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Performance enhancements of conventional solar still using reflective aluminium foil sheet and reflective glass mirrors: energy and exergy analysis

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Abstract:

Many researchers are seeking simple and successful solutions to increase the output from the solar distiller. In this research work, reflective mirrors and reflective aluminium foil sheet was fixed on inner surfaces of single-slope solar distiller, leading more water production. The presence of reflective mirrors and reflective aluminium foil sheet on inner surfaces of the solar distillate permits the reflection of solar radiation falling inside the basin. Experiments were carried out on three stills: the first distiller is conventional solar still with black painted walls (CSS-BPW); The second distiller is conventional solar still with reflective aluminium foil-sheet walls (CSS-RAFW), and; The third distiller is conventional solar still with reflective glass mirrors walls (CSS-RGMW). The maximum total drinking water production from the CSS, CSS-RAFW and the CSS-RGMW are 3.41, 5.1 and 5.54 kg/m^2, respectively. Compared to the CSS-BPW, the production of drinking water was increased by 68.57% when using the reflective glass mirrors, and 48.57% when using the reflective aluminium foil sheet.

Keywords: solar energy; reflective glass mirrors; aluminium foil sheet; storage energy

1. Introduction

Water is the main component of the living organisms. It covers nearly three-quarters of the earth surface, and it is home to millions of marine organisms such as fish and other marine plants (Ghadamgahi et al., 2020). The location of the earth in the world receives tremendous solar energy. It is possible to take advantage of solar energy directly or indirectly by converting it to another type of energy such as thermal, mechanical, electrical or chemical (Al-Nimr et al., 2019; Zhuang, 2016; Gonzalo et al., 2019). Dependence on traditional energy sources are being lower, e.g., oil and gas are reduced, because the use of such resources causes environmental problems (Manokar et al., 2018a; Márquez et al., 2018). Scientists are working on the possibility of using renewable energy in all industrial fields, including desalination. The insufficiency of safe drinking water has become the main problem that threatens people's lives (Hilarydoss et al., 2020). Therefore, desalination of saline water using solar distillation can be used for producing drinking water (Nabil and Khairat Dawood, 2020; Malik et al., 2019; Thalib et al., 2020). Many researchers are working to enhance the daily output of solar distillers by adding heat storage materials and by changing the design of distiller(Hassan et al., 2020b; Zouari et al., 2019). (Kostić et al., 2010; Kostic et al., 2010) studied the impacts of using aluminium mirrors on the performance of solar still. They found that using the reflectors with an angle of 66° improved the system performance. In Algeria, (Tabet et al., 2014) enhanced the performance of a PV/T air collector using a plane reflector. The results show that use of the plane reflector improves the PV/T air collector performance. In the Indian city of Kolkata, (Naik and Palatel, 2014) studied the installing a mirror attached to the top with angles ranging from 85° to 100° in the hybrid solar collector. The results revealed that the solar collector efficiency was improved by using a reflective mirror. (Baccoli et al., 2015) mathematically studied the effect of external reflector on the flat solar collector. (Bahaidarah et al., 2015) reported the effect of the reflective mirrors on the performance of a hybrid solar collector. The obtained results published that efficiency of the solar collector was improved. (Belhadj et al., 2016) studied the effect of position between the angles of two reflecting panels on solar cells. The researchers confirmed that this process increased the solar radiation input to the system.

(Chowdhury, 2016) published the influence of concentrated hybrid PV/T collector design to improve the total efficiency of the collector, see also (Kabir and Chowdhury, 2017). (Mohd Rosli et al., 2014) studied the unglazed PV/T system to increase the thermal efficiency of a polymer collector. By using an unglazed PV/T system, the thermal efficiency of the system was augmented by 47%. (Khechekhouche et al., 2020b) conducted the experiments on the CSS with a simple external mirror. The experimental results revealed that the daily production was equal to 4.84 L/m^2/day with the reflecting mirror. However, it is about 3.40 L/m^2/day in the CSS. (Tanaka and Nakatake, 2009) reported the impact of the inclination of the flat plate external reflector. Compared to the vertical reflector in the case of the reflector's length half, the results revealed that the daily accumulation increased by 15 to 27% when it was used the oblique reflector. (Omara et al., 2016) reported the comparative study of corrugated solar still (CrSS) using layer wick and reflectors and the CSS. The results indicated that an improvement in daily accumulation in CrSS was 145.5% higher than the CSS and daily efficiency of the CrSS and CSS was about 59 and 33%, respectively.(Omara et al., 2014) investigated the impact of internal and external reflectors in the modified stepped solar still. They concluded that the daily productivity with internal and external reflectors was 125% higher than the CSS. (Abdallah et al., 2008) investigated the CSS with internal mirrors, step-wise basin and sun tracking system. In this system, the CSS performance was enhanced by 30% when using the interior mirrors, and 180% when using the stepwise basin and 380% when using the step-wise basin coupled with a sun tracking system. (Shanmugan et al., 2008) studied the efficiency of solar distillation with acrylic mirror supported just above the glass cover. With the possibility of adjusting, the supporting mirrors, the maximum productivity was obtained according to the angle of movement of the sun. Results indicated that output was about 4.2 kg/m^2/d, the rate increases was 45% when using the mirror booster as compared to the CSS.

(Parsa et al., 2019) studied the effect of height on the productivity of solar distillers. Productivity of the solar still in the Tochal Mountains summit at the height of 3964 m was higher as compared with productivity of the solar still in Tehran, at the height of 1171 m. The results confirm that the distillate productivity in the highest Tochal Mountains was 56.17% higher as compared to the measured distillation yield in Tehran. They also concluded that the cost of distilled water produced in the mountains is more expensive than Tehran.(Parsa et al., 2020a) examined active thermoelectric solar stills, one still on top of Tochal and the second in Tehran, with a height difference of 2793 m. The researchers concluded that productivity at the Tochal summit is higher than Tehran due to the decrease in pressure and wind velocity at the top of Tochal. The performance of the photovoltaic plate at the Tochal summit is better because it is cooler than Tehran. Efficiency and productivity of the solar still at the Tochal summit was improved by 27.8 and 42.5%, than the solar still at the Tehran, respectively. (Parsa et al., 2020b) compared two similar active and passive solar stills in Tochal and in Tehran for a period of seven consecutive days. For active still, the system uses a photovoltaic panel with Peltier electrical heat units. The results showed that the height rise has a major impact on the efficiency of the solar still (passive and active). (Parsa et al., 2020d) published the effect of the silver nanofluids on the efficiency of solar stills at the height of Mount Tochal (4000 m) and the city of Tehran. The results showed that the energy efficiency was enhanced at Tochal site without using silver nanofluids. The addition of an external mirror to the CSS improved the distillate water productivity by 9 to 21% (Omara et al., 2017; Tanaka and Nakatake, 2007; Tanaka, 2009). Recently waste material/low-cost material was used as energy storage material by many researchers (Balachandran et al., 2021; Attia et al., 2020; Attia et al.; Attia et al.; El-Agouz et al., 2019; Madhu et al., 2018; Khechekhouche et al., 2020a; Ramalingam et al.).

According to the state of the art, it is found that some researchers are used reflecting glass for increasing the productivity. The detailed review does not consider use of aluminium foil sheet to improve the productivity. Hence the present research aims to improve the productivity of solar distillation by using the reflective glass mirrors and reflective aluminium foil sheet on inner surfaces of the solar distillate. The presence of reflective mirrors and reflective aluminium foil sheet on inner surfaces of the solar distillate increases the water temperature due to the focusing of sun's rays inside the basin. The manuscript is presented as follow: Section 2 presents the experimentation and principle of operation of the CSS; Results and discussions are discussed in Section 3; Section 4 gives the comparison of the present study with published similar works; and; Finally, Section-5 shows the conclusion of the manuscript.

2. Experimentation and Principle of operation of CSS

The CSS is a very simple device with easily available and inexpensive components. The cycle of producing distilled water uses the principle of evaporation/condensation. This simple device converts non-drinking water into drinking water in an isolated areas (El-Agouz et al., 2019; Hassan et al., 2020a). Algeria has sunny areas with higher number of sunlight hours equal to 3300 h/year (Achour et al., 2017; Nia et al., 2013; Cheniti et al., 2020). Experiments were carried out in June 2020 from 8:00 AM to 5:00 PM. The testing setup was placed in El Oued, Algeria, with the latitude of 33.3676 °N and a longitude of 6.8516 °E.

In these experiments, three solar distillers were made with basin surface area of 50 cm x 50 cm in wood with a thickness of 2.5 cm. From the horizon, the angle of the distiller is set to 10°. The front side presents 6 cm of height, and the opposite side has 14 cm of height. The basin and inside sides are painted with the black silicon, considered as absorbent. Reflective mirrors and reflective aluminium foil sheet are fixed on the inner walls of the distiller to reflect the maximum amount of sunlight to the basin water. 1 cm water depth was maintained in solar still basin using ball floating arrangement. The water evaporates and condenses into droplets at the collector surface. Droplets are collected in a water collection tank using PVC tube.

The thickness of the aluminium foil sheet is about 0.2 mm. Aluminium foil has a shiny side and a matte side. The inside surface is dull, which decreases both the absorption and emission of radiation, and the outside surface is shiny, which increases the reflectivity. The reflectivity of aluminium foil is 88% and reflectivity of the mirrors is about 99%. (Hanlon and Kelsey, 1998). In experiments, the aluminium foil sheet and glass mirrors are fixed onto the inner walls of the solar distillery. Figures 1 (a,b) and 2 (a,b) shows the schematic and photo of the experimental set-up of solar still with the reflecting glass mirrors and reflecting sheet of aluminium foil, respectively. The experiments were conducted for a period of three days in a row: 20, 21 and 22 June 2020 for 9 hours: the first distiller is conventional solar still with black painted walls (CSS-BPW); The second is a modified solar basin with reflective aluminium foil sheet (CSS-RAFW), and; The third is a modified solar still with reflective mirrors (CSS-RGMW).

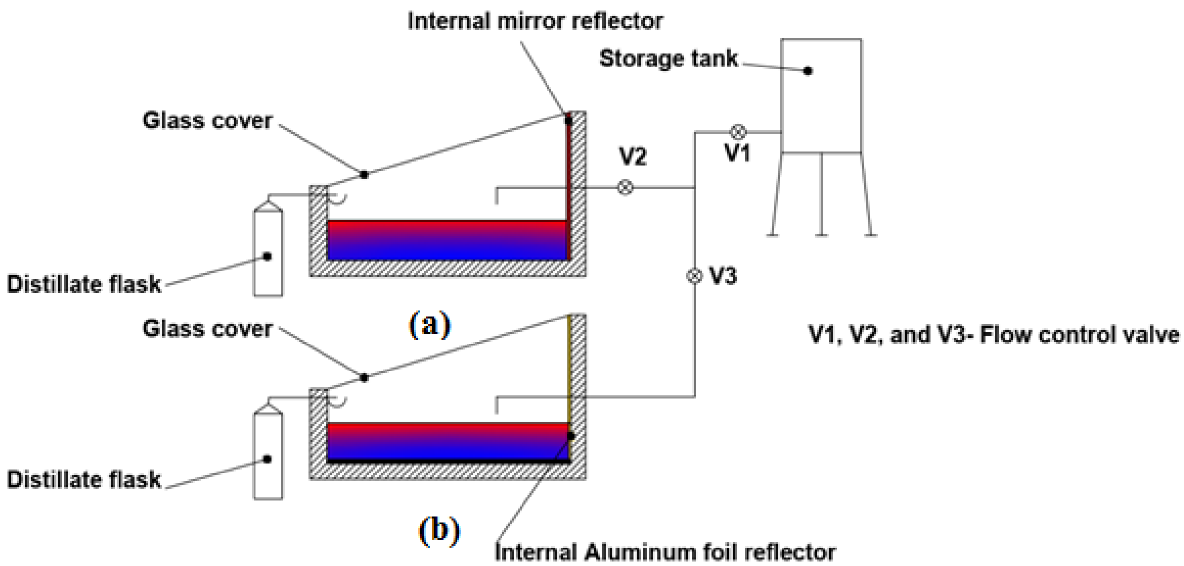

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Fig. 1. Schematic of solar still with (a) reflective glass mirrors and (b) reflective aluminium foil sheet

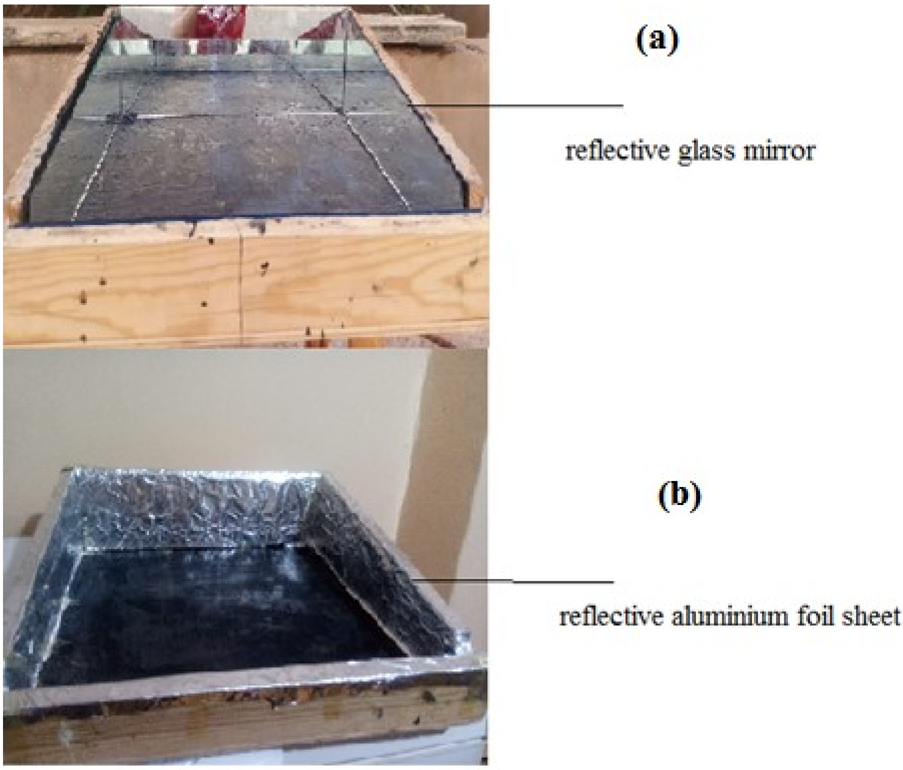

Fig. 2. Photo of Solar still with (a) reflective glass mirrors and (b) reflective aluminium foil sheet

3 Results and discussions

3.1 Hour-wise variation of solar intensity [I(t)], ambience (T_a), saline water ($T_{s.w}$), and collector cover ($T_{c.c}$) temperatures

Figure 3 (a and b) shows the hour-wise variation of I(t), T_a, $T_{s.w}$, and $T_{c.c}$ for the CSS-BPW, CSS-RAFW and CSS-RGMW on 20-6-2020 and 22-6-2020, respectively. Figure 4(a and b) shows that I(t) hike in the sunrise hours and measured its peak value of 1008 W/m^2 at 12 P.M on 20-6-2020, and 1020 W/m^2 at 12 P.M on 22-6-2020. Similarly, T_a also increases in the sunrise hours and measured its peak value of 44 °C at 1 P.M on 20-6-2020, and 45 °C at 1 P.M on 22-6-2020. Hour-wise variations of T_a, $T_{s.w}$ and $T_{c.c}$ have trends similar to I(t) as it is the cause for changes in T_a, $T_{s.w}$ and $T_{c.c}$. Each day mean value of I(t) and T_a on 20-6-2020 are 756.6 W/m^2, and 39 °C, respectively and on 22-6-2020 is 773 W/m^2, and 39.5 °C, respectively. The highest $T_{s.w}$ of the CSS-BPW is 70 °C at 2 P.M; CSS-RAFW is 75 °C at 2 P.M, and; CSS-RGMW is 77 °C at 2 P.M on 20-6-2020. Similarly, on 22-6-2020: highest $T_{s.w}$of the CSS-BPW is 71 °C at 2 P.M; CSS-RAFW is 76 °C at 2 P.M, and; CSS-RGMW is 77 °C at 2 P.M. The highest $T_{s.w}$ of the CSS-RAFW and CSS-RGMW is 5 and 7 °C higher than the CSS-BPW on 20-6-2020 and maximum $T_{s.w}$ of the CSS-RAFW, and CSS-RGMW is 5 and 6 °C higher than the CSS-BPW on 22-6-2020. Each day average $T_{s.w}$ of the CSS-BPW is 56.6 °C, CSS-RAFW is 61.1 °C, and CSS-RGMW is 62.6 °C on 20-6-2020, and each day average $T_{s.w}$ of the CSS-BPW is 57.6 °C, CSS-RAFW is 62.2 °C, and CSS-RGMW is 63.2 °C on 22-6-2020. Each day average $T_{s.w}$ of the CSS-RAFW and CSS-RGMW is 7.95% and 10.6% higher than the CSS-BPW on 20-6-2020, and each day average $T_{s.w}$ of the CSS-RAFW and CSS-RGMW is 7.98% and 9.72% higher than the CSS-BPW on 22-6-2020. Each day average $T_{s.w}$ of the CSS-RGMW is 2.45% higher than the CSS-RAFW on 20-6-2020, and each day average $T_{s.w}$ of the CSS-RGMW is 1.6% higher than the CSS-RAFW on 22-6-2020. Due to higher reflectivity materials in the CSS-RGMW and CSS-RAFW, maximum and each day average $T_{s.w}$is higher than the CSS-BPW.

Figure 3 (a and b) shows that the peak $T_{c.c}$ of 50, 51 and 52 °C was recorded on 20-6-2020, and 50, 52 and 53 °C on 22-6-2020 for the CSS-BPW, CSS-RAFW and CSS-RGMW, correspondingly. Each day mean $T_{c.c}$ of the CSS-BPW, CSS-RAFW and CSS-RGMW are 42.4, 43.4 and 44.3% on 20-6-2020, and 43.3, 44.5 and 45.3% on 22-6-2020, correspondingly. The aluminium foil sheets and glass mirrors used in the CSS-RAFW and CSS-RGMW were used to augments the $T_{s.w}$ throughout the experimental days by reflecting the solar intensity on the basin saline water. Hence, the incorporation of aluminium foil sheets and glass mirrors improves the $T_{s.w}$ by adding some extra heat energy input to the basin saline water whereas in the CSS-BPW heat energy was absorbed by the wall surfaces, therefore, it has minimum heat energy input to the $T_{s.w}$.

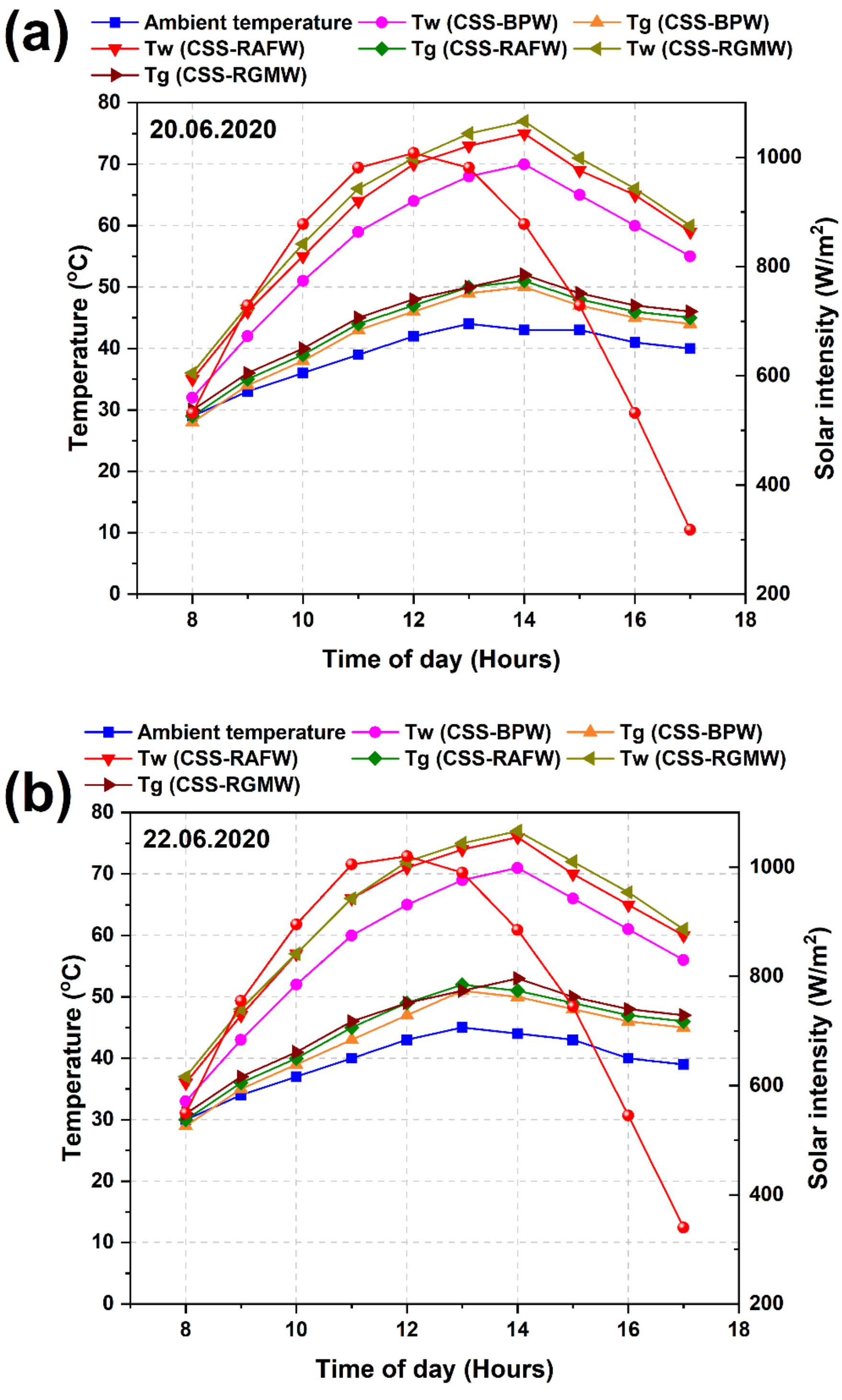

Fig. 3 Hour -wise variation of I(t), T_a, $T_{s.w}$, and $T_{c.c}$ for the CSS-BPW, CSS-RAFW and CSS-RGMW on (a) 20-6-2020 and (b) 22-6-2020

3.2 Hour-wise variation of Evaporative Heat Transfer Coefficient (EHTC) and hourly potable water yielding

Figure 4 (a and b) shows the hour-wise difference of EHTC and hourly production of potable water from the CSS-BPW, CSS-RAFW and CSS-RGMW on 20-6-2020 and 22-6-2020, respectively. The highest calculated EHTC of the CSS-BPW, CSS-RAFW and CSS-RGMW are 36.94, 45.06 and 48.75 W/m^2Kon 20-6-2020 and 38.46, 46.81 and 48.86 W/m^2Kon 22-6-2020, respectively. Each day average EHTC of 22.75, 27.96, and 29.48 $W/m^2K$was calculated on 20-6-2020 and each day average EHTC of 23.74, 29.25 and 30.55 $W/m^2K$was calculated on 22-6-2020 for the CSS-BPW, CSS-RAFW and CSS-RGMW, respectively. Each day average EHTC of the CSS-RGMW is higher than the CSS-BPW, CSS-RAFW due to the higher reflective materials at the inner sidewalls of the solar still. Each day average EHTC value of the CSS-RAFW and CSS-RGMW is 23.21% and 28.68% higher as compared to each day average EHTC of the CSS-BPW and daily average EHTC value of the CSS-RGMW is 4.44% higher as compared to the CSS-RAFW. In the CSS-RGMW, glass mirrors enhance the saline water temperature, and so it has maximum hourly and each day average EHTC than the CSS-RAFW and CSS-BPW.

Figure 4 (a and b) shows the hourly potable water production from the CSS-BPW, CSS-RAFW and CSS-RGMW on 20-6-2020 and on 22-6-2020, respectively. Hourly productivity from the solar stills is increasing during the sunrise hours and decreases during sunset hours. The highest hourly yield of 0.65, 0.96 and 1.08 kg was produced on 20-6-2020 and highest hourly yield of 0.70, 0.98 and 1.04 kg was produced on 22-6-2020 from the CSS-BPW, CSS-RAFW and CSS-RGMW, respectively. Each day water production from the CSS-BPW on 20-6-2020 is 3.28 kg and on 22-6-2020 is 3.41 kg, from the CSS-RAFW on 20-6-2020 is 4.95 kg and on 22-6-2020 is 5.1 kg, from the CSS-RGMW on 20-6-2020 is 5.34 kg and on 22-6-2020 is 5.54 kg. When using the reflective glass mirrors at the surface of the wall of the CSS, water production was increased by about 63.15% and 7.94% on 20-6-2020 and water production was increased by about 62.53 and 8.57% on 22-6-2020 as compared to the CSS-BPW and CSS-RAFW, respectively. In the CSS-RGMW, due to the reflective material properties, it reflects maximum heat energy to the saline water and thus enhances the water temperature so water yielding from the CSS-RGMW is maximum as compared to the CSS-BPW and CSS-RAFW.

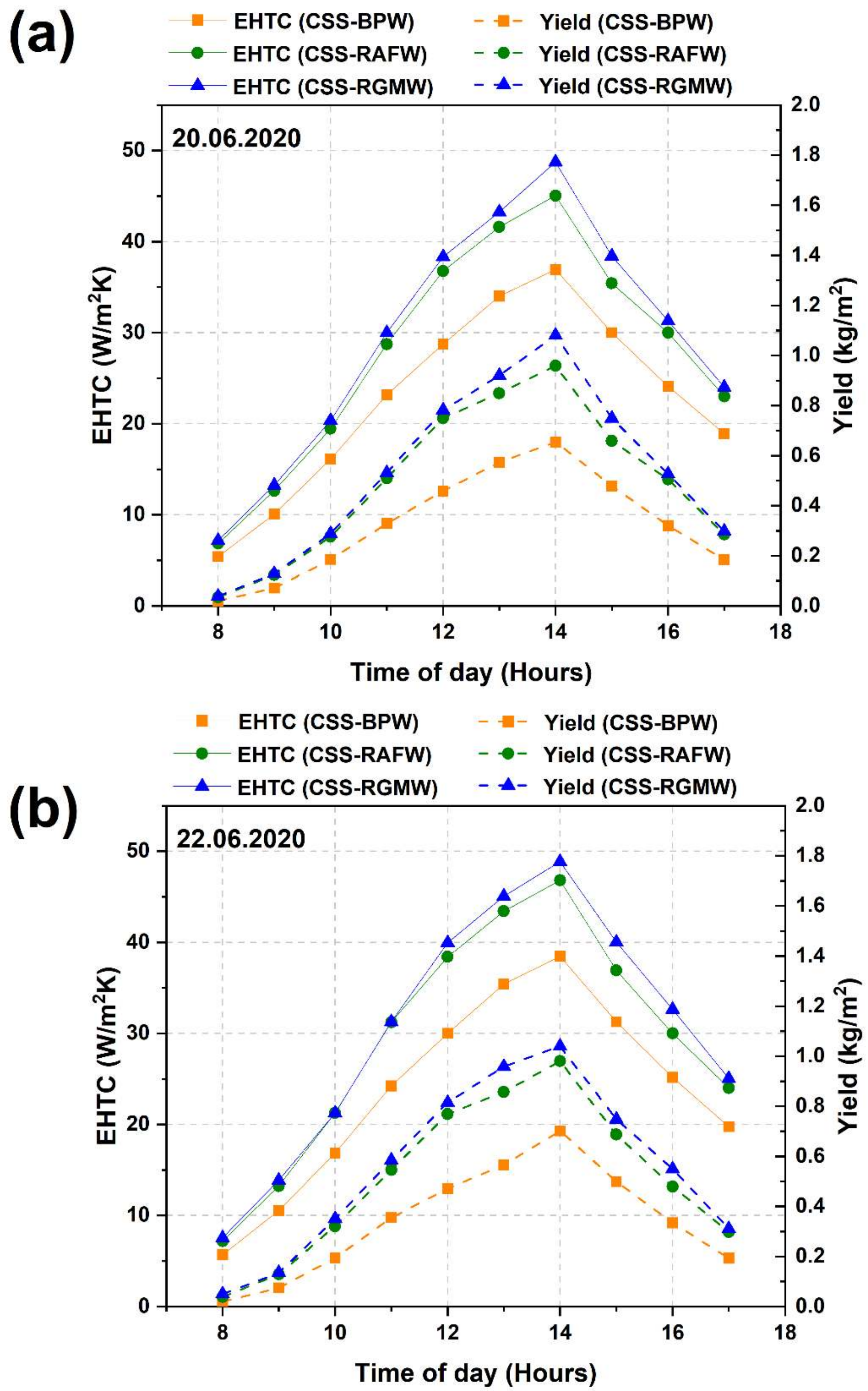

Fig. 4 Hour wise variation of EHTC and yield from the CSS-BPW, CSS-RAFW and CSS-RGMW (a) on 20-6-2020 and (b) on 22-6-2020

3.3 Hour-wise variation of Energy and Exergy efficiency

Hour -wise variations of energy and exergy efficiency of the CSS-BPW, CSS-RAFW and CSS-RGMW on 20-6-2020 and 22-6-2020 are shown in Figure 5 (a & b), respectively. The energy efficiency of the CSS-BPW, CSS-RAFW and CSS-RGMW were increasing during the morning and reached the highest value at 2 P.M, and then it decreases. The energy efficiency of the CSS-BPW starts at 2.30% at 8 A.M has a rising tendency and reached 50.7% at 2 P.M, and then it has a declining tendency up to 5 P.M (35.52%). Also, the energy efficiency of the CSS-RAFW starts at 4.36% at 8 A.M has an increasing tendency and reached 69.46% at 2 P.M and then it has a declining tendency up to 5 P.M (50.94%). Similarly, the energy efficiency of the CSS-RGMW starts with 7.57% at 8 A.M, have enhanced tendency and reached 73.61% at 2 P.M and then it has a declining tendency up to 5 P.M (57.32%). Each day average energy efficiency of the CSS-BPW, CSS-RAFW and CSS-RGMW are 27.68, 40.47 and 47.7% on 22-6-2020, respectively. The energy efficiency of the CSS-RGMW is 72.35 and 17.87% higher than the CSS-BPW and CSS-RAFW on 22-6-2020, respectively. The presence of glass mirrors in the CSS-RGMW augments $T_{s.w}$, EHTC and production of freshwater and consequently it produced higher energy efficiency than the CSS-RAFW and CSS-BPW. Since energy efficiency of the stills are directly proportional to the production of freshwater and radiation.

The exergy efficiency of the CSS-BPW, CSS-RAFW and CSS-RGMW was rising in the sunrise hours and reached the highest value at 2 P.M, and then it has a decreasing trend. The exergy efficiency of the CSS-BPW starts with 2.3% at 8 A.M has a rising tendency and reached a maximum value of 4.08% at 2 P.M, and then it has a decreasing tendency up to 5 P.M (1.92%). Also, the exergy efficiency of the CSS-RAFW starts at 0.09% at 8 A.M has a rising tendency and reached the maximum value of 7.25% at 2 P.M, and then it has a decreasing tendency up to 5 P.M (3.72%). Similarly, the exergy efficiency of the CSS-RGMW starts with 0.11% at 8 A.M has a rising tendency and reached 7.97% at 2 P.M, and then it has to decrease tendency up to 5 P.M (3.96%). Each day exergy efficiency of the CSS-BPW, CSS-RAFW and CSS-RGMW are 2.19, 3.41 and 3.82%, respectively on 22-6-2020. The exergy efficiency of the CSS-RGMW is 74.73% and 12.16% higher than CSS-BPW and CSS-RAFW, respectively on 22-6-2020. The maximum and daily average exergy efficiency of the stills is maximum in the case of CSS-RGMW and CSS-RAFW since exergy efficiency directly related to water yield production and solar intensity available. During the sunset moment, the difference between $T_{s.w}$ and $T_{c.c}$ is maximum, so the exergy efficiency of the stills during the evening is higher as compared to the morning. Also, it is found that reflecting the solar intensity on the saline water surface has produced better performance than the CSS-BPW.

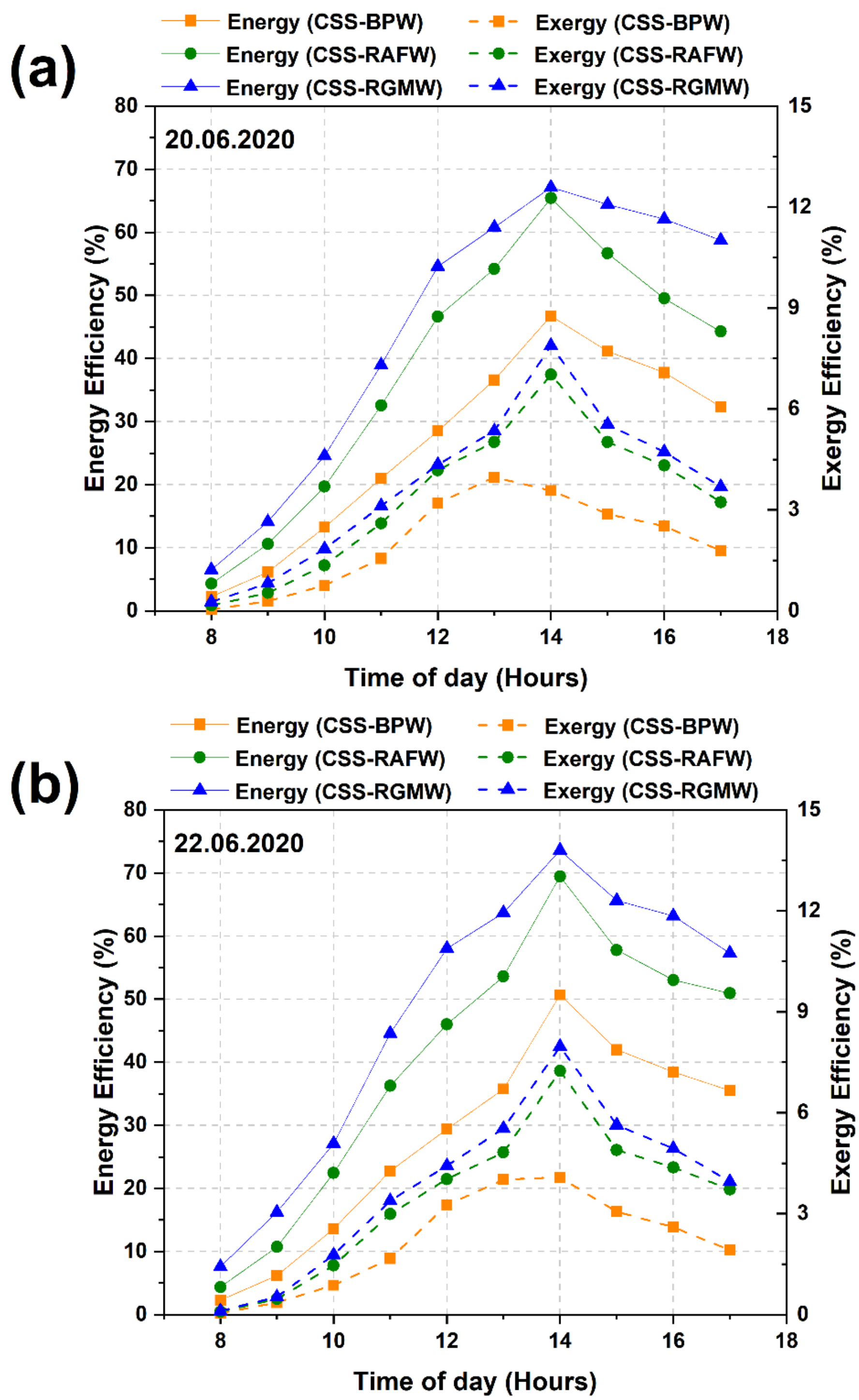

Fig. 5 Hour -wise changes of energy and exergy efficiency of the CSS-BPW, CSS-RAFW and CSS-RGMW (a) on 20-6-2020 and (b) on 22-6-2020

4. Comparison of the present study with published similar works

Comparison of present results with published similar works has been provided in Table 1. Through the results, it has been noted that the cumulative yield of a solar still containing reflective glass mirrors increases the productivity by 68.57% compared to the CSS-BPW and cumulative yield increasing by 48.57% when using reflective aluminium foil sheet. Thus, the reflective glass mirrors greatly enhances the productivity of solar distillation. Table 1 shows that the productivity improvement of "V" type solar still with mirror has minimum value of 11.92% (Kumar et al., 2008). However, for the double solar still with finned corrugated basin, black granite, wick and reflector, has the maximum value of 171.43% (Omara et al., 2016). The present study produced maximum daily productivity of 5.54 and 5.1 kg/m^2 using reflective glass mirrors and reflective aluminium foil sheet, respectively.

Table 1: Comparison between the productivity

S.N°	Author name	Type of solar still	Enhancement techniques	Improvement in Productivity
1	(Tanaka and Nakatake, 2005)	vertical multiple-effect diffusion-type solar still	- flat-plate mirror	50%
2	(Kumar et al., 2008)	"V" type solar still	- Mirror - Mirror and charcoal	11.92% 14.11%
3	(Gnanaraj and Velmurugan, 2019)	Double slope solar still	- Reflector - Finned corrugated basin, black granite, wick and reflector	93.39% 171.43%
4	(Omara et al., 2013)	Stepped solar still	- Internal reflectors	75%
5	(Abdullah et al., 2020)	Trays solar still	- Internal reflectors - External reflectors	58% 75%
6	(Parsa et al., 2020c)	double-slope condenser	- Nanofluid and condenser - condenser	100.5% 50.8%
7	Our results	Single slope solar still	- Reflective glass mirrors - Reflective aluminium foil sheet	68.57% 48.57%

5. Conclusions

This experimental work highlights the impact of reflective glass mirrors and reflective aluminium foil sheet on the yield produced from the conventional solar distillers. This simple technique involves placing a mirrors and reflective aluminium foil sheet on the inner walls of the solar distillate. This technique is simple, inexpensive, and effective. Moreover, it has no negative impact on the environment. This newly proposed solution provides significant productivity improvement rates as compared to other researches. The obtained conclusions can be written as follows:

- The glass mirrors with 99% of reflectivity and the aluminium foil sheet with 88% of reflectivity enhance the yield and efficiency of the solar stills. The glass mirrors material is much better than using aluminium foil sheet.
- The daily distilled water production from the CSS-BPW is equal to 3.41 kg/m^2. However, it is equal to 5.54 kg/m^{2}for the CSS-RGMW and 5.1 kg/m^2 for the CSS-RAFW.
- Compared to the CSS-BPW, the daily accumulation was improved by 68.57% and 48.57% by using the reflective glass mirrors and the reflective aluminium foil sheet, respectively.
- The energy efficiency of the CSS-RGMW is higher than the CSS-RAFW and CSS-BPW. The highest energy efficiencies of the CSS-BPW, CSS-RAFW and CSS-RGMW were noted as 50.7, 69.46 and 73.61%, respectively.
- The highest exergy efficiencies of the CSS-BPW, CSS-RAFW and CSS-RGMW were noted as 4.08, 7.25 and 7.97%, respectively.
- The amount invested is recovered in the distiller as a conventional solar still with black painted walls in 38 days. However, this period is equal to 23 days for the CSS-RGMW and 26 days for the CSS-RAFW.
- The productivity of the distillate with the mirrors is much better than that of the distillate with an aluminium foil sheet. From the economic study, it has been noted that the cost recovery period is very close in both cases. This fact is due to the price of the glass mirrors is about 40 times more than the price of the aluminium foil sheet.

Nomenclature

CrSS	Corrugated Solar Still
CSS-BPW	Conventional Solar Still with Black Painted Walls
CSS-RAFW	Conventional Solar Still with Reflective Aluminium Foil-sheet Walls
CSS-RGMW	Conventional Solar Still with Reflective Glass mirrors Walls
EHTC	Evaporative Heat Transfer Coefficient
[I(t)]	solar intensity
T_a	Ambience temperature
$T_{s.w}$	saline water temperature
$T_{c.c}$	collector cover temperature

APPENDIX-1 Error analysis

The variable parameters are measured using thermocouples, pyranometer, and graduated beaker. All the errors are recorded in Table 2.

Table2. Standard uncertainties

Instrument	Accuracy	Range	Standard uncertainty
Solar power meter	± 10 W/m^2	0-1999 W/m^2	5.72 W/m^2
Thermocouple	± 0.1 °C	−100–500 °C	0.07 °C
Graduated cylinder	± 1 ml	0–550 ml	0.6 ml

APPENDIX-2

1. The EHTC from $T_{s.w}$, to$T_{c.c}$ (Manokar et al., 2018b):

$$h_{e,w-g} = 16.273X10^{-3}xh_{c,w-g}\left[\frac{P_w - P_{cc}}{\mathrm{T}b.w - T_{cc}}\right]$$

2. Convective heat transfer coefficient from $T_{s.w}$, to $T_{c.c}$ (Manokar et al., 2018b):

$$h_{c,w-g} = 0.884\left[\left(T_w - T_g\right) + \frac{\left(T_w + 273.15\right)\left(p_w - p_g\right)}{\left(268900 - p_w\right)}\right]^{1/3}$$

3. Partial vapour pressure at the $T_{s.w}$ (Manokar et al., 2018b):

$$P_w = exp\left(25.317 - \left(\frac{5144}{273 + \mathrm{Tb.w}}\right)\right)$$

4. Partial vapour pressure at the $T_{c.c}$ (Manokar et al., 2018b):

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

5. The energy efficiency of the CSS-BPW, CSS-RAFW and CSS-RGMW (Manokar et al., 2018b):

$$\eta_{passive} = \frac{\sum \dot{m}_{ew} L}{\sum I(t) A_s x 3600} x100$$

6. The exergy efficiency of the CSS-BPW, CSS-RAFW and CSS-RGMW (Manokar et al., 2018b):

$$\eta_{overall,exe} = \frac{\sum Ex_{output}}{\sum Ex_{input}}$$

7. The hourly exergy output of the CSS-BPW, CSS-RAFW and CSS-RGMW (Manokar et al., 2018b):

$$Ex_{output} = \frac{m_{ew} L_{fg}}{3600} \times \left[1 - \frac{T_a}{T_w}\right]$$

8. The hourly exergy input of the CSS-BPW, CSS-RAFW and CSS-RGMW (Manokar et al., 2018b):

$$Ex_{input} = A_w I^{'}(t) \times \left[1 - \frac{4}{3}\left(\frac{T_a}{T_s}\right) + \frac{1}{3}\left(\frac{T_a}{T_s}\right)^4\right]$$

Ethical Approval

Not Applicable

Consent to Participate

Not Applicable

Consent to Publish

Not Applicable

Authors Contributions

Conceptualization, Methodology, Resources, Formal analysis and investigation were carried out by Mohammed El Hadi Attia, Athikesavan Muthu Manokar, Fausto Pedro Garcia Marquez, Zied Driss and Ravishankar Sathyamurthy, Writing - original draft preparation, review and editing, Supervision were carried out by V.S.Chandrika

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