

## Research Article

# Effect of Design Parameters on Fresh Water Produced from Triangular Basin and Conventional Basin Solar Still

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Received 19 December 2020; Revised 3 February 2021; Accepted 16 February 2021; Published 2 March 2021

Academic Editor: Hafiz Muhammad Ali

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This paper reported the experimental testing of a triangular and conventional basin solar still (TBSS and CBSS). Solar basin and absorber are made of glass and a polyethylene cover, respectively, with an area of 0.25 m<sup>2</sup>. Square and triangular absorber with the same area of 0.25 m<sup>2</sup> with square and triangular glass cover for condensation was fixed. Experimentations were conducted during the month of December 2018, and different natural criteria such as intensity, wind speed, and surrounding ambient temperatures were considered. Also, the modified model was compared to the CBSS on its performance and efficiency characteristics. The experimental results also revealed that the temperature of the water inside the TBSS was higher as compared with that of the CBSS. The daily yield obtained from CBSS and TBSS was found to be 2.7 and 3.2 kg/m<sup>2</sup>, respectively. Also, the daily efficiency of the TBSS was improved by 11.36% than the CBSS.

## 1. Introduction

Renewables appear to be the one of the source which is inexhaustible, clean, ecofriendly, and cost economic. Also, it appears to be the competitive energy among the other nonrenewable energy sources. Due to their abundance and its potential to use in the globe, they differ from the use of fossil fuel. Renewables will not even produce any kind of greenhouse gases which normally affect the climate which includes the reduction in annual rainfall and increased ambient temperature [1–4].

The utilization of solar energy in the distillation process appears to be an economical method to produce fresh water [5–8]. Manokar et al. [9] reviewed the different types of techniques employed in pyramidal solar still (PSS) for fresh water improvement. The different heat exchange mechanism employed in solar still for enhanced fresh water was reviewed by Kabeel et al. [10]. Similarly, Sathyamurthy et al. [11] surveyed the different geometries employed in cover and absorber of solar still for enhanced yield. The factors that affect the performance of PSS with a triangular basin and cover were experimentally studied by Sathyamurthy

et al. [12]. Two different parameters, namely controlling the depth of water and cover cooling techniques, were employed to achieve optimum yield. Essa et al. [13] studied a solar still and augmented the yield using a coffee-based colloid. The use of acrylic material as cover material in the PSS was analyzed by Manokar et al. [14].

Kumar et al. [15] used a double collector cover in the PSS. Their results exhibited that double collector cover reduces the thermal efficiency of the PSS as the air gap between the collector cover increased the cover temperature. Nayi [16] made a comprehensive review of the PSS. Experimental studies on the PSS with phase change materials (PCM) were carried out by Sathyamurthy et al. [17, 18]. Kumar et al. [19, 20] carried out theoretical and experimental studies on PSS integrated with an inclined solar still for enhancing fresh water. Kabeel et al. [21] used  $\text{TiO}_2$  nanoparticles in black paints and coated in the absorber material of the triangular PSS. On the same PSS, Nagarajan et al. [22] theoretically studied the effect of glass cooling using a DC powered fan.

The performance of triangular solar still (TSS) in two different directions was experimentally analyzed by Rubio-Cerda et al. [23]. It was reported that the performance of the TSS at glass cover facing the east-west direction was higher as compared to the TSS at glass cover facing north-south direction. Varying water depths in the TSS were reported by Ahsan et al. [24]. The maximum yield of 1.6 and 1.55  $\text{kg/m}^2$  was obtained from water depth of 1.5 and 2.5 cm, respectively. A comparison between PSS and CSS was hypothetically studied by Fath et al. [25]. The annual yield produced from the CSS was 1532.7 L and PSS was 1510.5 L. It was reported that both CSS and PSS produced the nearly same daily yield of about 2.6 L. The performance of the PSS using fan was augmented the yield by 25% as compared to the conventional PSS by Taamneh and Taamneh [26]. The PSS with a fan has produced the maximum yield of 3 kg per day, whereas PSS without fan has produced a maximum yield of 2.5 L per day. Kabeel et al. [27] made a comparative study of conventional PSS and modified PSS basin with V-corrugated absorber surface and PCM. It was reported that modified PSS with PCM produced a daily yield of 6.6 kg, and conventional PSS has a daily yield of 3.5 L. Abdelal and Taamneh [28] introduced a novel composite absorber plate integrated PSS. It was reported that PSS with 5% CNT-coated plate has a maximum daily production of 3.3  $\text{kg/m}^2$ , whereas the black painted plate has yield of 1.73  $\text{kg/m}^2$ . Various existing solar still designs such as concave [29], spherical [30], hemispherical [31, 32], vertical [31–36], inverted absorber [37–40], tubular [41], pyramid [42], inclined [43–45], and hybrid solar still [46] are reviewed.

From the various review of literature, it is found that the use of triangular basin/absorber and single-slope triangular cover is not extensively studied. Various criteria such as water temperature, glass temperature, yield, evaporative, and convective heat transfer coefficient (EHTC and CHTC) have been studied in detail from the TBSS and CBSS. The present study is aimed at improving the fresh water produced from a triangular basin with a single-slope arrangement. An

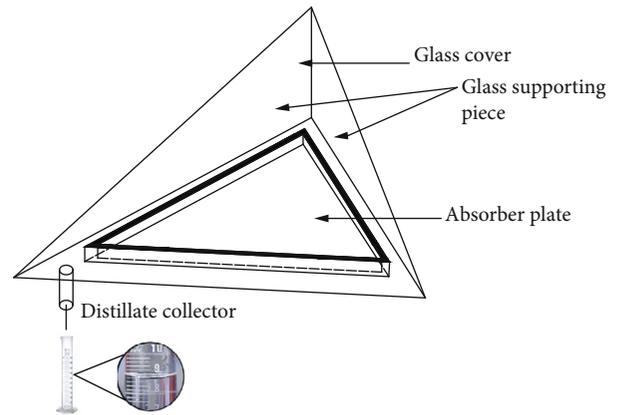


FIGURE 1: Graphical representation of TBSS.

experimental investigation is carried out to study the obtained fresh water produced from the modified absorber and condensing cover of the TBSS.

## 2. Experimentation

Figure 1 shows the graphical representation of the TBSS with an absorber plate made of a triangular section. Figure 2 shows the schematic diagram of the CBSS and TBSS. It consists of a triangular basin with an area of  $0.25 \text{ m}^2$ . The dimensions of the conventional basin type solar still are 0.5 m long and 0.5 m wide with higher end wall height of 0.2 m. Similarly, to have equivalent basin area, a triangular basin with sides of 0.57 m each forms an equilateral triangle, and the basin height is 0.2 m. Two triangular supporting pieces are kept vertical in the absorber, while the cover material is made of polyethylene sheet, which transmits the solar radiance. The sea water is fed into the absorber using a plastic hose, and the flow is controlled using a flow control valve. The evaporated water from the absorber gets condensed in the cover and glides through the smooth inclined surface to the distillate collector and collected in a calibrated flask. Insulation are provided at the bottom and side walls of the solar still to prevent the loss of heat. For comparison and experimental validation, a CBSS with a basin area of  $0.25 \text{ m}^2$  is fabricated and tested for the same outdoor experimental condition. The flow of sea water into the basin is under control using a control valve. At each interval of evaporation from the upper surface of the water, fresh sea water is fed into the basin to maintain the stable water depth. The whole experiment is fabricated and researched in conditions of Chennai, India. Testing is conducted from 8 a.m. to 6 p.m. during the month of December 2018, while the covers of TBSS and CBSS are facing south direction. On a triangular and conventional basin solar still, four sensors each on the basic elements are placed, and the average values are taken. The water depth inside the TBSS and CBSS is measured on an hourly basis, and sea water is feed into the basin for maintaining stable water depth. Table 1 shows the details of instruments, range, accuracy, and error. The elemental temperatures of the TBSS and CBSS, namely, water, glass, and basin temperature, are measured using PT100 type thermocouple, whereas the wind

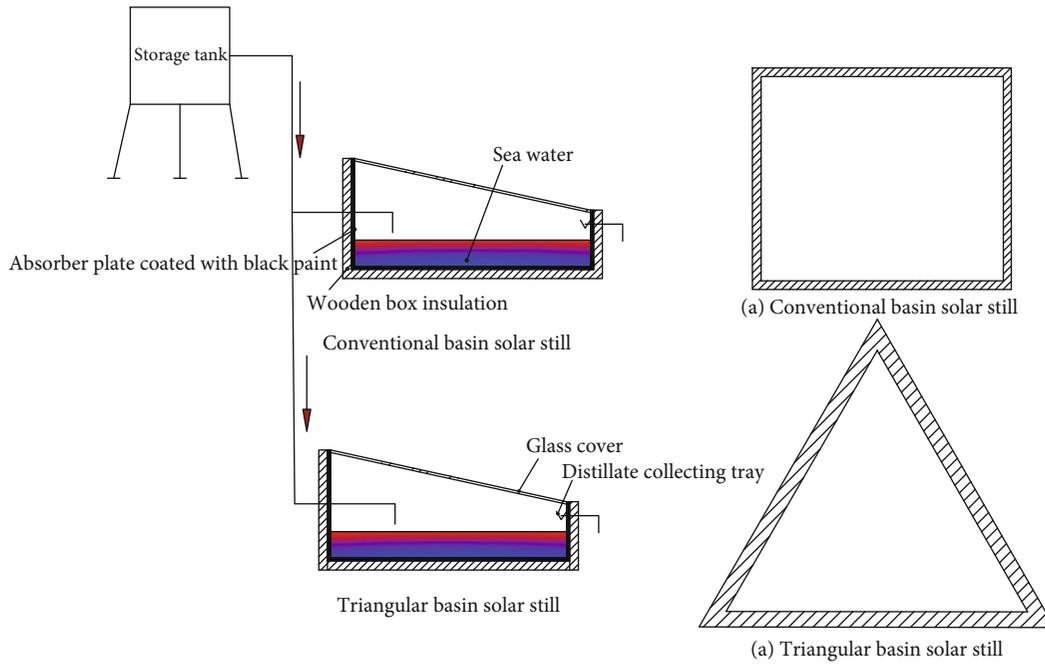


FIGURE 2: Schematic diagram of conventional and triangular basin solar still.

TABLE 1: Range, accuracy, error, and instruments used in the study.

Instrument	Range	Accuracy	Error
Temperature sensor (PT-100 type)	0-500°C	±0.1°C	±1.5%
Distillate collecting flask	0-2000 ml	±10 ml	±1.5%
Wind velocity meter	0-45 m/s	±0.1 m/s	±3%
Solar power meter	0-3500 W/m <sup>2</sup>	±10 W/m <sup>2</sup>	±3.5%

velocity and solar radiance are measured using anemometer and solar power meter, respectively. On an hourly basis, temperatures, solar intensity, and distillate collected are measured.

The daily efficiency of TBSS and CBSS is the ratio of the product of latent heat of vaporization and the amount of accumulated potable water produced to the accumulated solar intensity for the entire day.

### 3. Uncertainty

The instruments used in the experiments produce some possible errors which is determined in the form of uncertainty. The uncertainties produced during the experiments from the instruments is tabulated in Table 1. It is defined as the ratio of smallest amount to the least value of output. The uncertainty produced by the calibrated flask in collecting the distilled water depends on the amount of water collected in the flask. It is mathematically expressed as

$$R_m = \sqrt{\left(\frac{\partial m}{\partial h} R_h\right)^2}. \quad (1)$$

For determining the uncertainty of TBSS and CBSS daily efficiency, the amount of water collected in the calibrated flask and solar radiation falling on the glass surface and is mathematically expressed as

$$R_\eta = \sqrt{\left(\frac{\partial \eta}{\partial m} R_m\right)^2 + \left(\frac{\partial \eta}{\partial I(t)} R_{I(t)}\right)^2}. \quad (2)$$

Using Equation (1), the uncertainties of distilled water collected from the calibrated flask, solar radiation, wind velocity, and temperature were calculated as 1.5, 3.5, 3, and 1.5%, respectively. Similarly, using (2), the calculated uncertainty of daily efficiency is found as 2.1%.

### 4. Results and Discussion

The fluctuation in solar intensity, basin, water, and glass temperature of the CBSS and TBSS is shown in Figure 3. The experiments were conducted for the December 2018 (30 days), and the best readings are taken for the analysis. The improvement in performance and efficiency of renewable energy system depends on external input parameters such as solar intensity, ambient temperature, and wind velocity.

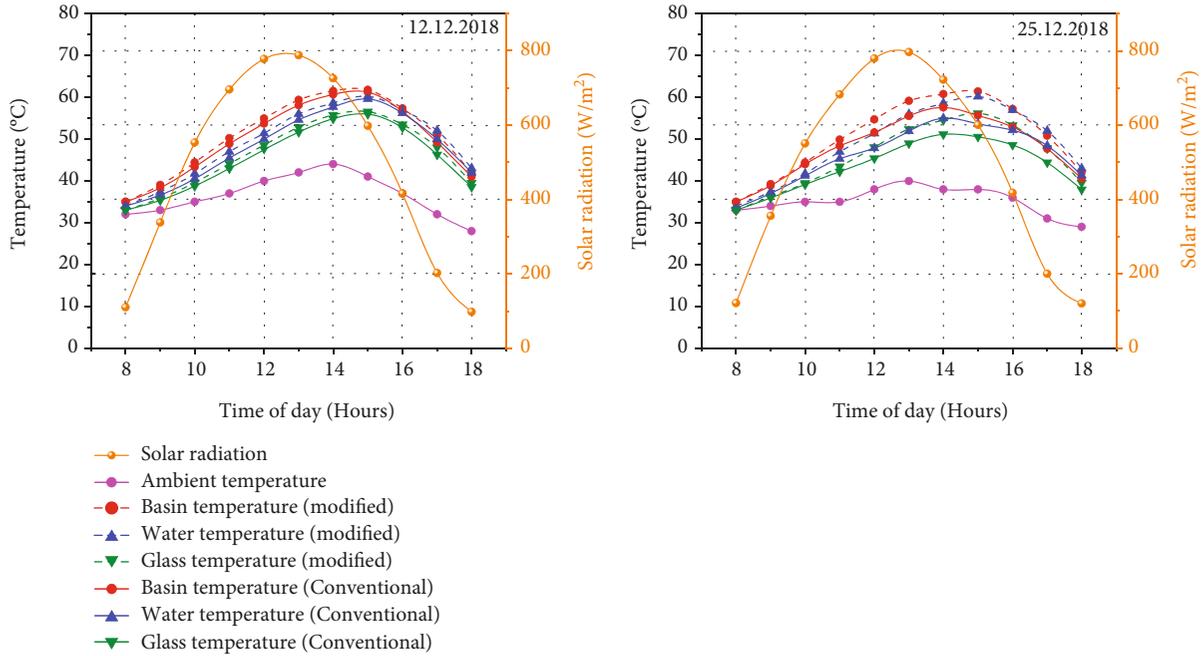


FIGURE 3: Variations in solar intensity, basin, water, and glass temperature of CBSS and TBSS on 12.12.2018 and 25.12.2018.

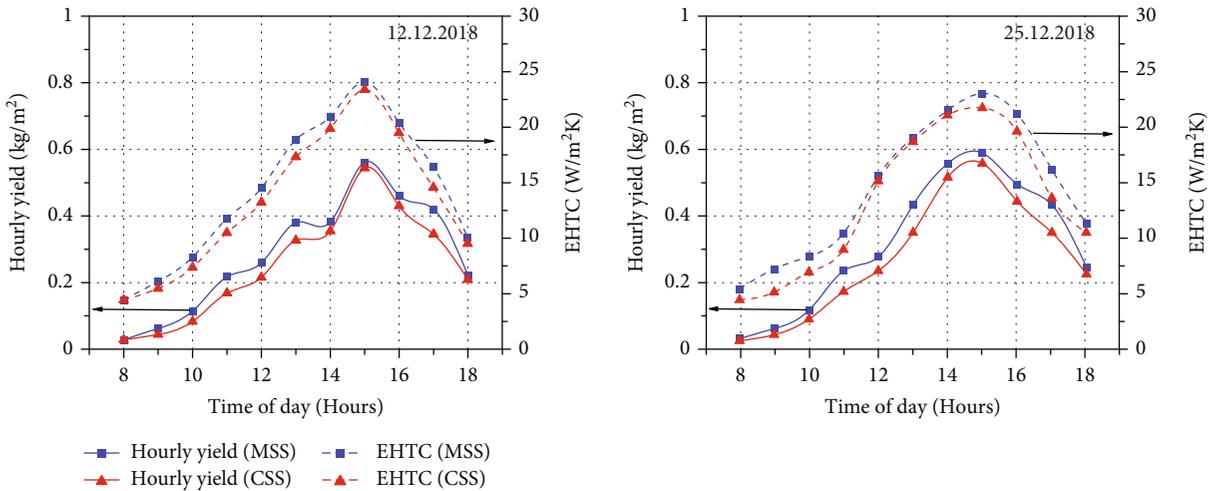


FIGURE 4: Variations in yield and EHTC from CBSS and TBSS.

With continuous solar intensity as heat input, the elements of the TBSS and CBSS such as water, glass, and basin temperature rise. As time varies, the solar intensity varies by reaching its peak during the midnoon. The whole experiment was conducted during the bright sky condition. The peak solar radiation recorded during the experiments on 12.12.2018 and 25.12.2018 were 778 and 797  $W/m^2$  while the ambient temperature recorded for the corresponding experiments was 42 and 40°C, respectively. It can be noticed that the maximum temperature occurs at 15:00 Hrs. The maximum temperature of the water using TBSS is found as 60.4°C, whereas the temperature of the water using conventional is 58.3°C. The water temperature peaks at 15:00 Hrs; as the heat energy is stored in the water as sensible heat and during the lower

sun shine hours, the energy is liberated. Also, it is clearly evident that the maximum exposure area of water with solar radiation is the cause for higher temperature in the modified solar still with triangular basin than conventional basin type solar still. Similarly, the cover glass temperature of TBSS is higher as compared to that of CBSS. Due to higher evaporation from the basin, the vapor gets accumulated in the glass cover which possibly increase the temperature of cover from the modified triangular basin solar still. The maximum temperature difference between water and glass is found as 3.6°C and 3.2°C for TBSS and CBSS.

The peak glass temperature of the TBSS and CBSS are found as 56.1 and 50.5°C on 25.12.2018, respectively. There is a maximum temperature difference between water and

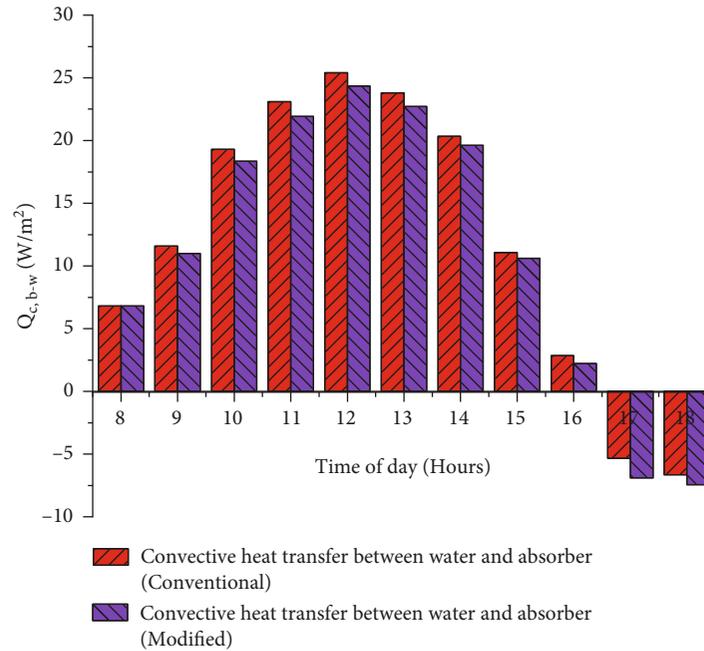


FIGURE 5: Variations in CHTC between water and basin of CBSS and TBSS.

TABLE 2: Comparison of yield and thermal efficiency from the CBSS and TBSS.

Date of experiment	Daily yield (kg/m <sup>2</sup> )		Daily efficiency (%)		Total solar radiation (W/m <sup>2</sup> )	Improvement in yield (%)
	MSS	CSS	MSS	CSS		
12.12.2018	3.24	2.82	38.28	33.32	5303	12.96
15.12.2018	3.35	2.84	38.79	32.88	5412	15.22
19.12.2018	3.12	2.74	37.24	32.70	5250	12.17
25.12.2018	3.41	2.91	39.24	33.49	5445	14.66

glass on 25.12.2018 using TBSS, and CBSS is found as 4 and 3.1°C, respectively. The increase in temperature of the water is due to the maximum absorption of solar radiance with the modified cover surface, which enhanced the evaporation and condensation rate inside the closed chamber. During the experiments, it is found that the elemental temperatures, such as basin, water, and glass, are higher using the TBSS compared to that of CBSS.

Similarly, the variations in yield and EHTC using the correlation from Appendix of the CBSS and TBSS for two different experimental days are shown in Figure 4. It can be seen that the evaporation rate is enhanced using the modified absorber geometry inside the TBSS. The maximum EHTC from the TBSS and CBSS are found as 24.3 and 23.2 W/m<sup>2</sup> K, respectively. On the other hand, the maximum distilled water produced from the TBSS and CBSS is found to be 0.56 and 0.54 kg/m<sup>2</sup>, respectively. The increase in freshwater yield is due to the effect of higher evaporation with higher water temperature within the modified basin. There is an increase of about 3.7% in the maximum productivity, and an increase of about 12.96% is observed in the total productivity of freshwater produced. On average, freshwater produced from the TBSS is improved by 12% than the CBSS.

The increase in output is due to the effect of a lower CHTC rate between water and basin (Figure 5). The CHTC between water and basin is higher in the case of the conventional basin, whereas, with the modified basin, the CHTC reduces. During the absence of solar radiation, the CHTC has a negative impact on the modified basin as the rate of CHTC is higher as compared to that of the conventional basin. A comparison of daily productivity and daily efficiency of the TBSS and CBSS during the experimental days is tabulated in Table 2. It is known that the daily yield from the TBSS and CBSS was found as 3.12–3.41 and 2.74–2.91 kg/m<sup>2</sup>, respectively. There is an improvement in yield of about 12.96–15.22% using the TBSS than the CBSS. It is also seen that the daily efficiency of the CBSS using a square absorber is lower as compared to that of TBSS using a triangular absorber. The daily efficiency of TBSS and CBSS ranges from 37.24 to 39.24 and from 32.7 to 33.49%, respectively.

The various published work related to our testing is provided in Table 3. From the table, it has been identified that PSS integrated with inclined solar still provided the maximum yield of 7.52 kg/m<sup>2</sup>, and triangular PSS coated with TiO<sub>2</sub> nanoparticle has a yield of 6.6 kg/m<sup>2</sup>. According to

TABLE 3: Comparison of present testing with previously published work.

S. No	Author name	Experimentation	Yield	Location
1	Kumar et al. [19, 20]	PSS integrated with an inclined solar still	7.52 kg/m <sup>2</sup>	Chennai, India
2	Kabeel et al. [21]	Triangular PSS coated with TiO <sub>2</sub> nanoparticle	6.6 kg/m <sup>2</sup>	Chennai, India
3	Ahsan et al. [24]	Experimentation on TSS by varying water depth	1.6 kg/m <sup>2</sup>	Japan
4	Taamneh and Taamneh [26]	The PSS with fan	3 L	Jordan
5	Kabeel et al. [27]	Modified PSS basin with V-corrugated absorber surface and PCM	6.6 kg/m <sup>2</sup>	Tanta, Egypt
6	Abdelal and Taamneh [28]	Novel composite absorber plate integrated PSS	3.3 kg/m <sup>2</sup>	Jordan
7	Kabeel et al. [47]	Tubular solar still using NPCM	5.62 kg/m <sup>2</sup>	Chennai, India
8	Kabeel [29]	Concave wick	4.1 L/m <sup>2</sup>	Tanta, Egypt
9	Dhiman [30]	Spherical solar still	2.75 kg/m <sup>2</sup>	India
10	Ismail [48]	Hemispherical solar still transportable type	5.7 L/m <sup>2</sup>	Saudi Arabia
11	Arunkumar et al. [49]	Hemispherical solar still	4200 mL/m <sup>2</sup>	Coimbatore, India
12	Minasian and Al-Karaghoulis [33]	Floating vertical solar still	5000 mL/m <sup>2</sup>	Baghdad
13	Boukar and Harmim [31]	Vertical solar still	2.3 kg/m <sup>2</sup>	Adrar
14	Tanaka [32]	Multi effect vertical diffusion solar still	13.3 kg/m <sup>2</sup>	Fukuoka, Japan
16	Boukar and Harmim [35]	One sided vertical solar still	1.2 kg/m <sup>2</sup>	Adrar, Algeria
17	El-Sebaei [36]	Vertical solar still	4.2 kg/m <sup>2</sup>	Tanta, Egypt
18	Abdul-Wahab and Al-Hatmi [37]	Inverted absorber solar still with refrigeration cycle	10.08 kg/day	Muscat, Sultanate of Oman
19	Abdul-Wahab and Al-Hatmi [38]	Inverted absorber solar still with refrigeration cycle	10.08 kg/day	Muscat, Sultanate of Oman
20	Present study	TBSS	3.2 kg/m <sup>2</sup>	Chennai, India

Ahsan et al. [24], TSS produced a yield of 1.6 kg/m<sup>2</sup>, but our work has produced maximum productivity of 3.2 kg/m<sup>2</sup>. The present TBSS has produced 50% higher productivity as compared to that of Ahsan et al. [24].

## 5. Conclusions

The present experimental investigation was conducted in the climatic situation of Chennai, India, and the following conclusions were arrived from the experimental results:

- (i) Water temperature from the TBSS with the triangular basin was increased by about 12% when compared to the CBSS
- (ii) The maximum total yield produced from the TBSS and CBSS was found to be 3.24 and 2.82 kg/m<sup>2</sup> while the total productivity using modified absorber was improved by 12.96% than CBSS
- (iii) The increased yield of freshwater was higher in the case of TBSS, and it was mainly due to its exposure area and the condensing cover area with the solar radiance
- (iv) The daily thermal efficiency of the overall system using TBSS and CBSS was found as 39.24 and 33.29%, respectively.

## Appendix

The EHTC from saline water to glass is calculated by [50, 51]

$$h_{e,w-g} = 16.273 \times 10^{-3} \times h_{c,w-g} \left[ \frac{P_w - P_{gi}}{T_{b,w} - T_{gi}} \right]. \quad (A1)$$

The CHTC from the saline water to the glass is calculated by [50, 51]

$$h_{c,w-g} = 0.884 \left[ (T_{b,w} - T_{gi}) + \frac{(P_w - P_{gi})(T_{b,w} + 273)}{(268.9 \times 10^{-3} - P_w)} \right]. \quad (A2)$$

Partial vapor pressure at the water is calculated by [50, 51]

$$P_w = \exp \left( 25.317 - \left( \frac{5144}{273 + T_{b,w}} \right) \right). \quad (A3)$$

Partial vapor pressure at the glass is calculated by [50, 51]

$$P_{gi} = \exp \left( 25.317 - \left( \frac{5144}{273 + T_{gi}} \right) \right). \quad (A4)$$

The energy efficiency of the TBSS and CBSS is estimated as [50, 51]

$$\eta_{passive} = \frac{\sum \dot{m}_{ew} \times L}{\sum I(t) A_s \times 3600} \times 100, \quad (A5)$$

where  $h$  is the latent heat of vaporization (kJ/kg) and  $I(t)$  is the solar intensity ( $W/m^2$ ).

The latent heat of vaporization is mathematically expressed by

$$h_{fg} = 10^3 [2501.9 - 2.40706T_w + 1.192217 \times 10^{-3}T_w - 1.5863 \times 10^{-5}T_w], \quad (A6)$$

where  $T_w$  is the temperature of water ( $^{\circ}C$ ).

## Nomenclature

TBSS: Triangular basin solar still  
 CBSS: Conventional basin solar still  
 PSS: Pyramidal solar still  
 EHTC: Evaporative heat transfer coefficient  
 CHTC: Convective heat transfer coefficient  
 TSS: Triangular solar still

## Data Availability

Will be made available on request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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