Journal Paper

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

Springer

2021

Vanitha Selvaraj Chandrika

Department of Electrical and Electronics Engineering, KPR Institute of Engineering and Technology, Tamilnadu, INDIA

Mohammed El Hadi Attia

Department of Physics, Faculty of Science, University of El Oued, ALGERIA

Athikesavan Muthu Manokar

Department of Mechanical Engineering, B.S. Abdur Rahman Crescent Institute of Science and Technology, Tamil Nadu, INDIA

Fausto Pedro Garcia Marquez

Ingenium Research Group, Universidad Castilla-La ManchaCiudad Real, SPAIN
Faustopedro.garcia@uclm.es

Zied Driss

Laboratory of Electromechanical Systems, National School of Engineers of Sfax, University of Sfax, TUNISIA

Ravishankar Sathyamurthy

Department of Mechanical Engineering, KPR Institute of Engineering and Technology, Arasur, Coimbatore, Tamil Nadu, INDIA

Cite as: Chandrika, V.S., Attia, M.E.H., Manokar, A.M. et al. Performance enhancements of conventional solar still using reflective aluminium foil sheet and reflective glass mirrors: energy and exergy analysis. Environ Sci Pollut Res (2021).

DOI: <https://doi.org/10.1007/s11356-021-13087-2>

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

Vanitha Selvaraj Chandrika¹, Mohammed El Hadi Attia², Athikesavan Muthu Manokar³, Fausto Pedro Garcia Marquez^{4,}, Zied Driss⁵ and Ravishankar Sathyamurthy⁶*

¹Department of Electrical and Electronics Engineering, KPR Institute of Engineering and Technology, Avinashi road, Coimbatore-641407, Tamilnadu, India,

²Department of Physics, Faculty of Science, University of El Oued, 39000 El Oued, ALGERIA

³Department of Mechanical Engineering, B.S. Abdur Rahman Crescent Institute of Science and Technology, Chennai - 600 048, Tamil Nadu, INDIA

⁴Ingenium Research Group, Universidad Castilla-La Mancha Ciudad Real, Spain

⁵Laboratory of Electromechanical Systems, National School of Engineers of Sfax, University of Sfax, BP 1173, 3038, Sfax, TUNISIA

⁶Department of Mechanical Engineering, KPR Institute of Engineering and Technology, Arasur, Coimbatore, Tamil Nadu, India

*Email: faustopedro.grcia@uclm.es

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/m², 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/m²/day with the reflecting mirror. However, it is about 3.40 L/m²/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/m²/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).

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 augment 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/m²K on 20-6-2020 and 38.46, 46.81 and 48.86 W/m²K on 22-6-2020, respectively. Each day average EHTC of 22.75, 27.96, and 29.48 W/m²K was calculated on 20-6-2020 and each day average EHTC of 23.74, 29.25 and 30.55 W/m²K 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

258 morning. Also, it is found that reflecting the solar intensity on the saline water surface has
 259 produced better performance than the CSS-BPW.

260
 261 **Fig. 5 Hour -wise changes of energy and exergy efficiency of the CSS-BPW, CSS-RAFW**
 262 **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/m² using reflective glass mirrors and reflective aluminium foil sheet, respectively.

Table 1: Comparison between the productivity

S.N ^o	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/m². However, it is equal to 5.54 kg/m² for the CSS-RGMW and 5.1 kg/m² 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.

306 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

307

308 APPENDIX-1 Error analysis

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

311 **Table2. Standard uncertainties**

Instrument	Accuracy	Range	Standard uncertainty
Solar power meter	$\pm 10 \text{ W/m}^2$	0-1999 W/m^2	5.72 W/m^2
Thermocouple	$\pm 0.1 \text{ }^\circ\text{C}$	-100–500 $^\circ\text{C}$	0.07 $^\circ\text{C}$
Graduated cylinder	$\pm 1 \text{ ml}$	0–550 ml	0.6 ml

312

313 APPENDIX-2

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

$$315 \quad h_{e,w-g} = 16.273 \times 10^{-3} x h_{c,w-g} \left[\frac{P_w - P_{cc}}{T_{b.w} - T_{cc}} \right]$$

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

$$317 \quad h_{c,w-g} = 0.884 \left[(T_w - T_g) + \frac{(T_w + 273.15)(p_w - p_g)}{(268900 - p_w)} \right]^{1/3}$$

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

$$319 \quad P_w = \exp \left(25.317 - \left(\frac{5144}{273 + T_{b.w}} \right) \right)$$

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):

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

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):

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

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

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

338 **Ethical Approval**

339 Not Applicable

340

341 **Consent to Participate**

342 Not Applicable

343

344 **Consent to Publish**

345 Not Applicable

346

347 **Authors Contributions**

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

352

353 **Funding**

354 There is no funding received for the research work carried out.

355

356 **Competing Interests**

357 The authors declare that there is no competing interest

358

359 **Availability of data and materials**

360 Not Applicable

361

362

References

- Abdallah, S., Badran, O. & Abu-Khader, M. M. 2008. Performance evaluation of a modified design of a single slope solar still. *Desalination*, 219(1-3), pp 222-230.
- Abdullah, A., Younes, M., Omara, Z. & Essa, F. 2020. New design of trays solar still with enhanced evaporation methods—Comprehensive study. *Solar Energy*, 203(164-174).
- Achour, L., Bouharkat, M., Assas, O. & Behar, O. 2017. Hybrid model for estimating monthly global solar radiation for the Southern of Algeria:(Case study: Tamanrasset, Algeria). *Energy*, 135(526-539).
- Al-Nimr, M. d. A., Al-Ammari, W. A. & Alkhalidi, A. 2019. A novel hybrid photovoltaics/thermoelectric cooler distillation system. *International Journal of Energy Research*, 43(2), pp 791-805.
- Attia, M. E. H., Driss, Z., Alagar, K., Athikesavan, M. M. & Sathyamurthy, R. Phosphate bags as energy storage materials for enhancement of solar still performance. *Environmental Science and Pollution Research*, 1-13.
- Attia, M. E. H., Driss, Z., Kabeel, A. E., Afzal, A., Manokar, A. M. & Sathyamurthy, R. Phosphate bed as energy storage materials for augmentation of conventional solar still productivity. *Environmental Progress & Sustainable Energy*, e13581.
- Attia, M. E. H., Driss, Z., Manokar, A. M. & Sathyamurthy, R. 2020. Effect of aluminum balls on the productivity of solar distillate. *Journal of Energy Storage*, 30(101466).
- Baccoli, R., Mastino, C. C., Innamorati, R., Serra, L., Curreli, S., Ghiani, E., Ricciu, R. & Marini, M. 2015. A mathematical model of a solar collector augmented by a flat plate above reflector: Optimum inclination of collector and reflector. *Energy Procedia*, 81(205-214).
- Bahaidarah, H. M., Tanweer, B., Gandhidasan, P. & Rehman, S. 2015. A combined optical, thermal and electrical performance study of a V-trough PV system—experimental and analytical investigations. *Energies*, 8(4), pp 2803-2827.
- Balachandran, G. B., David, P. W., Rajendran, G., Ali, M. N. A., Radhakrishnan, V., Balamurugan, R., Athikesavan, M. & Sathyamurthy, R. 2021. Investigation of performance enhancement of solar still incorporated with Gallus gallus domesticus cascara as sensible heat storage material. *Environmental Science and Pollution Research*, 28(1), pp 611-624.
- Belhadj, M., Benouaz, T. & Bekkouche, S. M. E. A. 2016. Modeling of Automatic Reflectors for PV panel Attached to Commercial PV/T Module. *International Journal of Applied Engineering Research*, 11(23), pp 11309-11314.

- Cheniti, H., Cheniti, M. & Brahamia, K. 2020. Use of GIS and Moran's I to support residential solid waste recycling in the city of Annaba, Algeria. *Environmental Science and Pollution Research*, 1-15.
- Chowdhury, N. 2016. Design and experimental validation of a photovoltaic-thermal (PVT) hybrid collector. *International Journal of Renewable Energy Research (IJRER)*, 6(4), pp 1446-1453.
- El-Agouz, E.-S., Athikesavan, M. M., Ramalingam, R. D., Sathyamurthy, R., Prakash, N. & Prasad, C. 2019. Comparative analysis on freshwater yield from conventional basin-type single slope solar still with cement-coated red bricks: an experimental approach. *Environmental science and pollution research*, 1-11.
- Ghadamgahi, M., Ahmadi-Danesh-Ashtiani, H. & Delfani, S. 2020. Comparative study on the multistage solar still performance utilizing PCM in variable thicknesses. *International Journal of Energy Research*, 44(6), pp 4196-4210.
- Gnanaraj, S. J. P. & Velmurugan, V. 2019. An experimental study on the efficacy of modifications in enhancing the performance of single basin double slope solar still. *Desalination*, 467(12-28).
- Gonzalo, A. P., Marugán, A. P. & Márquez, F. P. G. 2019. A review of the application performances of concentrated solar power systems. *Applied Energy*, 255(113893).
- Hanlon, J. F. & Kelsey, R. J. 1998. *Handbook of package engineering*: Crc Press.
- Hassan, H., Yousef, M. S., Ahmed, M. S. & Fathy, M. 2020a. Energy, exergy, environmental, and economic analysis of natural and forced cooling of solar still with porous media. *Environmental Science and Pollution Research*, 27(30), pp 38221-38240.
- Hassan, H., Yousef, M. S. & Fathy, M. 2020b. Productivity, exergy, exergoeconomic, and enviroeconomic assessment of hybrid solar distiller using direct salty water heating. *Environmental Science and Pollution Research*, 1-13.
- Hilarydoss, S., Delhiraja, K., Reddy, K. S., Philip, L., Chand, D. & Benny, B. 2020. Thermal modeling, characterization, and enviro-economic investigations on inclined felt sheet solar distiller for seawater desalination. *Environmental Science and Pollution Research*, 1-17.
- Kabir, F. & Chowdhury, S. 2017. Arsenic removal methods for drinking water in the developing countries: technological developments and research needs. *Environmental Science and Pollution Research*, 24(31), pp 24102-24120.
- Khechekhouche, A., Benhaoua, B., Manokar, M., Sathyamurthy, R. & Driss, Z. 2020a. Sand dunes effect on the productivity of a single slope solar distiller. *Heat and Mass Transfer*, 56(4), pp 1117-1126.

449 Khechekhouche, A., Kabeel, A., Benhaoua, B., Attia, M. E. H. & El-Said, E. M. 2020b. Traditional solar
 450 distiller improvement by a single external refractor under the climatic conditions of the El
 451 Oued region, Algeria. *Desalination Water Treatment*, 177(23-28).

452

453 Kostić, L. T., Pavlović, T. & Pavlović, Z. 2010. Optimal design of orientation of PV/T collector with
 454 reflectors. *Applied Energy*, 87(10), pp 3023-3029.

455

456 Kostic, L. T., Pavlovic, T. M. & Pavlovic, Z. T. 2010. Influence of reflectance from flat aluminum
 457 concentrators on energy efficiency of PV/Thermal collector. *Applied Energy*, 87(2), pp 410-416.

458

459 Kumar, B. S., Kumar, S. & Jayaprakash, R. 2008. Performance analysis of a “V” type solar still using a
 460 charcoal absorber and a boosting mirror. *Desalination*, 229(1-3), pp 217-230.

461

462 Madhu, B., Balasubramanian, E., Sathyamurthy, R., Nagarajan, P., Mageshbabu, D., Bharathwaaj, R. &
 463 Manokar, A. M. 2018. Exergy analysis of solar still with sand heat energy storage. *Applied Solar*
 464 *Energy*, 54(3), pp 173-177.

465

466 Malik, K., Rahman, S. M., Khondaker, A. N., Abubakar, I. R., Aina, Y. A. & Hasan, M. A. 2019. Renewable
 467 energy utilization to promote sustainability in GCC countries: policies, drivers, and barriers.
 468 *Environmental Science and Pollution Research*, 26(20), pp 20798-20814.

469

470 Manokar, A. M., Winston, D. P., Kabeel, A. & Sathyamurthy, R. 2018a. Sustainable fresh water and
 471 power production by integrating PV panel in inclined solar still. *Journal of cleaner production*,
 472 172(2711-2719).

473

474 Manokar, A. M., Winston, D. P., Mondol, J. D., Sathyamurthy, R., Kabeel, A. & Panchal, H. 2018b.
 475 Comparative study of an inclined solar panel basin solar still in passive and active mode. *Solar*
 476 *Energy*, 169(206-216).

477

478 Márquez, F. P. G., Karyotakis, A. & Papaelias, M. 2018. *Renewable energies: Business outlook 2050*:
 479 Springer.

480

481 Mohd Rosli, M. A., Mat, S., Sopian, K., Sulaiman, M. Y., Salleh, E. I. & Sharif, M. K. A. Thermal
 482 Performance on Unglazed Photovoltaic Thermal Polymer Collector. *Advanced Materials*
 483 *Research*, 2014. Trans Tech Publ, 238-242.

484

485 Nabil, T. & Khairat Dawood, M. M. 2020. Productivity enhancement of single-slope solar still using oxy-
 486 hydrogen gas as fuel: An experimental approach. *International Journal of Energy Research*.

487

488 Naik, P. S. & Palatel, A. 2014. Energy and exergy analysis of a plane reflector integrated photovoltaic-
 489 thermal water heating system. *International Scholarly Research Notices*, 2014(

490

491 Nia, M., Chegaar, M., Benatallah, M. & Aillerie, M. 2013. Contribution to the quantification of solar
 492 radiation in Algeria. *Energy Procedia*, 36(730-737).

493
 494 Omara, Z., Kabeel, A. & Abdullah, A. 2017. A review of solar still performance with reflectors.
 495 *Renewable and Sustainable Energy Reviews*, 68(638-649).

496
 497 Omara, Z., Kabeel, A., Abdullah, A. & Essa, F. 2016. Experimental investigation of corrugated absorber
 498 solar still with wick and reflectors. *Desalination*, 381(111-116).

499
 500 Omara, Z., Kabeel, A. & Younes, M. 2013. Enhancing the stepped solar still performance using internal
 501 reflectors. *Desalination*, 314(67-72).

502
 503 Omara, Z., Kabeel, A. & Younes, M. 2014. Enhancing the stepped solar still performance using internal
 504 and external reflectors. *Energy conversion and management*, 78(876-881).

505
 506 Parsa, S. M., Javadi, D., Rahbar, A., Majidniya, M., Aberoumand, S., Amidpour, Y. & Amidpour, M. 2019.
 507 Experimental assessment on passive solar distillation system on Mount Tochal at the height of
 508 3964 m: Study at high altitude. *Desalination*, 466(77-88).

509
 510 Parsa, S. M., Javadi, D., Rahbar, A., Majidniya, M., Salimi, M., Amidpour, Y. & Amidpour, M. 2020a.
 511 Experimental investigation at a summit above 13,000 ft on active solar still water purification
 512 powered by photovoltaic: A comparative study. *Desalination*, 476(114146).

513
 514 Parsa, S. M., Rahbar, A., Javadi, D., Koleini, M., Afrand, M. & Amidpour, M. 2020b. Energy-matrices,
 515 exergy, economic, environmental, exergoeconomic, enviroeconomic, and heat transfer
 516 (6E/HT) analysis of two passive/active solar still water desalination nearly 4000m: Altitude
 517 concept. *Journal of Cleaner Production*, 121243.

518
 519 Parsa, S. M., Rahbar, A., Koleini, M., Aberoumand, S., Afrand, M. & Amidpour, M. 2020c. A renewable
 520 energy-driven thermoelectric-utilized solar still with external condenser loaded by
 521 silver/nanofluid for simultaneously water disinfection and desalination. *Desalination*,
 522 480(114354).

523
 524 Parsa, S. M., Rahbar, A., Koleini, M., Javadi, Y. D., Afrand, M., Rostami, S. & Amidpour, M. 2020d. First
 525 approach on nanofluid-based solar still in high altitude for water desalination and solar water
 526 disinfection (SODIS). *Desalination*, 491(114592).

527
 528 Ramalingam, V. K., Karthick, A., Jeyalekshmi, M. P. V., Decruz, A. M. M. A. J., Manokar, A. M. &
 529 Sathyamurthy, R. Enhancing the fresh water produced from inclined cover stepped absorber
 530 solar still using wick and energy storage materials. *Environmental Science and Pollution*
 531 *Research*, 1-17.

532
 533 Shanmugan, S., Rajamohan, P. & Mutharasu, D. 2008. Performance study on an acrylic mirror boosted
 534 solar distillation unit utilizing seawater. *Desalination*, 230(1-3), pp 281-287.

535

536 Tabet, I., Touafek, K., Bellel, N., Khelifa, A. & Adouane, M. 2014. Performances Improvement of
537 photovoltaic thermal air collector by planer reflector. *Rev. des Energies Renouvelables*, 1(219-
538 225.

539

540 Tanaka, H. 2009. Tilted wick solar still with external flat plate reflector: optimum inclination of still and
541 reflector. *Desalination*, 249(1), pp 411-415.

542

543 Tanaka, H. & Nakatake, Y. 2005. A simple and highly productive solar still: a vertical multiple-effect
544 diffusion-type solar still coupled with a flat-plate mirror. *Desalination*, 173(3), pp 287-300.

545

546 Tanaka, H. & Nakatake, Y. 2007. Improvement of the tilted wick solar still by using a flat plate reflector.
547 *Desalination*, 216(1-3), pp 139-146.

548

549 Tanaka, H. & Nakatake, Y. 2009. Increase in distillate productivity by inclining the flat plate external
550 reflector of a tilted-wick solar still in winter. *Solar Energy*, 83(6), pp 785-789.

551

552 Thalib, M. M., Manokar, A. M., Essa, F. A., Vasimalai, N., Sathyamurthy, R. & Garcia Marquez, F. P.
553 2020. Comparative study of tubular solar stills with phase change material and nano-enhanced
554 phase change material. *Energies*, 13(15), pp 3989.

555

556 Zhuang, W. 2016. Eco-environmental impact of inter-basin water transfer projects: a review.
557 *Environmental Science and Pollution Research*, 23(13), pp 12867-12879.

558

559 Zouari, M., Souguir, D., Bloem, E., Schnug, E., Hanchi, B. & Hachicha, M. 2019. Saline soil reclamation
560 by agroforestry species under Kalaât Landelous conditions and irrigation with treated
561 wastewater in Tunisia. *Environmental Science and Pollution Research*, 26(28), pp 28829-28841.

562

563