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Comparative 3E Analysis of Semi-Cylindrical Solar Still and Double-Slope Solar Still

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Abstract

Potable clean water is the prime requirement for the human being. There is an urgent requirement to shift to the non-conventional method of water desalination. Solar desalination is one of the economical methods that has no adverse effect on the environment due to environmental constraints and climate change. Experiments have been performed to find out the performance of SCSS (semi-cylindrical solar still with iron wick) and DSSS (double-slope solar still with jute wick). The experimental results show good hourly and cumulative productivity of the Stills. The cumulative yield of SCSS is 44.35% more than DSSS. The maximum energy and exergy efficiency received for SCSS are 47.92% and 18.28% respectively. The cost per litre (CPL) of SCSS is also low which is 0.88 Rs./lt.

Keywords: Solar still, desalination process, energy, exergy, economic analysis

INTRODUCTION

The use of potable water is a major global problem. Saline and brackish water are widespread throughout the world, and developing countries are keen to use solar desalination processes to obtain potable water. Solar energy is available in ample amounts, and no harmful gases are released during the desalination process [1]. There are conventional methods of water desalination but that is the reason for pollution. This directly affects the environment through the release of GHGs. Solar desalination is one of the best methods to obtain potable water. In this method, no conventional fuel is burned, but the energy of the sun is trapped inside the solar still, where this energy is used to evaporate the water inside the still, and condensation occurs inside the glass cover of the still [2]. The scarcity of potable water is due to rapid industrialization, urbanization, and population growth. The available water on the Earth is limited which is 2.5% for consumption. The remaining 97.5% of water is saline and brackish, which cannot not directly useful for any purpose [3]. The water available for human use is either supplied by municipal or other rural authorities, not by drinking water. There is a common idea that boiling water can reduce contamination as well as salts, and there is a need for several stages of boiling, but solar desalination provides a very good option in which we obtain distilled water without harming the environment and can get around 3-5 lit of water per day [4]. Millions of people do not get potable water for several reasons. The quality of groundwater also deteriorates daily. Developing countries, such as Asia and Africa, face a major problem with potable water [5]. Several factors influence still yield, such as ambient temperature, humidity, solar insolation, and wind velocity [6]. Different wick materials were used to increase the yield of stills. During the investigation, black cotton was used as a wicking material and showed superior productivity compared to jute, cotton, stones, etc. [7]. K. Kalidasa Murugavel and K. Srithar in their investigation

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found that when a fin is covered with wick material, it improves the yield of the still. He used different wick materials, in which black cotton clothes showed improved yields [8]. Water coral fleece materials are also good wick materials, as per the investigation conducted by Hansen et al. During his investigation, he found that when fleece materials with 69.67% porosity were used, productivity increased by 71.2% [9]. In another investigation performed by Shraavana A. and Murugan, they found that when woollen cloth is used as a wicking material, it yields more productivity than polystyrene, terry cotton, and jute material [10]. Sharshir et al. investigated the effect of different factors on the performance of still-like wick materials, reflectors, use of Phase Change Material (PCM), stepped tray arrangement, and the use of nanoparticles. The impact of all arrangements was positive in terms of yield [11].

EXPERIMENTAL SETUP AND METHODOLOGY

Two different types of solar stills were fabricated to experiment on solar stills. All solar stills have a common basin material of the GI Sheet. The MDF board and plywood were used to surround the basin to reduce heat losses. Transparent glass with a uniform thickness of 5 mm was used for all solar stills to receive the maximum. The experiment was conducted in June in Bhopal Location. External factors such as wind speed and relative humidity were also considered during the test. There are K-type sensors, and a data logger is used to monitor the temperature of solar stills at different locations inside the stills. The basin, basin water, glass, and vapor temperatures were monitored at intervals of 1 h. All readings were recorded from 7:00 am to 7:00 pm. Different wick materials were used in both experimental setups. In the semi-cylindrical solar still steel wick, a double-slope jute wick was used for experimental purposes (Figure 1).

Theoretical Analysis

Energy Analysis

The energy of the system can be calculated using the formula mentioned below for the entire day. The first law of thermodynamics is the base for this calculation [12, 13].

$$\eta_{\text{th}} = \frac{\sum P_d \times \lambda_{fg}}{A_b \times \sum I_d(t) \times 3600} \tag{1}$$

In this equation

λ_{fg} = Vaporization Enthalpy
A_b =Area of the basin
P_d =Fresh water yield
I_d = Solar Intensity

Figure 1. Experimental setup of SCSS (semi-cylindrical solar still with iron wick) and DSSS (double-slope solar still with jute wick).

Exergy Analysis

The second law of thermodynamics is used to calculate the exergy efficiency of the solar still. Analysis to measure the useful work that can be performed by the system.

$$\sum E_{x,\text{ in}} - \sum E_{x,\text{ out}} = \sum E_x,\text{dest} \tag{2}$$

$\sum E_{x,\text{ in}}$ =Input Exergy
$\sum E_{x,\text{ out}}$ =Output Exergy
$\sum E_x$,dest= exergy destruction rate

$$E_{x,in} = E_{x,\text{ sun}} = A_b I_t \left[1 - \frac{4}{3}\left(\frac{T_{amb}+273}{T_s}\right) + \frac{1}{3}\left(\frac{T_{amb+273}}{T_s}\right)^4\right] \tag{3}$$

T_{amb}=Ambient temperature
$E_{x,\text{ sun}}$ = sun energy of the sun
T_s =Temperature of the Sun estimated at 6000

$$E_x,\text{ out } = E_x,\text{ evap } = \frac{M_{\text{ew}}\lambda_{fg}}{3600}\left[1 - \left(\frac{T_{amb}+273}{T_\omega+273}\right)\right] \tag{4}$$

E_x, evap= exergy of evaporated water.

Exergy Efficiency

The ratio of the exergy of evaporated water to the inlet exergy is known as exergy efficiency [14–17].

$$\eta_{ex} = \frac{E_x,\text{ out}}{E_x,\text{ in}} = \frac{E_x,\text{ evap}}{E_x,\text{ im}} \tag{5}$$

Economic Analysis

Shoeibi et al. [18] and Kabeel et al. [19] in a research paper showed that enhancing the yield of distilled water along with a reduction in the production cost of water in terms of cost per litre (CPL) [20, 21].

The first annual cost (FAC) of the solar still is calculated as

$$FAC = CRF \times P_S \tag{6}$$

The Capital Recovery Factor is Computed by

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{7}$$

Annual Salvage Value

$$ASV = SSF \times S \tag{8}$$

ASV=Annual Salvage Value

SSF= Sinking Funding Factor

S=Salvage Value of Solar Still

$$S = 2 \times p_s \tag{9}$$

p_s=Net present cost of solar stills

Sinking Funding Factor (SSF)

$$SSF = \frac{\boldsymbol{i}}{(\boldsymbol{1+i})^{\boldsymbol{n}}\boldsymbol{-1}} \tag{10}$$

Annual Maintenance Cost is given by

$$AMC = 1 \times FAC \tag{11}$$

Uniform Annual Cost

$$\text{UAC=FAC+AMC-ASV} \tag{12}$$

Cost Per Litre

$$CPL = \frac{UAC}{P_n} \tag{13}$$

P_n= Average annual freshwater yield.

RESULT AND DISCUSSION

Solar insulation and ambient temperature affect the yield of the till. The experiments were performed from 7:00hrs to 19hrs. The value of the insolation varies throughout the day. The maximum insolation during morning is received in the eastern direction while during evening western direction receives the maximum insolation. The ambient air temperature was varied from 23 to 41°C, as shown in Figure 2.

Yield also depends on the humidity of the surroundings. The variation in yield depended on the humidity percentage during the experiment. During morning hours, the humidity was 15%, and the yield was also low. As the insolation increases and the day moves, the humidity % decreases, and the yield increases. The maximum yield was received at 14:00 hrs with 10% humidity and 0.450 litre water for an hour. Figure 3 depicts the relationship between hourly yield and humidity %.

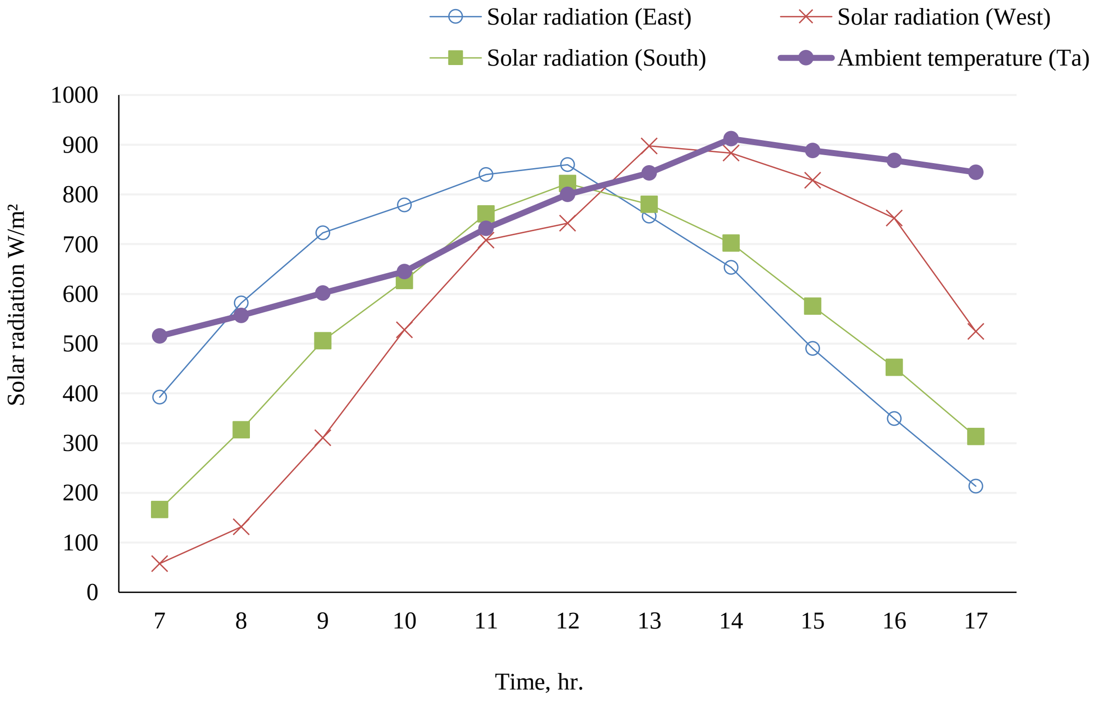

Figure 2. Variation of the solar radiations and ambient temperature with time.

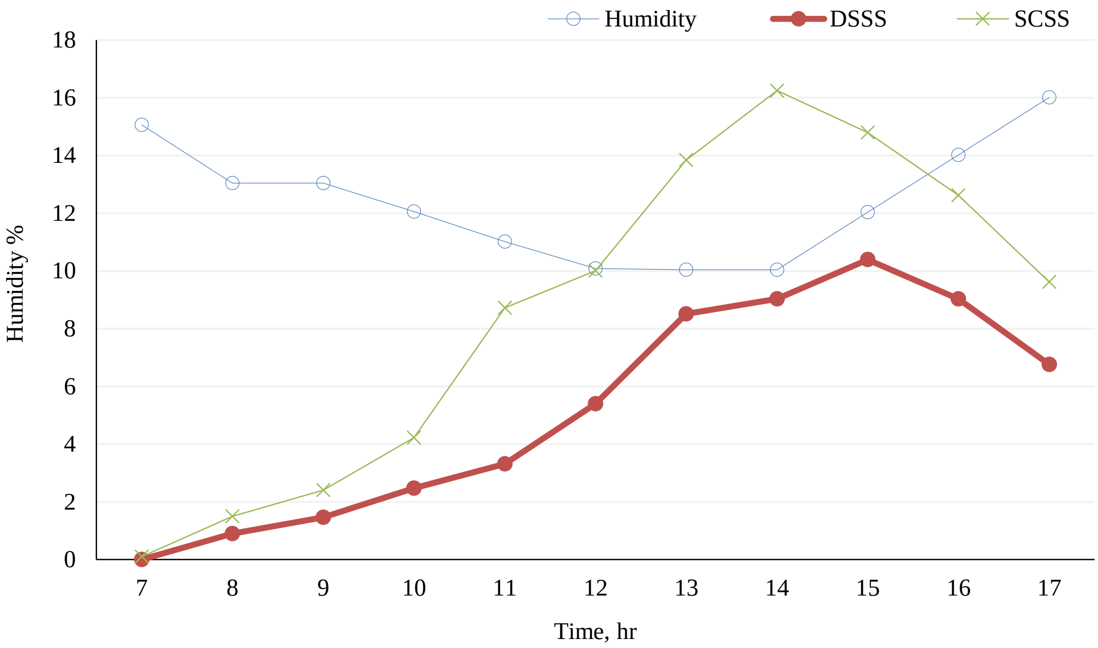

Figure 3. Variation of the hourly yield and relative humidity with respect to time for SCSS (semi-cylindrical solar still with iron wick), DSSS (double-slope solar still with jute wick).

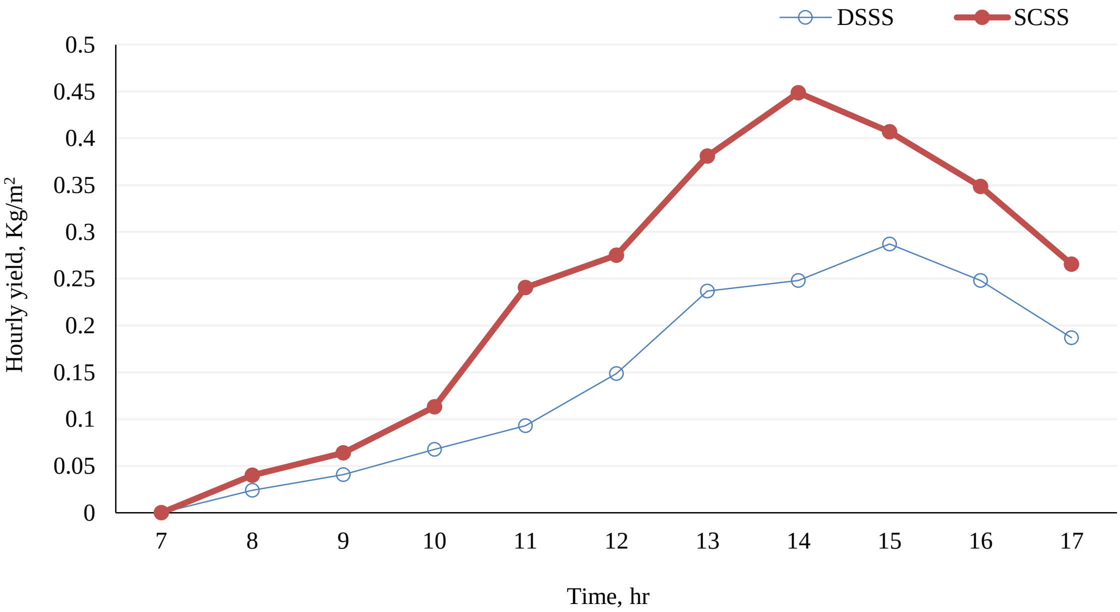

Figure 4. Variation of the hourly yield for SCSS (semi-cylindrical solar still with iron wick), DSSS (double-slope solar still with jute wick).

The hourly productivity still depends on various factors such as solar insolation and ambient temperature. It is clear from Figure 4 that SCSS (semi-cylindrical solar still with iron wick) shows a good hourly output in comparison with DSSS (double-slope solar still with jute wick). In the early hours, the yield of both stills was low, but later started increasing, and after 12:00 hr, both stills received higher output. The highest hourly yield was obtained by SCSS at 14:00 hr.

The cumulative output of different setups depends on the design of the still, the availability of solar insolation, and the ambient temperature of the surroundings. As per Figure 5, it is very clear that SCSS shows the highest cumulative yield in comparison to the DSSS. In the early morning, both stills show lower yields, but with time, all start giving output. The highest yield received for SCSS is 3.58 kg/m^2 which is 38.43% higher than DSSS, as shown in Figure 5.

The energy efficiency of both stills varied over time. This is also dependent on factors such as solar insolation while still working, and the yield of each still. As the insolation increased and yield increased, the efficiency still increased. During the investigation, the highest efficiencies received for SCSS and DSSS were 47.92% and 33.83% as shown in Figure 6.

The exergy efficiencies of the SCSS and DSSS also varied for both stills. Different stills exhibited different exergy efficiencies. As the experiments were conducted, the highest exergy efficiencies received for SCSS and DSSS were 18.28% and 13.88%. The exergy efficiency of the SCSS was greater than that of the DSSS, as shown in Figure 7.

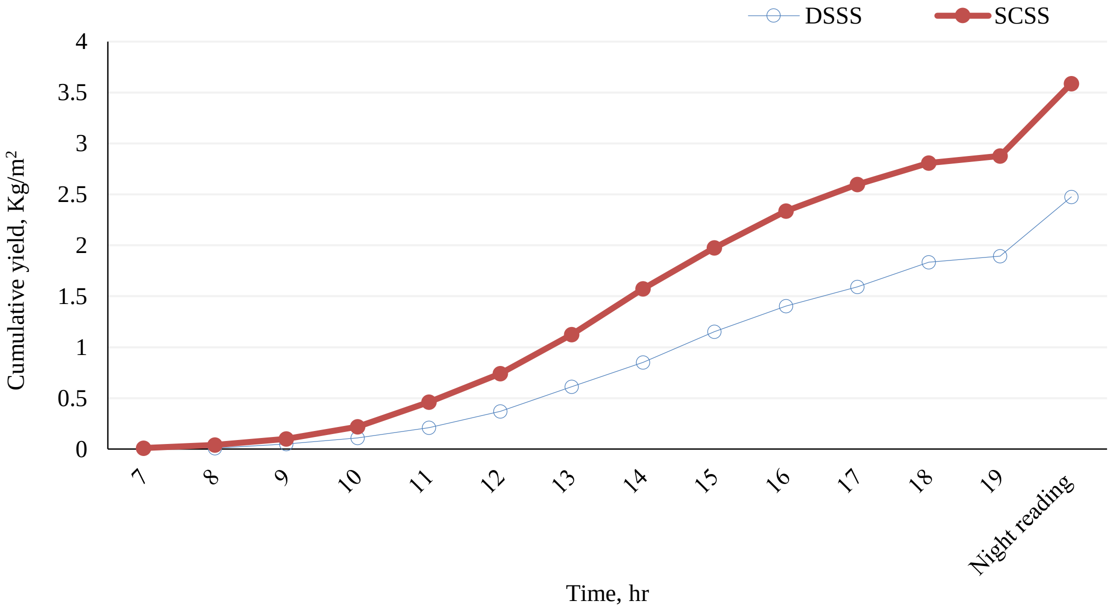

Figure 5. Variation of the cumulative yield for SCSS (semi-cylindrical solar still with iron wick), DSSS (double-slope solar still with jute wick).

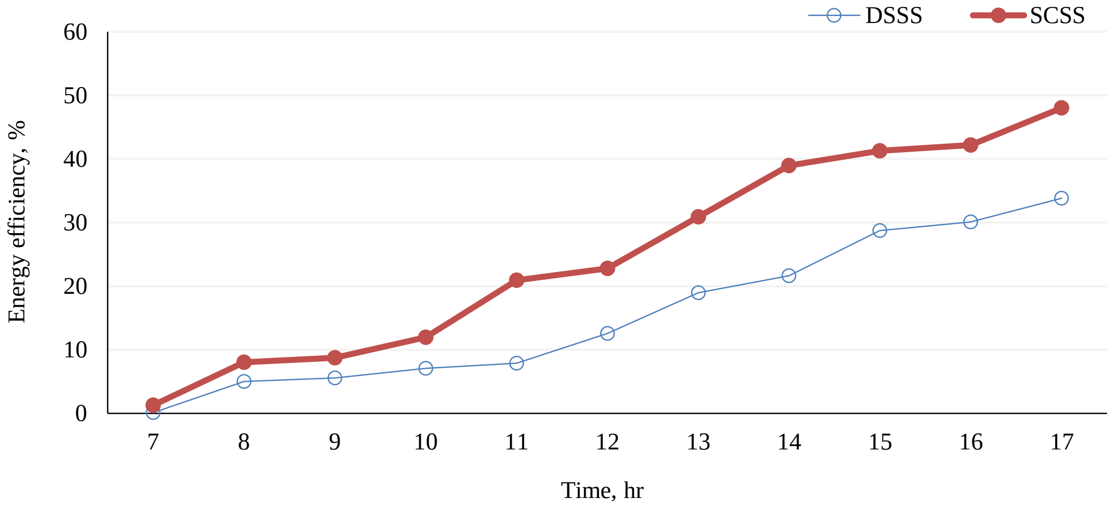

Figure 6. Variation of the hourly energy efficiency for SCSS (semi-cylindrical solar still with iron wick) and DSSS (double-slope solar still with jute wick).

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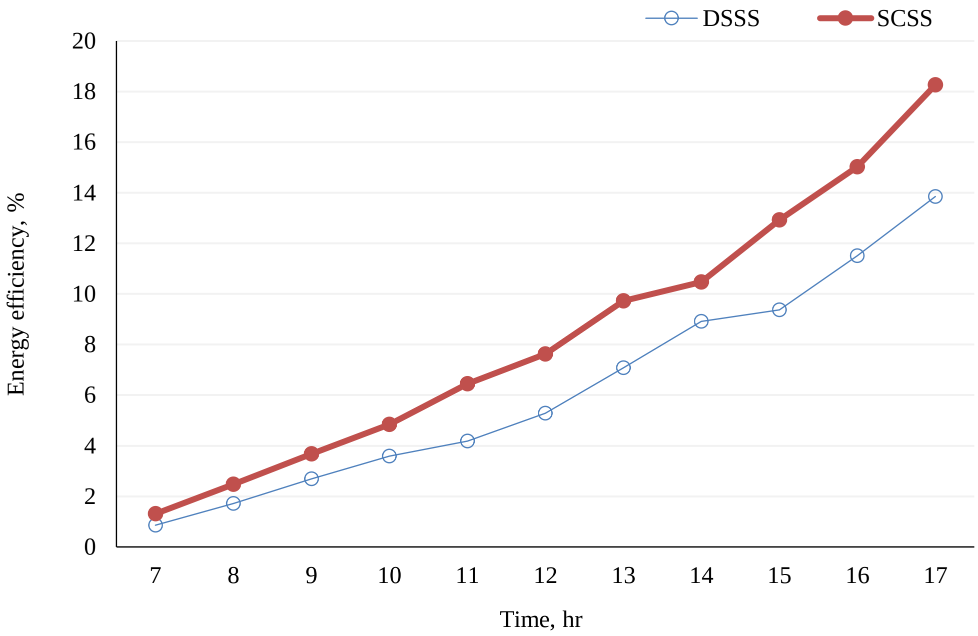

Figure 7. Variation of the hourly exergy efficiency for SCSS (semi-cylindrical solar still with iron wick), DSSS (double-slope solar still with jute wick).

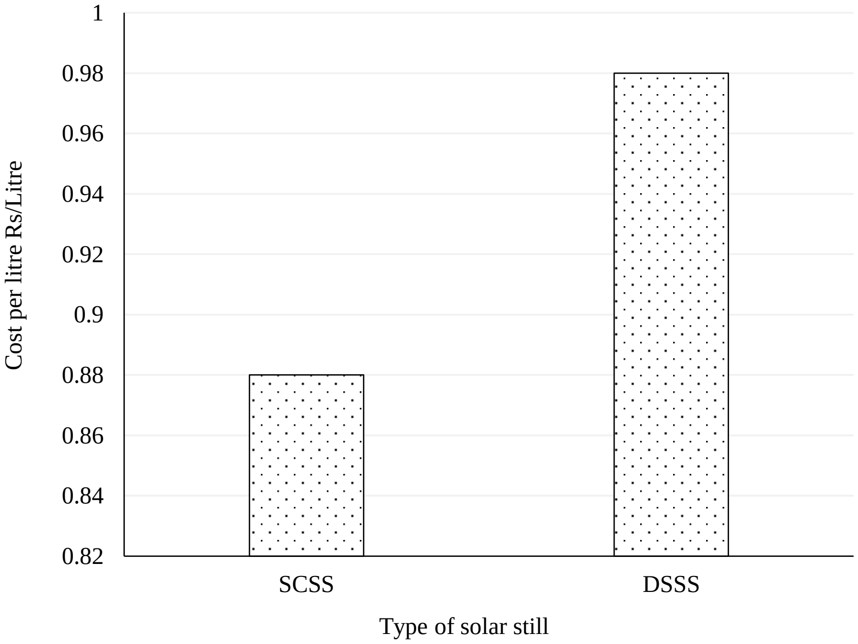

Figure 8. Cost per litre of SCSS (semi-cylindrical solar still with iron wick) and DSSS (double-slope solar still with jute wick).

ECONOMIC ANALYSIS

Cost Per Litre

Table 1 shows that the SCSS is more economical in comparison to the DSSS. The CPL of the SCSS is less than the CPL of the other two solar stills. The economic analysis is mentioned in Table 1. The CPL is very important for stills. Higher productivity still affects the CPL of the Still. According to experimental investigations, the CPL of SCSS is lower than that of DSSS. The CPL of SCSS is 0.88 $/lt. SCSS is more economical than DSSS, as shown in Figure 8.

Table 1. Economic analysis for SCSS (semi-cylindrical solar still with iron wick) and DSSS (double-slope solar still with jute wick).

Cost components	SCSS	DSSS
n	15	15
r	0.08	0.08
S	1444	1110
CRF	0.12	0.12
SFF	0.04	0.04
FAC	843.58	648.46
ASV	53.14	40.85
AMC	126.54	97.27
TAC	916.98	704.88
AY	1045.36	721.24
CPL	0.88	0.98

CONCLUSION

Based on the experimental analysis conducted on three different SS setups, the following results were obtained.

1. The Cumulative yield of the SCSS and DSSS are 3.58 and 2.47 kg/ m^2, respectively.
2. The SCSS is 44.93% more productive than the DSSS.
3. The maximum energy efficiencies received for SCSS and DSSS were 47.92% and 33.83%, respectively.
4. The maximum exergy efficiencies for SCSS and DSSS were 18.28% and 13.88%, respectively.
5. The CPL for SCSS and DSSS are 0.88 and 0.98 (Rs./L).
6. Lower relative humidity also improved the yield. At 10% relative humidity, a maximum output of 0.45 kg/m^2 was received at 14:00 hrs.

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