Experimental Investigation of a PV-Powered Blower-Assisted Solar Still: Effects of Seawater Volume on Evaporation–Condensation Efficiency

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Abstract: This study investigates the performance of a photovoltaic-assisted solar still integrated with a blower system to enhance desalination efficiency. The system was experimentally evaluated to examine the influence of thermal parameters on freshwater productivity and system efficiency. The results show that distilled water production ranges from 0.35 to 0.55 L/day, with an efficiency of 7–8%. The highest productivity occurred at an evaporator temperature of 47.6–48 °C, confirming temperature as the dominant parameter. The PV-powered blower increased the temperature gradient between the evaporator and condenser by promoting forced air circulation, improving heat and mass transfer. However, the system performance remains within the conventional range, indicating that heat losses and limited condensation efficiency are key constraints. This study demonstrates the potential of photovoltaic-powered, blower-assisted solar stills to enhance evaporation–condensation processes and provides a baseline for further system optimization.

Keywords: Solar desalination, Photovoltaic-assisted solar still, Blower-assisted evaporation, Evaporation–condensation process.

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Introduction

The availability of clean water remains one of the most pressing global challenges of the 21st century. Rapid population growth, urbanization, and climate change have significantly intensified the pressure on freshwater resources. It is estimated that more than two billion people still lack access to safe drinking water, and this number is expected to increase in the coming decades (Al-Addous et al., 2024; Kumar et al., 2024). This issue not only threatens public health but also affects economic development, agriculture, and social stability worldwide. Although approximately 97% of the Earth's water is seawater, only about 2.5% is freshwater, most of which is not easily accessible due to its storage in glaciers or deep aquifers. These limitations have driven the development of desalination technologies to convert seawater into potable water (Martínez-Medina et al., 2024). Among existing technologies, such as reverse osmosis (RO), multi-stage flash (MSF), and multi-effect distillation (MED), high energy consumption and operational costs remain major challenges (Elfaqih et al., 2024). In addition, reliance on fossil fuels contributes to environmental concerns, particularly greenhouse gas emissions. To address these challenges, the integration of renewable energy into desalination systems has gained increasing attention. Solar energy, in particular, is considered a promising solution due to its abundance, especially in tropical and coastal regions where freshwater scarcity is most critical (Alwan et al., 2024). Solar energy can be utilized either directly as a thermal source or indirectly through photovoltaic (PV) systems to supply electrical power. One of the simplest solar-driven desalination technologies is the solar still, which operates based on evaporation and condensation processes (Chorghe et al., 2024). Solar stills offer advantages such as simple design, low cost, and suitability for small-scale applications in remote areas (Tony & Nabwey, 2024). However, their main limitation lies in relatively low productivity and efficiency compared to modern desalination systems. Previous studies report that the efficiency of conventional solar stills typically ranges between 20–40%, depending on system design and environmental conditions (Khalaf et al., 2025). This limitation is primarily attributed to heat losses, inefficient condensation, and limited heat and mass transfer mechanisms (Zakaria et al., 2025). To overcome these limitations, various enhancement techniques have been proposed, including design modifications, the use of advanced materials, nanofluids, and integration with auxiliary technologies such as thermoelectric modules and photovoltaic systems (Hussein et al., 2024). The integration of PV systems enables the use of additional components, such as blowers or cooling systems, to improve evaporation and condensation processes (Al-Obaidi et al., 2025; Tareq Abdel Hameed Almajali et al., 2025). Despite these advancements, reported performance improvements vary significantly. Some studies demonstrate substantial productivity enhancement, while others indicate that system performance is highly dependent on configuration, operating conditions, and heat transfer characteristics (Kabeel et al., 2024; Rashid et al., 2024). This inconsistency highlights the need for further investigation into the optimal integration of auxiliary systems within solar still technology. Moreover, previous studies have predominantly focused on material enhancement and nanofluid applications, whereas limited attention has been given to the integration of photovoltaic-powered airflow systems, such as blowers, to control pressure and enhance condensation processes (Al-Addous et al., 2024; Khalaf et al., 2025). This gap indicates the need for a more comprehensive evaluation of the role of PV-assisted auxiliary components in improving overall system performance. Therefore, this study aims to experimentally investigate the energy efficiency and productivity of a photovoltaic-assisted solar still integrated with a blower system as a pressure-reduction mechanism. A 20 Wp photovoltaic panel is utilized to supply electrical energy to the blower, with the objective of enhancing the evaporation–condensation process. System performance is evaluated through key parameters, including ambient temperature, evaporator temperature, condenser temperature, seawater temperature, and distillate yield. The findings of this study are expected to contribute to the development of more efficient and sustainable solar desalination systems, particularly for applications in coastal and remote areas.

Research Method

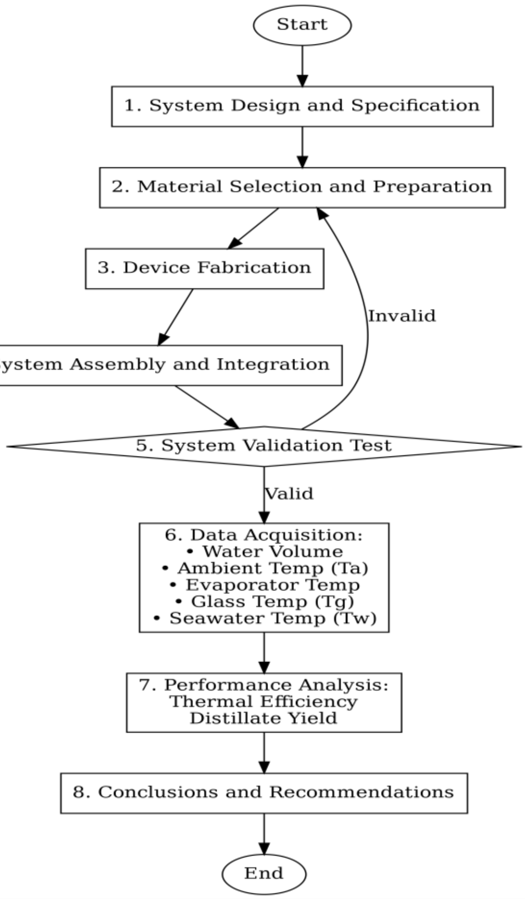

Figure 1 Flowchart Research

Flowchart Design

The flowchart in Figure illustrates the systematic procedure of the solar-powered seawater desalination research conducted using an experimental approach. The study begins with literature review and problem identification to define the research focus on improving the efficiency and productivity of the solar still system. This is followed by the system design stage using SolidWorks 2016, which includes the design of the evaporator and condenser, as well as material selection based on thermal properties and corrosion resistance. The next stages involve fabrication and assembly and system integration, where thermal and electrical subsystems, including the photovoltaic panel and blower, are combined. The system is then evaluated through functional testing to ensure proper operation. If the system does not meet the operational criteria, system improvement and optimization are performed until the desired performance is achieved. Once the system meets the required criteria, experimental data acquisition is conducted by measuring key parameters such as temperature and freshwater output. The collected data are then analyzed in the data processing and performance analysis stage to assess temperature distribution and system productivity.

Finally, performance evaluation is carried out based on thermal efficiency, which serves as the basis for drawing conclusions and providing recommendations.

Research Design

This study employs a quantitative experimental approach to evaluate the performance of a solar-powered seawater desalination system integrated with photovoltaic panels and a blower system. The experimental method was selected due to its capability to provide direct insight into heat and mass transfer phenomena within the solar still system, as well as to analyze the relationship between operational variables and freshwater productivity. Previous studies have emphasized that experimental approaches are fundamental in solar desalination research, as they enable detailed evaluation of thermal behavior and system efficiency (Tony & Nabwey, 2024). Furthermore, this approach is widely applied in hybrid renewable energy-based desalination systems to assess real-time performance under varying operating conditions (Abu El-Maaty et al., 2023; Najaf & Aslan, 2024).

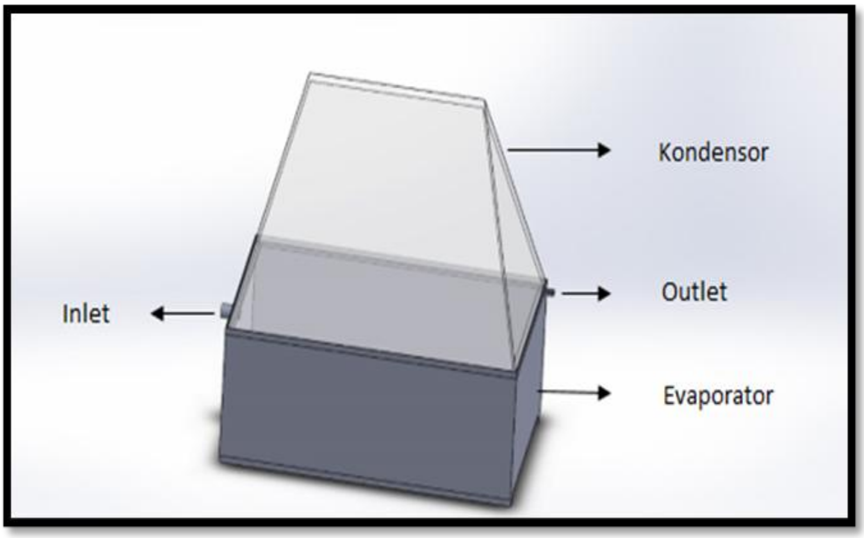

Figure 2 Design Research

The research design focuses on analyzing the effect of seawater volume variation and blower system integration on energy efficiency and distilled water production. Therefore, this study adopts both descriptive and comparative analyses across different operating conditions to obtain comprehensive performance characteristics. Such an approach is considered appropriate for generating reliable empirical data and contributes to the development and optimization of solar-based desalination technologies.

Experimental Setup

The system was designed using SolidWorks 2016 to ensure dimensional accuracy and manufacturability. The desalination unit consists of an evaporator basin and a transparent glass condenser. Previous studies confirm that integrating active cooling mechanisms can significantly improve condensation rates and freshwater yield by enhancing heat transfer at the condenser surface (Elashmawy & Ahmed, 2021; Kabeel et al., 2020). The desalination system used in this study is a single-basin solar still. The main specifications of the apparatus are shown in Table 1.

Table 1 Equipment Specifications

No.	Component	Specifications
1	Dimensions	50 × 30 cm
2	Absorber	Stainless steel (1 mm)
3	Cover	Transparent glass (5 mm)
4	Solar panel	20 W
5	System type	Single-basin solar still

Table 1 shows that the system is designed with compact dimensions (50 × 30 cm) and uses a stainless-steel absorber to enhance heat absorption. The 20 W solar panel serves as an additional energy source to support the condensation process.

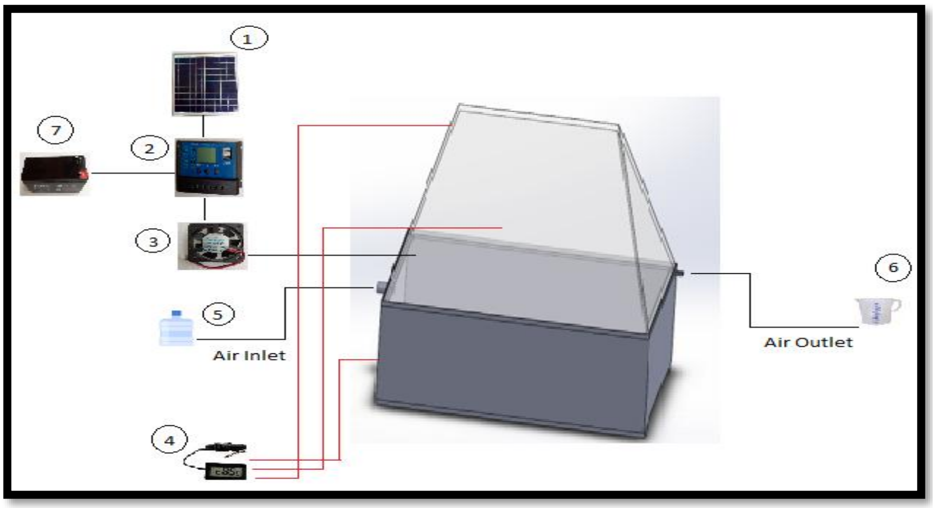

Figure 3 testing scheme

Figure 3 Schematic of a single-basin solar still seawater desalination system integrated with solar panels, consisting of solar panels (1), a solar charge controller (2), a blower (3), a digital thermometer (4), a seawater reservoir (5), a freshwater reservoir (6), and a battery (7).

Figure 3 shows the configuration of the solar-powered desalination system used in this study. This system operates by utilizing solar energy as the primary source for the seawater evaporation process within the evaporator chamber. The resulting water vapor condenses on the glass surface and is channeled into the freshwater reservoir. The solar panels serve as the electrical energy source to operate the blower, which accelerates the condensation process, while the battery and solar charge controller are used to maintain a stable energy supply during testing. The design used is the single-basin solar still type, which is known for its simplicity and is widely used in small-scale applications due to its ease of construction and relatively low cost (Shalaby et al., 2022).

Methodology Approach

This study adopts a direct experimental method using a basin-type solar still system modified with a photovoltaic (PV) panel to supply electrical energy for a blower unit. The integration of auxiliary technologies such as forced airflow or cooling mechanisms has been widely reported to enhance condensation rates and improve overall system efficiency in solar still applications (Alkilani et al., 2023). Recent developments in hybrid PV-based desalination systems further demonstrate that optimized energy distribution and control strategies can significantly improve freshwater productivity and system performance (Hussein et al., 2024). The operating principle of the system is based on solar-driven evaporation and condensation processes, where solar radiation heats seawater within the basin to generate vapor, which subsequently condenses into freshwater on a cooler surface. The incorporation of a blower in this study aims to enhance internal air circulation, reduce vapor partial pressure, and accelerate the condensation process. Previous studies have shown that improving internal airflow can significantly enhance heat and mass transfer mechanisms, leading to higher energy efficiency and water production rates. Therefore, the proposed methodology not only evaluates the performance of a conventional solar still system but also investigates the effectiveness of integrating renewable energy-based modifications. This approach enables a comprehensive assessment of system behavior and supports the development of more efficient and sustainable desalination technologies.

Research Subject and Object

The subject of this study was a hybrid basin-type solar still desalination system, while the object of investigation focused on thermal performance and freshwater productivity. Seawater was used as the working fluid with varying volumes to evaluate the influence of thermal load on system performance. The geometric configuration of the system was considered a critical factor, as it significantly affects evaporation and condensation efficiency (Wiener et al., 2024). Supporting components, including a 20 W photovoltaic panel and a blower, were integrated to enhance system performance. Previous findings have indicated that the incorporation of auxiliary technologies, such as energy storage materials or cooling systems, can substantially increase freshwater productivity under certain conditions (Khalaf et al., 2025).

Data Collection

Data were collected from both primary and secondary sources. Primary data were obtained through direct experimental measurements, including ambient temperature, evaporator temperature, condenser temperature, seawater temperature, and distilled water output. Measurements were recorded periodically to capture the temporal variation of system performance. These parameters are widely recognized as key indicators for evaluating solar still performance (Elfaqih et al., 2024). Secondary data were obtained from relevant scientific literature to support data interpretation and validation. The integration of primary and secondary data sources enhances the reliability and comparability of the results

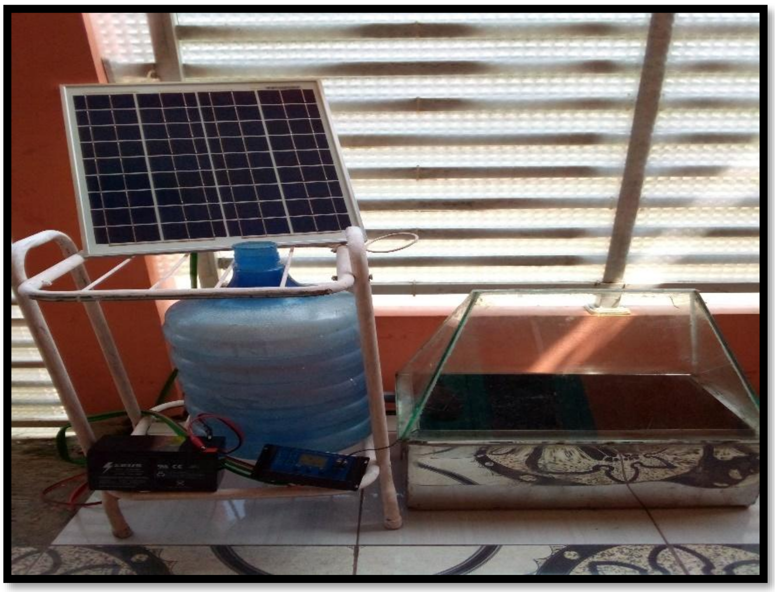

Figure 4 The distiller uses solar panels

Data Analysis

Data analysis was conducted using a quantitative descriptive and comparative approach with the assistance of data processing software such as Microsoft Excel. The relationship between operational parameters and system performance was analyzed to determine optimal operating conditions. Temperature distribution analysis was performed to examine heat transfer mechanisms within the system, while comparative analysis across different seawater volumes was conducted to evaluate performance improvement due to system modification. Quantitative analysis is essential in characterizing desalination systems and identifying performance enhancement strategies (Abu El-Maaty et al., 2023; Bellila et al., 2024).

Performance Evaluation

System performance was evaluated by calculating thermal efficiency and freshwater productivity. Thermal efficiency was defined as the ratio of energy utilized for evaporation to the total solar radiation energy received by the system. This parameter is widely regarded as a key indicator in assessing solar desalination performance (Abu El-Maaty et al., 2023; Hussein et al., 2024). In addition, freshwater productivity was used as a primary performance metric to assess system output under varying operating conditions. A multi-parameter evaluation approach was adopted to ensure a comprehensive assessment of system performance, as recommended in recent studies on solar still systems (Tei et al., 2025)

Result and Discussion

Experimental Results

Distilled Water Production and System Efficiency

The graphical results in Figure 5 illustrate a consistent increase in distilled water production as the volume of seawater input rises from day 1 to day 3. The distilled water output ranges approximately from 0.35 L to 0.55 L per day, indicating a positive but relatively modest production trend. This behavior confirms that although higher input volume contributes to increased freshwater yield, the improvement remains limited in magnitude. The corresponding system efficiency also exhibits a slight increase, from approximately 7.10% to 7.86%, which still falls below the typical efficiency range of conventional solar still systems (10–40%). This suggests that the system experiences constraints in effectively utilizing available thermal energy.

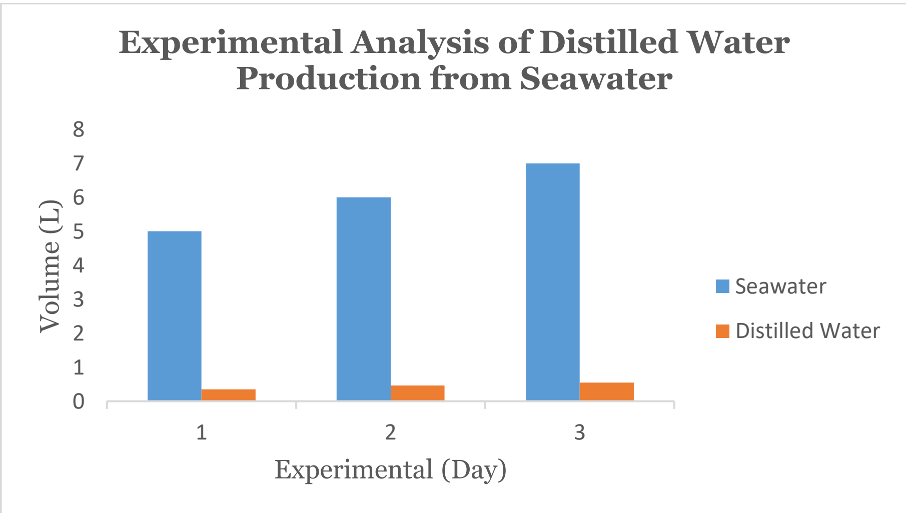

Figure 5 Experimental analysis of seawater volume and distilled water production over a 3-day desalination process.

Furthermore, the observed non-linear trend between seawater input and distilled water output indicates the presence of thermal losses and uneven heat distribution within the system. These inefficiencies reduce the effectiveness of evaporation and condensation processes, thereby limiting overall productivity. The results obtained in this study are consistent with previous findings, where conventional solar stills generally exhibit low productivity due to inherent design and thermal limitations. In comparison, research conducted by (Kabeel et al., 2022) demonstrated that the incorporation of porous materials can significantly enhance water production, achieving more than double the output of conventional systems. This improvement is primarily attributed to increased evaporation surface area and improved heat transfer performance. Therefore, the relatively lower productivity observed in this study highlights the absence of mechanisms that enhance heat transfer efficiency (Kabeel et al., 2022) . Additionally, the findings align with the work of (Singh & Verma., 2024), which emphasizes that evaporator temperature plays a critical role in determining water productivity. In this study, the highest yield was observed when the evaporator temperature reached approximately 48 °C, confirming that system performance is strongly influenced by thermal conditions and follows established thermodynamic principles (Singh & Verma., 2024). Moreover, (Alwan et al., 2024) reported that conventional solar still systems are generally constrained by low energy efficiency, environmental factors, and design limitations. The present results support this conclusion, as the productivity trend, although increasing over time, remains relatively low when compared to modified or enhanced desalination systems (Alwan et al., 2024).

Thermal Characteristics of the System

The thermal behavior of the system was analyzed based on temperature distributions across key components, including ambient air, evaporator, condenser, and seawater. In general, all parameters exhibited an increasing trend toward midday, corresponding to the rise in solar radiation intensity. The experimental results reveal that the integration of the PV-powered blower enhances the temperature gradient between the evaporator and condenser. This temperature difference plays a crucial role in accelerating the evaporation–condensation cycle within the solar still. Physically, this improvement is attributed to the ability of the blower to promote forced air circulation within the system, which reduces vapor partial pressure at the condensing surface and accelerates vapor transport from the evaporator to the condenser. This mechanism aligns with previous findings indicating that forced airflow can significantly enhance condensation rates and freshwater production (Mandev et al., 2024). Moreover, recent studies emphasize that controlling temperature distribution is a key factor in improving the efficiency of solar still systems (Elsheikh et al., 2024). Therefore, the developed system offers a conceptual advantage by enabling simultaneous control of both evaporation and condensation processes.

Ambient Temperature

The ambient temperature ranged from 28.8°C to 36.8°C, with peak values occurring around 13:00. This pattern reflects the typical daily solar radiation cycle, where maximum intensity occurs at midday and directly influences system performance. Variations in ambient temperature across different days indicate fluctuating environmental conditions that affect system output. The second day exhibited the highest temperature, suggesting a greater potential for enhanced evaporation. This observation is consistent with previous studies reporting that higher ambient temperatures and solar radiation directly improve evaporation rates in solar still systems (M. Yusop et al., 2026).

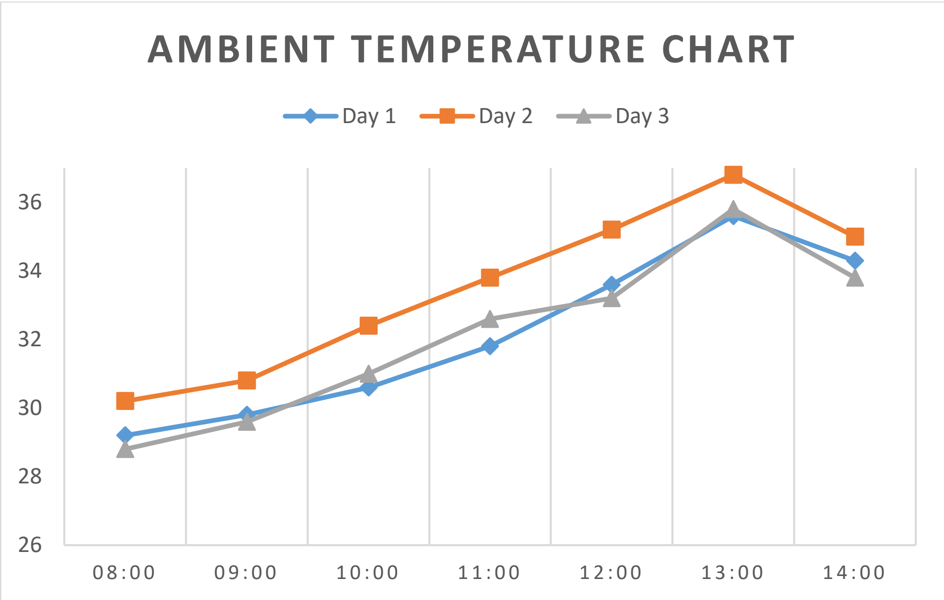

Figure 6 Comparison chart of environmental temperature measurement results

Furthermore, the consistent temperature patterns observed over the three testing days indicate stable system operation. The increase in temperature during midday contributes to a higher temperature gradient between the evaporator and condenser, which is essential for improving freshwater productivity.

Evaporator Temperature

The evaporator temperature reached maximum values of 44.4°C (day 1), 47.6°C (day 2), and 45.2°C (day 3). These values indicate effective absorption and retention of solar thermal energy within the evaporation chamber, directly contributing to vapor generation. The temperature profile shows a steady increase from morning until midday, followed by a decline after 13:00, corresponding to the reduction in solar radiation intensity. This trend highlights the strong dependence of evaporation rates on solar input.An increase in evaporator temperature enhances the kinetic energy of water molecules, thereby accelerating the evaporation process. This finding is consistent with previous research demonstrating a direct relationship between evaporator temperature and freshwater productivity (Shoeibi et al., 2022)

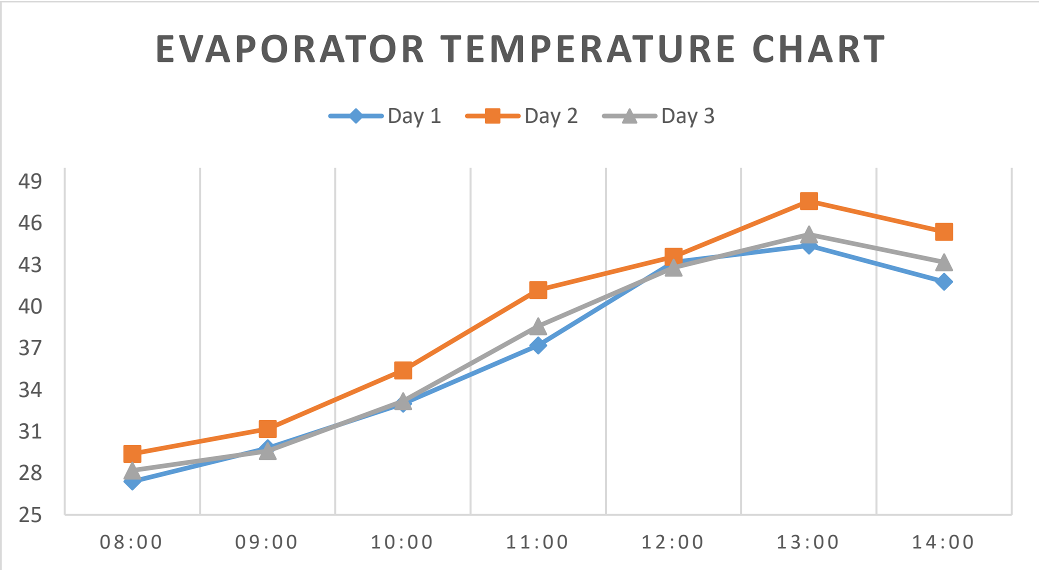

Figure 7 Comparison chart of evaporator temperature measurement results

The subsequent temperature decline in the afternoon reflects reduced solar input, which in turn lowers the evaporation rate. This observation aligns with studies identifying weather conditions as a dominant factor influencing desalination system efficiency (Alwan et al., 2024).

Condenser Temperature

The condenser temperature remained consistently lower than that of the evaporator, with maximum values of 36.2°C, 38.6°C, and 37.2°C. This temperature difference establishes the thermal gradient necessary for condensation to occur. The observed trend of increasing temperature followed by a decline indicates that operational variables, particularly temperature and solar radiation, significantly influence system performance. Higher temperatures contribute to enhanced evaporation and condensation processes, ultimately improving productivity.

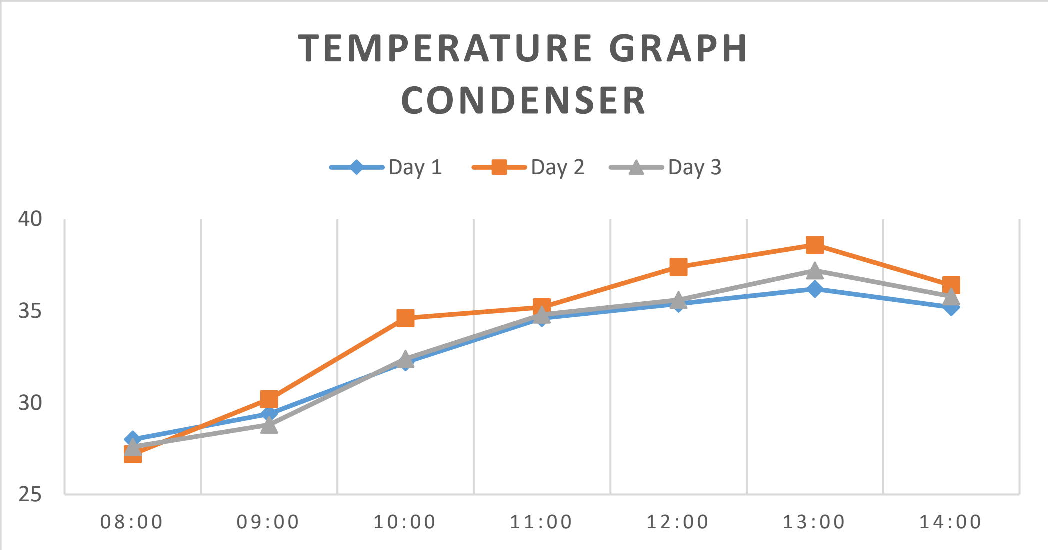

Figure 8 Graph of the results of the comparison of condenser temperature measurements

These findings are in agreement with previous studies, which report that solar still performance is strongly affected by thermal and environmental conditions, with evaporator temperature playing a critical role in system efficiency (Alwan et al., 2024; Shalaby et al., 2022; Singh & Verma, 2024).

Seawater Temperature

The seawater temperature reached maximum values between 52°C and 54°C, exceeding the evaporator temperature. This difference occurs because the seawater temperature sensor recorded the bulk liquid temperature at the base of the basin, where solar radiation is directly absorbed by the stainless-steel absorber, whereas the evaporator temperature sensor measured the air/vapor space above the water surface, which is subject to convective and evaporative heat losses. As a result, the seawater layer in direct contact with the absorber retains more thermal energy than the evaporator air space, indicating that seawater acts as a thermal energy storage medium within the system. The temperature increased steadily from morning until midday, reflecting the direct influence of solar radiation. Elevated seawater temperature enhances vapor pressure, thereby accelerating the evaporation process.

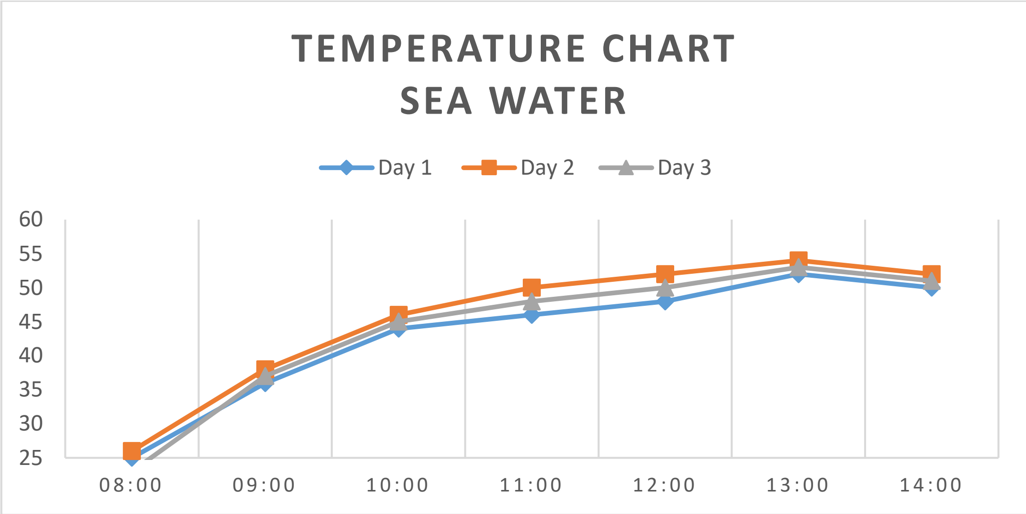

Figure 9 Graph of the results of comparing sea water temperature measurements

This result is consistent with previous studies identifying seawater temperature as a key parameter in improving solar still productivity (Alwan et al., 2024; Shalaby et al., 2022; Singh & Verma, 2024).

Effect of Temperature on Water Production

The results demonstrate a strong correlation between distilled water production and the increase in evaporator and seawater temperatures. This confirms that temperature is the dominant parameter controlling system performance. From a thermodynamic perspective, higher temperatures increase molecular kinetic energy, thereby accelerating evaporation. Additionally, elevated seawater temperature increases vapor pressure, promoting mass transfer from liquid to vapor phase. However, the relationship between temperature and productivity is not strictly linear. This is due to system limitations such as heat losses and uneven temperature distribution. Furthermore, the effectiveness of condensation depends on the temperature difference between the evaporator and condenser. Thus, overall system performance is governed by the balance between evaporation and condensation processes rather than temperature alone.

Freshwater Productivity

The results indicate an improvement in freshwater productivity compared to conventional systems, which correlates with enhanced evaporation and condensation efficiency. Quantitatively, previous studies report that integrating thermoelectric modules can increase freshwater production by approximately 35% compared to conventional solar stills (Mandev et al., 2024). In addition, such systems can reduce the cost per liter of produced water by 26–36% under optimized conditions (Attar & Ramiar, 2024) Nevertheless, the improvements observed in this study remain limited, suggesting that further optimization strategies are required to achieve significant performance enhancement.

Energy Efficiency and Thermodynamic Analysis

The system efficiency improved as a result of enhanced heat and mass transfer within the solar still. This improvement is reflected not only in energy efficiency but also in exergy efficiency, which represents the quality of energy utilization. Previous studies have shown that thermoelectric cooling can significantly improve both energy and exergy efficiency, particularly under optimal operating conditions. However, the present results indicate that the improvement remains modest, highlighting the need for further system optimization. Critically, while the integration of the PV-powered blower enhances the temperature gradient, it is insufficient to fully overcome fundamental limitations such as heat losses and limited condensation efficiency.

Conclusions

This study experimentally investigated the performance of a photovoltaic-assisted solar still integrated with a blower to enhance evaporation–condensation processes. The results show that freshwater productivity ranged from 0.35 to 0.55 L/day, with a system efficiency of approximately 7–8%. The highest productivity was achieved at an evaporator temperature of around 47.6–48 °C, confirming that temperature is the dominant parameter influencing system performance. The integration of a PV-powered blower contributed to improving internal airflow and vapor transport, which enhanced the temperature gradient between the evaporator and condenser. However, despite these improvements, the overall system performance remains within the range of conventional solar stills. This indicates that heat losses, limited condensation efficiency, and the absence of advanced heat transfer enhancement mechanisms are still the primary constraints. This study demonstrates that active airflow control using a simple photovoltaic-driven system can improve solar still performance, although its impact is relatively limited compared to more advanced modification techniques. The present experiments were conducted over a 3-day testing period. Similar or even shorter testing durations have been employed and accepted in comparable solar still studies; for instance, (Diarra et al., 2024) characterized a mobile wick solar still with an external condenser over a 4-day campaign, while several single-basin and modified solar still studies have reported consistent, reproducible diurnal thermal and productivity trends across 3-day measurement campaigns under stable weather conditions. In the present study, the close similarity of the diurnal temperature and productivity trends across day 1 to day 3 (Figures 5-9) supports the repeatability of the observed system behavior within the tested period. Nonetheless, a 3-day period constitutes a limitation of the study, as longer-term testing (e.g., a minimum of 7 consecutive days) is recommended to more rigorously verify the reliability and repeatability of the system's performance under varying environmental conditions and across different seasons. Future work should therefore extend the testing duration and focus on integrating additional enhancement strategies, such as improved thermal insulation, advanced absorber materials, or hybrid cooling systems, to achieve higher efficiency and productivity.

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