Case Studies in Thermal Engineering 29 (2022) 101687

Contents lists available at ScienceDirect

Case Studies in Thermal Engineering

journal homepage: www.elsevier.com/locate/csite

Investigation and performance analysis of solar still with energy storage materials: An energy- exergy efficiency analysis

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ARTICLE INFO

Keywords:
Solar still (SS)
Conventional solar still (CSS)
Solar still with energy storage materials (SSWESM)
Phase changing materials(PCMs)
Efficiency
Energy
Exergy
Distillate output

ABSTRACT

Researchers have attempted different Energy storage materials (ESM) in solar stills (SS) to improve distillate yield. In this experimental work, an attempt was made to increase the distillate yield & efficiency of SS, using good absorbing and heat transfer capacity of ESM. A comparison was made between a conventional solar still (CSS) and a solar still with energy storage materials (SSWESM) in this experiment. Different energy storage materials like black color glass ball (BCGB), black granite (BG) and white marble stone (WMS) were used in equal quantity during experimental work. CSS and SSWESM had daily distillate yield of 1.4 kg/m2 and 2.5 kg/m2, respectively. The ESM boosts water evaporation during the day and releases heat at night, resulting in a higher distillate yield than CSS. Meanwhile, the exergy efficiency (η_{exe}) of CSS and SSWESM were 4.99% and 12.55% respectively. Also the SSWESM gives 72.6% more daily efficiency (η) than CSS.

Nomenclature

Abbreviation

SS	Solar still
ESM	Energy storage materials
CSS	Conventional solar still
FPC	Flat plate collector
BCGB	Black color glass ball

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https://doi.org/10.1016/j.csite.2021.101687
Received 18 July 2021; Received in revised form 26 November 2021; Accepted 3 December 2021
Available online 6 December 2021

BG	Black granite
WMS	White marble stone
PCMs	Phase changing materials
TSS	Tubular solar still
PTC	Parabolic trough collector
HE	Heat exchanger
CPL	Cost per liter
SSWESM	Solar still with energy storage materials

Variables

a	Area, m^2
I_t	Total solar radiation W/m^2
C	heat capacity, J/kg °C
k	Thermal conductivity, W/m K
m	Mass/water production, kg
L	Latent heat of vaporization, J/kg
T_a	Ambient temp. (°C)
T_w	Basin water temp. (°C)
T_{gi}	Inner glass cover temp. (°C)
I	Solar intensity (W/m^2)
P_{bw}	Partial pressure of basin water vapor N/m^2
P_{ig}	Partial pressure of inner glass surface N/m^2
$h_{e,bw\text{-}ig}$	Evaporative heat transfer coefficient (W/m^2 K)
$h_{c,bw\text{-}ig}$	Convective heat transfer coefficient (W/m^2 K)
$E_{xc,bw\text{-}ig}$	Exergy convection value for water and glass cover (W/m^2 K)
$E_{xe,bw\text{-}ig}$	Exergy evaporation value for water and glass cover (W/m^2 K)
$F_{e,bw\text{-}ig}$	Fractional exergy for evaporation (%)
$F_{c,bw\text{-}ig}$	Fractional exergy for convection (%)
η_{exe}	Exergy Efficiency (%)
η_{energy}	Energy Efficiency (%)

Greek Letter

η	Thermal efficiency, %

1. Introduction

The demand for clean drinking is increasing day by day. It is necessary to supply clean drinking water to all human beings. The available water sources on earth are 3/4th of the earth's total area, but it is not directly useable for drinking and other requirements [1,2]. The available clean water sources are minimal, so can't full fill the demand of the world population. Clean water is also demandable for industry, agriculture, households, etc. Also, the sources of clean water are not distributed equally in many areas of the world. In some regions country populations, the sources of clean water are higher than its populations, whereas, in many countries like Africa, Uganda the sources of clean water are lower [3–6]. It becomes necessary to fulfill the demand around the world. This could be possible by converting salty water of the sea into clean drinkable water with desalination technology. In the desalination technique, the salt contents can be removed, and water can be reused for drinking purposes [7,8].

Solar desalination is a very technique in which, by using solar energy, distillate water can be achieved. A solar still (SS) is a simple device that uses this method. It is a simple box-type device that desalinates water using evaporation and condensation [9,10]. A solar still (SS) can produce 1–1.5 L of distillate water per m2 per day. The distillate output of SS is lower due to different parameters like losses generated, design and configuration parameters of SS, materials used to manufacture the SS. So, it becomes necessary to increase the daily distillate yield of SS [11–15].

By minimizing the bottom and side heat losses, the distillate yield of SS could be improved. The temperatures of basin water and glass cover have a higher impact on the productivity of SS [16]. To achieve higher distillate productivity of SS, many researchers have used different techniques. They have changed configuration parameters, and the design of SS used different attachments like evacuated tubes, condenser, flat plate collector (FPC), heat exchanger, and energy storage materials with SS. Additionally, Mu et al. [17] reviewed that to enhance the performance of solar still the different parameters like thermal resistance, energy, and economic value should be considered. A review made by Shoeibi et al. [18] found that using hybrid technology to increase the water temperature and lower the glass cover temperature for SS gives six times higher performance than conventional solar still (CSS). It is found that the thermal performance of phase change materials (PCMs) also varied with the geometry of containers and orientations [19]. To concentrate more solar radiation with tubular solar still (TSS), Ahmed et al. [20] incorporated a parabolic trough collector (PTC) with TSS and achieved up to 50% higher efficiency than CSS. Essa et al. [21] used an absorber surface in a convex shape in TSS to increase the evaporative surface area and lower the basin water depth. They achieved better results in productivity with new modifications in TSS. The performance of CSS could be increased by changing geometry with single slope, double slope, hybrid, pyramidal, hemispherical, and using different absorbing materials [22–24]. To increase the convection rate of SS. Serradj et al. [25] have used a baffle inside the solar still, which increased the convective heat transfer coefficient of SS achieved a 26% higher distillate yield than CSS. To concentrate the solar radiation and heat transfer coefficient of SS, Madiouli et al. [26] have used an FPC and PTC with solar still (SS). Abu-Arabi et al. [27] experimentally proved that adding FPC, PCMs, and glass cooling technique gives 2.4 times higher productivity than CSS. Subramanian et al. [28] experimented on pyramid-shaped SS coupled with FPC. FPC preheats the temperature of the water inside the SS, which enhances an evaporative coefficient, hence higher distillate yield could be achieved (Morad et al. [29]). Fins with SS increase the evaporative area and improve its thermal performance; the material of fins does not have any considerable effect on the performance of SS [30,31]. Modi & Jani [32] checked the performance of SS with and without circular hollow fins. Due to more evaporative area, Hollow circular fins give a higher distillate yield than without hollow fins. Abdelgaied et al. [33] check the performance of SS using different geometry of fins. They found that a circular fin gives higher productivity than a square type due to higher evaporative surface area. Islam et al. [34] experimentally proved that optimum number fins with suitable dimensions attached with SS give better performance in the distillate productivity of SS. Kaviti et al. [35] used truncated conic shape fins within solar still and found that truncated shape transfers more heat to water and reduces heat loss. It increases 60% more productivity than CSS. Tuly et al. [36] experimentally proved that attachment of condenser with SS increased its distillate productivity by minimizing the glass cover and heat losses. To increase the condensing and surface area of SS, Toosi et al. [37] prepared a stepped-type solar still and attached a condenser within it. They obtained a 104% higher distillate output compared to CSS. Patel et al. [38] used a helical coil to condense the vapor inside a condenser. With this modification, solar's condensation rate was still increased, and the higher distillate was achieved. Attachment of condenser within SS increases its heat transfer rate and thermal efficiency [39,40]. In the conventional type of solar still, the exhaust heat losses are higher; to reduce heat losses, Rastegar et al. [41] have prepared an active type SS with an attachment of heat exchanger (HE) to recover exhaust heat losses. Newly developed active type solar still double the distillate output compared to CSS. Mohammadi et al. [42] found that by changing the design of HE, the performance of SS could be improved. They designed a HE in which the heat transfer area was divided into different parts. A novel design of HE gives 34% more distillate than a parallel and serpentine type of HE. Heat exchanger recovers the exhaust heat losses in SS and maintains the water pressure inside the basin; the exergy parameters could be minimized [43,44]. The energy storage materials play an important role in the distillate productivity of SS. It absorbs the heat energy during sun time and releases on off-sunshine period; it also increases the heat transfer rate of basin water [45,46]. Vigneswaran et al. [47] made an exergy-energy-economic analysis of SS using different PCMs. They found that acrylic material gives the best performance in SS. It lowers the capital liter cost (CPL) of distilled water. It gives a better charging/-discharging heat transfer rate of SS compared to other PCMs. Benhammou & Sahil [48] have improved the performance of single slope solar still using a separate heat storage system with energy storage materials. It was found that separate heat storage systems increase

Table 1
Comparison of present work with other researchers.

Sr. no	Author(s)	Workdone	Result
1.	Punniakodi & Senthil [19]	Experiment conducted using PCMs with different geometry of containers	• Melting rate of PCMs improves up to 71%.
2.	Ahmed et al. [20]	Used a PTC with tubular SS.	• Without increasing the production cost the 31.65% higher distillate was achieved.
3.	Essa et al. [21]	Used a convex shape absorber and nano materials with tubular SS	• By convex surface the vaporization rate was increased, which increased the distillate of SS.
4.	Serradj et al. [25]	Experiment was conducted using Baffle in single slope SS	• Baffles increased the natural convection of SS, which ultimately increased it distillate productivity.
5.	Subramanian et al. [28]	Experiment was conducted pyramid type SS with FPC	• The gap between water surfaces to glass was reduced, also FPC preheat the water inside basin, which 50% gives higher distillate.
6.	Modi & Jani [32]	Experiment was conducted in double slope SS with & without hollow circular fins	• In hollow circular fins SS gives 47% higher distillate output.
7.	Abdelgaied et al. [33]	Experiment was conducted in tubular SS with square and circular hollow fins	• Due to more evaporative expose area of circular hollow fins gives more distillate yield than square fins
8.	Kaviti et al. [35]	Used a truncated conic shape fins with SS	• Truncated conic shape fins transfer more heat to the basin water, hence higher evaporative temperature was achieved.
9.	Toosi et al. [37]	Experiment was conducted in stepped type SS coupled with condenser	• With new modification in SS increased the evaporative area of SS and gives 104% more distillate productivity than CSS.
10.	Rastegar et al. [41]	HE attached with SS	• HE recovers the waste heat losses from the SS and gives 2.04 times more result in productivity than CSS.
11.	Mohammadi et al. [42]	Experiment was conducted by changing the design of HE	• A novel HE with different parts inside it gives 34% more distillate output than parallel and serpentine type HE.
12.	Vigneswaran et al. [47]	Exergy-Energy-Economic analysis was done in SS using PCMs	• Addition PCMs improve the economic performance and reduce the CPL in SS.
13.	Nien et al. [49]	Economic analysis was in SS using PCMs	• It was found that PCMs improve the diurnal, nocturnal and daily distillate of SS. It also reduce the energy payback period of SS.

SS's day & night productivity and energy efficiency. A simulation study by Nien et al. [49] found that SS with PCMs higher energy efficiency than CSS. It also lowers the annual cost and payback period compared to CSS. Ultimately, SS with PCMs decreases the CPL and exergy parameters; the addition of nanomaterial increases the CO2 mitigation and fabrication cost of SS [50,51].

Based on the literature review findings, the performance of SS could still be improved with various design changes and attachments. It was also discovered that adding PCMs increases distillate productivity while lowering SS CPL. Table 1 shows a critical comparison of SS's distillate output with that of other researchers.

This study aims to use various energy storage materials to improve the daily distillate yield and energy-exergy performance of SS. From the above literature, numerous researchers have used different techniques to improve the performance in SS. Energy storage material increases the energy efficiency of SS and gives better performance from an economic point of view [52,53]. In current research work, energy storage materials like black color glass ball (BCGB), black granite (BG), and white marble stone (WMS) were used during the experimental work. The energy-exergy efficiency analysis and economic performance of SS were done and compared with other researchers.

2. Experimental analysis

2.1. Experimental procedure

In this study, the experiment analysis was done between CSS and SSWESM under the latitude of Gandhinagar, Gujarat, India. Figs. 1 and 2 illustrate the line diagram and actual experimental setup. Here both CSS and SSWESM were prepared from the same wooden material, having a basin area of 1m2. The basin area of both SS was prepared from a 1.5 mm thickness of galvanized iron material. The basins of both SS were painted black to maximize their exposure to solar radiation. Additionally, proper insulation was used to diminish the heat loss, including insulation from the bottom and sides [54]. To pass the solar radiation directly on the bottom absorber surface, a 4 mm thickness of transparent glass cover was used [55]. During the manufacturing of SS, proper care was taken from dimension to smooth finish. The basin areas of both the SS were filled up to 3 cm water level depth. For the supply of water to SS, three vales V1, V2 and V3 are provided, The lower depth of water inside the basin increases the performance of SS [56]. The level of water was controlled using the water level indicator for both still. The ESM like BCGB, BG, and MS were added in the second SS to compare CSS performance.

The experimental readings were taken for 24 h on all sunny days. The different parameters like ambient temperature (Ta, °C), water temperature (Tw. °C), inner glass cover temperature (Tgi, °C), solar intensity (I, W/m2), wind speed (V, m/s) were measured. To measure temperature at different intervals of SS, five k-type thermocouples were fitted. To calculate the solar intensity and wind speed

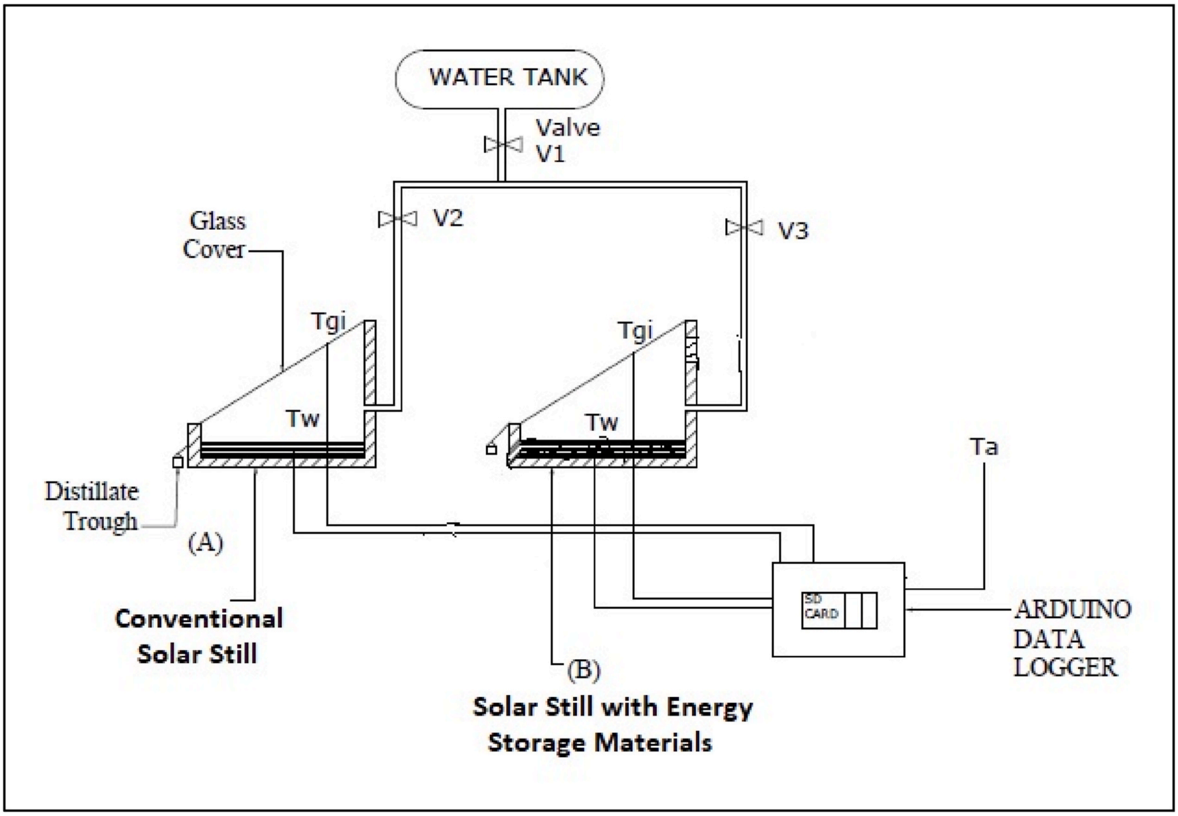

Fig. 1. Line diagram of experimental set up.

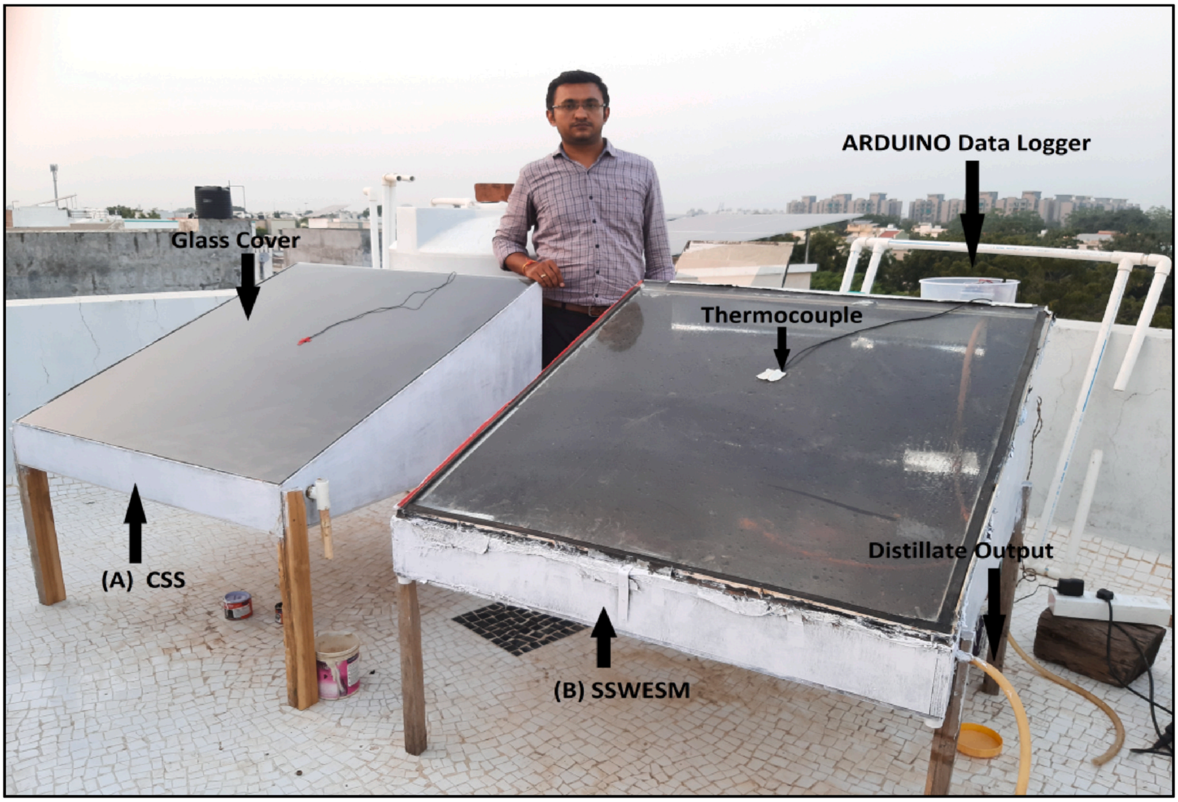

Fig. 2. Experimental set up photograph (A) CSS & (B) SSWESM.

solarimeter and anemometer were used. ARDUINO-based data logger stored the experimental readings for all experimental days.

2.2. Energy storage materials

In this study, as energy storage materials, black color glass ball (BCGB), black granite (BG), and white marble stone (WMS) were added in equal quantity according to 1m2 of the basin area of SS. The energy storage materials used in SS are shown in Fig. 3. BCGB (kanchey) has more heat storage capacity than other ESM [57]; also, WMS and BG give better results in charging/discharging of energy during day & night time in SS [58]. These energy storage materials are easily available from the market with minimum cost. So, from an economical point of view, it is feasible to use it.

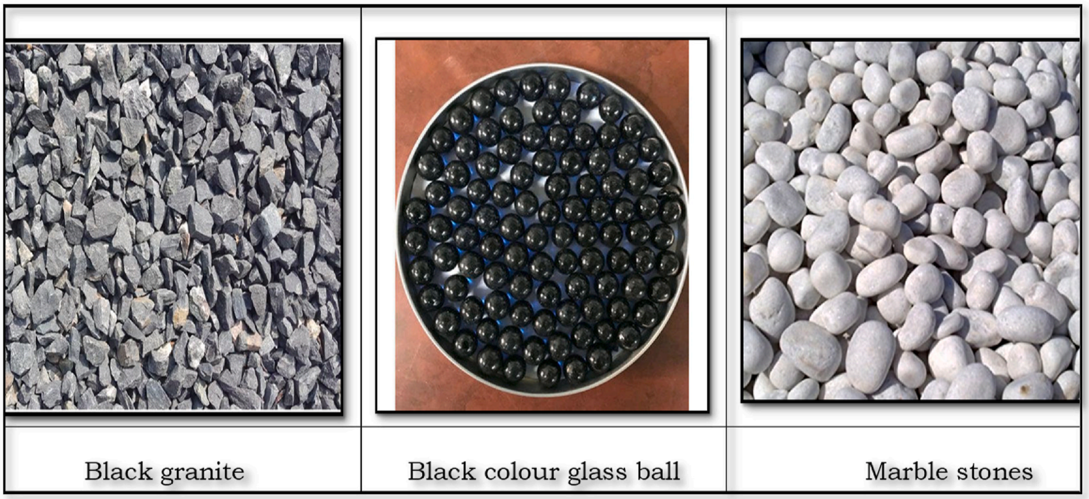

Fig. 3. Different energy storage materials.

3. Energy-exergy efficiency analysis

The energy-exergy efficiency analysis is important parameter to check the performance of SS. It also, helps to find out the economic performance of SS. An energy-exergy analysis were done for CSS and SSWESM. The different thermal parameters like P_{bw}, P_{ig} , $h_{e,bw\text{-}ig}$, $h_{c,bw\text{-}ig}$,L, $Ex_{e,bw}$,$Ex_{c,bw\text{-}ig}$ were calculated during the analysis [14, 59]. In Table 2 the calculated value for different parameters are shown.

3.1. Energy efficiency analysis

The daily energy efficiency for CSS and SSWESM were measured after the experimental work. To find out the energy efficiency of both CSS and SSWESM equation (1) was used [60,61].

$$nD = \frac{\sum mD \times L}{\sum Ag \times It} \tag{1}$$

In above equation, m_D = Total freshwater yield during the day (kg), L = latent heat of evaporation (J/kg), A_g = Glass cover surface area (m^2), I_t = Total solar radiation (W/m^2)

To find out the latent heat of evaporation equation (2) was used.

$$L = 3.1615 \times 10^6 \times \left[1 - \left(7.616 \times 10^{-4} \times T_W\right)\right] \tag{2}$$

Here, Tw= Average temperature of basin water in °C.

3.2. Exergy efficiency analysis

Exergy efficiency is the most important parameter of system; it computes the effectiveness of system relevant to its performance. To calculate the exergy value, it is necessary to consider the evaporative and convective heat transfer coefficient of system. Exergy efficiency was found using the equation no. (3) as taken by Ref. [14].

$$\eta exer = \frac{Exout}{Exinp} \tag{3}$$

Where, Ex_{out}= Exergy output value, It is equal to evaporation of exergy between basin water and inner glass cover ($Ex_{e,bw\text{-}ig}$), Ex_{inp} = Exergy input value, exergy input value is equal to absorbed solar radiation Ex_{sun}.

- To calculate the value of evaporative exergy value ($Ex_{e,bw\text{-}ig}$) equation (4) can be used [14].

$$Exe, bw\text{-}ig = he,bw\text{-}ig \times Abw \times (Tbw - Tig) \times \left(1 - \frac{Ta}{Tbw}\right) \tag{4}$$

In above equation, $h_{e,bw\text{-}ig}$ = Evaporative heat transfer coefficient (W/m^2 K), which could be found using equation (5) [14].

$$h_{(e,bw\text{-}ig)} = 16.273 \times 103 \times hc,bw\text{-}ig \times \left[\frac{Pbw - Pig}{Tbw - Tig}\right] \tag{5}$$

To find out the value of P_{bw} and P_{ig} equation (6 &7) were used [14].

$$Pbw = \exp\left(25.317 - \frac{5144}{Tbs + 273}\right) \tag{6}$$

$$Pig = \exp\left(25.317 - \frac{5144}{Tig + 273}\right) \tag{7}$$

In equation (5) convective heat transfer coefficient ($h_{c,bw\text{-}ig}$) could be calculated using equation no. (8) [14].

Table 2
Measured parameters of Energy-Exergy analysis for CSS and SSWESM.

Sr.	Parameter	Unit	CSS	SSWESM
1.	Partial pressure of basin water vapor (P_{bw})	N/m^2	8956.2	12048.85
2.	Partial pressure of inner glass surface (P_{ig})	N/m^2	5982.8	7280.75
3.	Evaporative heat transfer coefficient ($h_{e,bw\text{-}ig}$)	W/m^2 K	13.28	17.84
4.	Convective heat transfer coefficient ($h_{c,bw\text{-}ig}$)	W/m^2 K	1.949	2.208
5.	Exergy for evaporation ($Ex_{e,bw\text{-}ig}$)	Joule	23.66	59.49
6.	Exergy for convection ($Ex_{c,bw\text{-}ig}$)	Joule	3.52	7.36
7.	Latent heat of vaporization (L)	J/kg	3056519.99	3041591.64
8.	Exergy Efficiency (η_{exe})	%	4.99	12.55
9.	Energy Efficiency (η_{energy})	%	25.08	43.29

$$hc,bw\text{-}ig = 0.884\left\{(T_{bw} - T_{ig}) + \frac{(Pbw - Pig)(Tbw + 273.15)}{268900 - Pbw}\right\} \tag{8}$$

- Exergy input value = Ex_{sun}, (exergy input value is equal to absorbed solar radiation) could be found using equation (9) [14].

$$EX_{sun} = Abw \times It \times 1 - \frac{4}{3} \times \left(\frac{Ta + 273.15}{Ts}\right) + \frac{1}{3}\left(\frac{Ta + 273.15}{Ts}\right)4 \tag{9}$$

Here, Ts= temperature of sun (~ 6000 K).

- The value of fractional exergy for evaporation ($F_{e,bw\text{-}ig}$)and convection ($F_{c,bw\text{-}ig}$)were calculated using equations (10) and (11) [14].

$$Fe,bw\text{-}ig = \frac{Exe,bw\text{-}ig}{Exti} \tag{10}$$

$$Fc,bw\text{-}ig = \frac{Exc,bw\text{-}ig}{Exti} \tag{11}$$

Where E_{xti} shows the total exergy heat transfer, which was found using following equation no. (12) [14].

$$Exti = ht \times Ag \times (Tbw - Tig)\left(1 - \frac{Ta}{Tbw}\right) \tag{12}$$

In above equation h_t shows total heat transfer coefficient which was found using equation (13) [14].

$$h_t = h_{e,bw-ig} + h_{c,bw-} \tag{13}$$

4. Results & discussion

In this experimental study, the performance of both CSS and SSWESM was investigated with equal depth of water in the geometrical location of Gandhinagar city. The different ESM like BCGG, BG, and WMS (as per shown in Fig. 3) were used in equal quantity. The experimental readings for all working days of 24hrs were taken and stored using ARDUINO data logger. The different temperature values *Ta, Tw, Tgi,* solar intensity (*I*), and wind speed (*v*) were measured during experimental analysis.

4.1. Variations of different temperature for SSWESM

In Fig. 4, the variations of different temperature like ambient (Ta), water (Tw), and inner glass cover (Tgi) for CSS and SSWESM is shown with time. In the morning time due to lower solar intensity, the ambient temperature remains lower. At 13:00 p.m., the maximum value of solar intensity was obtained, which was 830 W/m2. After 17:00 p.m., ambient temperature decreases due to lower

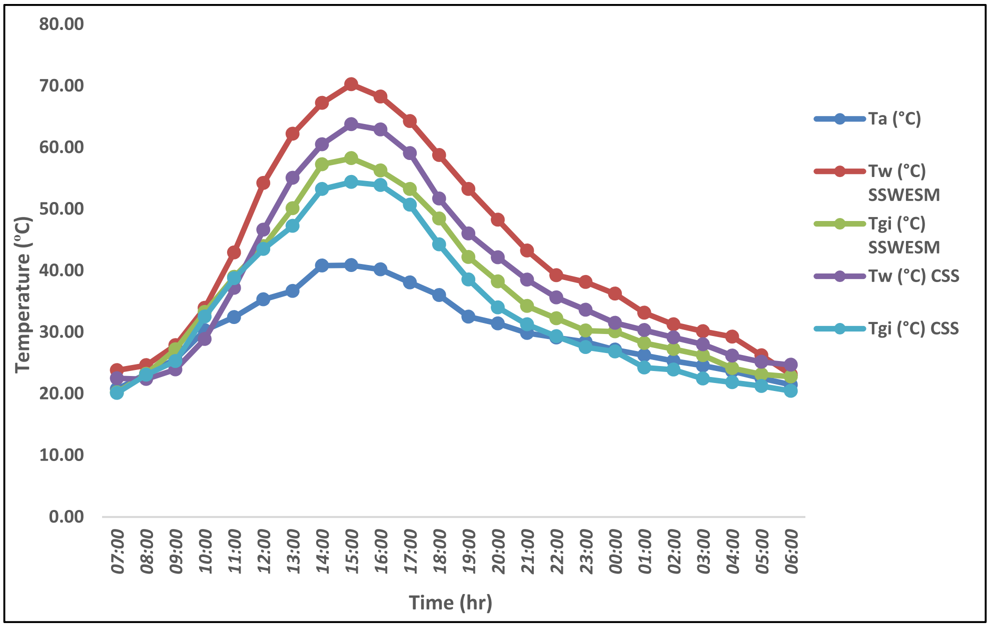

Fig. 4. Variations of different temperature for CSS & SSWESM.

solar intensity. In the figure, the water temperature shows a maximum in the case of SSWESM compared to CSS. The achieved maximum water temperature (Tw) for CSS and SSWESM was 63.75 °C and 70.24 °C, respectively. The reason behind this is the addition of energy storage material with SSWESM, which increases the heat storage capacity of water; hence higher evaporative heat transfer coefficient of water could be achieved. Also, it was found that the temperature of the inner glass cover for SSWESM remains higher compared to CSS.

4.2. Variations in distillate yield between CSS and SSWESM

The ESM has better heat storage capacity, which stores the heat during day time & releases it at night time, hence day and night productivity could be increased [62]. In Figs. 5 and 6, the hourly and cumulative distillate yield of both CSS and SSWESM are shown. As an ESM, BCGB, BG & WMS were used during experimental work. These ESM have better heat storage and release capacity than other ESM. In Fig. 5, the hourly distillate variation of CSS & SSEWSM is shown. It can be found that hourly distillate yield varied with time. During morning hours, the distillate yield remains the same for both CSS & SSWESM because of lower solar intensity and evaporation rate, but in peak hours, due to higher solar intensity, the distillate yield of SSWESM shows maximum than CSS. At 15:00 h the maximum distillate achieved for CSS & SSWESM were 0.190 (L/m2), & 0.350 (L/m2) respectively. The reason behind this is ESM. An ESM generates more heat inside the basin area; hence evaporative heat capacity of water could be increased, which gives more distillate yield. Also, during off sunshine hours, SSWESM gives a higher distillate yield than CSS. This happens due to additional energy storage materials, which release stored heat during a time, and higher nocturnal productivity could be achieved than CSS.

In Fig. 6 the cumulative distillate output for CSS & SSEWSM is shown. Higher hourly distillate in productivity gives higher cumulative distillate output. The obtained total distillate output for CSS & SSEWSM were 1.422 (L/m^2) & 2.551 (L/m^2) respectively.

4.3. Fractional exergy variations for evaporation ($F_{e,bw\text{-}ig}$)

In Fig. 7, the evaporative exergy variation for CSS and SSWESM is shown. The exergy evaporation for CSS and SSWESM remains between 0.72% and 0.89%. This is due to the higher basin water temperature, which increases the evaporative heat transfer coefficient of water. From the figure, it was found that the fractional exergy efficiency value for SSWESM remains maximum during peak hours and shows higher till evening. This was possible due to the addition of energy storage materials, which have higher heat storage & release capacity during day & night time. Here the higher performance in exergy efficiency could be achieved in SSWESM than CSS.

4.4. Fractional exergy variations for convection ($F_{c,bw\text{-}ig}$)

In Fig. 8, the fractional variation in convective exergy for CSS and SSWESM is shown. The fractional exergy efficiency value remains lower from morning to evening for SSWESM than CSS. It decreases from 0.11% at 7:00 a.m. morning to 0.05% at peak solar radiation time. In Table 2, the different calculated parameters for evaporation and convection are shown. Due to the higher value of exergy convection and convective heat transfer coefficient, the fraction exergy for convection remains lower in SSWESM. Also, the latent heat of vaporization (L) remains lower in the case of SSWESM than CSS. An energy storage material inside SS generates the lower convective energy, which gives a lower convective heat transfer coefficient value. Lower convective exergy efficiency enhances the distillate productivity of SSWESM compared to CSS.

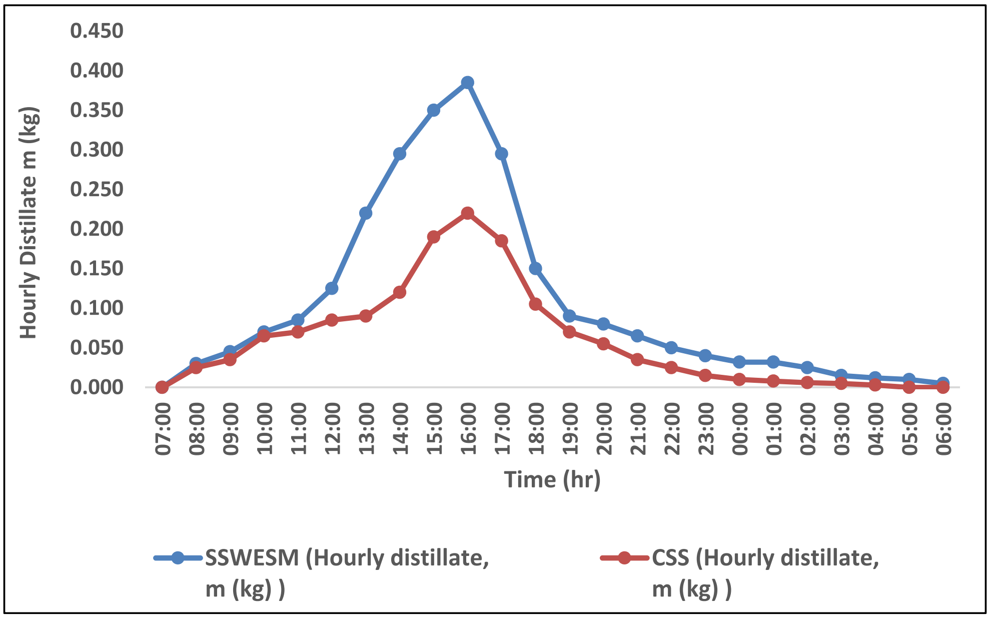

Fig. 5. Variations of hourly distillate between CSS & SSWESM.

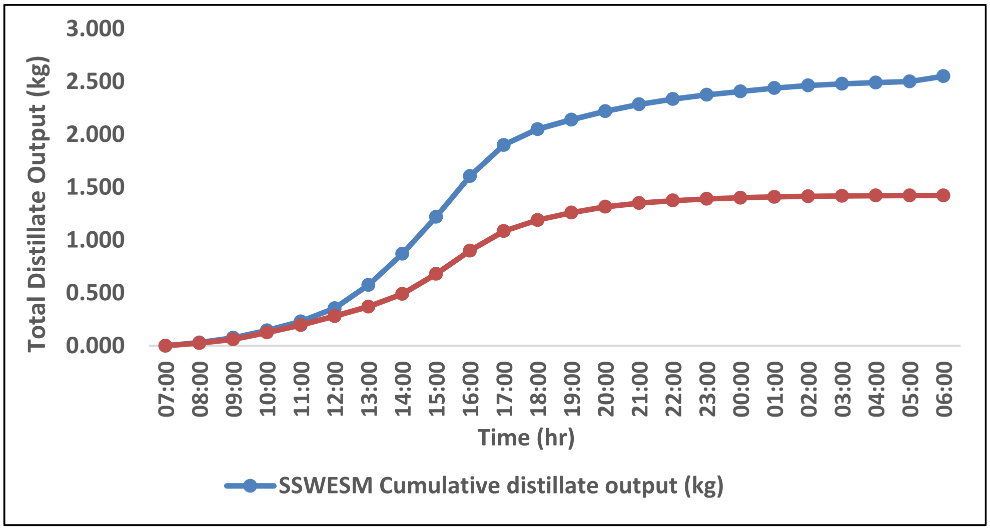

Fig. 6. Variations of cumulative distillate between CSS & SSWESM.

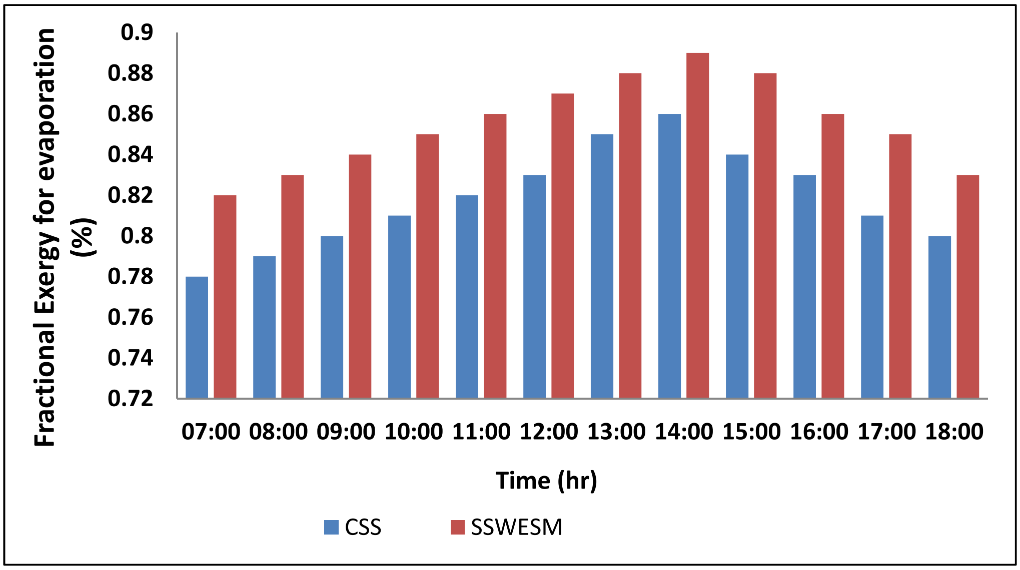

Fig. 7. Variations of fractional exergy for evaporation.

4.5. *Comparison of full day energy efficiency*

In Fig. 9, a comparison of energy efficiency (ηenergy) for CSS and SSWESM is shown. ηenergy for both CSS and SSWESM were determined from experiment data value. The value for energy efficiency of CSS and SSWESM was 25.08% and 43.29%, respectively. The full-day energy efficiency of SSWESM remains 72.60% higher than CSS. The reason behind this is the higher distillate output & exergy value of SSWESM. ESM increases the heat storage capacity of water, which enhances the evaporative heat transfer coefficient also; hence higher distillate productivity could be achieved. In the morning time, the distillate yield of both CSS & SSWESM remains the same, but in the afternoon period and during night time, the SSWESM gives more freshwater yield compared to CSS.

4.6. *Comparison of full day exergy efficiency*

A comparison in exergy efficiency (η_{exe}) between CSS and SSWESM is shown in Fig. 10. In Table 2, the values of exergy efficiency for CSS and SSWESM are shown. The η_{exe} for CSS and SSWESM was 4.99% and 12.55%, respectively. In the morning period, due to the lower evaporation rate of water, the exergy for both CSS and SSWESM remains the same. In the afternoon period, the SSWESM shows a higher value in exergy generation compared to CSS due to the addition of heat storage materials. Heat storage materials increase the evaporation rate of water; hence higher exergy efficiency could be achieved.

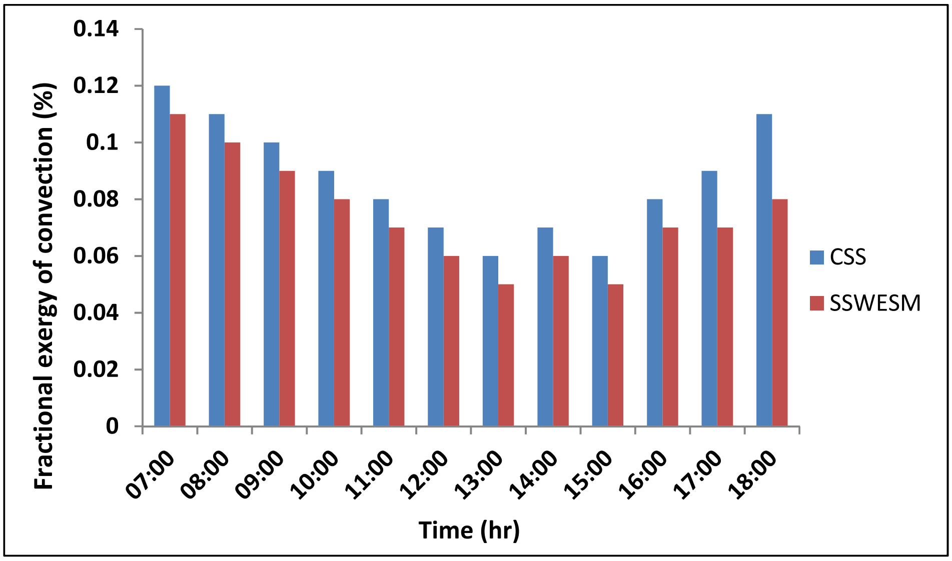

Fig. 8. Variations of fractional exergy for convection.

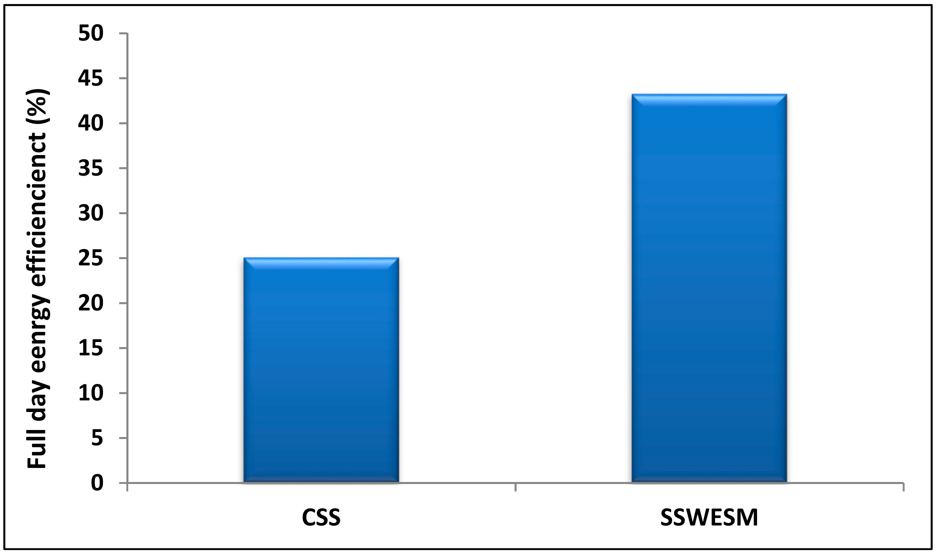

Fig. 9. Energy efficiency comparison between CSS & SSWESM.

5. Conclusion

In this study, an energy-exergy analysis of SS with different ESM has been compared with CSS. As energy storage materials, black color glass balls, black gravels, and white stones were added within the solar still, and the experiment was conducted under Gandhinagar (India). ESM stores heat during the day and release it at night, increasing the water's evaporative heat transfer capacity. Following the completion of the experiments, it was discovered that SSWESM produces a higher distillate yield than CSS. Meanwhile, the following conclusions were reached based on the experimental findings:

- SSWESM's basin water and inner glass cover temperatures were found to be higher than CSS's. The maximum value of basin water temperature could be reached during peak hours.
- In addition, ESM increases the evaporative heat transfer coefficient of water; it also helps to enhance faster charging and slower discharging in the release of heat.
- CSS and SSWESM had total distillate yield of 1.42 L/m2 and 2.50 L/m2, respectively. The daily distillate yield of SSWESM is 76% higher than that of CSS.

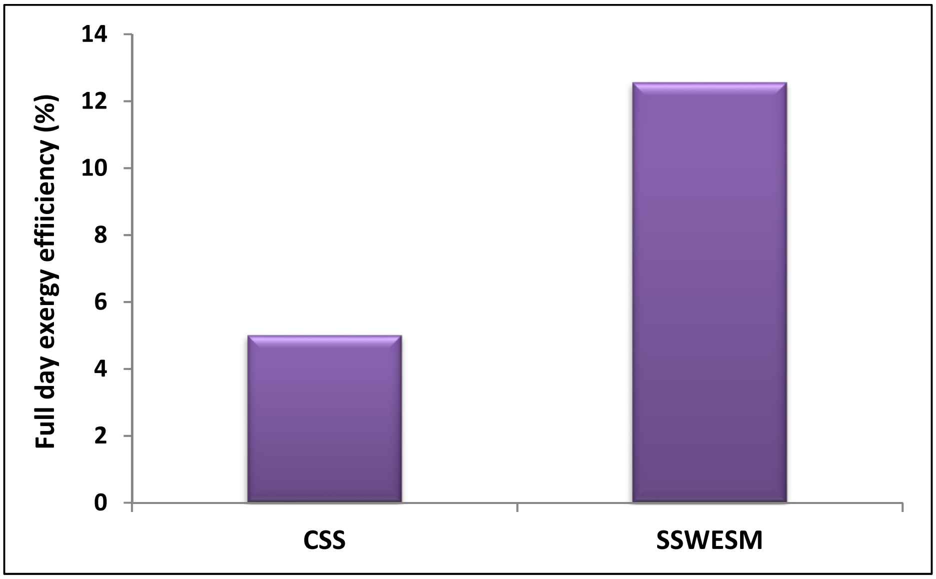

Fig. 10. Exergy efficiency comparison between CSS & SSWESM.

- The SSWESM generates the maximum value in evaporation of exergy in the afternoon time but shows lower convection of exergy during that period compared to CSS.
- The Energy efficiency ($\eta energy$) of CSS and SSWESM was 25.08% and 43.29%, respectively.
- The Exergy efficiency (ηexe) of CSS and SSWESM was 4.99% and 12.55%, respectively in this present research work.

Author statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

The authors extend their appreciation to the Deanship of Scientific Research at Imam Mohammad Ibn Saud Islamic University for funding this work through Research Group no. RG-21-12-03.

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