



Experimental Studies on the Performance of Metallic and Non-Metallic Basin Tray Materials in the Solar Still for Renewable Energy Solutions

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Abstract: Depletion and over-exploitation of water resources, owing to an ever-increasing population and industrialization-driven urbanization, necessitates the purification of brackish water and the recycling of treated contaminated water as a conservative measure. Renewable Energy Solutions, especially using solar stills, are the simplest among purification choices despite their limitations. The volume of distillate collected, and performance are influenced perceptibly by various parameters. In this article, the performance and distillate production of the passive double-slope solar still with Metallic basin trays have been compared with those of the same with a glass fiber-reinforced Plastic basin tray. The experimental study indicates that copper, as a basin material, has exhibited better performance, with higher distillate output among the choices. However, the performance and distillate production of a solar still with a GFRP-made basin are comparable to those of other metallic tray materials, considering cost, life, and ease of maintenance.

Keywords: Solar Still, Basin Materials, Metals, GFRP composite,
Distillation, Renewable Energy Solutions.

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1. Introduction

Water is an elixir of life; 97% of the resource is saline in the ocean, 2% as ice in Polar Regions, and the remaining 1% is considered freshwater, such as rivers, lakes, and groundwater (Fathy et al., 2018). Water is essential for human survival and sustainable overall development. The demand for fresh water is continuously increasing worldwide (Abdelal & Taamneh, 2017). Scarcity of good water is one of the greatest challenges to the human community (Shannon et al., 2008). Desalination using solar energy is a viable technology to address water scarcity (Sharshir et al., 2016). Solar desalination is simple and eco-friendly (Fath & Hosny, 2002). Pure water is obtained from brackish water by utilizing solar energy for desalination in a simple device called a solar still (Nayi & Modi, 2018).

Solar stills are a green energy technology that uses the sun's natural radiation to remove salinity from waste or brackish water resources. Solar stills provide pure water for a broad range of applications, including drinking and cooking, even in places where no other energy sources are available. A solar still operates on two scientific principles: evaporation and condensation. A solar still structure comprises an insulated basin housed within a protective casing, fed with brackish water that evaporates due to insolation passing through the transmissive cover plate, beneath which the condensate trickles into the collection channels. The conventional solar still is considered inadequate for domestic and industrial applications due to its limitations (Kabeel et al., 2019).

Passive double-slope solar stills (PDSS) are simpler, with two condensation surfaces that reduce condensate backflow into the basin tray due to their shorter run than that of single-slope stills, and are a low-cost alternative to active stills, making them more suitable for arid and remote areas. It has the distinct advantage of being a simple, eco-friendly, renewable energy-based, low-cost water purification solution that doesn't require skilled manpower. The major limitation being its low distillation rate and climate dependency.

The performance-driven distillate production of a solar still is affected by meteorological parameters, namely insolation and wind velocity, that are non-controllable (Ayoub et al., 2013). Thus, in order to improve performance and to augment the distillate production the controllable parameters should be addressed properly starting from designing of the solar still (Abujazar et al., 2016). Parameters like insolation, wind velocity, surface water-top cover temperature gradient, temperature of basin feed water, depth of basin water, net area of the

absorption, thickness, transmissivity and inclination of top cover plate affects the rate of distillate production (Sharshir et al., 2016; Narayanan et al., 2020). It is worth noting that lower-basin water depth or mass maintenance techniques have increased productivity (Abdullah et al., 2023). The rate of purification can be further enhanced by suitably improving the design through the integration of heat storage, vacuum technology, and reflectors (Prakash & Velmurugan, 2015).

Non-controllable parameters such as solar radiation intensity and controllable parameters like heat-absorbing area, basin water depth, and the temperature difference between the transmissive top cover and the basin water surface are the most influential factors. Focusing on these controllable parameters can increase distillate production (Selvaraj & Natarajan, 2018).

2. Related Works and Scope

2.1 Related Works

The researchers across the globe have made significant attempts to enhance the rate of distillate production, and one such way to maximize the production rate is by employing a suitable basin tray material that can absorb, transfer heat, and withstand elevated temperatures effectively (Muftah et al., 2014; Ahsan et al., 2014). The authors (Omara et al., 2016) have done an experimental investigation on a conventional solar still by using a 1 m² galvanized iron basin tray with a water depth of 1 cm in Kafrel Sheikh, Egypt (latitude 31°) and obtained an efficiency of 33%. Panchal and Shah (2012) conducted an experimental study on a solar still using aluminum and galvanized iron absorber plates, with a water depth of 4 cm, in Mehsana, Gujarat. They have reported a distillate collection of 3.7 liters for the solar still with an aluminum plate and 2.3 liters for the galvanized iron plate. Mohammed Shadi (Abujazar et al., 2016) recommends the solar still with a copper-made basin tray due to its superior thermal conductivity of 390 W/m·K.

Panchal (2010) also conducted an experimental analysis using Galvanized Iron, Mild Steel, and Copper as absorber plate materials, with a water depth of 3 cm, and inferred that the distillate production is higher for the solar still with the Copper plate than for the other two absorber basin plate materials. In another comparative study of solar stills conducted in Mehsana, Gujarat, using copper and aluminum plates, an increase of 20% in distillate production for the copper plate and 10% for the aluminum plate over the conventional one was reported for a water depth of 3 cm (Panchal & Shah, 2014).

The authors (Abujazar et al., 2017) reported that the thermal capacity of Copper is higher than that of aluminum and Steel. Also, they have reported a distillate production of 4383 ml/m²/day and an efficiency of 58% for a solar still with a copper tray. The experiment was conducted in Malaysia with a water depth of 3 cm.

Jathar et al. (2022) recommended aluminum as a basin material due to its corrosion resistance, with a dust-free top glass cover for solar stills (Jathar et al., 2022). Le et al. (2021) compared popular basin material options and concluded that copper yielded the highest distillate output and thermal efficiency. From this, it is clear that a solar still with a copper-made absorber resulted in higher distillate production among the metallic basin trays studied by the researchers. It is understood that, among metallic options, copper is more expensive but offers excellent heat transfer properties, while aluminum is a more affordable alternative. However, the absorber tray must be durable with low thermal expansion, high corrosion resistance, and resist degradation from Ultra-Violet (UV) radiation, while selective coatings significantly improve the absorption of solar radiation.

2.2 Scope

In considering the economic viability of solar stills, the balance between performance and cost should be maintained. Further, the lighter weight of the basin tray facilitates handling during maintenance. In this research article, the inferences from an experimental study comparing a PDSS with metallic and non-metallic absorber basin tray materials are discussed. The objective of the research is to compare and contrast the performance

and distillate collection of PDSS with metallic and non-metallic composite basin trays, and to assess the techno-economics involved. Three metallic basin trays, each made of stainless steel, aluminum, and copper, were used in the study. Despite challenges related to recyclability, glass fiber-reinforced plastic (GFRP) has been chosen as a non-metallic basin tray material due to its versatility, low cost, ease of maintenance, corrosion resistance, and longevity.

Also, GFRP is more resistant to deforming forces and has less weight than metals.

3. Experimental Work

3.1 Experimental Setup

The PDSS was designed and fabricated to be easily dismantled for maintenance and other needs. The solar still includes two units: a base unit and three transparent top cover plates. The base unit holds the basin tray with an absorption area of about 1 m², polyurethane insulation (PU) of 0.05 m thickness on all sides and the bottom, and is housed in a support structure that serves as a protection cover, along with stainless steel collection channels. The absorber basin trays are made from stainless steel, aluminum, copper sheets, and non-metallic GFRP composite. The transparent top cover comprises three 3 mm-thick clear glass plates with 83% transmissivity, inclined at 20° toward the north and south to facilitate the trickling of condensate into the respective channels. A provision for collecting precipitation exists over the top clear glass cover, with stoppers at the bottom to guide the distillate into the channels.



Figure 1. Fabricated test setup with sensors.

3.2 Methodology and Experimental Procedure

A basin water depth of 5 mm was maintained in the tray by controlling the solenoid valve using a flow control circuit during the experimental study. The fabricated test setup is located on the rooftop terrace of Krishnasamy College of Engineering and Technology, Cuddalore (latitude 11° 76'), India, and is shown in Figure 1. The local solar irradiance in W/m² was measured using a Solar power meter (TES 1333R). A professional mini weather station (PCE-FWS 20) was used to read the ambient temperature in °C and wind velocity in m/s. Resistance Temperature Detectors (RTD) connected to a logger were used to record the feed water, basin water, absorber, and top clear glass cover temperature in °C. The distillate collection was measured periodically by using a jar in mL. The performance assessment includes a study of energy fractions, distillate collection, estimation of efficiency, input energy per liter of distillate, and conclusions are derived by also taking into account the simple payback period. Further, the amount of distillate collected in real time is compared with that predicted by the fundamentals using Dunkle's model (Beng Yeo et al., 2014).

The experiments were performed under similar conditions in the PDSS, exclusively developed for this study, with metallic and non-metallic basins made of stainless steel (SS), aluminum (Al), copper (Cu), and glass fiber-reinforced plastic (GFRP) composite. Water is fed into the PDSS through a solenoid valve, and a depth of 5 mm is maintained using a flow control circuit throughout the experiment for both metallic and non-metallic absorber basin trays. Parameters such as irradiance, wind speed, basin, water surface, top clear glass cover, and ambient temperatures were observed periodically from 9.00 h to 17.00 h IST. The hourly distillate collection was recorded, in addition to overnight production (17.00 h to

9.00 h), using a measuring jar. The performance of the PDSS with different basin materials has been assessed under actual climatic conditions. The average irradiance during the study was 566 W/m², while the average ambient temperature and wind velocity were 29.8°C and 3.0 m/s, respectively.

4. Results and Discussions

The results of PDSS with metallic and non-metallic absorber basin trays are discussed in detail in this section.

The energy and exergy analyses have been carried out using the observed and computed values. The results obtained have been presented and discussed herein. Further, a cost analysis has been carried out by calculating the payback period to assess economic viability, in addition to technological feasibility.

From Figure 2, it can be inferred that the evaporative heat transfer fraction begins increasing at 9:00 hrs, while the radiative heat transfer fraction of basin water starts decreasing. This trend continues until midday and then reverses. It is notable that both fractions nearly converge at sunset, thereby limiting the distillate production. This supports the effective distillate production duration from 09:00 hrs to 17:00 hrs IST. The amount collected from 17:00 hrs to the next day at 09:00 hrs is attributable to stored thermal energy in the basin water and is considered overnight collection.

From the instantaneous energy efficiency variation presented in Figure 3, it is inferred that the PDSS with a basin made from a copper sheet has exhibited a better performance throughout the day than all the other basin materials and has attained a maximum instantaneous efficiency of 41.10 % at 13.00 hrs. On the other hand, the PDSS with a non-metallic GFRP basin has exhibited the

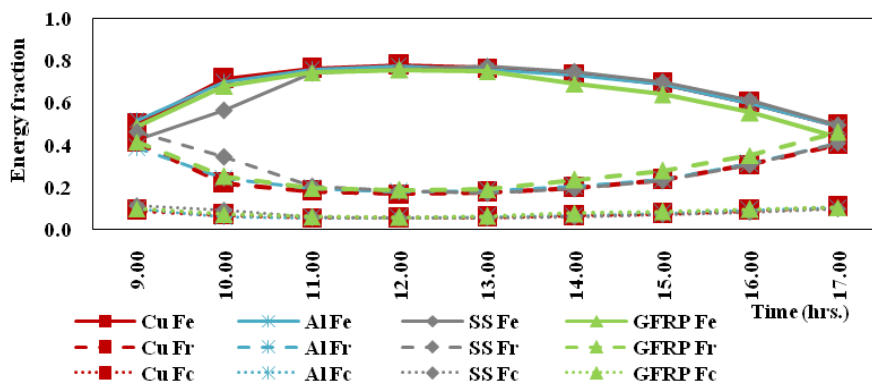


Figure 2. Energy Fractions.

least performance, especially in the afternoon, as the basin material was unable to support a better heat transfer after peak insolation. It has reached a maximum instantaneous efficiency of 35.12%.

The instantaneous exergy efficiency is presented in Figure 4. The exergy efficiency is also consistently high for PDSS with a copper basin tray. The maximum exergy efficiencies are attained at 13.00 h in all the cases. The maximum exergy efficiency computed for PDSS with a

copper basin of 4.07% is the highest among the materials studied, whereas it is the lowest at 3.33% for PDSS with a GFRP basin.

The cumulative mass of distillate obtained from 9.00 h to 17.00 h is shown in Figure 5, which indicates that the experimental yield and the computed theoretical mass of water evaporated closely agree. The disagreement between theoretical and experimental distillate collection are 7.39%, 10.60%, 16.36%, and 13.90% for PDSS with

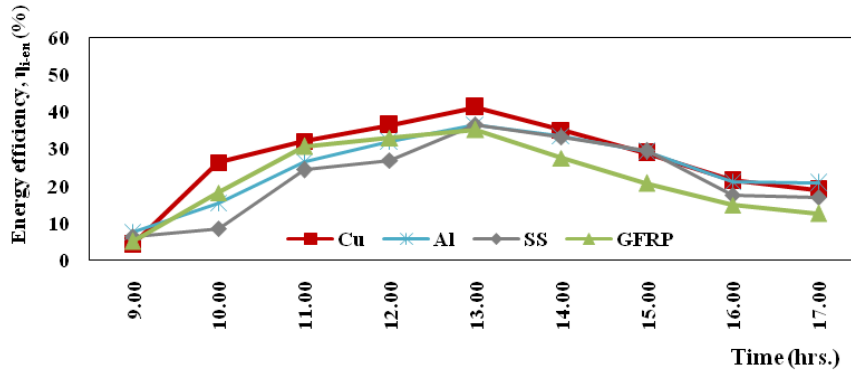


Figure 3. Instantaneous Energy Efficiency.

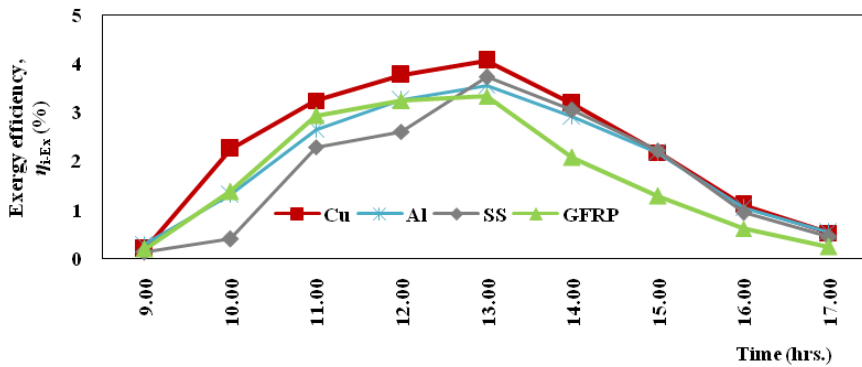


Figure 4. Instantaneous exergy efficiency.

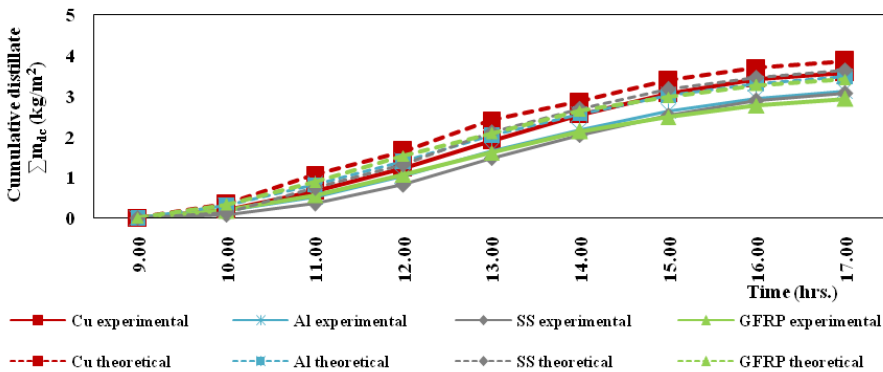


Figure 5. Cumulative distillate collection.

copper, aluminum, stainless steel, and GFRP basin trays, respectively.

The daily distilled water collection, including overnight production from the PDSS, is shown in Figure 6 for various basin materials. The volume of distillate produced during the day for PDSS with basins made from copper, aluminum, stainless steel sheets, and GFRP composite is 3.580 kg/m², 3.115 kg/m², 3.055 kg/m², and 2.935 kg/m², respectively. Further, corresponding night productions of 0.220 kg/m², 0.225 kg/m², 0.210 kg/m² and 0.190 kg/m² have been realized.

The input energy per liter of distillate produced is shown in Figure 7, which indicates that the PDSS with the Copper basin is the best among the choices. The overall thermal efficiency of distillation, calculated based on the corresponding distillate collection, is presented in Figure 8. The overall thermal efficiency of the PDSS with a copper basin tray is 41.20%, while the corresponding values for PDSS with aluminum, stainless steel, and GFRP basin trays are 35.97%, 35.54%, and 34.00%, respectively.

The detailed comparison of results for PDSS across different basin materials is shown in Table 1. Based on the

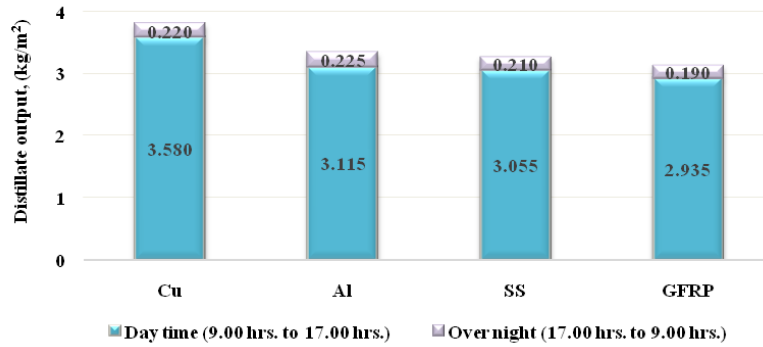


Figure 6. Overall distillate yield.

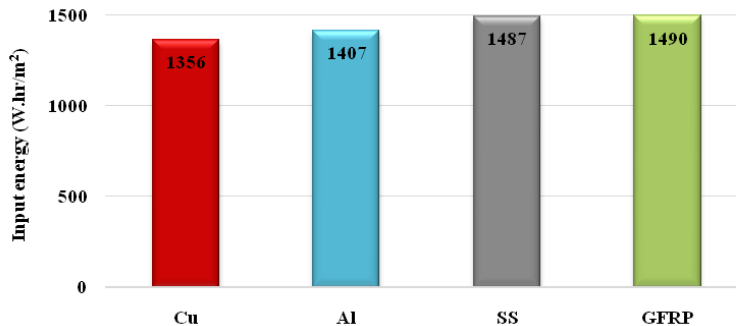


Figure 7. Input energy per litre of distillate production.

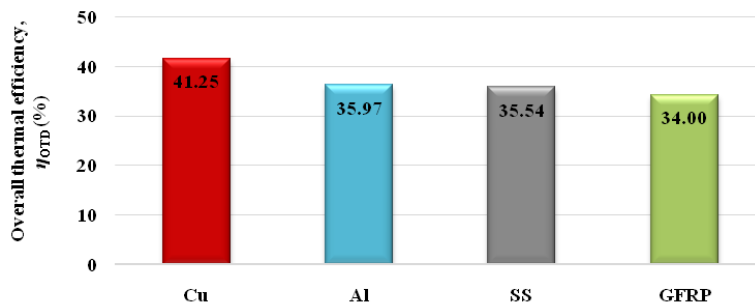


Figure 8: Overall thermal efficiency.

Table 1. Particle size and power consumption.

Results	Copper (Cu)	Aluminum (Al)	Stainless Steel (SS)	Glass Fiber Reinforced Plastic (GFRP)
Distillate Yield (During Day) in kg/m ²	3.580	3.115	3.055	2.935
Distillate Yield (During Night) in kg/m ²	0.220	0.225	0.210	0.190
Input Energy per Litre in kW.hr/m ²	1.356	1.407	1.487	1.490
Overall Thermal Efficiency in %	41.25	35.97	35.54	34.00
Payback Period in days	467	271	467	314

studies, the PDSS with a Copper basin tray demonstrated better performance than the other basin materials, with a total distillate yield of 3.800 kg/m²/day. PDSS with GFRP basin showed the lowest performance, with a total distillate collection of 3.125 kg/m²/day. Additionally, the payback periods for PDSS with metallic and nonmetallic basin tray materials were calculated. With an estimated payback period of 467 days and a high annual yield of 1082.30 kg/m², PDSS with a Copper basin is the preferred choice among metallic trays as a greener option.

Though PDSS with an aluminum basin has a shorter payback period of 271 days, prolonged exposure to saline water induces severe pitting corrosion. The PDSS with a GFRP basin has a relatively short payback period of 314 days, with an estimated annual yield of 983.70 kg/m². When it comes to real-time applications of solar stills in arid, remote locations, the lower payback period, ease of maintenance, and longevity influence the choice. Also, the Isophthalic resin used in GFRP is black, eliminating the need for a selective coating. Thus, GFRP, being a non-metal, offers ease of maintenance and handling, as well as longer life, with comparable productivity, making it an economically viable choice, though its recyclability remains a challenge.

4. Conclusion

Upon employing metallic and non-metallic basin trays in a customized PDSS, wherein a water depth of 5 mm was maintained throughout the study, the following were inferred: PDSS on deploying a copper absorber basin resulted in a higher distilled water yield of 3800 kg/m² with an overall thermal efficiency of 41.20%, and performed better. The solar still with GFRP composite made absorber basin tray yields 3.125 kg/m² with an overall thermal efficiency of 34.00%. The insolation input per liter of

distillate produced is computed as 1356 W/m² for PDSS with a copper basin tray and 1490 W/m² for PDSS with a GFRP composite-made basin. Hence, based on performance-driven distillate production, PDSS with a copper absorber basin emerged as the best among the materials considered in the study. However, its payback period is on the higher side. Any further cost-effective design improvement of the PDSS with non-metallic GFRP composite-made absorber basin tray would make it a viable alternative, given its anticorrosive nature and longevity, with ease of maintenance over metallic choices. However, copper's recyclability makes it a truly greener choice.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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