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Analysis of the performance of V-type solar stills coupled with flat plate collectors and the potential use of artificial intelligence

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ABSTRACT

The exponential rise in global population and pollution from industrialization exacerbates water scarcity. Solar desalination offers a carbon-neutral solution to freshwater production. The V-type double-sloped solar desalination system, renowned for its simplicity and compact size, outperforms single-sloped systems. This study compares the performance of a double inward slope desalination still with and without a flat plate collector. Results show a 74 % increase in water production with the modified still, achieving 3020 mL/day and 633 mL/hr on clear, sunny days. Energy efficiency also improves by 18 % to 0.13 mL/kJ with the addition of the flat plate collector. Conducted in Thalassery, India, the experiment demonstrates potential for home applications. Shadowing on the collector plate can diminish solar energy gain, addressed through mathematical modeling using Artificial Neural Networks (ANN) in this study.

1. Introduction

The climate changes, industrialization, and population growth have led to increased demand for fresh water. Fresh water is essential for human survival. On Earth, over 96.5 % of available water constitutes seawater, whereas freshwater constitutes only 2.5 %. Out of the available freshwater, only 0.36 % is available for human use. Solar desalination is a technique to convert saline water or brackish water into fresh water. Solar desalination functions with the help of solar power. Solar desalination achieves its maximum efficiency when radiation is at its peak [1]. The normal solar still has limited output, but it can be increased by coupling with pre-heaters [2]. Researchers have also used solar flat plate collectors. The solar flat plate collector device can affordably warm saline water for small-scale desalination applications [3]. Experimental observations of solar stills incorporating flat plate collectors and Sodium Thiosulfate Pentahydrate used as PCM in flat plate collectors resulted in an increase in freshwater productivity during nighttime [4]. PCMs are used in flat plate collectors to maintain heat long after the sun sets, particularly in cold climates [5]. When a solar still is combined with a flat-plate solar collector, the best productivity of 8.52 l/m^2day is achieved when the saline water depth is reduced to 1 cm, and the glass cover is 3 mm thick. The highest productivity of 10.06 l/m^2day is achieved when a cooling glass cover is applied. The glass cover's orientation depends on the area's range [6,7]. Different solar concentrators are also used to preheat water for solar desalination techniques [8]. Tabular solar stills are also used for the desalination process for fresh water production [9]. Solar desalination is accomplished via parabolic concentrators, which are easily adjustable with sun tracking [10]. In a solar thermal desalination system, hard (salt) water is heated using sun radiation and then supplied through copper tubes, where a compound parabolic concentrator is positioned at the bottom to produce steam at the highest temperature possible. After creating steam in this way, the steam is sent via a condenser and condenses to produce soft water. Based on theoretical calculations, 3–4 liters of soft water can be produced every hour [11]. The height of the basin and the rate of circulating air mass flow have a negative impact on solar desalination productivity [12]. Experiments were carried out using semi-continuous insertion of saline solutions comprising concentrations of 0–4 % of sea salt to evaluate the effectiveness of the solar dish concentrator in terms of water desalination. Distilled water yields varied by 4.95 kg/m [13]. Economic studies reveal that the flat plate collector basin cost of distilled water is less than that of the traditional still [14]. For small-scale freshwater production, a solar-powered humidification–dehumidification desalination (HDD) system is a potential method. The approximate cost of producing freshwater is \$0.075 L− 1 [15]. The productivity of the combined flat plate water solar collector

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Fig. 1. Experimental setup of the inverted type solar still coupled with flat plate collector.

and basin solar still was 56 % and 82 % higher, respectively, than that of the traditional basin solar still when hot water was sprayed (passive and active circulations) [16]. The maximum temperature was 51.4 ˚C and 49 ˚C at flow rates of 5.3 and 6.51 L/min, respectively, in the study on solar water heating for flat plate collectors. This is because the water at the flow rate of 5.3 L/min heated more than the flow rate of 6.51 L/min, which causes the higher efficiency and effectiveness of the collector [17]. There are two heating modes for the flat plate solar collector: direct and indirect. Heat recovery integrated into a modular solar thermal desalination system. Using a direct radiation reflector together with a flat plate collector can yield superior results [18]. Compare the performance of a solar still using a combination flat plate collector and fresh tap water. The combined solar still-flat plate collector daily efficiency was found to be 20.4 % and 23.6 % higher than the fresh water and salt water systems operating alone, respectively [19]. The system's temperature increase is heavily influenced by the amount of solar radiation that is available, while the system's heat loss is significantly influenced by the wind velocity. An overall collector efficiency of 43.7 % is found with a maximum temperature gain from the two-pass flow of water across the absorber plate [20]. The effectiveness of the still is dependent on the thickness of the glass. For example, a desalination still with 4 mm thick glass produces 48 % more fresh water than one with 6 mm thick glass [21]. The production of fresh water is impacted by wind variance. With a wind speed of 4 m/s, double slope solar desalination still yields 17.8 % better productivity than that of 3 m/s [22]. Internal parameters also contribute a major role in fresh water production. Heat storage materials are given fourth priority, wick materials are given third, and the basin plate is given first priority. The basin water depth is given second priority [23].

This study focuses on evaluating the performance of a double slope inward solar still integrated with a solar flat plate collector. A key challenge in solar desalination systems, as observed in previous research, is the energy loss due to shadowing on flat plate collectors. This paper proposes a theoretical approach leveraging AI to mitigate shadow effects. Experiments were conducted on a clear, sunny day in February in Thalassery, Kerala, India (11˚45′2.24″N 75˚29′13.28″E). Comparison plots illustrate the total fresh water production per unit of energy for both scenarios: standalone solar still and combined solar still with a flat plate collector. Additionally, relevant parameters are plotted and analyzed for comparison.

1.1. Objective and methodology adopted

This comprehensive integration of artificial intelligence (AI) into solar still systems with flat plate collectors indeed holds significant potential for enhancing performance and efficiency. Let's break down the objectives outlined:

1.**Optimization of Solar Collector Performance:** AI algorithms can dynamically adjust collector tilt angles and track the sun's position to maximize energy absorption.

2.**Enhanced Heat Transfer Efficiency:** AI control systems can regulate temperature distribution and optimize heat transfer processes, improving water evaporation and condensation.

3.**Adaptive Water Production Control:** AI-driven strategies can adjust freshwater production rates based on real-time factors, optimizing operation while minimizing energy consumption.

4.**Prediction of Environmental Conditions:** AI models can forecast environmental factors, enabling proactive adjustments to optimize performance in changing weather conditions.

5.**Fault Detection and Diagnostics:** AI algorithms can detect system faults early, preventing downtime and maintaining efficiency.

6.**Energy Management and Optimization:** AI-based energy management can optimize solar energy utilization for thermal and electrical production, including effective scheduling and energy storage.

7.**Water Quality Monitoring and Control:** AI-driven sensors and control systems ensure freshwater quality meets standards by adjusting operating parameters based on feedback.

8.**Data Analytics for Performance Evaluation**: AI-powered data analytics analyze historical data to identify optimization opportunities, leading to continuous improvement.

By addressing these objectives, AI integration can indeed contribute significantly to improving the performance, efficiency, and reliability of solar still systems, thereby increasing access to clean drinking water in water-scarce regions.

2. Design and implementation of experimental setup

The experiments were conducted in Kerala at 11˚ 04' 5.24" N, 75˚ 02' 13.28" E. V-type solar stills were built using zinc sheet. A flat plate collector was constructed from galvanized zinc sheet and mild steel, and the tubes were made of copper. Two types of experiments were carried out: first, solar desalination using a V-type still coupled with a flat plate collector, and second, desalination using a V-type still without coupling with a flat plate collector. Detailed design specifications are provided in Fig. 1.

2.1. V-type solar still

The double slope V-type inward type solar still has been fabricated using zinc sheet painted black and insulated from the outside. The roof of the basin is made using 3 mm thick glass plates, tilted at a 20˚ angle inward on both sides, as shown in Fig. 2. Thermocouples are utilized to measure the temperature at the inlet and outlet water tube valves, at the glass surface (inside and outside), in the basin water, and in the ambient

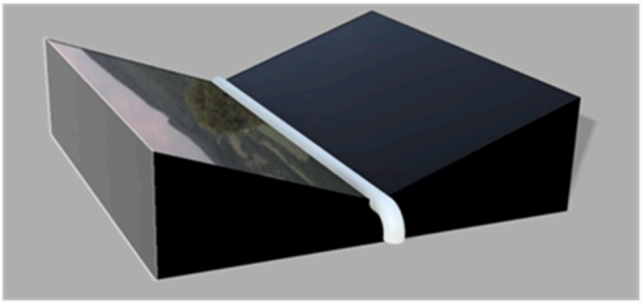


Fig. 2. Experimental set-up of inverted still without modification.

air. The outlet valve from the still is connected to a vessel to collect the fresh water produced, and the inlet valve to the still is connected to the saline water tank. The radiation collection area is 1 m x 1 m.

2.2. Flat plate collector

The rectangular flat plate collector measured 1 m in length, 0.5 m in width, and 0.1 m in height. Its purpose was to preheat the water before supplying it to the desalination still. The top of the flat plate collector was covered with 6 mm glass. Copper tubes were employed to carry water inside the flat plate collector, arranged as depicted in Fig. 3. Three tubes were longitudinally placed, connecting two tubes positioned laterally. The outlet valve of the saline water tank was connected to the flat plate collector, and the outlet valve of the flat plate collector was connected to the desalination still. Both the flat plate basin and tubes were coated with black color. Water flow between the components was controlled using valves. Thermocouples were utilized to measure water temperature at the inlet and outlet valve, as well as inside and outside the glass of the plate. The dimensions of the tubes were ¼ inch vertically and 1 in. horizontally. The experimental setup is illustrated in Fig. 3.

3. Experimental procedure

The experimental procedure involved the fabrication of two solar stills with identical dimensions. One of them was connected to the flat plate collector, and the experiments were conducted simultaneously on the same date and time. The trials were conducted from 8 a.m. to 8 p.m. under clear sunny skies. A solarimeter was employed to measure the solar radiation received.

The experiments were conducted using the following two methods:

- Solar desalination still without coupling with the flat plate collector.
- Solar desalination still coupled with the flat plate collector.

3.1. Solar desalination still without coupling with the flat plate collector

In this experiment, the solar radiation receiving area was the projected area of the top glass cover, which measures 1 m^2. The saline water tank was directly connected to the solar still without any pre-heaters in between. The output valve was then connected to the fresh water collecting tank shown in Fig. 2. A floating scale was utilized to maintain the water level in the basin. Readings were taken every half an hour between morning 8 a.m. and evening 8 p.m. The solarimeter readings and thermocouple readings were also recorded every hour.

3.2. Solar desalination still coupled with flat plate collector

In the experiment involving the solar desalination still coupled with the flat plate collector, the inlet valve of the flat plate collector was connected to the saline water tank, and the outlet valve of the flat plate collector was connected to the inlet of the V-type desalination still. The outlet valve of the desalination still was connected to the fresh water tank.

Readings were taken at half-hour intervals, and water from the flat plate collector passed to the desalination still at the same intervals. These readings were tabulated and plotted. The output valve was then connected to the fresh water collecting tank shown in Fig. 2. A floating scale was employed to maintain the water level in the basin. Readings were taken every half-hour between morning 8 a.m. and evening 8 p.m. Solarimeter readings and thermocouple readings were also recorded every half an hour.

4. Thermal energy assessment of V-type solar still (daily yield)

The output of the modified still was determined employing the methodology delineated by Gnanaraj and Velmurugan [24].

Evaporative heat transfer (water to glass)

$$Q_{e,w-g} = h_{e,w-g}(T_w - T_g) \quad (1)$$

Evaporative heat transfer coefficient (water to glass)

$$h_{e,w-g} = 16.273 \times 10^{-3} \times h_{c,w-g}\left[\frac{(P_w - P_g)}{(T_w - T_g)}\right] \quad (2)$$

Saturated pressure for water

$$P_w = \exp\left[25.317 - \frac{5144}{(T_w + 273)}\right] \quad (3)$$

Saturated pressure for glass

$$P_g = \exp\left[25.317 - \frac{5144}{(T_g + 273)}\right] \quad (4)$$

Convective heat transfer coefficient (water to glass)

$$h_{c,w-g} = 0.884\left[(T_w - T_g) + \frac{(Pw - Pg)(Tw + 273)}{268.9 \times 10^3 - P_w}\right]^{\frac{1}{3}} \quad (5)$$

Determination of per hour production

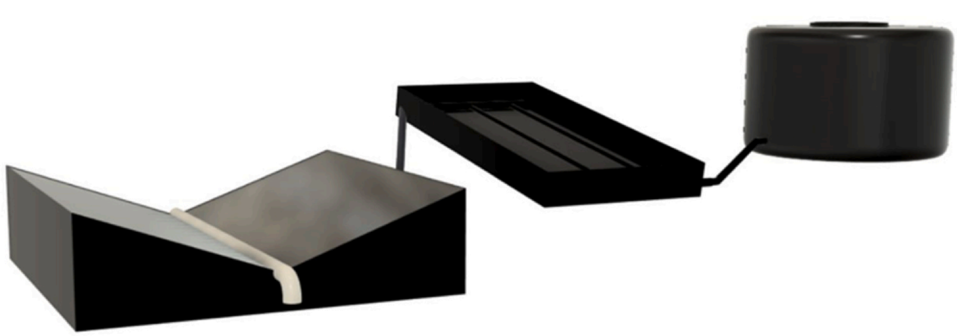


Fig. 3. Experimental setup of the inverted type solar still coupled with flat plate collector.

$$m_e = \frac{Q_{e,w-g} \times 3600}{L} ml/m^2 \quad (6)$$

L − Latent heat of vapourization = **2372000 J/kg**.

Determination of daily production

$$yeild_{per\ day} = \sum_{7am}^{6pm} m_e \quad (7)$$

Efficiency of the still is as follows

$$\eta_{still} = \frac{\sum m_e \times L}{\sum H \times A \times 3600} \quad (8)$$

Where,

m_e = Daily production (mL).

H = Hourly solar radiation (W/m^2).

A = Area of basin (m^2).

Assessing the thermal energy output of the V-Type Solar Still on a daily basis provides crucial insights into its performance. By quantifying the daily yield, researchers can gauge the efficiency of the solar still in converting solar energy into usable heat for water purification. This assessment aids in optimizing operational parameters and enhancing overall system efficiency. It also contributes to the ongoing development of sustainable water desalination technologies. The daily thermal energy assessment serves as a key metric in evaluating the effectiveness of V-Type Solar Stills in addressing water scarcity challenges.

5. Results and discussion

The desalination of saline water utilizing the V-type solar desalination still, both with and without the flat plate collector, was accomplished effectively. Observations were recorded, and graphical representations were generated, as depicted below. These trials took place in February 2023. The collected water underwent testing and validation for potability.

5.1. Evaluation of solar radiation performance during testing

The graph depicted in Fig. 4 illustrates the energy flux measured by the Solarimeter at half-hour intervals from 8 a.m. to 8 p.m. The Solarimeter reading starts from 148 W/m^2 since the experiments commenced at 8 a.m., gradually increasing until 10 a.m., and then gradually decreasing from 5 p.m. to 8 p.m. As expected, the Solarimeter recorded a high amount of radiation between 10 a.m. and 3 p.m., tapering off toward zero after 6:30 p.m. The experiments were stopped after 8 o′clock as there was no additional effect due to solar radiation becoming zero. The maximum solar radiation received was 633 W/m^2, occurring at 1 p.m.

5.2. Performance of solar irradiation and cumulative water yield during still with flat plate collector

The figure above illustrates the experimental findings of a V-type solar desalination system integrated with a flat plate collector. In Fig. 5, the solarimeter readings and cumulative freshwater yield are depicted from 8 am to 8 pm. Solar radiation intensity initiates at 418 W/m^2 at 8 am, peaks at 633 W/m^2 by 1 pm, and diminishes to 0 W/m^2 post-sunset. Freshwater generation commences at 10 mL at 8:30 am, progressively escalating with solar radiation intensity. In comparison to the trial devoid of a flat plate, this configuration demonstrates a marked surge in freshwater output. The cumulative freshwater production of the V-type solar desalination system coupled with a flat plate collector amounts to 3020 mL/day.

5.3. Performance of solar irradiation and cumulative water yield during still without flat plate collector

The above graph illustrates the cumulative water collection report of solar desalination using a V-type solar still without coupling with a flat plate collector, along with the solarimeter readings. In Fig. 6, it is evident that water production depends on the intensity of solar radiation. The solarimeter reading starts at 148 W/m^2 at 8 am, gradually increasing to 633 W/m^2 at 1 pm, and then gradually decreasing to 0 W/m^2 after 6:30 pm, signifying sunset. Cumulative fresh water production commences at 0 mL at 8 o′clock and gradually increases up to 1735 mL/day. However, there is no sudden increment in water production compared to the experiment conducted with a coupled flat plate collector. Water production increases proportionally with the rise in solar intensity.

5.4. Performance of V-type still inside temperature

Fig. 7 displays the fluctuations in inner temperatures of the V-type solar still throughout the experiment. The graph includes readings for inner air temperature, inner basin liner temperature, and inner water temperature, all recorded using digital thermocouples. These temperature variations are intricately linked to the intensity of solar radiation, thereby affecting the rate of freshwater generation. Peak temperatures are typically recorded between 12 pm and 2 pm.

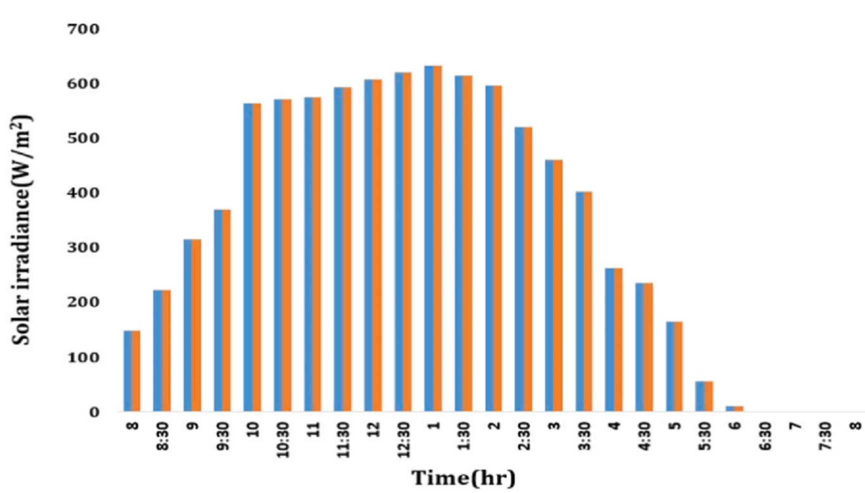


Fig. 4. Solarimeter reading Vs time.

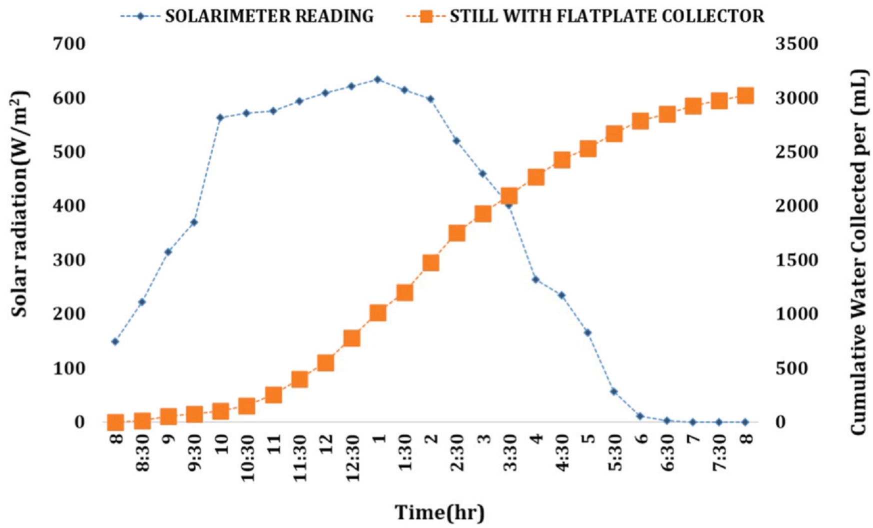


Fig. 5. Solari-meter reading and cumulative water collected Vs time.

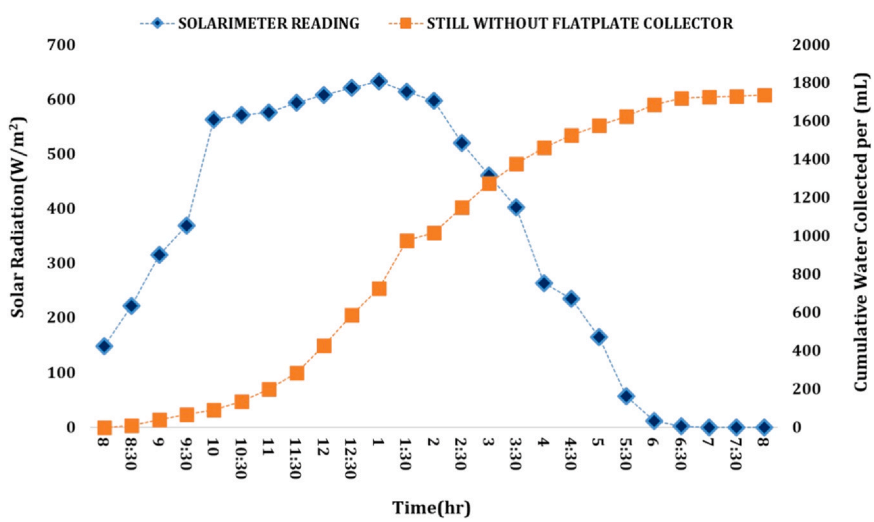


Fig. 6. Solari-meter reading and cumulative water collected Vs time.

5.5. *Performance of the inner and outer glass temperature*

Fig. 8 illustrates the inner and outer glass temperatures of the V-type solar desalination still during the conducted experiment. A 3 mm thickness glass was utilized to cover the roof of the still. The inner and outer temperatures vary according to the intensity of solar radiation.

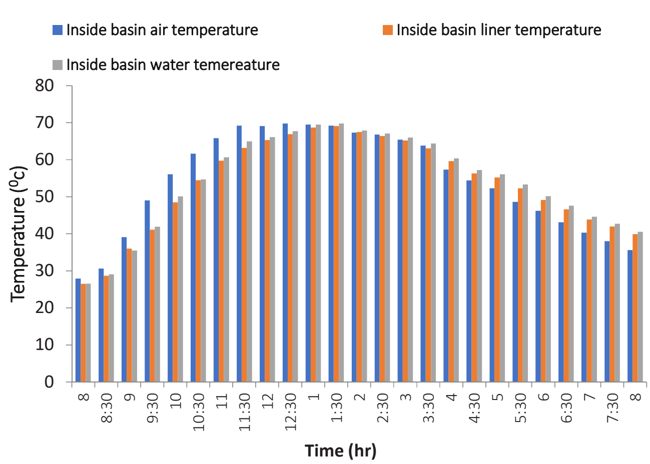


Fig. 7. Performance of V-type still inside temperature.

Notably, the outer temperature consistently remains lower in comparison to the inner glass temperature. This characteristic facilitates a smoother condensation process and contributes to an enhanced production rate. Additionally, the inner and outer glass temperatures are employed in the theoretical calculation of daily production.The inner and outer glass temperatures play pivotal roles in solar desalination systems by impacting heat transfer, evaporation, and condensation processes.

Heat Transfer: The temperature difference between the inner and outer glass surfaces facilitates heat transfer within the solar still. Solar energy absorbed by the inner glass surface heats the saline water, stimulating evaporation. Meanwhile, the outer glass temperature regulates heat loss to the surroundings, ensuring efficient heat retention within the system.

Evaporation: Elevated inner glass temperatures expedite the evaporation of saline water, transforming it into water vapor. This vapor ascends, condenses on the cooler inner glass surface, and subsequently drips down into a collection basin as purified water. Thus, maintaining an optimal inner glass temperature is critical for maximizing evaporation rates and water production.

Condensation: The temperature variance between the inner and outer glass surfaces also facilitates condensation. As water vapor encounters the cooler inner glass surface, it condenses into liquid water due to the temperature contrast. This condensed water is collected and

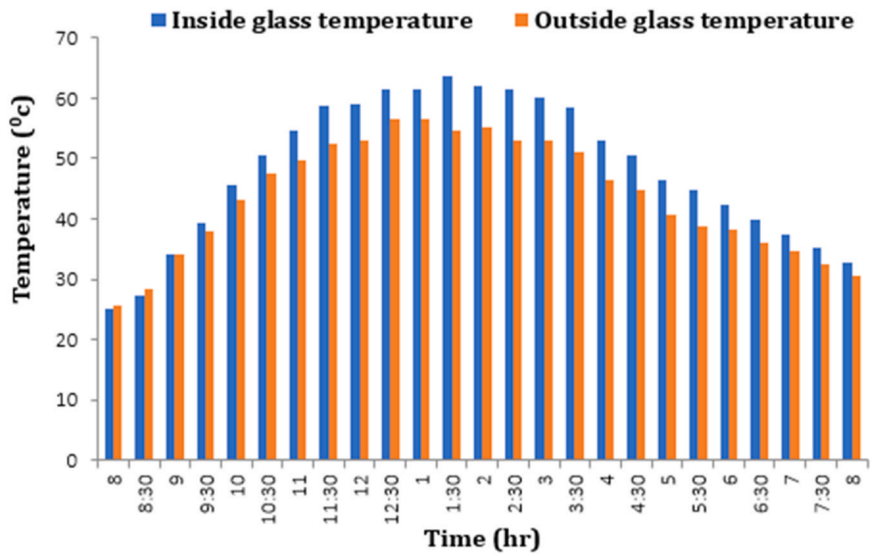
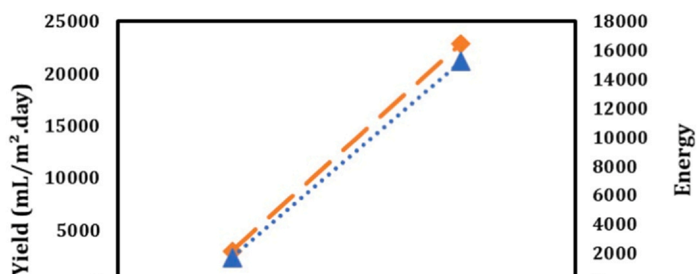


Fig. 8. Performance of V-type still inside and outside glass temperature.



	Fresh water yield	Total energy(kJ)
V-type still with linked with flat plate collector	3020	22866.3
V-type still without linked with flat plate collector	1735	15244.2

Fig. 9. Fresh water yield Vs Energy received.

directed into a separate reservoir as fresh water. Therefore, controlling the outer glass temperature helps regulate the condensation process, ensuring efficient water collection.

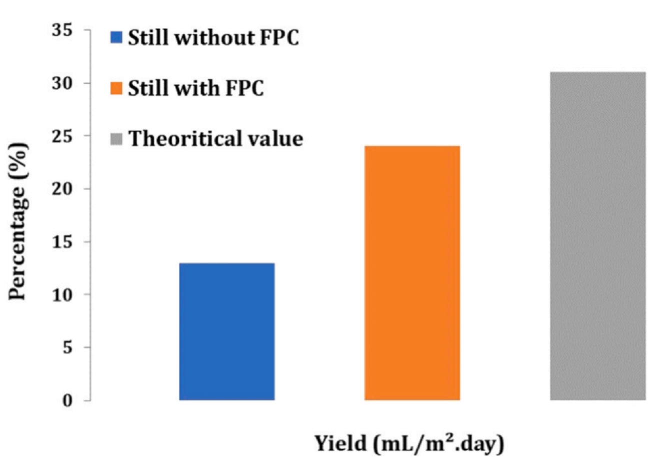


Fig. 10. Comparison of Production.

6. Performance of external modification

The incorporation of external modifications, specifically coupling with a flat plate collector, has significantly increased the efficiency of V-type solar stills. Fig. 9 illustrates the cumulative water collection of these solar stills. The total fresh water collection by using a V-type solar desalination still without coupling with a flat plate collector amounts to 1735 mL/day. However, with the V-type solar desalination still coupled with a flat plate collector, the total fresh water production increases to 3020 mL/day, representing nearly a 74 % higher yield. This substantial improvement is attributed to the larger area of radiation absorbed in the experiment with the flat plate collector. In this setup, the area of both the flat plate collector and the V-type still are combined, leading to enhanced efficiency. Moreover, the total energy used in the V-type still alone is calculated to be 15244 kJ. In contrast, when coupled with a flat plate collector, the total energy used for fresh water production rises to 22866 kJ. This difference in energy consumption further underscores the efficiency gains achieved by integrating the flat plate collector into the system.

6.1. Comparison of production

Fig. 10 presents a comparison of the fresh water yield between the V-type solar desalination still alone, the V-type solar still coupled with a flat plate collector, and the theoretical method. The graph indicates that the theoretical value of fresh water production is higher than the practical values obtained through experimentation. Specifically, the theoretical value exceeds the practical yield by more than 20 % for the conventional V-type still production. When considering the modified still production, which involves coupling with a flat plate collector, the theoretical value surpasses the practical yield by nearly 10 %. This comparison highlights the potential for further optimization and improvement in fresh water production through theoretical modeling and analysis. It suggests that there is room for enhancing the efficiency of both conventional and modified solar still setups, potentially leading to even higher yields of fresh water.

7. Application of artificial intelligence

AI improves solar desalination through system optimization, predictive maintenance, energy management, water quality monitoring, dynamic control, grid integration, and remote monitoring. This enhances efficiency, reliability, and sustainability, effectively tackling water scarcity challenges by optimizing energy usage and ensuring water quality.

7.1. Data collection

Due to their simplicity and affordable price, flat-plate solar collectors are gaining popularity every day. These collectors feature transparent glass above and heat-insulated walls completely surrounding the absorber plate to prevent heat loss. However, a portion of the absorber plate is often covered in shadow, which diminishes performance. A mathematical model was utilized in a previous study [25] to identify the latitude, tilt angle, and collector dimensions that impact shadow production. The findings demonstrated that latitude had the least influence on shadow generation, while height and width had the greatest impact. The authors of the current study employ artificial intelligence to predict the energy loss caused by shadows in flat plate solar collectors. The necessary information was derived from the study of [26]. The data were initially categorized according to dimensions. Thus, six categories were chosen based on their popularity and usefulness [27]. All of the data were analyzed in the second segment. More than 8000 rows of data were extracted from this section and prepared for ANN analysis..

7.2. Artificial neural network

Upon receiving the input vector (xq), the MLP neural network will generate the output vector (z q) for each q (where q = 1, 2, 3,… Q). The objective is to select the appropriate network parameters to ensure that the actual output is accurate and closely resembles the desired output [29]. In this study, the basic Back Propagation (BP) technique was utilized to train the network. The data were initially divided randomly into two groups: the training set (comprising 60 % of the total data) and the test set (comprising 40 % of the total data). This step might be repeated once more if the segmentation does not yield the expected outcomes. Since the learning algorithm cannot achieve the desired results with raw data, the data must be normalized before use [27]. The ideal data conversion range for utilizing the Tangent Sigmoid activation function is [1 to + 1]. The data were normalized using linear normalization [30].

$$x_n = ((x - x_{min} / (x_{max} - x_{min})) * ((r_{max} - r_{min}) + r_{min}) \quad (1)$$

In this work, Levenberg Marquardt (LM) and Bayesian regularization (BR) were both utilized as training techniques. A single-layer network was employed in this investigation since it responds quickly and avoids complexity [31]. The number of neurons in the hidden layer increased as the results improved and remained constant when the error increased. In this study, the hidden layer could accommodate up to 30 neurons. The overall structure of the MLP model for this study is depicted in Fig. 10 [27].

7.3. K-fold cross validation

The confidence in ANN outputs was bolstered by employing the K-fold cross-validation method. In this method, the validation data are divided into several K categories based on their type and quantity and analyzed by each algorithm. K subsets are utilized for training in each phase, while the remaining subsets (K-1) are utilized for validation [32]. All data are utilized for training and validation during each repetition of this K procedure. The average results can then be validated as a final estimation [33]. By utilizing K-fold as a stochastic subdivision in this method, which increases the distribution in the ANN process, the neural network can be employed as a practical approach with respectable results [34]. This strategy has been employed in various

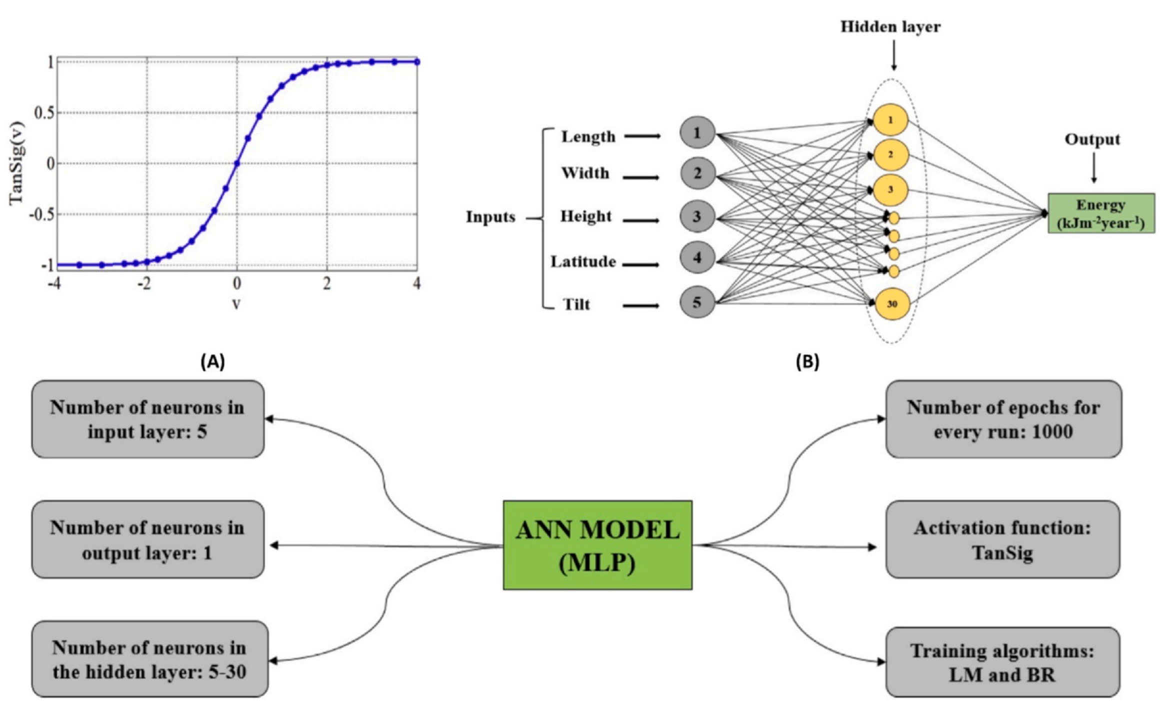


Fig. 11. Tan Sig activation function [28] Overall structure of MLP applied for modeling, The organization of MLP structure in this study.

research endeavors, and according to the authors, the results are reliable enough to be used in the experimental sections [37–39]. Mean Absolute Percentage Error (MAPE), coefficient of determination (R2), Root Mean Square Error (RMSE), and Efficiency Factor (EF) were utilized to evaluate the performance of the ANN-MLP model [30].

8. Conclusion

Two double slope inward type stills were fabricated and tested, one individually and the other coupled with a solar flat plate collector, to enhance the efficiency of fresh water production. Black color coating was applied to the inner surfaces, and insulation was added to the outer surfaces. The experimental results of the individual still were compared with those of the solar still coupled with the solar flat plate collector. Here are the findings:

- A 3 mm thick glass cover was found to be more efficient.
- A basin water depth of 10 mm proved to be exceptionally useful.
- On a clear, sunny day, the maximum result obtained was 3020 mL/day and 633 mL/hr.
- The theoretical value of water collection was higher than the experimental value for both conventional stills and modified stills.
- The estimation value using AI was nearly 60 % higher than that of the still coupled with the flat plate collector.
- The modified solar still (coupled with a flat plate collector) achieved a total fresh water production of 0.13 mL/kJ, approximately 18 % more efficient than the normal still.
- The total water production increased by 74 % in the modified solar still compared to the normal still.
- Energy loss due to shadowing on the absorber plate of solar collectors reduce solar energy gain. Mathematical modeling, particularly using Artificial Neural Networks (ANN), is used to determine this energy gain reduction caused by shadowing in flat plate solar collectors.

9. Limitations of the present work

The main disadvantage of utilizing solar energy for desalination is its potential to operate less efficiently at night and particularly on cloudy or foggy days. Additionally, AI-assisted desalination systems can be costly, particularly for larger-scale installations.

10. Future scope

In the future, artificial intelligence will be employed to design desalination systems in a manner that achieves both maximum efficiency and lowest cost, thereby reducing the reliance on human resources. Optimal outcomes, including minimizing bias and overcoming limitations, may be achieved through parameter prediction facilitated by artificial neural networks (ANNs). ANNs possess the capability to establish the connection between inputs and outputs, thus enabling accurate predictions. The accuracy of predictions is influenced by the number of neurons that link various levels within a single mathematical model.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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