An Experimental Study on Eco-Friendly and Cost-Effective Natural Materials for Productivity Enhancement to Single Slope Solar Still

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**An experimental study on eco-friendly and cost-effective natural materials for productivity enhancement
of single slope solar still**

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Abstract

The proposed research study aims to improve the productivity of solar still (SS) by using low-cost and eco-friendly materials. The aforementioned objective was achieved by enhancing the evaporation rate of seawater in the absorber basin and the condensation rate over the glass cover of the solar still. In this study, the low-cost and eco-friendly materials used for enhancing the evaporation rate in the solar still were Molasses Powder (MP), Sawdust (SD), Rise Husk (RH). In addition to these materials, Bamboo Straw (BS), Banana Leaf stem (BL), and Rice Straw (RS) were used as absorbing materials over the glass cover for enhancing the condensation rate. The experiments were carried out under similar meteorological conditions and the results of the modified solar still were compared with Conventional Solar Still (CSS). The productivities of CSS, SSMP, SSRH, SSSD, SSBS, SSBL and SSRS were about 2250 mL/m², 2383 mL/m², 2467 mL/m², 3033 mL/m², 2700 mL/m², 2683 mL/m², and 3367 mL/m², respectively. The results of the experimental investigation highlighted that the SSSD had a comparatively better evaporation rate and 34.81% higher yield than CSS. Besides, SSRS had a comparatively better condensation rate and a 51.88% higher yield than CSS. Later, the combination of sawdust (SD) and rice straw (RS) was investigated for combined enhancement of evaporation and condensation. The solar still with sawdust and rice straw (SSSDRS) showed a 62.88% improvement in productivity with 3633 mL/m² when compared to CSS. Also, the economic analysis showed that the cost per litre (CPL) of freshwater obtained from SSSDRS was about ₹ 1.9 (\$ 0.025) with a payback period of 4.4 months which was the least when compared to all the considered cases.

Keywords: Solar Still; Sawdust; Rice Straw; Evaporation; Condensation; Productivity Enhancement.

Highlights

- The performance of solar still was examined with low-cost and eco-friendly materials.
- SSSD had a better evaporation rate and enhanced yield by 34.81%.
- SSRS had a better condensation rate and enhanced yield by 51.88%.
- SSSDRS enhanced evaporation and condensation rates with a 62.88% increase in yield.
- Cost/litre and Pay Back Period of SSSDRS were ₹1.9 and 4.4 months, respectively.

1. Introduction

The freshwater demand has been rapidly increasing across the world by about 1% since the 1980s due to industrialization, urbanization, modernization in agricultural practices and growth in the population. It has been estimated that more than 2 billion people are living in water stress areas and over 4 billion people in the world are facing water scarcity at least for a month during a year. Further, climate change may affect the accessibility, quality and quantity of freshwater resources on the earth. In this situation, the recognition of water resources, safeguarding the water resources and valuing the water has become the primary goal to overcome the water stress/scarcity across the globe. A plausible solution to overcome this problem is to convert the available seawater into freshwater through desalination approaches. The energy required for driving the desalination process is another concern that is to be addressed immediately. The utilization of conventional energy sources in the current situation is not recommendable since global warming and depletion of energy sources are the other alarming glitches to the world along with freshwater scarcity. Hence, the desalination approach driven by renewable energy sources is the best possible way to address the global freshwater and energy demands.

In the available seawater desalination approaches, solar still is considered as one of the economical and sustainable ways of desalination. Also, the solar still have been successful in desalinating not only seawater but also the industrial effluents, reverse osmosis reject and sewage water (Velmurugan et al. 2008a, 2009; Reddy et al. 2018; Sleiti et al. 2021). Solar still is an economical and environmentally friendly desalination approach since it utilises solar energy for its operation which is abundant and thereby, reducing the energy-related costs. Also, the utilization of solar energy for desalinating the seawater reduces the carbon footprint. The solar still is simple in its construction with a fewer number of components compared to other desalination approaches (Thirugnanasambandam et al. 2010; Sharon and Reddy 2015; Xevgenos et al. 2016). However, the efficiency of conventional solar still is comparatively less (~ 20 – 30%). This opens up a wide opportunity for improvising the productivity of the solar still.

Typically, the efficiency or the productivity of the solar still can be enhanced by increasing the evaporation and condensation rate. The evaporation rate is commonly improved by decreasing the humidity and increasing the temperature. A warmer environment creates a dry ambience inside the solar still which will increase the water vapour carrying capacity of air. Several other parameters to be considered for increasing the evaporation rate include absorption rate of basin water and still basin, the volumetric heat capacity of the basin, water depth, inlet temperature of the basin and the temperature of the surface of the water (Muthu Manokar et al. 2014). On the other hand, the condensation rate can be enhanced by lowering the temperature of condensing plate and by

increasing the convective heat transfer rate (from condensing plate to surroundings)(Muthu Manokar et al. 2014; Prakash and Velmurugan 2015). This will decrease the water vapour carrying capacity of the surrounding air and in turn droplets of water will be condensed. Many kinds of research are focusing on several approaches to enhance the productivity of solar still which is discussed in Section 2. Such approaches mainly concentrate on increasing the evaporation and condensation rates via different design of solar stills, incorporating energy storage components, and by enhancing the heat transfer rates. However, a simple yet effective means of productivity enhancement is far from reality. In context, this study is propounded to analyse the influence of eco-friendly and cost-effective materials for enhancing the productivity of solar still. Section 2 emphasize various existing methods and recent researches involved in solar still. Section 3 provides deep insight into the materials utilized and the experimentation. Section 4 presents the thermal and economic analysis associated with this research. Section 5 highlights the results and conclusions are drawn in Section 6.

2. Literature Review

Many researchers across the world are working to improve the efficacy of solar still through several modifications in the system design and incorporations such as fins/energy storage, nanofluids and nanomaterials into the still and glass cooling techniques to enhance the condensation rate(Al-Nimr and Al-Ammari 2016; Kabeel et al. 2019b; Patel and Modi 2020; Sleiti et al. 2020). This section is dedicated to elaborate on the various approaches in enhancing the productivity of the solar still.

2.1. The role of design parameters in productivity enhancement

(Tripathi and Tiwari 2005; Tiwari and Tiwari 2006) assessed the effect of water depth in the still on heat and mass transfer. The investigation results showed that the internal heat and mass transfer is substantially influenced by the depth of water in the still. It is observed that as the depth of water increases, the lower water temperature has resulted which in turn decreases the convective heat transfer coefficient. (Akash et al. 2000) investigated the effect of the tilt angle of glass cover on the productivity of solar still under Jordan city climatic conditions. It was observed that the solar still with a 35° tilt angle (~equal to the latitude of Jordan) had better productivity when compared to the other tilt angles such as 15°, 25°, 45° and 55°.(Khalifa and Hamood 2009) analysed the influence of insulation thickness on the freshwater productivity of solar still. It was noticed that an increase in the thickness of insulation results in increased productivity and the thickness of insulation influenced productivity by over 80%. (Nagarajan et al. 2017) studied the influence of baffles on the productivity of solar still. It was found that the solar still with baffles had productivity of 5.4 kg/m² whereas the solar still without baffles had productivity of 3.4 kg/m² per day.(Tabrizi et al. 2010) studied the weir type cascade solar still for

enhancing the distillate yield. It was found that the flow of inlet water substantially decreased the productivity of solar still as influenced by a reduction in the internal heat and mass transfer rates. The productivity of solar still was about 7.4 kg/m² and 4.3 kg/m² per day for minimum and maximum flow rates of inlet water.(Dev et al. 2011) analysed the effect of inverted absorber on the productivity of solar still. It was noticed that the inverted absorber solar still had productivity of 6.302, 5.576 and 4.299 kg/m²/day for the 1 cm, 2 cm and 3 cm water depths, respectively. Whereas for the same water depths, the traditional solar still had a yield of 2.152, 1.931, 0.826 kg/m²/day.(Gad et al. 2015) developed and studied the influence of conical solar still on freshwater yield. It was reported that the conical solar still had a yield of 3.38 L/m² whereas the conventional solar still had a yield of 1.93 L/m². This is primarily attributed due to the higher values of evaporative, convective and radiative heat transfer coefficients during the daytime when compared to conventional solar still. (Attia et al. 2021b) investigated the performance of hemispherical solar still with iron, zinc and copper absorber trays and the results were compared with conventional hemispherical still. The results showed that the hemispherical solar still with copper, zinc and iron absorbers had an improvement in yield by 53.12%, 31.25% and 14.58%, respectively when compared with the productivity of conventional hemispherical solar still.(Saadi et al. 2018) studied the performance of stepped solar still with a multi evaporator tray. It was found that the productivity of stepped solar still had improved productivity of 47.18%, 62.73%, 94.21% and 104.73% for spring, autumn, winter and summer, respectively.

2.2. External collectors and hybrid solar stills for improving evaporation rate

(Sampathkumar et al. 2013) investigated the effect of evacuated tube collector connected to solar still on freshwater productivity. It was observed that the solar still with evacuated tube collector had a yield of 7.03kg/m²/day whereas the conventional solar still had a yield of 3.225 kg/m²/day at a depth of 4 cm. (Kumar et al. 2014) studied the influence of evacuated solar still under forced circulation mode. It was found that the maximum yield obtained from the solar still was about 3.47 kg for 1 cm basin water depth with an optimum flow rate of 0.006 kg/s. (Jafari Mosleh et al. 2015) investigated the effect of solar still with a combination of the heat pipe, evacuated tube and parabolic trough collector on the daily freshwater productivity. It was observed that the modified solar still with aluminium conducting foils as a heat transfer medium had a yield of 0.27 kg/(m² h) with 22.1% energy efficiency. Whereas, the solar still with oil as heat transfer medium had a yield of 0.933 kg/(m² h) with 65.2% energy efficiency.(Kabeel et al. 2019a) studied the performance of solar still integrated with two solar dish concentrators. It was found that the solar still with one solar dish concentrator had a yield of 8.8 and 5.45 kg/day for 1 cm and 2 cm water depths. Whereas, the solar still with two solar dish

concentrators had a yield of 13.63 and 7.69 kg/day for 1 cm and 2 cm water depths, correspondingly. (Manokar et al. 2020) studied the performance of solar still with photovoltaic panel and flat plate collector. It was found that the freshwater yield from the modified solar still was about 7.5, 6.5 and 5.4 kg, and the electrical efficiency was about 7.2%, 7.6% and 8.1% for 1.8, 3.2 and 4.7 kg/h mass flow rates, respectively. The results also indicated that when the mass flow rate is increased, the yield of distillate, overall thermal efficiency is decreased but it increases the PV power production and overall exergy efficiency. (Sharshir et al. 2016) investigated the performance of solar still integrated with humidification – dehumidification (H-DH) desalination system. In this hybrid system, the warm water rejected from the H-DH system serves as feed water for solar still. The productivity of single solar still in the hybrid system was improved by almost 200% compared to the productivity of CSS. (Shehata et al. 2020) assessed the performance of solar still with energy storage material and ultrasonic humidifiers integrated with evacuated tube collectors. It was observed that the highest productivity was obtained for the case of solar still with energy storage and ultrasonic humidifier integrated with evacuated solar collectors. The maximum productivity obtained from the solar still was about 5.34 and 7.4 kg per day for 2.5 cm and 3.5 cm water depths.

2.3. Productivity enhancement by increasing wet surface area

(Velmurugan et al. 2008b) Velmurugan et al. investigated the influence of fins, wick materials and sponges on the productivity of solar still. The results indicated that the solar still with fins, sponges and wicks enhanced productivity by 45.5%, 15.3% and 29.6%, respectively, compared to CSS. (Omara et al. 2011) investigated the performance of solar still with fins and corrugate absorber plate. It was observed that the solar still with fins and corrugated absorber plate had an improved freshwater yield by 40% and 21% respectively in relative to CSS. (Jani and Modi 2019) studied the performance of solar still with circular and square hollow fins for better productivity. Hollow fins are used to provide an enlarged surface area to absorb solar radiation as well as to improve the heat transfer to the water. It was found that the solar still with circular fins obtained productivity of 1.4917 kg/m² per day whereas the solar still with hollow fins obtained productivity of 0.9672 kg/m² per day. (Kabeel et al. 2020) investigated the effect of hollow circular fins and phase change materials on the productivity of pyramid solar still. It was noticed that the integration of hollow fins enhanced the productivity by 43% whereas the productivity of solar still with both fins and energy storage improved the freshwater productivity by 101.5% relative to the productivity of CSS. (Suraparaju et al. 2021; Suraparaju and Natarajan 2021a) studied the influence of absorber basin with bottom solid fins and hollow fins inserted in energy storage (paraffin wax) on the freshwater yield of solar still. It was found that the solar still with solid finned absorber

inserted in energy storage enhanced productivity by 24.26% compared to CSS. Whereas, the solar still with hollow finned absorber basin inserted in energy storage showed an improvement in yield by 52.4% relative to CSS. This phenomenon was mainly due to the more space in hollow fins for heat transfer between absorber and energy storage compared to solid fins. (Suraparaju and Natarajan 2020) studied the influence of ridge gourd natural fibre on the performance of solar still. It was found that the productivity was reduced by almost 3% when compared with the productivity of CSS. The reduction in productivity was mainly due to more fibres in the absorber basin which hindered the incoming solar radiation to the absorber basin.

2.4. Increasing productivity by using nanomaterials

(Kabeel et al. 2019c) investigated the influence of TiO₂ nano-coated absorber plate on the productivity of pyramid solar still at various water depths varying from 1 cm to 3.5 cm. The TiO₂ nanocoating is provided to improve the absorptivity of solar radiation in the solar still. The experimental investigation of TiO₂ nanocoated absorber resulted in improved productivity of 6.1% at 1 cm basin water depth relative to conventional solar still. (Panchal et al. 2019) investigated the effect of MgO and TiO₂ nanofluids with lower specific heat capacity and higher thermal conductivity in the solar still for better productivity. It was observed that the solar still with MgO nanofluids of 0.1% and 0.2% concentration had an increase in productivity by 33.33% and 45.8%, respectively compared to CSS. Whereas the solar still with TiO₂ nanofluids of 0.1% and 0.2% concentration had an increase in productivity by 4.1% and 20.4%, respectively, compared to CSS. (Sharshir et al. 2019) assessed the performance of pyramid solar still with evacuated collectors and nanofluids. It was observed that the solar still with copper oxide and carbon black nanofluids enhanced the freshwater yield by 27.85% and 33.59%. (Elango et al. 2015) studied the effect of different nanofluids on the productivity of solar still. It was reported that the solar still with Al₂O₃, ZnO and SnO₂ had an increase in the potable water yield by 29.95%, 12.67% and 18.63%, respectively, in relative to CSS. (Sharshir et al. 2018) investigated the influence of graphite and CuO nanofluids on the productivity of solar still. It was found that the solar still with graphite and CuO nanofluids had an augmented output of 41.18% and 32.35%, respectively, compared to CSS. (Sathyamurthy et al. 2020) studied the influence of fumed silica nano-coating with different concentrations varying from 10% to 40% on the freshwater yield of solar still. It was observed that the solar still with a modified coating at 20% concentration had the highest improvement in the yield by 34.2% compared to CSS. (El-gazar et al. 2021) investigated the influence of hybrid nanofluids (combination of Al₂O₃-CuO) on the performance of solar still. It was observed that the solar still hybrid nanofluid enhanced the freshwater yield by 27.2% in summer and 21.7% in winter, respectively, when compared to CSS.

2.5. Productivity enhancement by using energy storage materials

(Attia et al. 2021a) studied the performance of phosphate bags as energy storage material in the solar still. It was found that the cumulative productivity of solar still with energy storage at 1 cm and 2 cm water depth was about 5.27 and 4.87 kg whereas the CSS had a yield of 3.8 kg. (Chamkha et al. 2020) analysed the performance of solar still with Carbon Nano Tubes doped paraffin wax for enhancing the freshwater yield. It was found the solar still with CNT doped paraffin wax improved the freshwater production by about 41.4% and 26.4% relative to CSS and solar still with paraffin wax, respectively. (El et al. 2021). investigated the performance of El Oued sand grains as energy storage in hemispherical solar still at a varying concentration from 0.5% to 7%. It was found that the hemispherical solar still with 3% El Oued sand grains had a better improvement in productivity by 52.1% compared to CSS. (Balachandran et al. 2020) studied the effect of Gallus gallusdomesticus cascara as energy storage material on the freshwater productivity of solar still. It was observed that the solar still with Gallus gallusdomesticus cascara had a yield of 2.46 L/m² whereas the yield of CSS was about 2.07 L/m². (Sathish Kumar et al. 2019) investigated the performance of finned absorber basin and energy storage on the productivity of solar still. It was found that there was an increase in efficiency by 64% and 95% when only fins and fins with energy storage are used respectively.

2.6. Productivity enhancement by increasing the condensation rate

(Arunkumar et al. 2012) investigated the effect of glass cooling using water on the freshwater productivity of hemispherical solar still. It was observed that the decrease in the glass cover temperatures increased the energy efficiency from 34% to 42% with a fixed flow rate of 10 mL/min. (Pounraj et al. 2018) investigated the performance of Peltier based integrated PV/T solar still. It was observed that the Peltier system used in the system enhanced the distillate during both the evaporation and condensation process. The efficiency of Peltier based PV/T solar still was improved by 30%. (Zanganeh et al. 2019, 2020) studied the performance of nano-coated condensing cover for improving the freshwater yield in solar still. It was found that the nano-coating over the condensing surface improved productivity (20% improvement for silicone coating) when compared to uncoated surfaces. This phenomenon was mainly because the uncoated surface had less water dripping from the condensing surface. Also, the coated surfaces turn the film-wise condensation to dropwise condensation which was a key factor for enhancing the productivity of solar still.(Elmaadawy et al. 2021) analysed the performance of double slope solar still with the combination of low-cost materials and glass cover cooling for enhancing freshwater productivity. It was found that the solar still with the combination of carbon black nanoparticles,

gravel-covered with black wick and glass cover cooling had 68% improvement in the freshwater productivity compared to CSS.

2.7. Combined improvement of evaporation and condensation rates for productivity enhancement

(Rabhi et al. 2017) investigated the performance of solar still with pin fins absorber and external condenser for better productivity. It was reported that the solar still with pin fins absorber and condenser had an improvement in freshwater yield by 41.95%, 23.39% and 11% in relative to CSS, solar still with pin-fin absorber and solar still with an external condenser, respectively. (Sathyamurthy et al. 2015) investigated the performance of solar still with separate evaporation and condensation chambers. It was found that the solar still with PCM had an improvement of 52% in the freshwater production compared to CSS. The separate condensation chamber enables the vapour to reject the heat to PCM due to higher temperatures of water vapour in the condensation chamber. Thus, the additional heat was absorbed by PCM in the solar still and hence the productivity was improved. (Morad et al. 2015) studied the performance of solar still with flat plate collector and glass cooling arrangement for enhancing freshwater productivity. The results indicated that the active solar still had a productivity of 10.06 L/m² per day whereas the passive still attained only 7.8 L/m² per day. (Kumar et al. 2016) analysed the performance of solar still with external condenser and agitating system for enhancing the potable water yield. In this research, the agitation effect by DC fan was accomplished to enhance the evaporation rate in the basin and the condenser was integrated to enhance the condensation rate of solar still. The results of the investigation reported that the modified solar still had an increase in yield by 39.49% compared to CSS.

2.8. Novelty of this study

Based on the above literature, it can be outlined that many researchers worked on the improvement of productivity of solar still by enhancing the evaporation or the condensation rate or by a hybrid approach. The evaporation rate of seawater in the absorber of the solar still was mainly enhanced by the usage of fins, energy storage materials, wick materials, absorber coatings and surface enhancers like nanofluids and nanopowders. In addition to the evaporation, the condensation rate over the glass cover of the solar still was mainly enhanced by several glass cooling techniques like equipping condensers, water dripping, nanofluids, glass coatings with different materials etc. However, there were very few researches on the combined enhancement of evaporation and condensation rates of solar still with various materials. It was also found that as of the authors' knowledge, there were no works with a specific focus on naturally available, low-cost and environmentally friendly materials to enhance the evaporation and condensation rate of solar still. In this regard, the current investigation focussed on enhancing the evaporation rate of seawater in the absorber basin by using powders like molasses

powder, rice husk and sawdust. Also, the materials such as bamboo straw, banana leaf stem and rice straw were utilized for enhancing the condensation rate over the glass cover of the solar still. Later, the best material which enhanced the evaporation and the best material that enhanced the condensation rate was considered for further investigation to analyse the combined influence of respective materials on the performance of single slope solar still. In the end, the cost-effectiveness of all considered cases was estimated using economic analysis.

3. Experimentation and Materials

The experiments were carried out at the Solar Energy Laboratory, National Institute of Technology Puducherry, Karaikal, India (10.92°N, 79.83°E), during March and April 2021.

3.1. An overview of selected low-cost and eco-friendly materials

The low-cost and eco-friendly materials were used in the experiment for enhancing the evaporation as well as condensation rate in the solar still. The materials chosen for this research was molasses powder, rice husk, sawdust, bamboo straw, banana leaf stem and rice straw. These materials were chosen because of their premium properties (Jagannadha Rao et al. 2008; Kalita et al. 2013; Bello RS and Onilude MA 2017) (mentioned in Table 1), low cost and their availability. The molasses powder, rice husk and sawdust enhance the evaporation rate due to improved wet surface area, which these powders had more absorptivity and more spread over the basin water. Besides, bamboo straw, banana leaf stem and rice straw enhance the condensation rate due to their porous structures (Ghaly et al.; Mounika et al. 2012; Sengphet et al. 2014; Sharma et al. 2015; Assis et al. 2015; Costes et al. 2017; Huang et al. 2017; Judawisastra et al. 2017), from which water can be continuously absorbed and reduce the glass cover temperatures throughout the experiment.

Table 1. Properties of the low cost and eco-friendly materials.

Material	Thermal			
	Conductivity (W/m.K)	Density (kg/m ³)	Porosity (%)	Absorption (%)
Molasses Powder	0.036	1200	-	-
Rice Husk	0.0523	1030.93	63.64	5% to 16%
Sawdust	0.08	210	74%	-
Bamboo Straw	0.18	1163	43.9%	26.2%
Banana Leaf stem	0.55	1370	18.5	9.7%
Rice Straw	0.05	450	71.21%	234%

3.2. Experimental Setup Description

In this research, the experiments were conducted as three groups for augmenting the freshwater productivity in the single slope solar still. The three groups considered for experimentation are as follows:

- a) Enhancing evaporation rate of seawater in the absorber basin
- b) Enhancing condensation rate over the glass cover
- c) Simultaneous enhancement of evaporation and condensation.

Besides this, eight various types of single slope solar stills were developed to carry out the three groups of experiments.

1. Conventional Solar Still (CSS)

a) Enhancing evaporation rate of seawater in the absorber basin

2. Solar Still with Molasses Powder (SSMP)
3. Solar Still with Rice Husk (SSRH)
4. Solar Still with Sawdust (SSSD)

b) Enhancing condensation rate over the glass cover

5. Solar Still with Bamboo straw (SSBS)
6. Solar Still with Banana Leaf Stem (SSBL)
7. Solar Still with Rice Straw (SSRS)

c) Simultaneous enhancement of evaporation and condensation

8. Solar Still with Sawdust and Rice Straw (SSSDRS)

3.3. Materials and Fabrication of Single Slope Solar Still

The single slope solar stills were made of strong and waterproof plywood and the inner structure of solar still was covered with an aluminium layer of 2 mm thickness that stops the direct contact between water vapour and plywood. The aluminium sheet was then coated with black paint for better absorption of incoming solar radiation. The absorber basin of each solar still was made of a 1 mm thick copper sheet. The dimensions of the absorber basin were 1000 mm × 600 mm × 50 mm (length × breadth × height) with an absorber area of 0.6m². Further, the solar still was covered with a 3 mm glass cover which was fixed at an angle of latitude of testing location (11°) for better working (Singh and Tiwari 2004). The absorber basins of all single slope solar stills were filled with seawater at a 2 cm basin water depth as it was found to be the optimum depth of water (Suraparaju and Natarajan 2021a). The outer structure of solar still was insulated with polystyrene sheets for reducing the heat losses to the ambient. The polystyrene sheets were chosen because it has better insulating properties and was cost-effective. The absorber basins of SSMP, SSRH and SSSD were filled with molasses

powder, rice husk and sawdust, respectively for enhancement of evaporation of seawater from the absorber basin. The glass covers of SSBS, SSBL and SSRS have equipped with a water dripping arrangement consists of a water tank, a dripping channel along with bamboo straw, banana leaf stem and rice straw, respectively, for enhancing the glass cover condensation by reducing the glass temperatures. The schematic of the solar still with glass cooling arrangement is as shown in Fig 1. The photograph of solar still arrangements of three sets of experiments is as shown in Fig 2a, 2b and 2c.

Fig. 1 Schematic of solar still with glass cooling arrangement.

(a)

(b)

(c)

Fig. 2(a) Photograph of experimental arrangement for enhancing evaporation rate

(b) Photograph of experimental arrangement for enhancing condensation rate

(c) Photograph of experimental arrangement for simultaneous enhancement of evaporation and condensation rate.

3.4. Experimentation and Error Analysis

The experiments were carried out at the Solar Energy Laboratory, NIT Puducherry, Karaikal, India. The feed water for the experiment was collected from the Bay of Bengal Sea located adjacent to the NIT Puducherry. The seawater in the absorber basin is filled to an optimum depth of 2 cm for better productivity (Suraparaju and Natarajan 2021a). The experiments on CSS, SSMP, SSRH and SSSD were conducted on 30th March 2021 and 31st March 2021 to investigate the effect of molasses powder (MP), rice husk (RH) and sawdust (SD) on the productivity of solar still by enhancing the evaporation rate of seawater in the absorber basin. The experiments on CSS, SSBS, SSBL, and SSRS were conducted on 1st April 2021 and 2nd April 2021 to investigate the effect of bamboo straw (BS), banana leaf stem (BL) and rice straw (RS) on the productivity of solar still by enhancing the condensation rate over the glass cover of the solar still. The experiments on the CSS and SSSDRS were conducted on 3rd April 2021 and 4th April 2021 to investigate the combined effect of sawdust and rice straw on the productivity of solar still by enhancing the evaporation rate and condensation rate simultaneously. The temperatures of the glass cover, seawater, absorber basin, glass cooling materials and ambient temperature were measured using K- type thermocouples connected to the “Data acquisition system”. The global radiation of the

particular testing day at the testing location was noted using the “Pyranometer”. The experiments were conducted for six consecutive days, and readings were recorded from 08:30 am to 05:00 pm (Indian Standard Time) for every half an hour. The uncertainty in the efficiency and hourly freshwater yield is given by the formulae in Equations (1) – (3); (Bhargva and Yadav 2019; Taheri Mousavi et al. 2020; Suraparaju and Natarajan 2021b)

$$u_{\eta} = \left[\left(\frac{\partial \eta_d}{\partial d_w} \times u_{d_w} \right)^2 + \left(\frac{\partial \eta_d}{\partial I(t)} \times u_{I(t)} \right)^2 \right]^{\frac{1}{2}} \quad (1)$$

The uncertainty in hourly yield (u_{d_w}) is given by

$$u_{d_w} = \left[\left(\frac{\delta d}{\delta y_1} u_y \right)^2 \right]^{\frac{1}{2}} \quad (2)$$

$$u_{d_w} = \left[\left(\frac{d_i - d_f}{\delta y_1} u_y \right)^2 \right]^{\frac{1}{2}} \quad (3)$$

Where d_i and d_f are the initial and final hourly yield in mL at any period and u_y is the uncertainty of yield in percentage. It was evaluated that the uncertainty in hourly yield was 1% and further taking all other uncertainties into the account, the error in total yield was about $\pm 1.5\%$. Besides that, the error in solar radiation and temperature measurement was 0.05% and 0.1%. Thus, the total error percentage in the solar still efficiency was about $\pm 2\%$.

4. Thermal and Economic Analysis

This section details the thermal and economic analysis performed for the experimented configurations of solar stills.

4.1. Thermal Analysis

The overall thermal efficiency of the passive solar still is calculated by using Equation (4) (Kabeel and Abdelgaied 2016; Hassan and Abo-Elfadl 2017; Mande and Manickam 2019)

$$\eta_{th} = \frac{P \times \lambda}{A_b \times G} \quad (4)$$

where P is the overall freshwater productivity in kg, λ is the latent heat of evaporation of water in J/kg, A_b is the absorber basin area in m^2 , G is daily overall incident solar energy in W/m^2 .

4.2. Economic Analysis

The key objective of the cost evaluation is to determine the cost per litre (CPL) per one m^2 area of the solar still by using the Equations (5) - (14) (Omara and Kabeel 2014; Agboola et al. 2015; Tiwari and Sahota 2017)

357 The first annual cost (F) of the solar still is given by,

358
$$F = C \times I \quad (5)$$

359 Where C is the capital recovery factor and I is the initial investment,

360
$$C = \frac{r(1+r)^l}{(1+r)^l - 1} \quad (6)$$

361 Where r is the rate of interest and l is the lifespan of the solar still

362 The rate of interest was taken as 15% and the salvage value was taken as 20% of fixed cost.

363
$$\text{The annual salvage factor } A = S_s \times S \quad (7)$$

364 Where S is the salvage value and S_s is the sinking fund factor

365
$$S = 0.2 \times I \quad (8)$$

366
$$S_s = \frac{r}{(1+r)^l - 1} \quad (9)$$

367 The annual maintenance cost (A_m) is anticipated to be 15% of the F,

368
$$A_m = 0.15 \times F \quad (10)$$

369
$$\text{The annual cost } A_c = F + A_m - A \quad (11)$$

370
$$\text{Cost Per Liter/m}^2 \text{ (CPL)} = \frac{A_c}{Y_l} \quad (12)$$

371
$$\text{Payback Period (PBP)} = \frac{\text{Investment}}{\text{Total revenue per day}} \quad (13)$$

372
$$\text{Total revenue} = \text{Market water price (per L)} \times \text{Productivity(L)/ day.m}^2 \quad (14)$$

373 Where Y_l is the average yield per annum. It is given by the daily average freshwater productivity multiplied by
374 the number of sunny and clear days (annually ~ 300days) available for the working of solar still. The payback
375 period of the particular solar desalination system is calculated by considering the initial investment, market price
376 of one-litre water and total productivity per days given in equation 13 & 14.

377 **5. Results and Discussion**

378 The experiments were carried out during March and April 2021 with SSMP, SSRH, SSSD, SSBS, SSBL and
379 SSRS to investigate the performance of solar stills with various low-cost and eco-friendly materials. The SSMP,
380 SSRH and SSSD were investigated for enhancing the evaporation rate in the solar still. Whereas, the SSBS,
381 SSBL and SSRS were investigated for enhancing the condensation rate in the solar still. Later, the SSSDRS was
382 investigated for combined enhancement of evaporation and condensation rate in solar still for better
383 productivity. The observed results were compared with the results obtained from CSS.

384 **5.1. Global Solar Radiation**

The incident global solar radiation on all testing days from 30th March 2021 to 04th March 2021 was plotted against time (08:30 to 17:00 IST) as shown in Fig 3. The minimum, average and maximum incident global solar radiation on all testing days was plotted in Fig 4. From Fig 3&4, it can be observed that the minimum, maximum and average solar radiation on all testing days were within the range of 210 W/m² to 250 W/m², 1029 W/m² to 1050 W/m², 778 W/m² to 794 W/m², respectively.

Fig.3. A plot of the variation of incident global solar radiation on all testing days for every 30 minutes.

Fig.4. Maximum, minimum and average solar radiation on all testing days.

5.2. Ambient Temperature and other System Temperatures

The ambient temperatures for six testing days were plotted against time as shown in Fig 5. It was observed that the ambient temperature on all testing days was almost similar, ranging from 29°C to 43°C. Also, the average ambient temperature on all six testing days was about 36°C. The highest ambient temperatures were recorded during the peak hours from 11.30 hrs to 14.30 hrs. The lowest ambient temperatures were recorded at the beginning and end of the experiment on all days.

Fig.5.A plot of variation in ambient temperature on all testing days.

The variations of different temperatures in the CSS, SSMP, SSRH and SSSD on 30th and 31st March 2021 were plotted against time as shown in Fig 6 and 7. The highest glass temperatures of the CSS, SSMP, SSRH and SSSD were recorded as 50.2°C, 57.8°C, 55.2°C and 57.2°C, respectively, on 30th March 2021 during the peak hours of experimentation. The maximum absorber temperatures of the CSS, SSMP, SSRH and SSSD were recorded as 69.7°C, 70.6°C, 70.5°C and 71.7°C, respectively, on 30th March 2021 during the peak hours of experimentation. The corresponding water temperatures of the CSS, SSMP, SSRH and SSSD were recorded as 68.2°C, 69.1°C, 68.9°C and 69.9°C, respectively, on 30th March 2021. It was observed that the addition of molasses powder, rice husk and sawdust into the absorber basin enhanced the water temperatures compared to CSS. From Fig 7, it was noticed that the maximum glass temperatures of the CSS, SSMP, SSRH and SSSD were recorded as 51.3°C, 52.3°C, 52.3°C and 51.6°C, respectively, on 31st March 2021 during the peak hours of experimentation. The maximum absorber temperatures of the CSS, SSMP, SSRH and SSSD were recorded as 69.1°C, 70.1°C, 70.2°C and 71.1°C, respectively, on 31st March 2021 during the peak hours of experimentation. The corresponding water temperatures of the CSS, SSMP, SSRH and SSSD were recorded as 67.6°C, 69.1°C, 69.2°C and 70.1°C, correspondingly, on 31st March 2021. It was observed that the addition of molasses powder,

rice husk and sawdust into the absorber basin enhanced the water temperatures compared to CSS. Also, it was reported that the addition of sawdust into the absorber basin raised the water temperature by almost 3% on both days which tends to improve the evaporation rate from the absorber basin. The significant increase in the temperature was mainly due to more absorption of heat by the sawdust compared to molasses powder and rice husk. However, the molasses powder and rice husk improved the water temperatures comparatively better than CSS due to their absorption from the incident solar radiation.

Fig.6. Solar Still temperatures on 30th March 2021 (Enhancing evaporation rate).

Fig.7. Solar Still temperatures on 31st March 2021 (Enhancing evaporation rate).

The variations of different temperatures in the CSS, SSBS, SSBL and SSRSon 1st and 2nd April 2021 were plotted against time as shown in Fig 8 and 9. The highest glass temperatures of the CSS, SSBS, SSBL and SSRS were recorded as 49.2°C, 35.1°C, 35.8°C and 33.7°C, respectively, on 1st April 2021. The maximum fibre temperatures over the glass cover for SSBS, SSBL and SSRS were observed to be 34.6°C, 35.3°C and 33.2°C, respectively. It was observed that the maximum temperatures of glass cover of SSBS, SSBL and SSRS were reduced due to glass cooling arrangement when compared to CSS without any glass cooling arrangement. Besides this, the maximum absorber temperatures of the CSS, SSBS, SSBL and SSRS were recorded at 67.7°C, 69.2°C, 69.1°C and 71.1°C, respectively, on 1st April 2021 during the peak hours of experimentation. The corresponding water temperatures of the CSS, SSBS, SSBL and SSRS were recorded as 66.8°C, 67.2°C, 68.8°C and 70.2°C, respectively on 1st April 2021. From Fig9, it can be observed that the maximum glass temperatures of the CSS, SSBS, SSBL and SSRS were recorded as 48.1°C, 34.3°C, 36.5°C and 34.4°C, respectively, on 2nd April 2021 during the peak hours of experimentation. The maximum fibre temperatures over the glass cover for SSBS, SSBL and SSRS were observed as 33.8°C, 36.1°C and 33.2°C, respectively. It was observed that the maximum temperatures of glass cover of SSBS, SSBL and SSRS were reduced due to glass cooling arrangement when compared to CSS without any glass cooling arrangement. In addition to this, the maximum absorber temperatures of the CSS, SSBS, SSBL and SSRS were recorded at 66.2°C, 67.7°C, 70.5°C and 72.5°C, respectively, on the 2nd April 2021 during the peak hours of experimentation. The corresponding water temperatures of the CSS, SSBS, SSBL and SSRS were recorded as 65.4°C, 66.2°C, 70.2°C and

71.7°C, respectively, on 2nd April 2021. The fibres absorbed the water after dripping and cool the glass till the next drip which significantly reduced the glass temperatures continuously throughout the experiment. The reduction of glass temperatures was mainly due to the porosity and water absorption capacity of the materials. It was reported that the addition of glass cooling arrangement reduced the glass temperatures by 40% which significantly increased the condensation rate over the glass and hence the productivity of solar still was augmented.

Fig.8. Solar Still temperatures on 1st April 2021 (Enhancing condensation rate).

Fig.9. Solar Still temperatures on 2nd April 2021 (Enhancing condensation rate).

The variations of different temperatures in the CSS and SSSDRS on 3rd and 4th April 2021 were plotted against time as shown in Fig 10 and 11. The highest glass temperatures of the CSS and SSSDRS were recorded as 49.8°C and 32.9°C, respectively, on 3rd April 2021. The maximum fibre temperature over the glass cover for SSSDRS was observed as 32.4°C. The maximum absorber temperatures of the CSS and SSSDRS were recorded at 68.6°C and 69.3°C, respectively, on the 3rd April 2021 during the peak hours of experimentation. The corresponding water temperatures of the CSS and SSSDRS were recorded as 67.7°C and 68.4°C, respectively, on 3rd April 2021. It was observed that the maximum temperatures of the glass cover of SSSDRS were reduced due to the glass cooling arrangement when compared to CSS. From Fig 11, the maximum glass temperatures of the CSS and SSSDRS were recorded as 50.6°C and 33.4°C, respectively, on 4th April 2021. The maximum fibre temperature over the glass cover for SSSDRS was observed to be 32.9°C. The maximum absorber temperatures of the CSS and SSSDRS were recorded as 69.7°C and 70.4°C, respectively, on 4th April 2021 during the peak hours of experimentation. The corresponding water temperatures of the CSS and SSSDRS were recorded as 68.8°C and 69.5°C, respectively, on 4th April 2021. It was noticed that there was a significant rise in the water temperatures and the maximum water temperature was maintained for a while which enhanced the evaporation rate in the absorber basin. The thermophysical properties of SD supported to absorb more heat and thereby, increasing the water temperature to aid in augmenting the evaporating rate. Similarly, the porosity and the water-retaining ability of RS produced a natural cooling effect on the glass by maintaining the glass temperature

as low as possible. The combined effect amplified the temperature difference between the glass and water surface which directly reflected in higher yield or productivity.

Fig. 10. Solar Still temperatures on 3rd April 2021 (Enhancing evaporation & condensation rate).

Fig. 11. Solar Still temperatures on 4th April 2021 (Enhancing evaporation & condensation rate).

Fig. 12. Difference between glass cover and basin water temperatures.

Fig. 13. The average difference between glass cover and basin water temperatures.

The variations in the water and glass temperature difference ($\Delta T = T_{\text{water}} - T_{\text{glass}}$) which was the key factor for enhancing the productivity was plotted against time as shown in Fig 12. The ΔT was plotted for the experiment days 01st April to 04th April 2021 where the novel glass cooling arrangement was equipped with

SSBS, SSBL, SSRS and SSSDRS, respectively. From Fig12, the maximum ΔT for CSS, SSBS, SSBL, SSRS and SSSDRS was attained as 22°C, 32°C, 33°C, 36°C and 36°C, respectively. It was noticed that the maximum ΔT of CSS and SSSDRS had a greater difference of 14°C which played a significant role in reducing the glass cover temperatures and increasing the condensation rate over the glass cover. Also, the average ΔT of all the considered cases were plotted as a bar diagram in Fig 13. It was observed that the average ΔT values of CSS, SSBS, SSBL, SSRS and SSSDRS were almost 9°C, 15°C, 15°C, 17°C and 17°C, respectively. The significant average ΔT values increased the condensation rate and hence the productivity of SSBS, SSBL, SSRS and SSSDRS was improved when compared to CSS.

5.3. Freshwater Yield

The cumulative yield of CSS, SSMP, SSRH and SSSD on 30th and 31st March 2021 were plotted as Fig 14. Besides, the cumulative yield of CSS, SSBS, SSBL and SSRS on 1st and 2nd April 2021 were plotted as Fig 15. The cumulative yield of CSS and SSSDRS on 3rd and 4th April 2021 were plotted as Fig 16. It was observed from Fig14 that the cumulative productivity of SSSD was higher when compared to SSMP, SSRH and CSS. The cumulative yield of SSSD was about 2983 mL/m² and 3033 mL/m² on 30th and 31st March 2021, respectively. On 1st and 2nd April 2021, it was observed that the cumulative productivity of SSRS was higher when compared to SSBS, SSBL and CSS. The cumulative productivity of SSSD was about 3367 mL/m² and 3350 mL/m², respectively. From Fig 16, it can be observed that the cumulative productivity of SSSDRS was higher when compared to CSS. The cumulative productivity of SSSDRS was about 3583 mL/m² and 3633 mL/m² on 3rd and 4th April 2021, respectively. The maximum productivities of all considered cases were plotted as a bar diagram in Fig17. From Fig17, it was observed that the maximum productivities of CSS on all testing days were about 2200 mL/m². The cumulative productivities of SSMP were about 2350 mL/m² whereas the cumulative productivities of SSRH were about 2450 mL/m². The cumulative productivities of SSBS and SSBL were about 2700 mL/m².

From the above inferences, it was clear that the sawdust in the absorber basin of solar still improved the evaporation rate comparatively better than rice husk and molasses powder. The main reason for this phenomenon was the better physio-thermal properties of sawdust compared to other materials. The density of sawdust was comparatively less than the molasses powder and rice husk. The less-dense sawdust float over the water in the absorber basin which enhanced the surface area of evaporation. Also, the thermal conductivity of sawdust was comparatively higher than the other two materials which enhanced the water temperatures in the absorber basin of solar still. The molasses powder and rice husk also showed an increment in freshwater yield

compared to CSS due to their individual physio-thermal properties. On the other hand, the condensation rate of solar still was improved better by rice straw than bamboo straw and banana leaf stem. The main reason for this occurrence was the better porosity and water absorption capacity of rice straw. The porosity of rice straw was almost 80% which was higher relative to banana leaf stem and bamboo straw. Also, the water absorption capacity of rice straw was significantly higher than that of the other two materials. Hence, the rice straw with better porosity and water absorption capacity had great contact with water from the dripping arrangement which subsequently reduced the glass cover temperatures of solar still. The reduced glass cover temperatures lead to improved freshwater yield from the solar still with rice straw. Nevertheless, the bamboo straw and banana leaf stem also improved the freshwater productivity relatively higher than CSS according to their inherent properties.

Fig. 14.The cumulative yield of solar stills during 30th and 31st March 2021 (Enhancing evaporation rate).

Fig. 15. The cumulative yield of solar stills during 1st and 2nd April 2021 (Enhancing condensation rate).

Fig. 16. The cumulative yield of solar stills during 3rd and 4th April 2021 (Enhancing evaporation & condensation rate).

Fig. 17. Comparison of maximum yield of all solar stills throughout the experimentation period.

The increase in the productivities of SSMP, SSRH, SSSD, SSBS, SSBL, SSRS, and SSSDRS compared to CSS were plotted as a bar diagram in Fig18. It was clear that the increase in the maximum yield of SSSD and SSRS was about 34% and 52%, respectively, when compared to CSS. The SSSD and SSRS were the highest among the evaporation group and condensation group experiments. The combination of SSSD and SSRS, termed as SSSDRS, was experimentally studied for enhancing the evaporation and condensation simultaneously. It was observed that the increase in the maximum yield of SSSDRS was about 62% when compared to CSS. Also, the increase in the productivities of SSMP, SSRH, SSBS and SSBL was about 6%, 9%, 21% and 22%, respectively, when compared to CSS.

Fig. 18. Increase in the yield % of modified solar stills compared to CSS.

5.4. Effect of low cost and eco-friendly materials on the system temperatures and productivity of solar stills

The inclusion of low cost and eco-friendly materials into the solar still improved the temperatures of the system. The molasses powder, rice husk and sawdust improved the evaporation rate in the absorber basin by absorbing more solar radiation through increasing the surface area in the absorber basin. The molasses powder, rice husk and sawdust augmented the water temperature by 3% when compared to CSS. Also, these materials helped to maintain the maximum water temperature for a while which enhanced the evaporation rate in the absorber basin when compared to CSS. The main reason behind the increased water temperatures was the more heat absorption from the materials used in the absorber basin. The surge in the water temperatures leads to an augmentation of freshwater yield in SSMP, SSRH and SSDD, respectively, when compared to CSS. Besides, the integration of bamboo straw, banana leaf stem and rice straw to the water dripping arrangement for glass cooling enhanced the condensation rate through their porous structures. The porous structures and water-absorbing capacity of materials continuously absorbed the water from the dripping arrangement and helped in reducing the glass cover temperatures throughout the experiment. The inclusion of bamboo straw, banana leaf stem and rice straw reduced the glass cover temperature by above 40% relative to CSS. The decrement in the glass cover temperatures enhanced the condensation rate over the glass cover when compared to CSS. The surge in the

condensation rate leads to an augmentation of freshwater yield in SSBS, SSBL and SSRS, respectively, relative to CSS. Nevertheless, the inclusion of low cost and eco-friendly materials into the solar still augmented the water temperatures and reduced the glass cover temperatures that led to an improvement in the freshwater yield of solar still.

5.5. Thermo – Economic Analysis

The overall thermal efficiency of the single-slope solar stills was assessed using equation (4). The thermal efficiency of all the considered cases was plotted as a bar diagram in Fig 19. From Fig 19, it was observed that the thermal efficiency of CSS on all days was about 36%. The thermal efficiencies of SSMP, SSRH and SSSD were about 37%, 39% and 48%, respectively. Whereas, the thermal efficiencies of SSBS, SSBL and SSRS were about 43%, 43% and 54%, respectively. The thermal efficiency of SSSDRS was reported as 59% which was the highest among all the other cases. From the above observations, it can be concluded that the inclusion of low-cost and eco-friendly materials into the system improved the performance of single slope solar still by increasing the system temperatures, productivity and energy efficiency.

Fig.19.Comparison of thermal efficiencies of all solar stills.

Fig. 20. Outcomes of economic analysis.

The principal investment was considered by taking the amount of each part of the solar still according to the Indian trade value. The capital cost was calculated by considering all the fabrication, maintenance and operation costs. The cost-effectiveness of both the solar stills was estimated using economic analysis and listed in Table 2. From Table 2, it was observed that the cost per litre (CPL) was about ₹ 3.1, ₹ 2.9, ₹ 2.8, ₹ 2.6, ₹ 2.6, ₹ 2.2, ₹ 2.1, ₹ 1.9 and the payback periods were about 6.8, 6.7, 6.4, 5.9, 5.9, 5.1, 4.7, 4.4 months for CSS, SSMP, SSRH, SSBS, SSBL, SSSD, SSRS and SSSDRS, respectively. The outcomes of the economic analysis of current research were plotted in Fig 20. The outcomes of the economic analysis were compared with existing literature and tabulated in Table 3 which infers that this research paves a way for the most economical approach to enhance productivity as the payback period and cost per litre is the lowest in this research. As a whole, the inclusion of low-cost and eco-friendly natural materials in the absorber basin and condensing glass plate is economically viable and sustainable.

Table 2. Parameters and outcomes of Economic Analysis.

Parameters	CSS	SSMP	SSRH	SSBS	SSBL	SSSD	SSRS	SSSDRS
P. I	₹ 9000	₹ 9200	₹ 9200	₹ 9200	₹ 9200	₹ 9200	₹ 9200	₹ 9400
I (years)	10	10	10	10	10	10	10	10
i	15%	15%	15%	15%	15%	15%	15%	15%

CRF	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
FAC	1800	1840	1840	1840	1840	1840	1840	1880
SF	88.8	90.78	90.78	90.78	90.78	90.78	90.78	92.76
MC	270	276	276	276	276	276	276	282
AC	1981.1	2025.2	2025.2	2025.2	2025.2	2025.2	2025.2	2069.2
CPL (₹)	₹ 3.1	₹ 2.9	₹ 2.8	₹ 2.6	₹ 2.6	₹ 2.2	₹ 2.1	₹ 1.9
PBP (months)	6.8	6.7	6.4	5.9	5.9	5.1	4.7	4.4

Table 3. Comparison of viability with the available literature.

Parameters	Current Study (SSSDRS)	(Modi and Modi 2019)	(Suraparaju and Natarajan 2021a)	(Nayi and Modi 2020)	(Raj et al. 2020)
CPL	₹ 1.9 / \$0.025	₹ 2.4	₹ 2.1	₹2.65	-
PBP	4.4 months	15 months	8.3 months	11.28 months	2.30 years

6. Conclusions

In this research, an experimental investigation of eight single slope solar stills had been evaluated at NIT Puducherry, Karaikal, India. The single slope solar stills considered for the experimental assessment were; i) Conventional Solar Still (CSS), ii) Solar Still with Molasses Powder (SSMP), iii) Solar Still with Rice Husk (SSRH), iv) Solar Still with Sawdust (SSSD), v) Solar Still with Bamboo Straw (SSBS), vi) Solar Still with Banana Leaf Stem (SSBL) and vii) Solar Still with Rice Straw (SSRS) and viii) Solar Still with Sawdust and Rice Straw (SSSDRS). The conclusions made from the current research were as following,

- The inclusion of Molasses Powder, Rice Husk and Sawdust in the absorber basin augmented the evaporation rate of seawater and thus the freshwater productivity was enhanced compared to CSS. The respective increase in the water temperature with the inclusion of these materials was about 3%.
- The glass cover cooling was significantly enhanced by Bamboo Straw, Banana Leaf Stem and Rice Straw which augmented the freshwater productivity compared to CSS. The respective decrease in the glass cover temperature with the inclusion of these materials was about 40%.
- The enhancement of evaporation and condensation rates by using the sawdust and rice straw simultaneously in the solar still resulted in a notable enhancement of productivity by 62.88%.

- The productivities of CSS, SSMP, SSRH, SSSD, SSBS, SSBL and SSRS were about 2250 mL/m², 2383 mL/m², 2467 mL/m², 3033 mL/m², 2700 mL/m², 2683 mL/m², and 3367 mL/m², respectively.
- The SSSD had a comparatively better evaporation rate and 34.81% higher yield than CSS. Besides, SSRS had a comparatively better condensation rate and a 51.88% higher yield than CSS.
- Later, the combination of sawdust (SD) and rice straw (RS) was investigated for combined enhancement of evaporation and condensation. The solar still with sawdust and rice straw (SSSDRS) showed a 62.88% improvement in productivity with 3633 mL/m² when compared to CSS.
- The overall thermal efficiencies of the CSS, SSMP, SSRH, SSSD, SSBS, SSBL, SSRS and SSSDRS were about 36.17%, 38.32%, 39.96%, 48.77%, 43.41%, 43.41%, 54.13% and 59.68%, respectively.
- The economic analysis of the eight solar stills was assessed and the cost of production per litre of fresh-water was about ₹ 3.1, ₹ 2.9, ₹ 2.8, ₹ 2.6, ₹ 2.6, ₹ 2.2, ₹ 2.1, ₹ 1.9 and the payback periods were about 6.8, 6.7, 6.4, 5.9, 5.9, 5.1, 4.7, 4.4 months for CSS, SSMP, SSRH, SSBS, SSBL, SSSD, SSRS and SSSDRS, respectively.

It has been concluded from the above observations that the Solar Still with Sawdust and Rice Straw (SSSDRS) had enhanced the evaporation and condensation rate simultaneously when compared to all other considered cases. Also, the potable water yield from the SSSDRS was comparatively better than all other considered cases. The economic analysis also evidenced that the SSSDRS was economically viable. From the above inferences, it can be concluded that SSSDRS has a promising capability to desalinate the seawater in an economic way and without causing any environmental pollution. Also, this work can be extended with other natural fibres with potential physio-thermal properties for enhancing the evaporation as well as condensation rate.

Declarations

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Consent for Publication: Not applicable

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CRedit authorship contribution statement:

632 *Sendhil Kumar Natarajan*: Conceptualization, Validation, Resources, Writing - Review & Editing, Supervision,
633 Project administration.

634 *Subbarama Kousik Suraparaju*: Conceptualization, Formal analysis, Investigation, Data Curation, Visualization,
635 Writing - Original Draft.

636 *Rajvikram Madurai Elavarasan*: Validation, Writing - Review & Editing.

637 *Rishi Pugazhendhi*: Formal Analysis, Writing - Review & Editing.

638 *Eklas Hossain*: Writing - Review & Editing.

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