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Analysing the Efficiency of a Single-slope Solar Still and the Effects of Glass Cover Cooling and Circular Cross-section Hollow Fins

S. Kumaravel[1]*, P. Raman[2], Ruth Ramya Kalangi[3], R. Selvameena[4], Hitesh Gehani[5], Md. Abdul Raheem Junaidi[6] and M. Yuvaperiyasamy[7]

[1]Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, TN, India
[2]Master of Business Administration, Panimalar Engineering College, Poonamallee, Chennai, TN, India
[3]Department of Computer Science and Engineering, Koneru Lakshmaiah Education Foundation, Vadeswaram, Guntur District, AP, India
[4]Department of Computer Science and Engineering, Dr. M. G. R Educational and Research Institute, Madurvoyal, Chennai, TN, India
[5]School of Computer Science and Engineering, Ramdeobaba University, Nagpur, MH, India
[6]Department of Mechanical Engineering, Muffakham Jah College of Engineering and Technology, Hyderabad, TG, India
[7]Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, TN, India

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*kumaravels1969@gmail.com

ABSTRACT

Water is essential for life, yet much of the available supply is either too salty or too polluted for safe consumption. The process of desalinizing salt water can be quite expensive. A better option is to use solar stills to convert the water vapor into freshwater by evaporating the salt water. This study details the results of an experimental investigation on a solar still featuring a single slope and a closed circular fin linked to an absorbing plate. The study also incorporated experimental evaluations of the potential for cooling the glass cover. Circular hollow fins measuring 30 mm in diameter and 70 mm in height were utilized. Pulsed glass cooling (40 s/35 min), continuous water spray (40 s/35 min), and a combination of both methods were evaluated as cooling techniques. The results indicated that incorporating fins into the single slope solar still (SSSS) led to a 50% enhancement in output relative to conventional solar stills. Integrating SSSS with glass cooling at various spraying rates increased yield by 13.3%, 17.8%, 36.7%, 24.2%, and 10%, respectively. This demonstrates that using pulse water cooling rather than the conventional solar still (CSS) time (40 s/15 min) produces superior results. The cumulative improvement from both processes is 62.4% when compared to a traditional SSSS.

Keywords: Single slope; Circular fin; Glass cover; Conventional solar still; Water spray.

1. INTRODUCTION

Approximately 75% of the Earth's surface consists of water, with the predominant portion being saline. Global concern regarding the swift increase in water scarcity is on the rise (Abdelgaied *et al.* 2021). Concerns about freshwater shortages have grown due to recent and expected population growth, along with other human activities (Kabeel *et al.* 2020; Altegoer *et al.* 2022; Zhang *et al.* 2022). A expensive way of purifying salt water may include evaporating the water and then condensing the vapor back into liquid form, depending on the chemical and physical characteristics of the water. The low energy usage and simplified system design of solar desalination make it a potential distillation method (Celik *et al.* 2021). Among various solar desalination methods, solar energy remains the most widely used. Solar stills come in various configurations, each optimized for a particular use and research (Soares *et al.* 2018). Single slope solar stills (SSSS) have become widely used solar still designs due to their low cost and simplicity. However, because of its slow pace of production, this technology is currently in the experimental phase (Trevelin *et al.* 2015). As a result, the SSSS system needs improvement to boost its daily production. Researchers worldwide have enhanced conventional solar desalination processes by using new methods and increasing efficiency (Hafs *et al.* 2018; Yousef *et al.* 2019). The feasibility of coating the glass top of SSSS with a water film (2.6 ×105 m to 6 ×106 m thickness) was studied, and the modified system showed an improved distillate productivity yields rising from 3.6 to 5.8 kg/m^2 compared to traditional solar still. A thermoelectric cooling duct mitigates the heat generated on the glass dome of SSSS (Lugassy *et al.* 1971; Tuly *et al.* 2022a; Tuly *et al.* 2022b). Integration of a cooling glass and basin preheating system with a SSSS resulted in a 41.8% improvement over conventional solar still (CSS) (Asadabadi and Sheikholeslami, 2022).

Jani and Modi (2019) showed that at the most effective basin water depth of 10 mm, both square-finned and circular-finned solar still reach their maximum output of 0.9672 kg/m^2-day and 1.4917 kg/m^2-day.

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Rajaseenivasan and Srithar (2016) examined the impact of fin shape and wick composition on the operation of solar stills. By demonstrating that a wick-covered square fin solar still can generate a maximum distillate output of 4.55 kg/m²-day, exceeding the typical still's 3.16 kg/m²-day, this study emphasizes the financial and environmental benefits of this technology. The ecological effect and ability of the solar still to accelerate condensation were investigated by the researchers using a natural fiber cover. In their tests, they used a combination of banana and jute fibers to cover the glass of the solar still. When compared to CSSs, banana and jute fibers decreased the cover temperature by 23% and 28%, respectively; solar stills with jute fibers had the greatest rate of condensation (Mevada *et al.* 2021; Natarajan *et al.* 2022). With the addition of an external mirror, PV-powered heating, and other upgrades, water output is increased by 242% to 3.251 L/m²-day from 0.952 L/m²-day for the conventional still (Abdallah and Abu, 2021). Khairat *et al.* (2021) found that, at water depths of 10, 20, and 30 mm, respectively, the highest daily freshwater output was 7.13, 4.97, and 3.36 kg/day, with vibration and cover cooling at a concentration of 1.5% nanofluid. According to these findings, efficiency gains over the conventional approach were 54%, 43%, and 36%.

Fang *et al.* (2021) enhanced efficiency by creating a new solar still that has a front lens, two side lenses, and a back reflector. Production was still 32% higher than with the conventional still, while energy and energy efficiency increased by 97.73% and 43.71%, respectively, on an hourly average. Additionally, it gradually reduced CO_2 emissions. Nazari *et al.* (2019) investigated the impact of thermoelectric cooling and nanofluid cooling on a single slope solar still's energy, exergy, and productivity. In contrast to conventional stills, they found that although nanofluid increases daily production by 81%, thermoelectric technology increases the temperature difference between the glass and the basin by 3.9°C.

An 81% increase in productivity, an 80.6% improvement in energy efficiency, and a 112.5% increase in exergy efficiency were seen when a thermoelectric cooling channel and Cu_2O nanofluid were included into a modified solar still. An optimal cost of $0.0218 per liter per square meter was determined by the cost research, with a payback period of 13.8 months (Nazari *et al.* 2019). Pakdel *et al.* (2017) obtained a daily efficiency of 81.72% compared to the conventional solar still, indicating a significant output improvement. Shielding the top glass cover reduced productivity, which was the opposite of what was first thought. The efficiency of a solar still with a hollow finned absorber (SSHFES) was 41.67% higher than that of traditional solar stills, with a maximum freshwater output of 4085 mL/m²/day. With a payback period of 6.3 months and a minimal cost per liter of $0.032, the economic assessment determined that this was the most sensible option (Suraparaju and Natarajan 2021). In comparison to a conventional solar still (CSS), a graphite plate and block magnet solar still (GPBMSS) increased production by 19.6% in the summer and 22.8% in the winter. Reducing energy destruction improved overall performance and resulted in a 19% improvement in exergy efficiency and a 20.6% increase in energy efficiency (Dhivagar and Mohanraj, 2021). A maximum freshwater output of 12,350 mL/day was attained using a solar desalination system with an external condenser and finned condensing pipes, which was a 300% improvement over traditional solar stills. It was found that the optimal cooling water flow rate was 50 L/h, with 79 L remaining in the condenser (Al-Dabbas *et al.* 2021). A redesigned single-slope solar still with expanded pin fins in the basin liner was experimentally evaluated to reach daily production rates of 4.375 kg/m² in the summer and 2.565 kg/m² in the winter. The modification resulted in a 13.2% increase in distillate output over the conventional solar still. Production rose as a result of the basin liner's increased surface area, which made heat absorption easier. The black-coated mild steel pin fins effectively increased solar energy absorption, increasing the rates of condensation and evaporation (Agrawal and Rana, 2020)

Reflectors enhanced the distilled water production by 82%, while nanofluids including phase transition materials had an energy efficiency of up to 21.56%. When run under identical circumstances, double-basin stills showed yields that were 85% higher than single-basin stills. Adding magnets and graphite materials greatly increased daily water output and thermal efficiency (Murad *et al.* 2024). The modified double-slope solar still featuring a trapezoidal channel attachment resulted in a reduction of CO_2 emissions by 5.33 tons over its operational lifespan, and the water samples collected during the experiments met WHO drinking water standards (Thavamani and Kumar, 2023). Using corrugated or stepped absorber plates increases the surface area accessible for solar energy absorption as well as the amount of contact between the plate and salt water. For the same volume of saline water, fins were shown to function better than corrugation. However, when looking at the same depth of water, corrugation was shown to be more effective than fins (Modi *et al.* 2023). (Akkala and Kaviti, 2023) examined the impacts of various fin geometric forms, such as square, pin, rectangular, and circular fins, as well as the factors influencing their performance. Round fins are renowned for their effectiveness in desalination using a sun still. The distillate production ranged from 0.49 to 6.5 kg/m² when fins were not utilized, and from 0.58 to 7.5 kg/m² when fins were used, according to their research. Combining concentrated photovoltaic thermal (CPV/T) technology with hybrid solar systems is a feasible method of producing both electrical and thermal energy simultaneously. The study found that on average, 7.259 kWh of thermal energy and 3.737 kWh of electrical energy were generated. Additionally, with an average efficiency of 34.713%, the recently built system improved the supply of hot, drinking water (Karimzadeh Kolamroudi and Kordani 2024). The study examined several configurations that might enhance the effectiveness and longevity of SSs. Coated SSs with different nanoparticles, reflectors, PCM, external condensers, wick materials, and solar modules were all part of these combinations. Developing more effective and sustainable solar energy technology may be guided by a comprehensive framework considering economic, environmental, and thermodynamic factors (Maurya *et al.* 2024).

This work combines SSSS with fins that have a hollow circular cross-section to enhance the performance of single basin solar stills. It also investigated if a controlled cooling system lowers the temperature of the glass cover to promote condensation. Tests were conducted in authentic environments.

2. EXPERIMENTAL SETUP

Two single-slope solar still models make up the experimental arrangement in the current study. The fundamental model remains unchanged from its CSS, with no added equipment or alterations. For the alternative design (modified solar still, MSS), the absorbing plate was fitted outside with circular fins, and the glass cover was cooled using a cooling system. Polystyrene, a thermal insulator, was cut and made into proper shape and size to make housing for a SSSS. The line diagram for a traditional solar still is seen in Fig. 1.

The interior of the box, which has a basin-like shape, measures 50 cm in width and 78 cm in length. A galvanized absorbent plate of identical dimensions is positioned at the bottom. The absorber plate in the MSS was fabricated by welding and affixing hollow fins with a circular cross-section of 30 mm in diameter. Fins were uniformly distributed across the entire absorber plate. Fig. 2(a) and Fig. 2(b) show the top view of the absorber plate of CSS and MSS.

The solar still's casing was finished by covering it with a 4 mm piece of glass. The used glass cover has a transmissivity of 0.88. Because the box and its glass cover were slanted and a sealing rubber cushion was positioned between them, leaks were prevented. The condensate water was collected via a tunnel that was carved into the box's bottom. The glass cover (channel width 7 mm) served as a place for solar radiation as well as a condensing surface.

The modified solar still incorporated a water spray cooling technology to improve the traditional way of using air to cool and clean the glass cover. A polystyrene container and lid were employed to shield the plumbing and the cooling water tank from the elements. The water used for cooling was fed in at 72 psi by a separate pump. Each still had its own multichannel digital display unit that recorded hourly temperature of water, vapor, absorber plate, and interior surface.

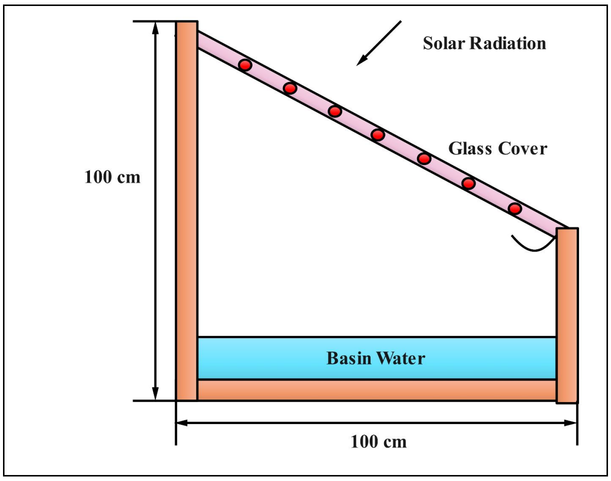

Fig. 1: An outline of conventional solar still

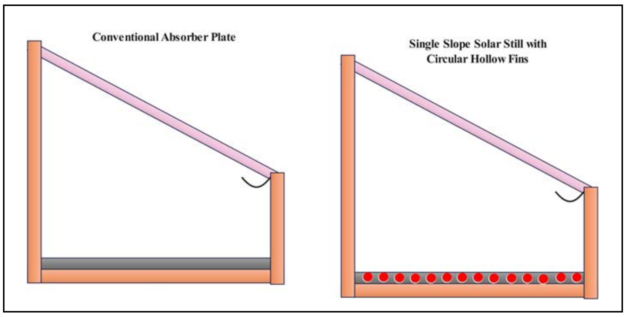

Fig. 2: Top view of absorber plate of (a) CSS, and (b) SSSS with circular hollow fins

3. EXPERIMENTAL WORK

The prefabricated SSSS was oriented southward for optimum sunlight exposure. Both stills were kept at a depth of only 1 cm. Many studies have shown that the daily yield of SSSS is directly proportional to the water depth and that 1 cm is optimal for maximum productivity (Suresh and Shanmugan, 2019; Yousef and Hassan, 2019). The water-supplying tip was elevated to a height of 1 cm above the absorber plate's surface, allowing for treatable amounts of salty water to be used in the experiment. Allowing air bubbles to enter the feeding tank helps replenish the water supply in the tank. A sufficient recovery below the feeding point is necessary before air bubbles can rise to the water tank from the SSSS enclosure, due to the pressure difference between them.

Single slope solar stills use the water thermal cycle to raise the temperature of salty water. This method includes heating the water by allowing incident sunlight to rise through a glass cover and boost the water's temperature below. Incoming solar radiation, however, may be partially penetrated, completely reflected, or completely absorbed, depending on the solar still regime they encounter. As a result, the water, absorber plate, and fins are exposed to the sunlight that enters through the glass cover. As the water temperature increases, vapor is produced and rises toward the condensation ceiling. Thus, water droplets in the condensate are directed down the incline into the collecting channel.

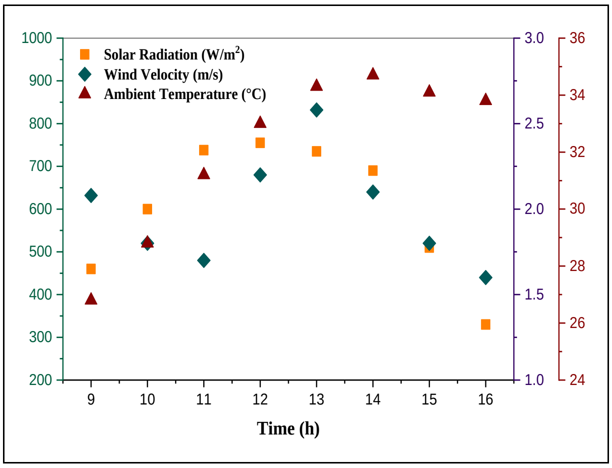

Fig. 3: Solar radiation, air temperature, and wind speed variations on February 18, 2023

Two basic methods of improvement are used in the current work. Inserting fins with a circular cross section was the first of several upgrades to the absorber plate. A glass cover cooling system was another option that was combined with the SSSS. The glass top of the solar still was cooled by using eight water sprayers that are positioned around its perimeter and pointed upwards. This work included 5 different types of cooling systems, including 1 continuous spray cooler and 4 pulse form coolers. The spray time was 40 s throughout all trials, but the standby time was changed to 35, 25, 15, and 5 minutes. Both fins were considered during the analysis, and the optimal cooling solution was chosen. The trials were carried out at SIMATS Engineering in Chennai, India. The experimental site had a latitude and longitude of 13.0843° N and 80.2705° E, respectively. The latitude of the study location was 13°, which was also the angle of the glass cover (Yuvaperiyasamy *et al.* 2024). A solar still's efficiency is mostly dependent on its placement and angle of cover. Cover inclination angle in relation to site latitude angle maximizes sun radiation reaching the still. This eventually increases production (Senthilkumar *et al.* 2024). Fig. 3 shows variations in wind speed, ambient temperature, and solar radiation on a certain day (February 18, 2023).

4. RESULTS AND DISCUSSION

The significance of enhancing SSSS plates with circular hollow fins and combining SSSS with a glass cover cooling was assessed. Adjustments in the production rate were used to determine the effects of temperature changes. The finned absorber plate provided a notable improvement in the SSSS experiment. The yield of CSS and SSSS throughout the day is shown in Fig. 4. Adding hollow fins to the absorbing plate improved efficiency by 50%, resulting in higher daily production. The hourly temperature change rate for the several studied regimes is summarized graphically in Fig. 5. The temperature of SSSS significantly increased once fins were added to various components. Basin water, particle absorber plate water, and glass top water were warmed by the increased surface contact. Heating up of the basin and all of its regimes take long time.

To maximize the condensation rate, the experimental approach additionally considers the effect of glass cover cooling on daily production from SSSS. Fig. 6 displays the hourly yield of daily production from CSS and SSSS with glass cooling (40 s/35 min). The daily production rate with latter was more significant than with CSS.

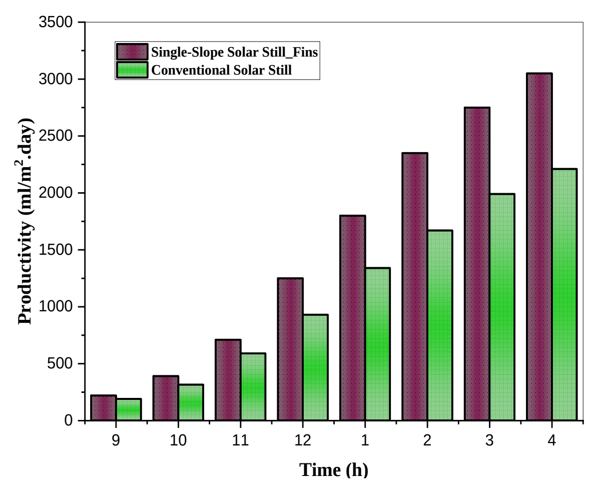

Fig. 4: Productivity of CSS and MSS

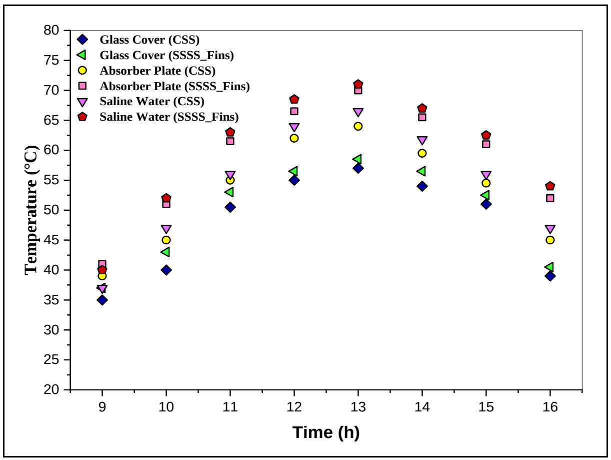

Fig. 5: Various temperature regimes of CSS and MSS

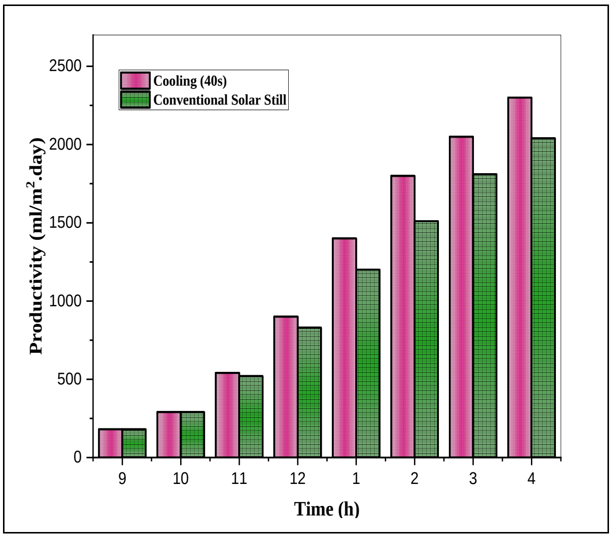

Fig. 6: Productivity yield of CSS and proposed SSSS with glass cooling (40 s/35 min)

Fig. 7 illustrates the temperature difference between the glass panel and the water. Through the glass cover, the temperature dropped much more than through the basin's water. As the pace of manufacturing grew, so did the rate of condensation. This modification resulted in an overall 13.3% improvement over CSS.

Increasing the amount of time, the equipment spends in standby mode allowed for an increase in daily production. When paired with a continuous water spray system and many glass chilling procedures, such as 45-, 40-, 15-, and 5-minute intervals, SSSS's productivity is seen in Fig. 8. The results showed that productivity rose when wait times were reduced. This result is valid up to 40 s/15 min of spray/standby time, after which the output rate decreases and the behavior reverts.

The water level may increase the reflection of incoming radiation instead of allowing it to interact with the glass and single slope solar still layers. In comparison to the CSS timing, this indicates that a spray timing of 40 s followed by 15 min increases production by 36.7%. The percentages of implementation for the 40 s/35 min, 40 s/25 min, 40 s/15 min, and continuous water spray systems were 13.3%, 17.8%, 36.7%, 24.2%, and 10%, respectively.

Productivity increased significantly as a consequence of the two upgrades working together. Fig. 9 shows the expected daily yield for the CSS and the single slope solar still at an astonishing rate of 40 s every 15 min, with a finned absorbent plate and a glass top. Daily productivity increased by 62.4% as compared to CSS after this integration was put into place. Fig. 10 shows the temperatures of the liquid in the basin, the absorber plates, and the glass covers of two different SSSSs (one with hollow circular fins and the other without), after 40 s and 15 min of cooling.

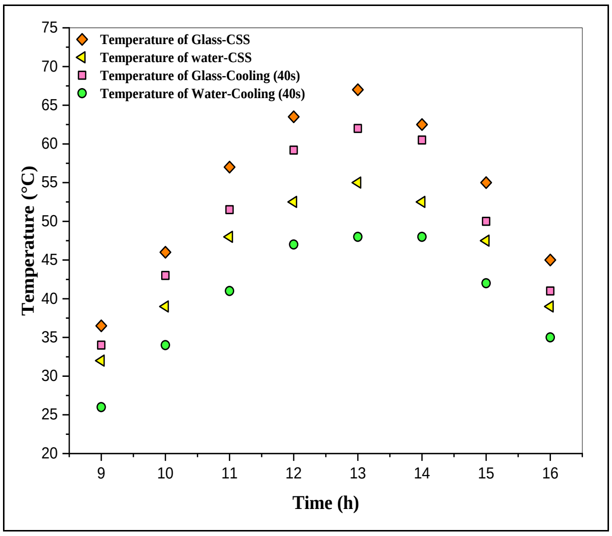

Fig. 7: Temperature difference between water and glass panel for CSS and SSSS with enhanced glass cooling (40 s/35 min)

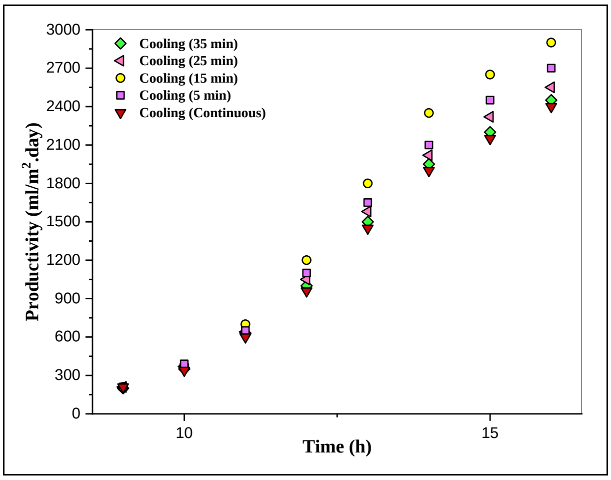

Fig. 8: Yield of SSSS at 40 s for different timings

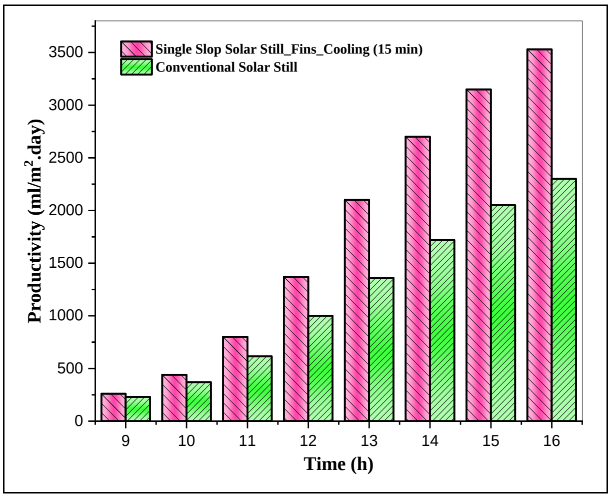

Fig. 9: Production rate of 1) CSS and 2) SSSS with glass cooling and hollow fins (40 s/15 min)

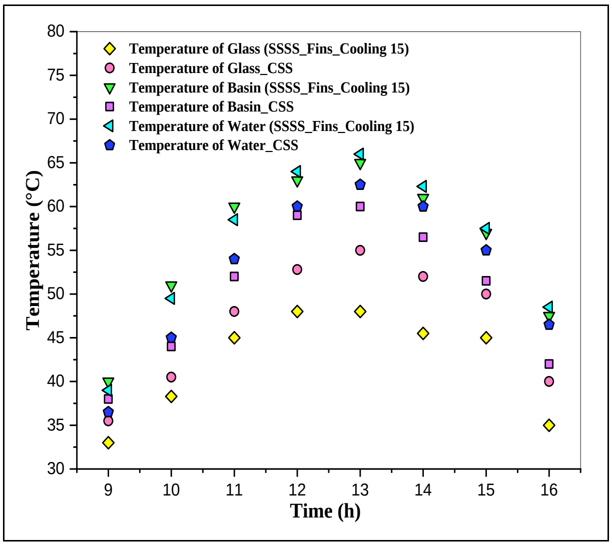

Fig. 10: Temperatures of various parameters for conventional and SSSS with hollow circular fins and glass cover cooling (40 s /15 min) against time

Heating the absorber plates and water in the basin leads to increased evaporation and condensation on the inner surface of the glass cover which is relatively cool.

5. COST ESTIMATION

There needs to be a cost estimate for each solar still. Table 1 lists the money spent on making and acquiring the current stills. All the components of stills are available in the local industrial zone.

Table 1. Budgeting for the manufactured systems

Factors	Cost (in ₹)	
	SSSS	CSS
CNC Shaping of the box	164	164
Hollow fins	410	-
Polystyrene box	820	820
Auxiliaries (silicon, tab, etc.)	410	410
Glass cover	328	328
Galvanized iron sheet	656	656
Cooling system	1230	-
Plastic pipe	164	164
Total fabricating cost of SSSS with an absorbing area of 100 cm^2	7462	5412
Paint	410	410
Flexible rubber band	82	82
Total fabricating cost of SSSS with an absorbing area of 0.41 m^2	4592	3034

6. CONCLUSION

The present study looked at the possible advantages of using SSSS in conjunction with glass cover cooling and hollow circular absorber panels. Data and testing results across various conditions show that incorporating a hollow circular particle absorbing plate made of stimulated iron increased daily cumulative production by up to 50%. Additionally, using SSSS with glass cooling improved efficiency by 13.3%, 17.8%, 36.7%, 24.2%, and 10% for durations ranging from 40 s to 35min, 20 s to 15 min, 10 s to 5 min, and 5 s to 30 s, respectively. However, standby times shorter or longer than the optimal 40 s to 10 min provided minimal benefit. The addition of hollow circular fins to the absorbing plate, combined with a (40 s/15 min) cooling system, further enhanced productivity by 62.4%. Future research will focus on integrating nanoparticles with PCM to improve the efficiency of single-slope solar stills.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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