: https://doi.org/10.3390/en10010018
91. Omara, Z., A. Abdullah, F. Essa, and M. Younes. (2021). *Performance evaluation of a vertical rotating wick solar still.* Process Safety and Environmental Protection, **148**, 796-804. DOI: https://doi.org/10.1016/j.psep.2021.02.004
92. Essa, F., Z. Omara, A. Abdullah, A. Kabeel, and G. Abdelaziz. (2021). *Enhancing the solar still performance via rotating wick belt and quantum dots nanofluid.* Case Studies in Thermal Engineering, **27**, 101222. DOI: https://doi.org/10.1016/j.csite.2021.101222
93. Hansen, R.S., C.S. Narayanan, and K.K. Murugavel. (2015). *Performance analysis on inclined solar still with different new wick materials and wire mesh.* Desalination, **358**, 1-8. DOI: https://doi.org/10.1016/j.desal.2014.12.006
94. Omara, Z., A. Kabeel, A. Abdullah, and F. Essa. (2016). *Experimental investigation of corrugated absorber solar still with wick and reflectors.* Desalination, **381**, 111-116. DOI: https://doi.org/10.1016/j.desal.2015.12.001
95. Abdelaziz, G.B., A.M. Algazzar, E.M. El-Said, A.M. Elsaid, S.W. Sharshir, A. Kabeel, and S. El-Behery. (2021). *Performance enhancement of tubular solar still using nano-enhanced energy storage material integrated with v-corrugated aluminum basin, wick, and nanofluid.* Journal of Energy Storage, **41**, 102933.

DOI: https://doi.org/10.1016/j.est.2021.102933

96. Murugavel, K.K. and K. Srithar. (2011). *Performance study on basin type double slope solar still with different wick materials and minimum mass of water.* Renewable Energy, **36**(2), 612-620. DOI: https://doi.org/10.1016/j.renene.2010.08.009

97. Sharshir, S.W., M. Salman, S. El-Behery, M. Halim, and G.B. Abdelaziz. (2021). *Enhancement of solar still performance via wet wick, different aspect ratios, cover cooling, and reflectors.* International Journal of Energy and Environmental Engineering, **12**(3), 517-530. DOI: https://doi.org/10.1007/s40095-021-00386-0

98. Manikandan, V., K. Shanmugasundaram, S. Shanmugan, B. Janarthanan, and J. Chandrasekaran. (2013). *Wick type solar stills: a review.* Renewable and sustainable energy reviews, **20**, 322-335. DOI: https://doi.org/10.1016/j.rser.2012.11.046

99. Velmurugan, V., M. Gopalakrishnan, R. Raghu, and K. Srithar. (2008). *Single basin solar still with fin for enhancing productivity.* Energy Conversion and Management, **49**(10), 2602-2608. DOI: https://doi.org/10.1016/j.enconman.2008.05.010

100. Essa, F., W.H. Alawee, S.A. Mohammed, H.A. Dhahad, A. Abdullah, and Z. Omara. (2021). *Experimental investigation of convex tubular solar still performance using wick and nanocomposites.* Case Studies in Thermal Engineering, **27**, 101368. DOI: https://doi.org/10.1016/j.csite.2021.101368

101. Alawee, W.H., F. Essa, S.A. Mohammed, H.A. Dhahad, A. Abdullah, Z. Omara, and Y. Gamiel. (2021). *Improving the performance of pyramid solar distiller using dangled cords of various wick materials: Novel working mechanism of wick.* Case Studies in Thermal Engineering, **28**, 101550. DOI: https://doi.org/10.1016/j.csite.2021.101550

102. Mahdi, J., B. Smith, and A. Sharif. (2011). *An experimental wick-type solar still system: design and construction.* Desalination, **267**(2-3), 233-238. DOI: https://doi.org/10.1016/j.desal.2010.09.032

103. Younes, M., A. Abdullah, F. Essa, Z. Omara, and M. Amro. (2021). *Enhancing the wick solar still performance using half barrel and corrugated absorbers.* Process Safety and Environmental Protection, **150**, 440-452. DOI: https://doi.org/10.1016/j.psep.2021.04.036

104. Mohamed, A., A. Hegazi, G. Sultan, and E.M. El-Said. (2019). *Augmented heat and mass transfer effect on performance of a solar still using porous absorber: experimental investigation and exergetic analysis.* Applied Thermal Engineering, **150**, 1206-1215. DOI: https://doi.org/10.1016/j.applthermaleng.2019.01.070

105. Peng, G., S.W. Sharshir, Y. Wang, M. An, D. Ma, J. Zang, A. Kabeel, and N. Yang. (2021). *Potential and challenges of improving solar still by micro/nano-particles and porous materials-A review.* Journal of Cleaner Production, **311**, 127432. DOI: https://doi.org/10.1016/j.jclepro.2021.127432

106. Rashidi, S., N. Rahbar, M.S. Valipour, and J.A. Esfahani. (2018). *Enhancement of solar still by reticular porous media: experimental investigation with exergy and economic analysis.* Applied Thermal Engineering, **130**, 1341-1348. DOI: https://doi.org/10.1016/j.applthermaleng.2017.11.089

107. Arunkumar, T., A. Kabeel, K. Raj, D. Denkenberger, R. Sathyamurthy, P. Ragupathy, and R. Velraj. (2018). *Productivity enhancement of solar still by using porous absorber with bubble-wrap insulation.* Journal of Cleaner Production, **195**, 1149-1161. DOI: https://doi.org/10.1016/j.jclepro.2018.05.199

108. Mohamed, A., A. Hegazi, G. Sultan, and E.M. El-Said. (2019). *Enhancement of a solar still performance by inclusion the basalt stones as a porous sensible absorber: experimental study and thermo-economic analysis.* Solar Energy Materials and Solar Cells, **200**, 109958. DOI: https://doi.org/10.1016/j.solmat.2019.109958

109. Hassan, H., M.S. Yousef, M.S. Ahmed, and M. Fathy. (2020). *Energy, exergy, environmental, and economic analysis of*

natural and forced cooling of solar still with porous media. Environmental Science and Pollution Research, **27**(30), 38221-38240. DOI: https://doi.org/10.1007/s11356-020-09995-4
110. Abdallah, S., M.M. Abu-Khader, and O. Badran. (2009). *Effect of various absorbing materials on the thermal performance of solar stills.* Desalination, **242**(1-3), 128-137. DOI: https://doi.org/10.1016/j.desal.2008.03.036
111. Rajaseenivasan, T., T. Elango, and K.K. Murugavel. (2013). *Comparative study of double basin and single basin solar stills.* Desalination, **309**, 27-31. DOI: https://doi.org/10.1016/j.desal.2012.09.014
112. Rajaseenivasan, T., K. Kalidasa Murugavel, and T. Elango. (2015). *Performance and exergy analysis of a double-basin solar still with different materials in basin.* Desalination and Water Treatment, **55**(7), 1786-1794. DOI: https://doi.org/10.1080/19443994.2014.928800
113. Rajaseenivasan, T. and K.K. Murugavel. (2013). *Theoretical and experimental investigation on double basin double slope solar still.* Desalination, **319**, 25-32. DOI: https://doi.org/10.1016/j.desal.2013.03.029
114. Zurigat, Y.H. and M.K. Abu-Arabi. (2004). *Modelling and performance analysis of a regenerative solar desalination unit.* Applied thermal engineering, **24**(7), 1061-1072. DOI: https://doi.org/10.1016/j.desal.2013.03.029
115. ElSherbiny, S.M. and H.E. Fath. (1993). *Solar distillation under climatic conditions of Egypt.* Renewable energy, **3**(1), 61-65. DOI: https://doi.org/10.1016/0960-1481(93)90131-Y
116. Elsafty, A., H. Fath, and A. Amer. (2008). *Mathematical model development for a new solar desalination system (SDS).* Energy conversion and management, **49**(11), 3331-3337. DOI: https://doi.org/10.1016/j.enconman.2008.04.016
117. El-Sebaii, A. (2004). *Effect of wind speed on active and passive solar stills.* Energy Conversion and Management, **45**(7-8), 1187-1204. DOI: https://doi.org/10.1016/j.enconman.2003.09.036
118. El-Sebaii, A. (2000). *Effect of wind speed on some designs of solar stills.* Energy Conversion and Management, **41**(6), 523-538. DOI: https://doi.org/10.1016/S0196-8904(99)00119-3
119. El-Sebaii, A. (2011). *On effect of wind speed on passive solar still performance based on inner/outer surface temperatures of the glass cover.* Energy, **36**(8), 4943-4949. DOI: https://doi.org/10.1016/j.energy.2011.05.038
120. Rajaseenivasan, T., K.K. Murugavel, T. Elango, and R.S. Hansen. (2013). *A review of different methods to enhance the productivity of the multi-effect solar still.* Renewable and Sustainable Energy Reviews, **17**, 248-259. DOI: https://doi.org/10.1016/j.rser.2012.09.035
121. Estahbanati, M.K., M. Feilizadeh, K. Jafarpur, M. Feilizadeh, and M.R. Rahimpour. (2015). *Experimental investigation of a multi-effect active solar still: the effect of the number of stages.* Applied Energy, **137**, 46-55. DOI: https://doi.org/10.1016/j.apenergy.2014.09.082
122. Shanazari, E. and R. Kalbasi. (2018). *Improving performance of an inverted absorber multi-effect solar still by applying exergy analysis.* Applied Thermal Engineering, **143**, 1-10. DOI: https://doi.org/10.1016/j.applthermaleng.2018.07.021
123. Xiong, J., G. Xie, and H. Zheng. (2013). *Experimental and numerical study on a new multi-effect solar still with enhanced condensation surface.* Energy conversion and management, **73**, 176-185. DOI: https://doi.org/10.1016/j.enconman.2013.04.024
124. Alshammari, F., M. Elashmawy, and M.M. Ahmed. (2021). *Cleaner production of freshwater using multi-effect tubular solar still.* Journal of Cleaner Production, **281**, 125301. DOI: https://doi.org/10.1016/j.jclepro.2020.125301
125. Mohanraj, M., L. Karthick, and R. Dhivagar. (2021). *Performance and economic analysis of a heat pump water heater assisted regenerative solar still using latent heat storage.* Applied Thermal Engineering, **196**, 117263. DOI:

https://doi.org/10.1016/j.applthermaleng.2021.117263
126. Dhivagar, R., B. Deepanraj, M. Mohanraj, and A. Prakash. (2022). *Thermal performance, cost effectiveness and environmental analysis of a heat pump assisted regenerative solar still using slack wax as heat storage material.* Sustainable Energy Technologies and Assessments, **52**, 102090. DOI: https://doi.org/10.1016/j.seta.2022.102090
127. Hidouri, K., R.B. Slama, and S. Gabsi. (2010). *Hybrid solar still by heat pump compression.* Desalination, **250**(1), 444-449. DOI: https://doi.org/10.1016/j.desal.2009.09.075
128. Halima, H.B., N. Frikha, and R.B. Slama. (2014). *Numerical investigation of a simple solar still coupled to a compression heat pump.* Desalination, **337**, 60-66. DOI: https://doi.org/10.1016/j.desal.2014.01.010
129. Shakir, Y., M. Mohanraj, Y. Belyayev, S. Jayaraj, and A. Kaltayev. (2016). *Numerical simulation of a heat pump assisted regenerative solar still for cold climates of Kazakhstan.* Bulgarian Chemical Communications, **48**(1), 126. DOI: http://dx.doi.org/10.2298/TSCI17S2411S
130. Hidouri, K. and M. Mohanraj. (2019). *Thermodynamic analysis of a heat pump assisted active solar still.* Desalination and Water Treatment, **154**, 101-110. DOI: https://doi.org/10.5004/dwt.2019.24047
131. Boutriaa, A. and A. Rahmani. (2017). *Thermal modeling of a basin type solar still enhanced by a natural circulation loop.* Computers & Chemical Engineering, **101**, 31-43. DOI: https://doi.org/10.1016/j.compchemeng.2017.02.033
132. Rahmani, A., A. Boutriaa, and A. Hadef. (2015). *An experimental approach to improve the basin type solar still using an integrated natural circulation loop.* Energy conversion and management, **93**, 298-308. DOI: https://doi.org/10.1016/j.enconman.2015.01.026
133. Balasubramanian, K., B. Jinshah, K. Ravikumar, and S. Divakar. (2022). *Thermal and hydraulic characteristics of a parabolic trough collector based on an open natural circulation loop: The effect of fluctuations in solar irradiance.* Sustainable Energy Technologies and Assessments, **52**, 102290. DOI: https://doi.org/10.1016/j.seta.2022.102290
134. Chaichan, M.T., H.A. Kazem, A.H. Al-Waeli, S.A. Mohammed, Z.M. Omara, and K. Sopian. (2023). *Performance enhancement of solar distillation system works in harsh weather conditions: An experimental study.* Thermal Science and Engineering Progress, **43**, 101981. DOI: https://doi.org/10.1016/j.tsep.2023.101981
135. Danish, S.N., A. El-Leathy, M. Alata, and H. Al-Ansary. (2019). *Enhancing solar still performance using vacuum pump and geothermal energy.* Energies, **12**(3), 539. DOI: https://doi.org/10.3390/en12030539
136. Verma, S., R. Das, and N.K. Mishra. (2023). *Concept of integrating geothermal energy for enhancing the performance of solar stills.* Desalination, **564**, 116817. DOI: https://doi.org/10.1016/j.desal.2023.116817
137. Forghani, A.H., A.A. Solghar, and H. Hajabdollahi. (2024). *Optimal design of a multi-generation system based on solar and geothermal energy integrated with multi-effect distillatory.* Applied Thermal Engineering, **236**, 121381. DOI: https://doi.org/10.1016/j.applthermaleng.2023.121381
138. Gaur, M. and G. Tiwari. (2010). *Optimization of number of collectors for integrated PV/T hybrid active solar still.* Applied Energy, **87**(5), 1763-1772. DOI: https://doi.org/10.1016/j.apenergy.2009.10.019
139. Kabeel, A., R. Sathyamurthy, S. El-Agouz, A. Muthu Manokar, and E.M. El-Said. (2019). *Experimental studies on inclined PV panel solar still with cover cooling and PCM.* Journal of Thermal Analysis and Calorimetry, **138**, 3987-3995. DOI: https://doi.org/10.1007/s10973-019-08561-6
140. Singh, D., J. Yadav, V. Dwivedi, S. Kumar, G. Tiwari, and I. Al-Helal. (2016). *Experimental studies of active solar still integrated with two hybrid PVT collectors.* Solar Energy, **130**, 207-223. DOI: https://doi.org/10.1016/j.solener.2016.02.024
141. Abd Elbar, A.R. and H. Hassan. (2019). *Experimental investigation on the impact of*

thermal energy storage on the solar still performance coupled with PV module via new integration. Solar Energy, **184**, 584-593. DOI: https://doi.org/10.1016/j.solener.2019.04.042

142. Manokar, A.M., D.P. Winston, A. Kabeel, and R. Sathyamurthy. (2018). *Sustainable fresh water and power production by integrating PV panel in inclined solar still.* Journal of cleaner production, **172**, 2711-2719. DOI: https://doi.org/10.1016/j.jclepro.2017.11.140

143. Winston, D.P., P. Pounraj, A.M. Manokar, R. Sathyamurthy, and A. Kabeel. (2018). *Experimental investigation on hybrid PV/T active solar still with effective heating and cover cooling method.* Desalination, **435**, 140-151. DOI: https://doi.org/10.1016/j.desal.2017.11.007

144. Riahi, A., K. Wan Yusof, B.S. Mahinder Singh, M.H. Isa, E. Olisa, and N.A.M. Zahari. (2016). *Sustainable potable water production using a solar still with photovoltaic modules-AC heater.* Desalination and Water Treatment, **57**(32), 14929-14944. DOI: https://doi.org/10.1080/19443994.2015.1070285

145. Moh'd A, A.-N. and W.A. Al-Ammari. (2016). *A novel hybrid PV-distillation system.* Solar energy, **135**, 874-883. DOI: https://doi.org/10.1016/j.solener.2016.06.061