

Performance evaluation of single basin double slope v-type desalination still coupled with tracked and non-tracked solar dish concentrator

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ABSTRACT

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Received: 16 June 2023

Revised: 30 May 2024

Accepted: 18 June 2024

Published: 20 May 2026

Citation:

Kumar, S., Yrobin, R., Kallada, S., Aby, S., Kumar P, M., & Sudhir, S. (2026).

Performance evaluation of single basin double slope v-type desalination still coupled with tracked and non-tracked solar dish concentrator. Science, Engineering and Health Studies, 20, 26040003.

This study investigates the enhancement in fresh water productivity of a double-slope solar desalination still when coupled with both tracking and non-tracking solar dish concentrators. The primary objective was to quantify the performance differential between the two concentrator types under clear-sky conditions and compare the maximum yields against conventional desalination. Experimental results demonstrated that the maximum daily and hourly fresh water outputs for the tracked concentrator system were 4,050 mL/d and 730 mL/h, respectively. In comparison, the non-tracking system achieved maximum outputs of 2,760 mL/d and 530 mL/h. The tracking system led to a significant overall increase in fresh water production, showing an improvement of 46% compared to the non-tracking configuration and a 100% increase when benchmarked against conventional desalination. The maximum energy consumed by the system utilizing the tracked concentrator was recorded at 23,113 kJ/day. The findings underscore the substantial advantage of solar tracking technology in maximizing the output of solar desalination stills, presenting a viable path toward increased efficiency in passive water purification systems.

Keywords: solar dish concentrator; v-type solar still; double slope solar still; water purification; solar desalination

1. INTRODUCTION

Numerous studies have been undertaken recently to increase the effectiveness of different fresh-water

production technologies. Backrush water and saline water are converted into fresh water using a solar desalination still. Solar desalination systems, however, are less expensive than conventional desalination methods,

according to analyses of earlier studies (Shanmugan et al., 2020). In this investigation, a tracking sun dish concentrator was used independently, and along with a double-slope solar desalination system. Reviews of earlier studies demonstrate that heating saline or backrush water before it enters the desalination process still results in higher outputs than when no heating is done (Gnanaraj & Velmurugan, 2019). Preheating often involves preheaters like solar flat plate collectors and solar dish concentrators. To increase the productivity of fresh water, energy-storing materials like phase change materials (PCM), wick materials, cooling glass covers, and thermal insulators are also used. Solar collectors are used to absorb the solar energy and convert it into thermal energy.

Water evaporates using the sun's energy, separating the vapor from the impurities (Hafez et al., 2018). Compound parabolic collectors (CPCs) are widely used in solar desalination systems due to their effectiveness in both low- and medium-temperature applications, and their performance can be further enhanced through integration with solar concentrators and PCM (Ullah & Kang, 2019). Solar concentrators and PCM work together to produce more effective outcomes. The system's operating time can be extended with the use of paraffin wax. A parabolic trough concentrator integrated with a focal pipe has been utilized to enhance the rate of solar desalination (Kadhem, 2018). In comparison to conventional concentrators, hybrid concentrators have a higher efficiency (Singh et al., 2020). Conventional solar concentrators and hybrid concentrators demonstrate average daily efficiencies of approximately 34% and 68%, respectively. Yousef and Hassan (2019) investigated tabular solar stills and parabolic concentrators, finding that freshwater yield reaches its maximum at the end of the day. Furthermore, research indicates that the highest freshwater supply is achieved during the summer season (Jamel et al., 2020; Yousef & Hassan, 2019). The freshwater output of solar desalination systems can be enhanced through the incorporation of humidification-dehumidification processes, and to further improve productivity, both single-slope (Jamel et al., 2020; Murugavel & Srithar, 2011) and double-slope (Gnanaraj & Velmurugan, 2019) solar desalination stills have been integrated with solar collectors. A cycle simulation model is used to drive a nanolayer-coated basin area using a combination of Cr_2O_3 and TiO_2 nanoparticles. The ability to raise the temperature of the basin by 60.1°C and 70°C , respectively, in winter and summer, is a benefit of nanolayer coated in bandgap energy of 1.5 eV in the basin area (Shanmugan et al., 2020). Calcium stones are one of the greatest sensible heat storage materials for increasing evaporation both during the day and at night (Shanmugan et al., 2012a). At higher operating temperatures of the system, the temperature difference between the water and glass cover has a greater impact on the production rate and energy transfer lags the energy transmission (Shanmugan et al., 2012b). Due to PCM and nanoparticles' impact on the heat transfer, storage density, and isothermal nature of the solar still, the system's performance was improved (Suresh & Shanmugan, 2019). This study aims to evaluate the effectiveness of slope solar desalination systems coupled with tracking and non-tracking solar dish concentrators. In the month of February 2023, an experiment was carried out in the Kerala town of Thalassery on a sunny, clear day.

2. MATERIALS AND METHODS

The experiments were conducted in Kerala, India. The solar still and solar dish concentrator were fabricated. The construction details are shown in Figure 1.

2.1 Solar desalination still

The structure of the solar still was of the double-slope inward type, and it was made of zinc sheet, still fully painted black, as shown in Figure 1. The roof of the basin was covered with a 3 mm-thick glass plate, tilted at 20 degrees inward from the center of the still. Thermocouples were used to measure the temperature of the water at the inlet and outlet. The outlet pipe of the solar panel was connected to the fresh water tank. The solar energy collecting area was 1 m by 1 m.

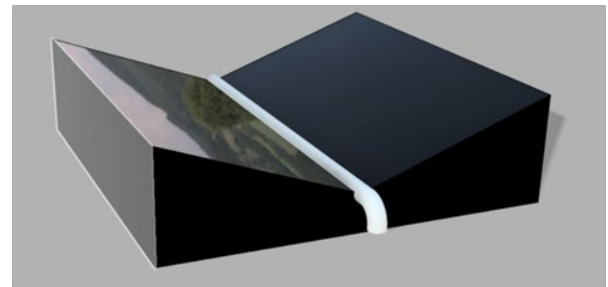


Figure 1. Double slope desalination still

2.2 Solar dish concentrator (SDC)

The solar dish concentrator was in the shape of a parabolic curve. The solar collecting area of the dish was covered with a zinc sheet strip of 1 mm thickness and an 80 cm aperture diameter. A boiler box (20 cm in height and 10 cm^2 base area) was placed at the focal point of the solar dish concentrator. The focal length of the dish concentrator was 30 cm. A thermocouple was used to measure the outlet and inlet temperatures of the water. The inlet valve of the boiler was connected to a saline water tank, as shown in Figure 2.



Figure 2. Still coupled with solar concentrator

2.3 Operation principle and experimental procedure

The experiments were conducted throughout the month of February under clear and sunny conditions, with daily measurements taken from 8:00 a.m. to 8:00 p.m. Two experimental configurations were evaluated. In the first configuration, the desalination still was coupled with a non-tracking solar dish concentrator, in which the parabolic reflector was fixed in a stationary position and did not follow the sun's apparent motion. In the second configuration, the parabolic dish concentrator was equipped with a solar-tracking mechanism to maintain continuous alignment with the sun. The complete experimental setup for both configurations is illustrated in Figure 3.

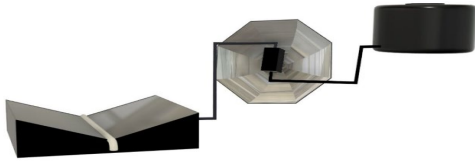


Figure 3. Double slope desalination still

2.4 Thermal energy calculation of solar still

The theoretical value for a solar still was calculated, and the production of the solar still with external modifications was calculated using the technique used by Gnanaraj and Velmurugan (2019).

Evaporative heat transfer (water to glass)

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

where, T_w – water temperature, °C

T_g – glass temperature, °C

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

$$P_w = \exp \left[25.317 - \frac{5,144}{(T_w + 273)} \right] \quad (3)$$

Saturated pressure for glass

$$P_g = \exp \left[25.317 - \frac{5,144}{(T_g + 273)} \right] \quad (4)$$

Convective heat transfer coefficient (water to glass)

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

Determination of production per hour

$$m_e = \frac{Q_{e,w-g} \times 3,600}{L} \text{ ml/m}^2 \quad (6)$$

where, L – latent heat of vapourization = 2,372,000 J/kg

Determination of daily production

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

Efficiency of the still is as follows

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

where, m_e = Daily production (ml)

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

A = Area of basin (m^2)

3. RESULTS AND DISCUSSION

3.1 Performance of the water collection

Figure 4 shows the hourly fresh water production rate. The maximum yield was achieved by combining SDS with

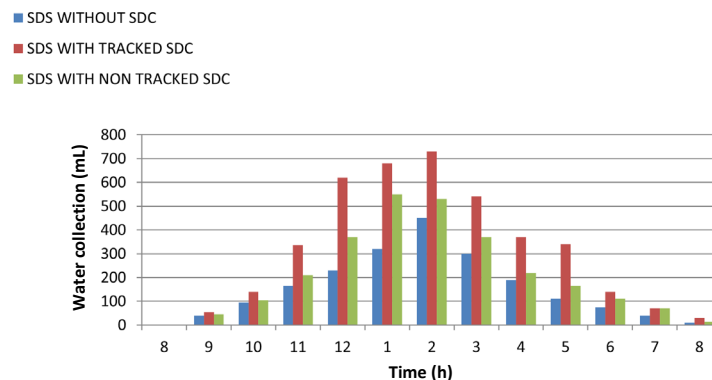


Figure 4. Hourly fresh water production

tracked SDC at an output of 730 mL/h. 530 mL/h and 450 mL/h are the other highest yields with respect to SDS incorporated with non-tracked SDC and SDS without SDC, respectively.

3.2 Performance of the cumulative water collection

Figure 5 shows the cumulative water collection rate from morning (8 a.m.) to evening (8 p.m.). The maximum yield was obtained from SDS incorporated with SDC, with an output of 4,050 mL/d. The other maximum fresh water yields were 2,760 mL and 2,025 mL, respectively, for SDS incorporated with non-tracked SDC and SDS without SDC.

3.3 Inner still temperature

Figure 6 shows the inner-still temperature readings during the experiment. The maximum temperature of the water inside reached 66.6°C, the air temperature reached a maximum of 65.7°C, and the inside basin liner temperature was 66.5°C.

3.4 Performance of inner and outer glass temperature

Figure 7 shows the inside and outside glass temperatures during the experiment. The maximum temperature reading reached 66.6°C for the inside glass temperature and 59.7°C for the outside glass.

3.5 Performance of solarimeter reading

Figure 8 depicts the solarimeter reading from the morning (8:00 a.m.) to the evening (8:00 p.m.), as well as the maximum solarimeter readings of 645 W/m^2 at 1 p.m., 0 W/m^2 at 8 p.m., and 179 W/m^2 at 8 a.m.

3.6 Performance of the cumulative water collected per unit energy

Figure 9 shows the cumulative water collected per unit energy received. The maximum value of 0.175 mL/kJ was obtained by SDS with tracked SDC. The values of 0.1314 mL/kJ and .0119 mL/kJ were recorded for SDS with non-tracking SDC and SDS without SDC, respectively.

3.7 Performance of the total utilized energy per hour

Figure 10 shows the total energy per kilo joule. The maximum energy used 23,113 kJ/day by SDS with tracked SDC. Both tracked and non-tracked values were the same because both areas were the same. The second highest value was 15,408 kJ/day obtained by using SDS without SDC.

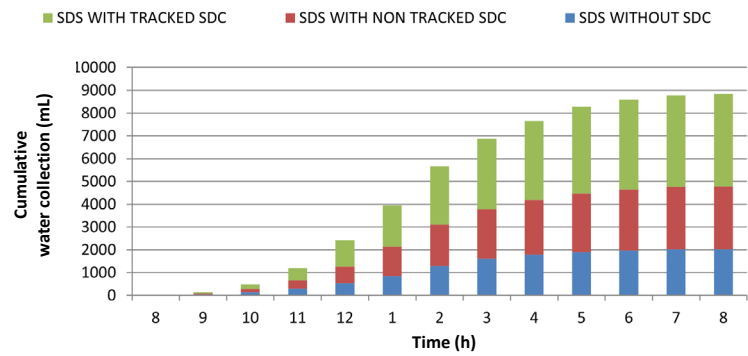


Figure 5. Cumulative water collection rate

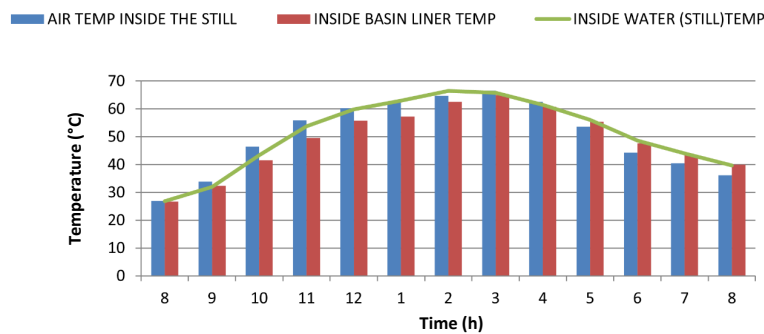


Figure 6. Inner still temperature readings

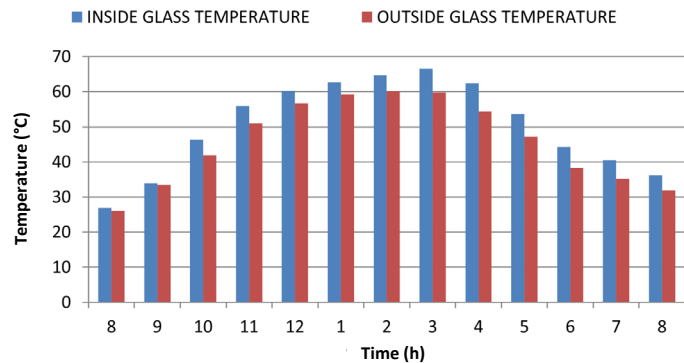


Figure 7. Inside and outside glass temperature

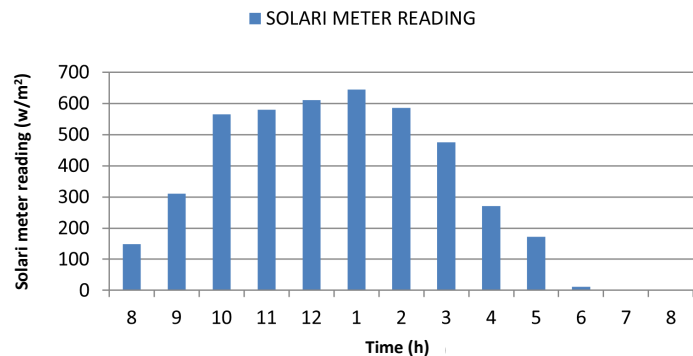


Figure 8. Solari meter readings

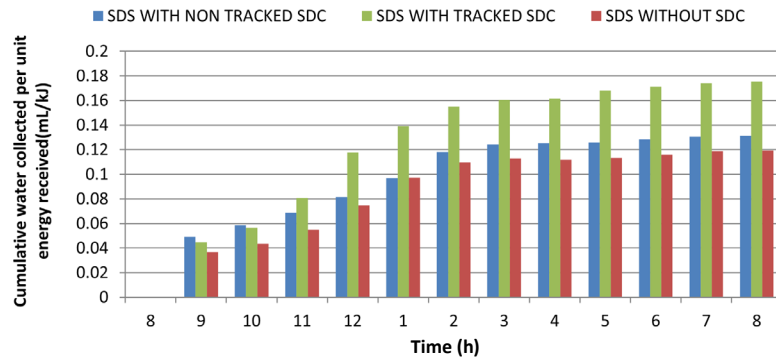


Figure 9. Performance of the total utilized energy per hour

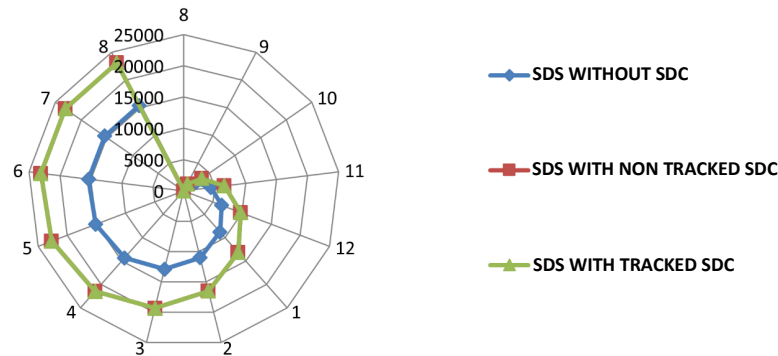


Figure 10. Performance of the total utilized energy per hour

3.8 Error analysis and instrumentation

To measure the temperatures of the basin water, glass cover, ambient environment, and the preheater's inlet and outlet, a digital thermometer with a probe was used. Solar insolation was recorded with a solar power meter (TENMARS TM-207), the yield was measured with a plastic measuring jar, and the wind velocity was determined using a vane-type digital anemometer. The accuracies of these instruments are detailed in Table 1.

Table 1. Error analysis and instrumentation

No.	Instrument	Range	Accuracy	Expected error (%)
1	Solar power meter	0–2,000 W/m ²	±10 W/m ²	5
2	Digital thermometer	0°C–120°C	±0.2°C	0.3
3	Anemometer	0–30 m/s	±0.2 m/s	10
4	Measuring jar	0–2,000 mL	±0.2 mL	1

4. CONCLUSION

The investigation into the performance optimization of a double-slope inward solar desalination still (SDS) utilizing both tracking and non-tracking solar dish concentrators (SDC) clearly demonstrated the superiority of the active tracking system in maximizing fresh water yield.

The main findings and results are given below:

(1) Enhanced productivity: The incorporation of a tracked SDC resulted in maximum fresh water production rates of 730 mL/h and 4,050 mL/d. This represented a substantial 46% increase in total fresh water production compared to the non-tracking SDC system, and a remarkable

100% increase when compared to the conventional SDS operating alone (2,025 mL/d experimental yield).

(2) Thermal correlation: The findings confirm a direct proportionality between the internal system temperature and the resulting fresh water yield. Furthermore, optimizing the condensation process was shown to be critical, with decreasing the outside glass temperature effectively enhancing condensation efficiency.

(3) Energy consumption: While the tracked system achieved the highest output, it also registered the maximum energy consumption at 23,113 kJ/day. The second highest value, 15,408 kJ/day, was obtained by the conventional SDS alone. The energy inputs were equivalent between the tracked and non-tracked SDC setups due to their identical collection areas.

(4) Model discrepancy: The experimental fresh water output of the conventional SDS (2,025 mL/d) was observed to be lower than its theoretical prediction (2,276 mL/d), suggesting that further work is needed to refine the theoretical model or identify experimental heat loss factors.

AUTHOR CONTRIBUTIONS

S.K. conceived the research concept and designed the experimental setup of the solar dish concentrator-coupled double slope solar still. R.Y. and S.K. carried out the experimental investigations under both tracking and non-tracking conditions and were responsible for data collection. S.K., S.K., and S.A. performed the data analysis and interpretation of the experimental results related to freshwater productivity and energy consumption. M.K.P. and S.S. assisted in experimental execution, validation of results, and technical discussions. S.K. prepared the original draft of the manuscript. R.Y., S.K., S.A., M.K.P., and S.S. contributed to

reviewing, editing, and improving the manuscript. All authors discussed the results, reviewed the final manuscript, and approved it for publication.

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