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A Literature Review On Performance Analysis Of Solar Still Using Forced Convection

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Abstract

The contemporary challenge facing human society is the pressing need to satisfy the substantial demand for freshwater, which is dwindling rapidly due to the burgeoning human population and rapid urbanization. Solar stills offer an economical means of obtaining fresh water, as they rely solely on the abundant and freely available energy from the sun for operation. However, a significant constraint in conventional solar stills lies in the requirement to maintain a large surface area of water with minimal water depth.

To address this constraint effectively, inclined solar stills emerge as a preferred solution, as they offer a large surface area of water while maintaining a shallow water depth. In pursuit of enhancing the performance and efficiency of inclined solar stills, numerous efforts have been directed towards increasing the free surface area of water. Studies have shown that passive inclined solar stills yield distillate ranging from 1000 to 8100 ml/m2, while active inclined solar stills produce distillate yields ranging from 1045 to 9000 ml/day.

This review aims to analyze the current status of various designs in inclined solar stills with the objective of inspiring further research in inclined solar still technology. By delving into the present advancements and challenges in this field, this review endeavors to foster innovation and development in inclined solar still technology to effectively address the growing demand for fresh water.

Keywords - Solar stills Phase change material Productivity

Introduction

Desalination through solar energy is widely recognized as a viable solution for producing potable water, particularly in remote regions facing water scarcity due to weak infrastructure and lack of connection to main water supply networks. In comparative experiments between conventional and modified solar stills conducted under identical time and weather conditions, it was observed that the modified solar still elevates the water temperature in the distiller basin. This temperature increase enhances the evaporation rate, consequently boosting hourly productivity. Integration of internal reflector panels with the solar still resulted in an approximately 18.5% increase in distillate water yield (excluding nighttime productivity), with a maximum improvement of 48%. Notably, the use of solar storage water heaters and gravel material in the still further increased distiller productivity [1].

Desalination of seawater and brackish water has become a widespread method for alleviating the global shortage of freshwater. On clear days, a maximum water commutation rate of 2-3 kg/m^{2-}day has been achieved, while on cloudy days in winter, the minimum cumulative water productivity has been measured at 0.03 kg/m^2-day [2].

Water, as a crucial life-saving renewable resource, has been meeting human needs since ancient times and will continue to do so in the future. However, only 1% of available water is freshwater suitable for domestic purposes. Due to exponential population growth and industrialization, the available freshwater source is at risk of transitioning from renewable to finite. Single Slope Solar Still (SSSS) and Pyramid Solar Still (PSS) were designed by Fath et al. (2003) for a comparative analytical study of thermal performance, productivity, and efficiency. According to Dunkle relations, the annual average daily productivity of PSS and SSSS was calculated to be 2.6 L/m^2-day, with corresponding annual average daily efficiencies of 30% and 33%, respectively. Kabeel (2007) introduced a PSS design with a parallel multi-shelf arrangement in the basin, resulting in a 90 to 95% increase in freshwater production compared to corrugated or horizontal beds [3].

Solar basin stills offer a straightforward, easily constructed, and operated solution, utilizing freely available solar energy to produce potable water. However, their limited productivity and significant land requirements offset these advantages. To enhance productivity, studies have concentrated on factors such as basin area, water surface exposure, basin water depth, and inlet water temperature. Comparative analysis of fresh water productivity accumulations from 9 am to 5 pm across three operation modes (SLPW, SLLW, and CSS) reveals distinct trends. The SLLW solar still outperformed both SLPW and conventional stills, demonstrating higher accumulated distillate water. Specifically, the distillate output from SLPW solar still was 90% greater than that from the conventional still (CSS). Furthermore, the productivity of SLLW solar still surpassed the CSS output by approximately 98%, as detailed in Table. Regarding daily average efficiency, the current operational modes stood at approximately 66% for SLPW, 68% for SLLW, and notably lower at 37.5% for CSS, [4].

Table-

Instrument	Solarimeter	Temp. Indicator	Calibrated Flask	Anemometer
Accuracy	1w/m^2	0.1 ^{o}C	1 ml	0.1 m/s
Range	0-2000 w/m^2	0-100 ^{o}C	0-2000 ml	0.4- 30 m/s
Error	0.15 %	1.8 %	1.17 %	3.5 %

In a study by A.E. Kabeel et al. [5], during the test days, wind velocity ranged from 0.3 to 5.5 m/s and solar radiation intensity varied from 185 to 914 W/m2. Three square pyramid solar stills were tested at the same water depth of 2 cm, yielding accumulated distillate water productivities averaging almost 4.13 L/m2 day in system-A, 3.5 L/m2 day in system-B, and 2.93 L/m2 day in system-C, under the same ambient conditions of Tanta City, Egypt in September 2019.

Previous literature surveys on Hybrid Solar Stills (HSS) have primarily focused on integrating the solar still with photovoltaic systems and photovoltaic-thermal hybrid systems. Manokar et al. [6] conducted a mini-review on photovoltaic-thermal systems integrated with solar stills, revealing that these PV/T integrated HSS are self-sustainable and capable of meeting both the freshwater and electrical energy demands of rural and remote areas. They also noted that integrating PV panels onto the side walls of the solar still could enhance the efficiency of the PV system and reduce the overall fixing costs of the solar panels. These insights highlight the potential of integrating renewable energy technologies to address water and energy needs in off-grid locations effectively.

Murugavel et al. [7] conducted a case study on a single basin double slope solar still with minimum basin depth and utilized quartzite rock as an effective basin material for energy storage. Testing different energy storing materials like quartzite rock, red brick pieces, and concrete pieces, they found that a basin depth of 0.75 mm with 3/4 inch quartzite rock yielded maximum production rates.

Agrawal et al. [8] performed an experimental performance evaluation of a single-slope single-basin solar still with multiple V-shaped floating wicks to enhance heat absorption and increase productivity. The modified solar still with floating wicks wrapped in V-shaped pieces of thermocol exhibited an evaporative surface area 26% larger than conventional solar stills, resulting in daily productivities of 6.20 kg/m² in summer and 3.23 kg/m² in winter, with daily efficiencies of 56.62% and 47.75%, respectively.

A. El-Sebaii et al. [9] presented a study on a single slope-single basin solar still with and without phase change material (PCM) under the basin liner. Using stearic acid as a PCM, they conducted numerical calculations in Jeddah, Saudi Arabia, revealing a significant increase in distillate output and daily efficiency when PCM was employed, compared to conventional operation.

M. Sakthivel and S. Shanmugasundaram [10] modified a single-basin solar still with an energy storage medium of black granite gravel. This modification aimed to maximize solar energy utilization and minimize heat loss. Experimental results showed a 17–20% increase in still yield with no significant cost, as black granite gravel is inexpensive.

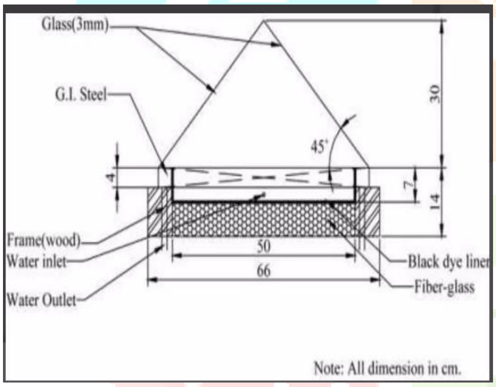

Fig.- single-basin solar still which is modified with energy storage medium of black granite gravel

Muthu Manokar et al. [11] investigated the performance of the pyramid solar still by varying the water depth from 1 to 3.5 cm under both insulated and uninsulated conditions. It was observed that the pyramid solar still with insulation outperformed the uninsulated still, especially at the lowest water depth of 1 cm. Without insulation, the freshwater production from the pyramid solar still ranged from 3.27 to 1.59 kg/m^2, while with insulation, it ranged from 3.72 to 2.08 kg/m^2.

In another study, Mr. A.Prabakaran, T.R.Sathishkumar, and S.Karthika [12] aimed to enhance the productivity of a single basin single slope solar still by incorporating thermal energy storage. Two types of solar stills were designed and fabricated for performance comparison. The results indicated that the modified solar still improved productivity by 41% and 61% compared to the conventional solar still under the same climate conditions for the first and second case, respectively.

From the table – 12

S. No.	Instrument	Range	Accuracy
1	Thermocouple	0-100 °C	0.1 °C
2	Temp. Indicator	0-300 °C	1 °C
3	Collecting Jar	0-1000 ml	10 ml
4	Solarimeter	0-2500 w/m^2	1 w/m^2

Wesley Jeevadason et al. [13] highlighted that Hybrid Solar Stills (HSS) demonstrate superior performance in freshwater yield and efficiency compared to various other Solar Still (SS) desalination systems. HSS systems facilitate the economical production of clean water. Among these, a solar still integrated with a heat pump, which absorbs heat from the condensation area and transfers it to the basin water, achieved the highest thermal energy efficiency of 80%.

Furthermore, the production cost per liter of freshwater was reported to be the lowest for solar stills with Concentrated Photovoltaic Thermal (CPVT) and Photovoltaic Thermal (PVT) systems, standing at 0.0015 $/L and 0.0026 $/L, respectively. These findings underscore the potential of integrating innovative technologies to enhance the efficiency and cost-effectiveness of solar desalination systems.

Sharshir et al. [11] have done a detailed report on thermal and exergy investigation of solar still. An enhancement method of solar still efficiency was studied by Sivakumaret al. [12]. Elango et al. [13] have done an extensive review of thermal models of solar still. Various design approaches used to improve the yield from multi-effect solar still was examined by Rajaseenivasan et al. [14]. A study on energy, exergy, and thermo-economic of solar still was done by Ranjan et al. [15]. Different design modifications of a solar still were reviewed by Durkaieswaran et al. [16], El-sebaii et al. [17], Panchal et al. [18], Samee et al. [19] and Kumar et al. [20]. Different factors' affecting the solar still yield has been summarized by Muthu et al. [21], Muftah et al. [22] and Velmurugan et al. [23]. Active solar still distillation system has been reviewed by Sathyamurthy et al. [24], Sampathkumar et al. [25] and Chandrashekara et al. [26] and Muthu et al. [27 & 28]. This review detail explains the different design configurations of inclined solar still developed by several researchers in order to increase the performance and efficiency.

Ranjan and Kaushik [30], in their review paper, have emphasized the necessity of conducting a review on hybrid solar stills, asserting that such an endeavor can significantly contribute to meeting the growing demand for freshwater while simultaneously advancing energy conservation for sustainable development.

Drawing from previous reviews and studies, several research gaps have been identified and are presented as follows:

- Previous reviews have predominantly focused on photovoltaic (PV) and PV/T based hybrid solar stills, neglecting other potential combinations.
- The productivity and additional benefits of all hybrid solar still combinations have not been comprehensively analyzed in prior works.
- The Energy efficiency, Exergy efficiency, and Economic analysis (3E) in terms of production cost per liter of freshwater for hybrid solar stills have not been thoroughly explored.
- There is a dearth of research on enviro-economic analysis concerning hybrid solar stills.

Conclusion

The performance analysis of a solar still with forced convection presents a promising avenue for enhancing the efficiency and reliability of freshwater generation from solar energy. Continued research and development in this field hold the potential to further optimize design parameters, leading to increased effectiveness and wider acceptance of solar stills as a sustainable and economically feasible solution for addressing global water challenges.

Furthermore, experimental findings suggest that solar stills equipped with forced convection mechanisms consistently perform well across various environmental conditions. These systems demonstrate resilience to fluctuations in solar radiation, ambient temperature, and wind speed, underscoring their robustness and reliability. Such adaptability is crucial for practical applications, where environmental factors can often be unpredictable.

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