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Evaluating the influence of coir fibres on solar still efficiency and economic viability

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Abstract. The primary objective of this study is to determine the Coir fibres (CF) utilization in solar stills (SS) to boost the quantity of freshwater production. By placing dry CF fibres in the absorber basin, researchers were able to accelerate the rate at which water evaporated from the SS. Under various CF densities, the freshwater production of the absorber basin was measured (8, 11, 14, 18, 20, 23, and 26). The outcomes demonstrated that yield was raised by 27.23 percent after 18-fiber SSCF was added to the absorber basin. There were 14.27 percent, 19.40 percent, 24.57 percent, 25.00 percent, 16.28 percent, and 6.23 percent yield improvements for solar stills with 8, 11, 14, 18, 20, 23, and 26 fibres in the absorber basin, respectively, as compared to a CSS. The results demonstrate that compared to CSS, the cost to produce one litre of freshwater with SSCF is reduced by 23.1%. The return of investment for SSCF is much more immediate than it is for CSS. An estimated ₹242 was needed to produce 1 litre of freshwater using CSS, while an estimated ₹199 was needed to produce 1 litre of freshwater using SSCF. The payback time for SS was only 6.23 months, which was significantly less than that of solar panels. CF are preferable to other materials for use in the solar still due to their lower cost and higher energy efficiency.

Keywords: Coir fiber, solar still, efficiency, production, economic viability.

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1 Introduction

The demand for freshwater from human, agricultural, and industrial sources is on the rise, but the supply is quickly dwindling. One possible option is to desalinate the easily accessible seawater to produce drinkable freshwater [1]. When it comes to desalination, a solar still is one of the most budget-friendly options [2]. The solar still is simple in design and operation. Desalination using a solar still saves money and is better for the environment [3]. Researchers from all over the world are working to improve the efficiency of solar stills by coming up with new ways of doing things, such as using fins and energy storage materials (ESM) [4]. Cover plate transmittance was found to have an impact on SS water production, as explored by researcher [5]. Partial-current-modulation was used to measure the effectiveness of a solar still that included a concentrator. Even after making the necessary changes, solar power increases output by 26 %. Author [6] examined the properties of various wick materials in an effort to maximize distillate production. The fluid coral swindle and the obstacle combine-stepped absorbing plate produced a maximum daily production of 6.23 L [7]. In recent studies [8], scientists investigated the feasibility of employing gravel's coarse aggregate as a storage medium for energy, hence boosting the production of solar stills. Increased to 4.21 kg/m^2, the solar still's production was nearly double that of a standard solar still (2.21 kg/m^2). Using a heat pump and a wide variety of energy-storage materials, researchers [9] replicated the functioning of a regenerative SS. In terms of efficiency and yield, numerical studies have shown that enhanced solar continues to surpass CSS. The effects of Gr plates and bulk magnetic performance on SS were analysed by the author [10]. An increase in hourly yield of 19.6 percent in the summer and 22.8 percent in the winter was discovered after the upgraded solar still was implemented. There was evidence that using graphite fins and magnets could decrease solar panel efficiency [11]. The improved solar system was found to increase output by 19.6 percent. Researchers [12] looked into how solar stills fared when exposed to Al_2O_3 micro/nanoparticles. When compared to microparticles and CSS desalination, the performance of Al_2O_3 nanoparticle solar was still superior. A SS using a jute and cotton wick was tested by the researcher [13]. The use of jute cloth in place of cotton fabric pile was found to boost solar still output by 21.46 percentage points. Coir fibres' potential impact on a SS performance was investigated [14]. As more fibres were placed in the SS absorber basin, its production decreased. The effectiveness of SS was examined in relation to the addition of algae like Spirulina. Using Spirulina algae in place of CSS increased solar energy production by 30.24 percent, according to the study's findings [15]. Researchers [16] have looked into ways to maximize the freshwater output of SS by optimizing physical characteristics such the glass cover tilt angle, the water depth in the basin, and the reflector's orientation. ESM, nanoparticles, and fins [17] were employed by a team of researchers to boost the efficiency of solar stills. Porous materials, including wicks and cloths, can boost evaporation rates by increasing wet surface area, although this fact has received surprisingly little attention. Additionally, the authors [18] did an experiment in which he placed Coir fibres in the absorber basin of an SS and found that the freshwater production was only marginally lower than that of a regular SS. The absorber's excessive size (nearly 65 % with 40 fibres) prevented as much sunlight from reaching the water as was ideal [19]. The decrease in output was caused by the prolonged time required to heat the seawater in the absorber basin. This research looked into the optimal quantity of CF to add to the absorber basin in SS to rise the production of freshwater. SS with a single incline were developed to test the efficacy of coir fibres in increasing solar still output. The number of fibres used was determined by the percentage of the absorber basin that was actually used. Researchers conducted trials in March 2023 utilizing 8, 11, 14,18, 20, 23, and 26 coir fibres and compared the results to those from regular solar still testing.

2 Experimental system and experimentation

Researchers hypothesized that increasing the amount of coir fibres used would boost production, so researchers built two single-slope SS and put them to the test. The two prototype solar stills that were made are as follows:

- CSS
- SSCF

2.1 Production and materials

To prevent the plywood used in the CSS from being damaged by moisture vapor, an aluminium layer 0.2 millimeters thick was applied to it. To maximize its sun absorption and consequently its effectiveness in the solar still, the aluminium sheet was sprayed with conventional black paint. An absorber basin constructed of copper sheets was a part of the system, and it was 1 width, 1 length, and 0.5 meters depth (width * length * height = 0.6 m^2 absorbing area). The SS features a glass solar collector. The glass was tilted at a latitude appropriate for Chennai to ensure smooth operation of the mechanism. According to the published works [20-21], the production of the solar still decreased because the fibres took up about 65 % of the absorber basin. The authors chose the figures of 25, 20, 15, 13, and 10 fibres for the absorber's proportion of space occupation (45, 35, 25, 20, and 15 % respectively). Based on the results, more experiments were undertaken using 14 and 16 fibres to determine the best number of fibres for increasing freshwater yield. Coir fibres were placed in the SS-CF absorber basin after seawater was put in. Adding increasing amounts of carbon dioxide to the water basin was tested to see how it would affect the SS ability to provide drinkable water (9, 12, 15, 18, 21, 24, 27 CF). To reduce heat loss, the whole outside of the setup was covered in Thermocol sheets. Both experiments were installed on the solar array at India. Finished desalination facilities on a single slope are depicted in Fig. 1.

2.2 Preparation of coir fibres

Finding out if coir fibres can be employed to boost the performance of a solar still is the key motivation behind this research. Over the past two decades, the market has been saturated with coir fibre due to the increased demand for sustainable materials. Because of their light weight, adaptability, and absorbency, coir fibres are utilized as fillers in the production of composites, as well as sponges in the kitchen and bathroom. Coir fibre can only be extracted from dry coir by further processing.

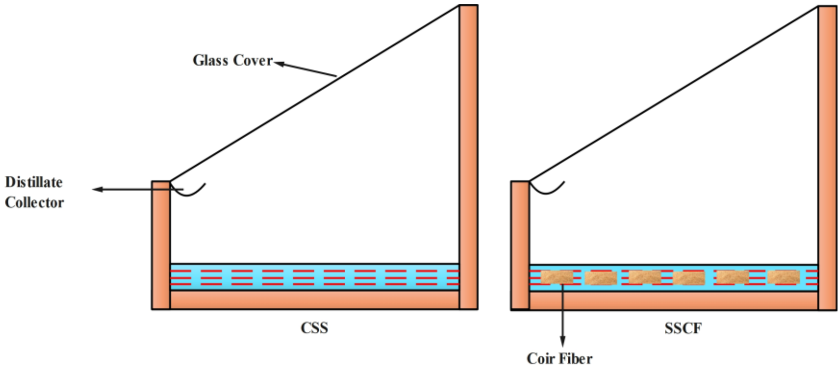


Fig. 1. Illustration of a CSS/SSCF experimental setup based on a schematic.

2.3 Characteristics of the coir fiber

A material's evaporation rate can be increased by modifying its permeability, absorption, capillary development, and heat exchange coefficient, among other properties. Different approaches to characterizing the content are studied at length in the academic literature [22].

2.3.1 Porosity

The desalination procedure relies heavily on the natural fiber's porosity. The absorber basin's seawater is heated, increasing its evaporation rate beyond that of the natural fibre. The porosity of a CF is determined by the volume of its pores, which may be calculated using Eqs. (1)-(3). It has been determined that each coir fibre is 6.7 % permeable.

$$\Phi = \frac{V_p}{V_{bk}} \tag{1}$$

where, V_p and V_{bk} - Pore volume (m^3) $V_P = \frac{W_w}{\rho_{ww}}$ (2)

$$W_w = W_{sat} - W_{dry} \tag{3}$$

where,

W_w - porosity water weight
W_{sat} - Saturation weight
W_{dry} - dry weight
ρ_w – Density of Water
Bulk volume (m^3) $V_{bk} = l * b * t$ (4)

2.3.2 Increase in Capillary

If researchers assume that the surface tension of water is 74 mN/m, then researchers can use equation (5) to evaluate the corresponding capillary increase in CF [23-24].

$$h = \frac{q}{\Delta T} (\mathrm{~W/m^2~K}) \tag{5}$$

where

θ = The contact angle.
g = gravity
ρ = density
T = surface tension
h = A measurement of the capillary's liquid's height
r = radius (bore) of the capillary

2.3.3 Heat transfer coefficient

The equation describes the heat transfer from the glass cover to the wet wick absorber.

$$h = \frac{q}{\Delta T} (\mathrm{~W/m^2~K}) \tag{6}$$

where
h = coefficient of heat exchange
q = rate of heat exchange from the solar (in W/m^2)
ΔT = Difference (in Kelvin) between the material and glass temperatures.

2.3.4 Water absorbency

To absorb water means to undergo a change in state or transformation into another material quickly. The time it took for one drop of water to be absorbed was used to calculate the material's water-holding capacity. It was also determined that the rate of capillary growth was roughly 5.8 mm/h. The characteristics of CF and other commercially available fibres are compared in Table 1.

Table 1. Coir fibre characteristics in comparison to other fibres

Material	Heat exchange coefficient (W/m^{2}K)	Absorbency (s)	Porosity (%)	Capillary rise (mm/h)
Jute cloth	16.5	129	17.3	10
Cotton	37.0	1	29.6	120
Wood pulp paper	38.4	2	18	66
Coir fibres	47.69	3	6.9	5.9
Coconut coir disks	38.42	2	74.26	10

2.3.5 Experimental analysis and analysis on uncertainty

Both of the aforementioned configurations had their solar stills pointing south. When saltwater reaches a depth of 2 centimeters in the absorber basin, its effectiveness is at its peak [25]. The impact of CF on SS output was evaluated in March 2023 through tests of both CSS and SSCF. In order to keep track of the temperatures of the glass cover, absorber, salt water, CF, and ambient air, a "data collection system" was set up using K-type thermocouples. Background radiation levels were measured using a 'Pyranometer' to keep track of daily and regional averages. The increased absorption phenomena made possible by coir fiber's higher surface area led to greater evaporation, which in turn increased freshwater productivity more so than CSS. From 8:30 a.m. to 4:30 p.m on March 21st-27th, 2023, measurements were obtained every half an hour. To reduce the likelihood of errors occurring during the experimental study, many safeguards were put in place. These precautions were taken: After carefully inspecting the solar still and the absorber, no leaks were discovered. Dust and other probable radiation-blocking imperfections were painstakingly looked for on the clean glass and eliminated. Carefully poured saltwater brought the absorber basin up to the correct level. Researchers made exact measurements of temperature, fresh water production and global radiation every half an hour. The following calculations can be used to calculate the efficiency and margins of error of the hourly freshwater output. Evidenced by their studies [26].

$$u_\eta = \left[\left(\frac{\partial \eta_d}{d_w} \times u_{d_w}\right)^2 + \left(\frac{\partial \eta_d}{I(t)} \times u_{I(t)}\right)^2\right]^{\frac{1}{2}} \tag{7}$$

The uncertainty in hourly output is represented by

$$\mathrm{u}_{d_w} = \left[\left(\frac{\delta \mathrm{d}}{\delta \mathrm{y}_1} \mathrm{u}_y\right)^2\right]^{\frac{1}{2}} \tag{8}$$

$$\mathrm{u}_{d_w} = \left[\left(\frac{\mathrm{d_i} - \mathrm{d_f}}{\delta \mathrm{y}_1} u_y\right)^2\right]^{\frac{1}{2}} \tag{9}$$

Whereas

$\mathrm{d_i}$ and $\mathrm{d_f}$: hourly yield at the starting and ending
$\mathrm{u_y}$: percentage of yield uncertainty.

An uncertainty of +1.5 percentage points was calculated for the entire yield, with the hourly yield uncertainty hovering around 1 percent. Temperature and sun radiation measurements both had errors of less than 0.1 percent. This means that the solar still's claimed overall efficiency is likely off by roughly 2 percent.

3 Results and discussions

Researchers conducted trials using conventional solar still and SSCF to analyze the effect of fibres on solar still output in March 2023. In this study, researchers compared the success rates of SSCF and CSS. In the SSCF absorber, CF fibres with varying densities are employed. The seven data sets were recorded simultaneously using a standard solar still by the authors.

3.1 Global radiation and system temperatures

The full range of readings from 8:30 AM to 4:30 PM were included. From the 14th through the 27th of March, 2023, daily fluctuations in global solar radiation (Fig. 2(a)) and ambient temperature (Fig. 2(b)) are presented. Mean sun radiation at the testing site ranged from 300 W/m2 to 670 W/m^2 as shown in Fig. 5. Researchers measured a high of 666 W/m^2 and a low of 312 W/m^2 for solar radiation. Between midday and 14:30, most locations had peak solar power levels of around 1,000 W/m^2. Fig. 2 shows that daily average temperatures ranged from 25 degrees to 34 degrees Celsius. Air temperatures averaged around 40 degrees Celsius throughout the evaluation period. On each day of the studies, it was also discovered that the average temperature experienced significant diurnal (morning-to-evening) changes.

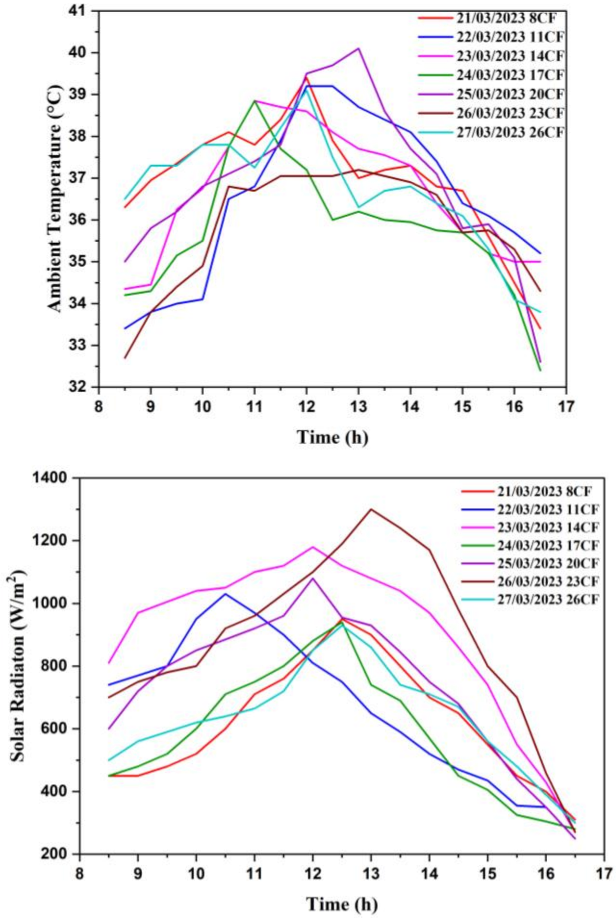
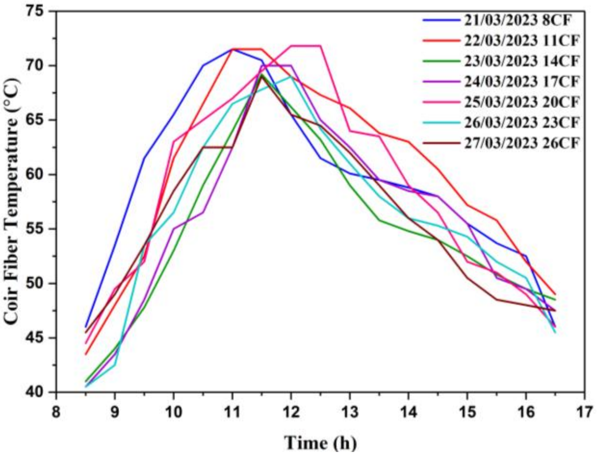


Fig. 2. Analyzing (a) daily variations in ambient temperature and (b) daily variations in solar radiation.

Each variable's recorded temperature was also included. The transition from day to night is graphically depicted in Fig. 3(a) - (d) alongside the temperatures measured by both systems. Fig. 3 (d) establishes that the glass surface temperature of a CF fibre SS is lower than that of a conventional still. The incident occurred because the CF structure in the basin water absorbed a lot of the energy from the internal permitted convectional currents. Despite claims that CSS can reach temperatures as high as 66.3 degrees Celsius, SSCF can only get its glass to 60 degrees Celsius. The surface temperature of glass was found to be significantly affected by both the magnitude of the temperature of ambient and the degree of isolation. Fig. 3 (b) displays that the SSCF had significantly warmer water than the CSS. The absorber, CF fibres, and water were able to convert the sun's rays into usable energy after being exposed to them through an open window. The water inside the absorber gets hot because of its ability to retain energy. Energy collected by the fibres is quickly dispersed into the water due to the low thermal mass of the basin. On all trial days, the SSCF had a higher water level than the CSS because the fibres absorbed more energy. The maximum temperature ever measured in SSCF and CSS are 66.8 and 65.8 degrees Celsius, respectively.


21/03/2023 8CF
22/03/2023 11CF
23/03/2023 14CF
24/03/2023 17CF
25/03/2023 20CF
26/03/2023 23CF
27/03/2023 26CF
Coir Fiber Temperature (°C)
75
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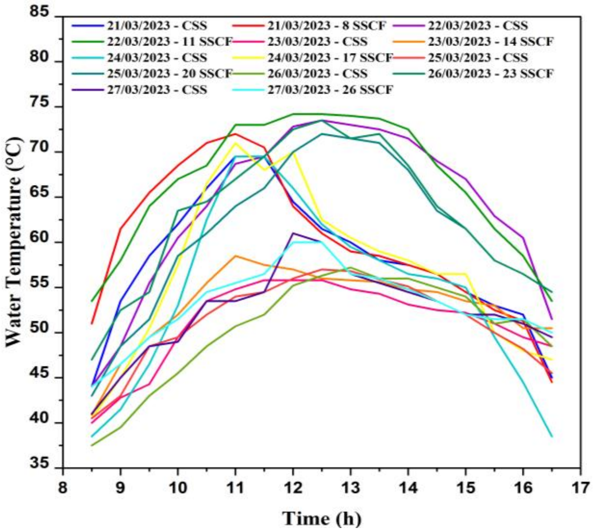
Time (h)


21/03/2023 - CSS
21/03/2023 - 8 SSCF
22/03/2023 - CSS
22/03/2023 - 11 SSCF
23/03/2023 - CSS
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24/03/2023 - CSS
24/03/2023 - 17 SSCF
25/03/2023 - CSS
25/03/2023 - 20 SSCF
26/03/2023 - CSS
26/03/2023 - 23 SSCF
27/03/2023 - CSS
27/03/2023 - 26 SSCF
Water Temperature (°C)
85
80
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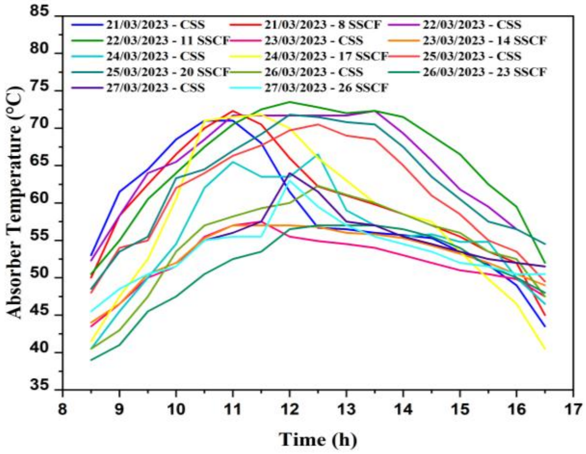
Time (h)


21/03/2023 - CSS
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26/03/2023 - CSS
26/03/2023 - 23 SSCF
27/03/2023 - CSS
27/03/2023 - 26 SSCF
Absorber Temperature (°C)
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Time (h)

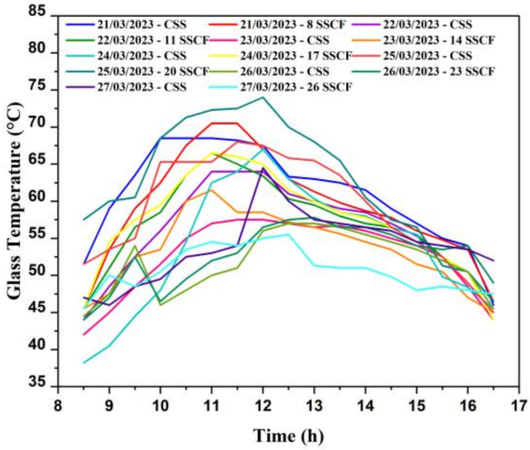

Fig. 3. Testing temperatures on different days for (a) coir fibre, (b) water, (c) the absorber, and (d) the glass.

The absorber temperature of the CF-fibered SS was higher than that of a CSS. Discrepancies in temperatures are shown in Fig. 3(c). The absorber basin was heated to greater temperatures than a regular still would need because dry CF fibres were used in each scenario. Maximum absorber basin temperatures for both CSS and SSCF reached 64.9 degrees Celsius. The highest surface temperature of CF fibres, 64.2 degrees Celsius, is shown in Fig. 3(d). CF fibre surface temperature was demonstrated to vary with fibre concentration. The highest temperatures reached by the fibres during the testing period were between 61.3 and 64.2 degrees Celsius. CF fibres evaporate quicker than other materials due to their higher surface temperature and porous structure. The temperatures of the CF and the water in the absorber basin were relatively stable over the course of each day of testing. From 8:30 a.m. to 12:30 p.m, temperatures in the CF increased, peaked at 1:30 PM, and subsequently fell to their lowest point by 4:30 p.m (Fig. 3(d)).

3.2 Productivities of the SS

The SS's ability to produce potable water was enhanced once CF fibres were added to its absorber basin. Coir (CF) fiber's absorptive qualities hastened the seawater's departure from the basin. Its porous structure allowed it to absorb seawater and quickly release the moisture through evaporation. More fibre samples were added to the system, which helped reduce evaporation. The water in the basin was protected from the sun's heat by the presence of the extra fibres. Absorber fibres may have CF variation, yet SSCF is still more productive than CSS. Despite the solar still's higher operating temperature, its maximum output and evaporation rate were both higher than those achieved by the CSS. In Fig. 4, researchers can see the combined output of the two SS from 8:30 a.m. to 4:30 p.m. The freshwater productivity of SSCF is shown to be higher than that of CSS in a histogram presented in Fig. 5. Fig. 4 displays that after 10:30 a.m., the cumulative yield began to rise. Between 11:30 a.m. and 4:30 p.m., the rate of freshwater production was maximum, and then it gradually fell until it stopped altogether. Fig. 5 displays that the freshwater result is 26.34 percent higher when there are fifteen CF fibres in SSCF compared to CSS, and that the difference decreases to 14.27 percent, 19.40 percent, 24.57 percent, 25.00 percent, 16.28 percent, and 6.23 percent for 8, 11, 14, 17, 20, 23 and 26 CF fibres, respectively. Fig. 5 illustrates that the maximum and minimum freshwater production from a solar still occur when the number of variant fibres is increased from 10 to 18.

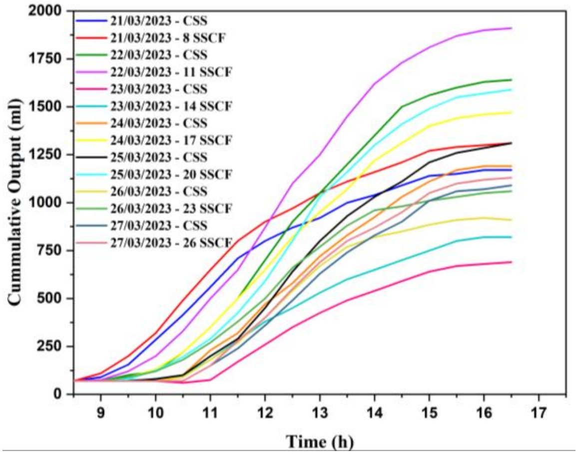

Fig. 4. Accumulated production of various solar stills on various dates.

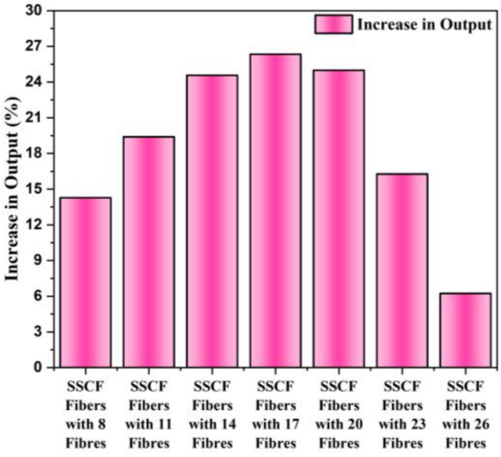

Fig. 5. The percentage rise in yield was calculated using different densities of coir fibre.

Having 40 times as many CF fibres in a solar still reduces its efficiency, according to studies [27], since the water in the basin absorbs more light. As can be seen in Fig. 4 and 5, the freshwater output of the solar was significantly increased after CF were added. Because CF fibres are so good at soaking up moisture, including more of them in a solar still means less water is lost to evaporation. Based on the solar still's design and the CF fibres selected, the researchers may conclude that the solar still coir fiber with 18 fibres yields the greatest output.

3.3 Increases in both evaporation rate and coir fiber production

The SS's capacity to produce drinkable water was greatly enhanced after CF was added to the absorber basin. Capillary motion kept refilling the absorber basin, but the natural fibres still lost some water to evaporation. Solar radiation warmed the absorber's water as well as the fibres. Warmer water is the result of CF fibers' higher heat transmission coefficient. The fiber's porosity meant that a greater volume of water could be absorbed into the absorber before it quickly dissipated. Because the fibre improves capillary enhancement, absorption, penetration, and the heat exchange coefficient, SSCF systems are superior to CSS systems in terms of efficiency. Fewer fibres in the basin of the absorber were associated with better evaporation performance. Because the fibres soaked up more water than necessary, heating them together took longer than intended. Less heat from the sun was delivered to the water because a wider area was covered by the absorber's fibres. The study's authors say they were able to maximize evaporation rates with a certain number of absorber fibres by strategically arranging those fibres in the basin. With the addition of fibres to the absorber basin, SSCF was proven to be more efficient and produce more energy than CSS. In addition, the highest output of potable water was obtained from the best design, which incorporated fibres [28].

3.4 Water quality analysis

The authors collected saline and fresh water samples to evaluate the water supplied by the CSS and SSCF. The data is summarized in Table 2. The measured values were compared to those established by the Bureau of Indian Standards (BIS). BIS assessed the distillate's properties to be within the acceptable range.

Table 2. Water quality factors

Factors	Sea water	CSS	BIS	SS with CF
pH	8.8	7.7	6.8 – 8.8	7.7
TDS	34,000 ppm	130	60 – 260	130

4 Conclusions

In this experimental study, researchers used both the SS with CF and the standard solar still as our two still types of choice. Theoretically, the SS output would increase when the number of CF utilized was increased from 8, 11, 14, 17, 20, 23, and 26. The investigation uncovered some interesting facts, such as: When testing SS with absorber basins having different numbers of CF samples, 18 was determined to be best. Fibre occupancy rates of 25 % in the absorber basin were shown to be the most effective, exceeding rates of 45 %, 35 %, 20 %, and 10 %. When 25 CF fibre samples were put in a solar still, the evaporation rate dropped and the water absorption capacity rise. Since more fibre was added to the absorber, freshwater productivity went down. Increases in freshwater yield were 14.27 % for SSCF with 18 CF fibre samples, 19.40 % for SSCF with 15 fibres, 24.57 % for SSCF with 21 fibres, 25.00 % for SSCF with 24 fibres, and 6.23 % for SSCF with 27 fibres compared to CSS. The energy usage of all evaluated SSCF systems is greater than that of CSS. Cost estimates for generating one liter of freshwater with SSCF were about ₹199, while those for CSS were about ₹242. The payback period for SS was 6.23 months, whereas that for solar panels was 6 months. Because of their low cost and strong energy and exergy performance, CF are favored in the SS.

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