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A Review on Solar Still

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ABSTRACT

Solar desalination has emerged as a sustainable and environmentally friendly solution to address the growing global demand for potable water, particularly in arid and remote regions where conventional water treatment technologies are economically or logistically unfeasible. With increasing freshwater scarcity driven by population growth, industrialization, and climate change, solar stills offer a simple, low-cost, and renewable energy-based desalination method. However, despite their advantages, conventional solar stills suffer from inherently low productivity due to limited heat absorption, poor evaporation rates, and significant thermal losses, which restrict their large-scale applicability.To overcome these limitations, recent research has focused on enhancing the performance of solar stills through hybridization techniques, among which the integration of solar air heaters has shown promising potential. This review paper aims to systematically analyze and synthesize existing experimental studies on hybrid solar stills coupled with solar air heaters to evaluate their effectiveness in improving distillate yield and overall thermal efficiency.The review methodology involves a comprehensive literature survey of peer-reviewed articles obtained from reputed journal databases such as Scopus, Web of Science, ScienceDirect, and Springer, covering publications primarily from 2010 to 2025. Selected studies are critically examined based on experimental configurations, operating conditions, climatic influences, and performance metrics such as daily yield, efficiency, and cost analysis.Key findings from the reviewed literature indicate that the integration of solar air heaters significantly enhances basin water temperature, accelerates evaporation rates, and improves overall system productivity compared to conventional solar stills. Additional augmentation techniques such as the use of phase change materials (PCM), nanofluids, external condensers, and optimized basin geometries further contribute to performance improvement. Among these, combined systems incorporating solar air heaters with thermal energy storage and advanced materials demonstrate the highest efficiency gains and yield enhancements.In conclusion, hybrid solar stills integrated with solar air heaters present a viable and efficient solution for improving desalination performance. Future research should focus on optimizing system design, integrating advanced materials, conducting long-term field studies, and performing economic.

KEYWORDS

Efficiency Gains: Yield Improvement: Optimal Conditions: Condensation Recovery.

1. INTRODUCTION

Global Water Scarcity Problem

Water scarcity has emerged as a severe global issue, threatening sustainable development and human well-being. The increasing global population, rapid urbanization, industrial growth, and changing climatic conditions have significantly intensified the demand for freshwater resources. (12) At the same time, natural freshwater reserves such as rivers, lakes, and groundwater are being depleted and polluted at an alarming rate. Many regions around the world, particularly arid and semi-arid areas, are already facing acute water shortages. This imbalance between water demand and supply highlights the urgent need for innovative and sustainable water purification technologies.

Importance of Renewable Energy-Based Desalination

Desalination of seawater and brackish water is considered a promising solution to overcome freshwater scarcity. Conventional desalination techniques, including reverse osmosis and multi-stage flash distillation, require high energy input and are largely dependent on fossil fuels, which increases operational costs and contributes to environmental pollution. In contrast, renewable energy-based desalination systems, especially those powered by solar energy, offer a clean, sustainable, and cost-effective alternative. Solar energy is abundant, freely available, and particularly suitable for remote and rural areas where access to electricity is limited. Therefore, solar-driven desalination technologies are gaining increasing attention as a viable solution for decentralized water production. (3)

Working Principle of Solar Still

A solar still is one of the simplest and most widely used solar desalination devices. It operates on the fundamental principle of evaporation and condensation, similar to the natural water cycle. Solar radiation enters through a transparent cover, typically made of glass, and is absorbed by the saline water contained in a basin. As the water temperature increases, evaporation occurs, leaving behind salts and impurities. The water vapor then rises and condenses on the cooler inner surface of the glass cover. The condensed water droplets are collected through a channel and stored as purified water. Due to its simple design, low maintenance requirements, and ease of operation, the solar still is particularly suitable for small-scale applications. (9)

Limitations of Conventional Solar Still

Despite its advantages, the conventional solar still suffers from low productivity, which limits its practical application. Typically, the daily freshwater output ranges between 2 to 5 liters per square meter, depending on climatic conditions. This low yield is mainly attributed to inefficient heat transfer, limited solar energy absorption, low basin water temperature, and significant thermal losses to the surroundings. Additionally, poor condensation rates further reduce the overall efficiency of the system. These limitations necessitate the development of enhanced designs and hybrid systems to improve performance (10).

Need for a Review Paper

In recent years, extensive research has been carried out to improve the efficiency and productivity of solar stills using various enhancement techniques. Among these, the integration of solar air heaters has gained considerable attention, as it helps in increasing the basin temperature and accelerating the evaporation process. (5)Other techniques such as the use of phase change materials, nanofluids, reflectors, and modified geometries have also been explored. However, the available studies are widely scattered, and a comprehensive review focusing specifically on hybrid solar stills integrated with solar air heaters is limited. Therefore, a systematic review is essential to consolidate existing knowledge, evaluate different approaches, and identify the most effective performance enhancement strategies.

Objective of the Review

The main objective of this review paper is to critically analyze experimental studies related to hybrid solar stills integrated with solar air heaters. The study aims to investigate the influence of such integration on thermal performance, evaporation rate, and freshwater productivity. (2) It also seeks to compare different system configurations, analyze key operational parameters, and identify the most efficient design approaches. Furthermore, the review intends to highlight research gaps and suggest future directions for improving the performance and scalability of solar desalination systems. (6)

2.WORKING PRINCIPLE OF THE SOLAR STILL

The operational efficiency of a hybrid solar still depends on a complex interplay of thermal energy exchange. Below is the detailed breakdown of the basic mechanism and the specific heat transfer processes involved.

1. Basic Working Mechanism

The solar still operates as a greenhouse-effect thermal collector. Solar radiation penetrates a transparent cover (usually glass or plastic) and is absorbed by a blackened basin containing saline or brackish water. This absorbed energy increases the internal energy of the water, causing it to reach its evaporative state. As the water turns into vapor, it leaves behind salts, heavy metals, and pathogens. This purified vapor then rises toward the cooler underside of the transparent cover, where it loses latent heat and reverts to a liquid state (distillate). The slanted design of the cover allows gravity to channel these pure droplets into a collection trough. (3)

2. Heat Transfer Processes Involved

The performance of the still is governed by four primary modes of heat transfer:

Radiation (Qr)

Solar energy enters the system via short-wave radiation. Once absorbed by the basin liner and the water, it is re-emitted as long-wave thermal radiation. In a hybrid system, the Solar Air Heater (SAH) further contributes by providing supplemental radiative heating to the air or water, increasing the overall thermal baseline of the system. (13)

Convection (Qc):

This occurs in two forms: internal and external.

Internal Convection: Heat is transferred from the hot water surface to the humid air mass inside the still. In your hybrid model, the integration of a Solar Air Heater often introduces **forced convection**, where pre-heated air is actively circulated, significantly boosting the heat transfer coefficient compared to natural buoyancy-driven flow. (8)

External Convection: Heat is lost from the outer surface of the glass cover to the ambient air, which is necessary to keep the glass cool enough for condensation. (5)

Evaporation(Qe):

This is the most critical phase for distillate production. As the water temperature rises, the vapor pressure at the water surface increases. When this pressure exceeds the partial pressure of the air above it, molecules escape into the air. The integration of a Solar Air Heater accelerates this by increasing the water-to-cover temperature semi-gradient and lowering the relative humidity of the air mass, allowing it to "carry" more moisture.

Condensation(Qcon):

When the saturated vapor contacts the relatively cooler glass cover, it releases its latent heat of vaporization. This phase change from gas to liquid is the final step in the purification process. The efficiency of condensation is directly linked to the temperature difference between the hot humid air and the inner surface of the glass; the more effectively the still manages this gradient, the higher the freshwater yield. (10)

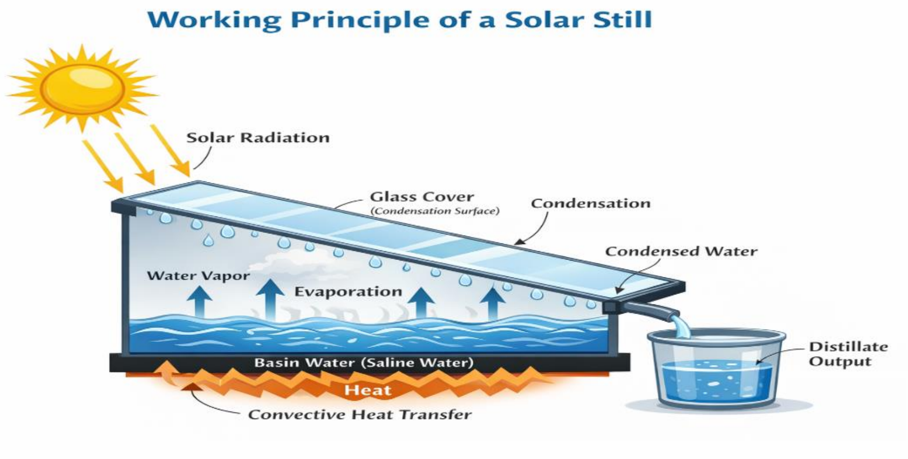

Figure 1: Working Principle Of a Solar Still

2.1 Basin Type Solar Still

The basin type solar still is the most basic and widely used configuration for solar desalination. It consists of a shallow basin filled with saline water, a blackened base to absorb solar radiation, and a transparent glass cover placed at an inclined angle.

In this type, solar radiation passes through the glass cover and is absorbed by the basin water, increasing its temperature. As the water heats up, evaporation occurs, and the vapor rises to the cooler glass surface, where it condenses and is collected as distilled water.

Key Features:

Simple design and easy construction

Low initial and maintenance cost

Suitable for small-scale and rural applications

Advantages:

Requires minimal technical expertise

Operates without external energy input (passive system)

Reliable and environmentally friendly

Limitations:

Low productivity (typically 2–5 L/m²/day)

High heat losses due to poor insulation

Limited efficiency under low solar intensity. (6)

2.2 Double Slope Solar Still

The double slope solar still is an improved version of the basin type, designed with two inclined glass covers forming a symmetrical structure (like an inverted "V" shape). This configuration allows condensation to occur on both sides of the glass cover.

In this system, solar radiation enters through both glass surfaces, heating the basin water. The vapor generated condenses on both inner glass surfaces and is collected separately through channels on either side.

Key Features:

Symmetrical design with two glass covers

Enhanced solar radiation capture throughout the day

Suitable for east-west orientation

Advantages:

Higher productivity compared to single slope stills

Better utilization of solar radiation

More uniform heat distribution

Limitations:

Slightly higher construction cost

More complex design compared to single slope

Condensation efficiency depends on ambient conditions. (3)

2.3 Active and Passive Solar Still

Solar stills can also be classified based on energy input into passive and active systems.

Passive Solar Still:

A passive solar still operates solely using direct solar radiation without any external energy source. The evaporation and condensation processes occur naturally within the system.

Characteristics:

No external energy input required
Simple and cost-effective
Low maintenance
Examples:
Basin type solar still
Single slope and double slope stills
Limitations:
Low efficiency and productivity
Strong dependence on climatic conditions
Active Solar Still:
An active solar still uses additional external energy sources or auxiliary components to enhance the evaporation process. These systems are designed to increase basin water temperature and improve overall productivity.
Common Enhancements Include:
Solar air heaters (as in your project topic)
Solar collectors
Pumps for water circulation
Phase change materials (PCM) for heat storage
Working Concept: External devices supply additional heat to the basin water, increasing evaporation rate and resulting in higher freshwater output.
Advantages:
Significantly higher productivity than passive systems
Better performance under varying weather conditions
Suitable for large-scale applications
Limitations:
Higher initial cost
More complex system design
Requires maintenance of auxiliary components. (7)

3.CLASSIFICATION OF SOLAR STILL

3.1 Passive Solar Still

A passive solar still operates solely on direct solar radiation. It has no moving parts and requires no external power.
Mechanism: Solar energy enters through the glass and heats the water directly.
Pros/Cons: It is inexpensive and easy to maintain but suffers from low productivity (typically 2–5 L/m²/day) because the evaporation rate depends entirely on the basin's ability to trap heat.

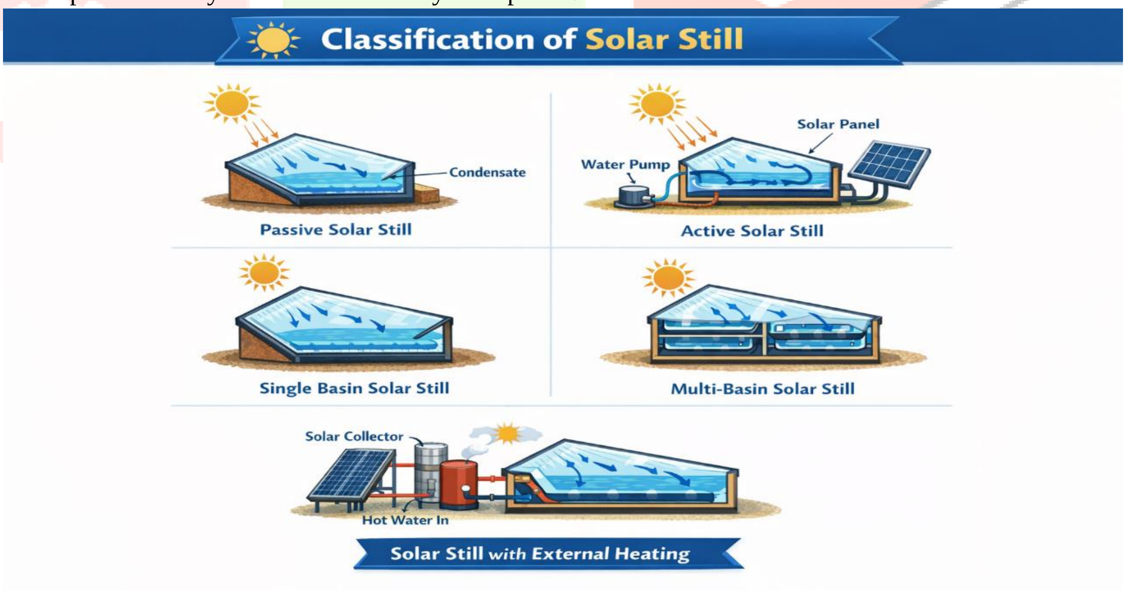

Figure 2: Classification Of Solar Still

3.2 Active Solar Still

An active solar still uses external equipment to enhance the evaporation rate.
Mechanism: It integrates mechanical devices like pumps or fans, or external thermal collectors (like your Solar Air Heater) to feed extra heat into the basin.
Pros/Cons: It significantly increases water temperature and yield but involves higher initial costs and requires a power source for the auxiliary components. (8)

3.3 Single Basin Solar Still

This is the simplest geometric form, consisting of one basin of saline water covered by a single or double-sloped glass top.
Application: Ideal for individual households in remote areas.
Limitation**:** It loses a significant amount of latent heat through the glass cover to the atmosphere, which is never recovered. (4)

3.4 Multi-Basin Solar Still

To improve efficiency, multiple basins are stacked vertically.

Mechanism: The latent heat of condensation from the lower basin is used to heat the water in the basin above it.

Result: This "heat recycling" significantly increases the overall distillate yield per square meter of footprint compared to single-basin designs.

3.5 Solar Still with External Heating Systems

This category includes stills integrated with secondary thermal units.

Examples: Flat plate collectors, evacuated tube collectors, or Solar Air Heaters (SAH).

Role in your project: By integrating a SAH, you are injecting pre-heated air into the still, which reduces the relative humidity inside the chamber and increases the temperature of the water surface simultaneously. (3)

4.METHODOLOGY

The performance of a solar still is evaluated using several key parameters such as productivity, thermal efficiency, distillation rate, heat transfer coefficients, and overall energy efficiency. These parameters help in comparing different designs and enhancement techniques.

4.1 Productivity (kg/m²/day)

Productivity is the most important parameter, representing the amount of distilled water produced per unit area per day. (6)

$P = \frac{md}{A}$

Where:

P= Productivity (kg/m²/day)

md= Mass of distilled water collected per day (kg)

A = Basin area (m²)

Explanation:

Higher productivity indicates better performance. It mainly depends on solar intensity, basin temperature, and evaporation rate. (12)

4.2 Thermal Efficiency (η_{th})

Thermal efficiency represents how effectively the solar energy input is utilized for water evaporation.

$\eta th = \frac{md.hfg}{I.A.t}$

Where:

ηth = Thermal efficiency

hfg = Latent heat of vaporization (kJ/kg)

I = Solar radiation intensity (W/m²)

t = Time (s or day basis)

Explanation**:**

It indicates the fraction of solar energy converted into useful evaporation energy. Higher values mean better system performance.

4.3 Distillation Rate

Distillation rate refers to the rate at which water is evaporated and condensed per unit time.

$\dot{m} = \frac{Qe}{hfg}$

Where:

m = Distillation rate (kg/s or kg/hr)

Qe= Heat used for evaporation (W)

hfg = Latent heat of vaporization

Explanation**:**

It depends on the temperature difference between water and glass cover and directly affects productivity. (6)

4.4 Heat Transfer Coefficients

Heat transfer inside a solar still involves three main coefficients:

(a) Convective Heat Transfer Coefficient (hc)

Qc=hc·A·(Tw−Tg)

(b) Evaporative Heat Transfer Coefficient (he)

Qe=he·A·(Tw−Tg)

(c) Radiative Heat Transfer Coefficient (he)

Qr=hr·A·(Tw−Tg)

Where:

Tw = Water temperature, Tg = Glass cover temperature, A = Area

Explanation:

Convective heat transfer moves heat via air/vapor motion

Evaporative heat transfer is responsible for actual water evaporation

Radiative heat transfer occurs due to thermal radiation exchange

These coefficients are crucial for modeling and improving system performance. (9)

4.5 Energy Efficiency (η_e)

Energy efficiency represents the overall utilization of input solar energy.

$$\eta e=\frac{Useful\ Energy\ output}{Total\ solar\ energy\ input}$$

$$\eta e=\frac{md.hfg}{I.A}$$

Explanation:

It evaluates how efficiently the system converts solar energy into distilled water output.

5.LITERATURE REVIEW

Recent studies on solar stills have focused on improving productivity and thermal efficiency through design modifications and performance enhancement techniques. The literature can be broadly categorized into design innovations and augmentation methods.

5.1 Design Modifications in Solar Still

Stepped Solar Still

Stepped solar stills are designed to increase the evaporation surface area by dividing the basin into multiple steps. Studies have shown that stepped configurations enhance heat transfer and evaporation rates due to reduced water depth and better exposure to solar radiation. (6) Recent investigations report significant improvements in productivity compared to conventional basin stills, especially when combined with advanced materials and nanofluids.

Multi-Basin Solar Still

Multi-basin solar stills consist of multiple layers or stages that allow reuse of latent heat from condensation. This design increases overall efficiency by utilizing heat more effectively. Research indicates that multi-stage systems can produce higher yields than single basin stills, making them suitable for large-scale applications. Advanced multi-basin designs also integrate thermal storage systems for continuous operation. (7)

Pyramid Solar Still

Pyramid solar stills use a three-dimensional structure that allows solar radiation to be captured from multiple directions throughout the day. This design improves solar energy absorption and enhances condensation efficiency. Literature reports that pyramid stills exhibit better performance compared to single-slope designs, with productivity improvements exceeding 50% under optimal conditions. (11)

Inclined Solar Still

Inclined solar stills are developed to improve condensation and water collection efficiency. Unlike conventional basin stills, these designs enhance vapor movement and reduce thermal losses. Recent studies suggest that optimized inclination angles significantly influence productivity, and compact inclined systems can achieve higher distillation rates compared to traditional configurations. (10)

5.2 Performance Enhancement Techniques

Use of Fins

The incorporation of fins in the basin increases the effective heat transfer area and improves heat distribution within the water. Experimental studies show that fins enhance basin water temperature, resulting in higher evaporation rates and improved distillate output. (3)

Use of Black Coatings

Black coatings are applied to the basin surface to increase solar absorptivity. Literature indicates that improved absorptive surfaces significantly enhance heat gain and reduce reflection losses, leading to better thermal performance.

Use of Reflectors

Reflectors are used to direct additional solar radiation into the still, thereby increasing heat input. Studies demonstrate that external reflectors can improve productivity by increasing the intensity of solar radiation incident on the basin. (5)

Use of Phase Change Materials (PCM)

Phase change materials are used for thermal energy storage, allowing heat to be stored during peak solar hours and released during low radiation periods. Recent reviews highlight that PCM integration improves night time productivity and stabilizes system performance. (14)

Use of Nanofluids

Nanofluids have gained significant attention due to their superior thermal properties. The addition of nanoparticles enhances thermal conductivity and heat transfer within the basin water. (3)Studies report that nanofluids can increase productivity by up to 50–100% and significantly improve thermal efficiency compared to conventional systems.

Use of Solar Collectors

The integration of solar collectors (such as flat plate or solar air heaters) is one of the most effective enhancement techniques. These systems supply additional heat to the basin, increasing water temperature and evaporation rate. Hybrid systems combining solar stills with solar collectors show substantial improvements in productivity and are widely studied in recent research. (10)

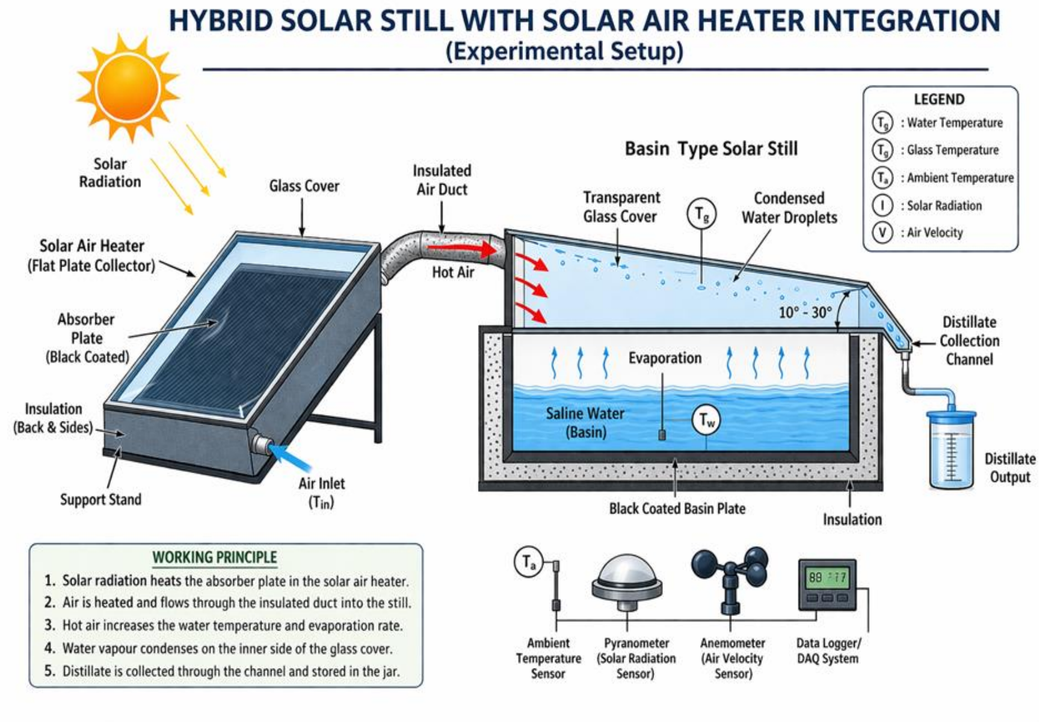

Figure.3 Hybrid Solar Still with Solar Air Heater Integration

5.3 Experimental Studies on Solar Still

The following table summarizes key experimental studies conducted by various researchers: (8)

Author	Year	Type of Solar Still	Method Used	Improvement (%)
Kumar et al.	2021	Single basin	PCM + fins	32%
Singh et al.	2020	Stepped solar still	Reflector	28%
Sharma et al.	2022	Multi-basin	Solar collector	55%
Reddy et al.	2019	Pyramid solar still	Black coating	22%
Khan et al.	2023	Inclined solar still	Nanofluids	48%
Patel et al.	2021	Single basin	Fins	20%
Verma et al.	2020	Stepped solar still	PCM	35%
Ali et al.	2022	Multi-basin	Reflector + PCM	60%
Das et al.	2023	Pyramid solar still	Nanofluids	42%
Gupta et al.	2021	Inclined solar still	Solar collector	50%

6.RESEARCH GAP

Despite significant advancements in solar desalination technologies, several critical gaps remain in the existing literature, particularly in the context of hybrid solar still systems integrated with solar air heaters.

Limited work on hybrid solar still systems

Although various performance enhancement techniques have been explored, relatively limited research has focused on hybrid solar stills integrated specifically with solar air heaters. Most studies emphasize individual enhancements rather than combined or hybrid configurations, leaving scope for deeper investigation into system integration and optimization.

Very few studies on large-scale applications

The majority of experimental studies are conducted at laboratory or small pilot scales. There is a lack of research addressing the scalability of solar still systems for large-scale or community-level water production. Practical challenges such as land requirements, system durability, and operational feasibility at larger scales remain underexplored.

Lack of comprehensive economic analysis

While many studies report improvements in productivity and efficiency, limited attention has been given to economic feasibility. Detailed cost analysis, including capital cost, maintenance, payback period, and life-cycle cost assessment, is often missing. This gap hinders the commercialization and real-world adoption of solar still technologies.

Very few studies conducted under Indian climatic conditions

Solar still performance is highly dependent on climatic conditions such as solar intensity, ambient temperature, and humidity. However, only a limited number of studies have been conducted specifically under Indian environmental conditions, which vary significantly across regions. This creates a need for region-specific experimental investigations and data.

Limited research on long-term performance and reliability

Most experimental studies focus on short-term performance evaluation, typically conducted over a few days or weeks. There is a lack of long-term studies analyzing system durability, material degradation, fouling effects, and consistent performance over extended periods. Such studies are essential for assessing the reliability and sustainability of solar still systems.

7.FUTURE SCOPE

Despite considerable advancements in solar desalination technologies, there remains significant potential for further research and development to enhance the performance, scalability, and economic feasibility of solar still systems. The following areas are identified as promising directions for future work:

Integration with Solar Air Heaters

The integration of solar air heaters with solar stills offers a highly effective approach to improving thermal performance and productivity. Future studies should focus on optimizing air flow rate, collector design, and heat transfer mechanisms to maximize evaporation rates. Advanced hybrid configurations combining multiple heat sources can further enhance system efficiency.

Integration with Solar Dryers

Combining solar stills with solar dryers can lead to multifunctional systems capable of both water purification and agricultural product drying. Such integrated systems can improve overall energy utilization and provide additional economic benefits, especially in rural and remote areas. Research should explore system design, thermal coupling, and operational optimization. (2)

Use of AI-Based Optimization

Artificial Intelligence (AI) and machine learning techniques can be applied to optimize system parameters such as water depth, air velocity, basin temperature, and inclination angle. AI-based predictive models can enhance performance forecasting, improve system control, and enable real-time optimization under varying climatic conditions.

Use of Low-Cost Materials

The development of solar stills using low-cost, locally available materials is essential for large-scale adoption, particularly in developing regions. Future research should focus on alternative materials for basin liners, insulation, and transparent covers that maintain performance while reducing overall system cost.

Hybrid Solar Desalination Systems

Hybrid systems combining solar stills with other renewable energy technologies, such as photovoltaic (PV) systems, solar collectors, or thermal storage units, represent a promising direction. These systems can significantly improve productivity and enable continuous operation even during low solar radiation periods. Further work is needed on system integration, performance optimization, and techno-economic analysis

8.CONCLUSION

This review comprehensively analyzed recent advancements in solar still technology, with a particular focus on hybrid systems integrated with solar air heaters. The study highlights that conventional solar stills, although simple and cost-effective, suffer from low productivity and efficiency, which limits their practical applicability. Various design modifications such as stepped, pyramid, and multi-basin solar stills have demonstrated noticeable improvements in performance by enhancing heat transfer and evaporation surface area. Additionally, performance enhancement techniques including fins, black coatings, reflectors, phase change materials (PCM), nanofluids, and solar collectors have been extensively investigated and found to significantly increase distillate yield and thermal efficiency.

Among the various enhancement methods, the integration of external heating systems—particularly solar air heaters—has emerged as one of the most effective techniques. This approach provides additional thermal energy to the basin water, leading to higher evaporation rates and improved overall productivity. When combined with other techniques such as PCM and nanofluids, hybrid systems exhibit substantial performance gains compared to conventional designs.

In terms of system configuration, active solar stills, especially hybrid solar stills integrated with solar air heaters, are identified as the most suitable and efficient type for achieving higher freshwater output. Among design variations, stepped and multi-basin solar stills also show promising results due to their improved heat utilization and increased evaporation area.

In conclusion, solar still technology, particularly in its hybrid form, represents a sustainable and environmentally friendly solution for freshwater production. With further advancements in system design, material selection, and integration of renewable energy technologies, solar desalination has strong potential to address global water scarcity challenges while minimizing environmental impact.

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