Performance Improvements of Hemispherical Solar Still Using Internal Reflector: Energy and Exergy Analysis

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Abstract

Various scientists are looking for effective and easy solutions for augmentation of yield from the Hemispherical Solar Still (HSS). In this study, aluminium foil-sheet was used to reflect the intensity hence augments the evaporation rate and daily yield. Experimentations were conducted on two SS: the first SS is HSS; the second SS is HSS with reflective aluminium foil-sheet walls (HSS-RAFW). The highest distilled water production from the HSS, HSS-RAFW are 3.36 and 4.1 kg/m², respectively. Compared to the HSS, the yield of distilled water was augmented by 22.21% when using the HSS- RAFW. The daily energy and exergy efficiency (EnE and ExE) of the HSS is 26.27 and 1.04%, respectively and daily EnE and ExE of the HSS-RAFW is 32.75 and 1.71%, respectively.

1. Introduction

Fresh water is one of the supreme significant part of all living things. It is a residence of aquatic species such as fish, marine plankton and many other marine plants and animals, and it occupies about seventy-one percent of the earth's surface (Kumar et al., 2021). The situation of the earth in the universe makes it receives a huge amount of solar energy. Solar energy may be transform it to alternative form of energy such as electrical, chemical, mechanical or thermal energy (Vaithilingam et al., 2020; Manokar et al. 2019). Traditional energy resources, such as oil, coal and gas, are becoming less relevant as their use produces environmental crises (Manokar et al., 2018a) (Ho et al., 2019). Researchers are investigating the use of renewable energy resources in all aspects of life such as industrial areas, desalination of waste water. The lack of clean pure water has become the most serious threat to public's survives (Choong et al., 2020). As a result, SS can be used to desalinate salt water and produce pure water (Ho et al. 2021; Bahar et al., 2013). Several scientists improve the SS output by incorporating heat storage materials and altering distiller design (Prasad et al., 2021; Essa et al., 2021; Balachandran et al. 2020a ; Ramalingam et al. 2021). (Kosti et al., 2010; Kostic et al., 2010a) investigated the effects of reflectors on SS efficiency. They discovered that using mirrors at a 66° angle enhanced the SS efficiency. (Tabet et al., 2014) used a plane reflector to increase the efficiency of a PV/T air collector. The results show that using a plane reflector for increases the efficiency of the PV/T air collector. In the Indian city of Kolkata, (Naik and Palatel, 2014) investigated the installation of a mirror coupled to the top of the hybrid solar collector with angles ranging from 85° to 100°. The impact of an outside reflector on a solar collector was mathematically studied by (Baccoli et al., 2015). The impact of reflector on the efficiency of a hybrid solar collector was stated by (Bahaidarah et al., 2015). The obtained results showed that the solar collector's performance had enhanced. (Belhadj et al., 2016) investigated the impact of angle between two reflectors on solar collector. This method augmented the solar radiation contribution to the device, according to the researchers. (Chowdhury, 2016 and Kabir and Chowdhury, 2017) examined the impact of a focused PV/T collector configuration on the collector's overall efficiency. (Mohd Rosli et al., 2014) used an unglazed PV/T device to enhance the performance of the solar collector. (Khechekhouche et al., 2020) used a simple external mirror to perform the CSS experiments. With the reflecting mirror, the output was equivalent to 4.84 L/m²/day, according to the experimental results. In the CSS, however, it is around 3.40

L/m²/day. Tanaka and Nakatake (2009) examined the influence of the external reflector's on inclined SS. The findings showed that when the oblique reflector was used instead of the vertical mirror in the situation of the reflector's length half, the daily yield was increased by 15 to 27 percent. (Omara et al., 2016) published a comparison analysis of the CSS and the corrugated SS (CrSS) using layer wick with reflectors. The outputs indicated that the CrSS had a 145.5% higher increase in daily accumulation than the CSS, and the CrSS and CSS had daily performance of about 59 and 33 percent, respectively. The effect of reflectors (internal and external) in the modified stepped SS was investigated by (Omara et al., 2014). They found that everyday efficiency was 125 percent higher with reflectors (internal and external) than with the CSS. Internal mirrors, a step-wise basin, and a sun tracking SS were investigated by (Abdallah et al., 2008). The efficiency of this system was improved by 30% when interior mirrors were used, 180 percent while the stepwise basin was used, and 380 percent when the stepwise basin was combined by a sun tracking system. (Omara et al., 2017; Tanaka and Nakatake, 2007; Tanaka, 2009). Many researchers have newly used waste/low-cost materials as energy storage materials (Balachandran et al., 2020, Attia et al., 2020, Attia et al., 2021, Attia et al., 2021a, Kabeel et al., 2019, Madhu et al., 2018, Khechekhouche et al., 2020, Ramalingam et al., 2021), Nano materials (Benoudina et al. 2021, Chamkha et al. 2020, Sathyamurthy et al. 2020, Arani et al. 2021, Kabeel et al. 2020) and hybrid SS (Manokar et al. 2019b, Sasikumar et al. 2020, Thalib et al. 2021, Manokar et al. 2020a, Manokar 2020, Taamneh et al. 2020, Kumar et al, 2018).

According to the current state of the art, some researchers were used reflective glass to improve efficiency. The use of low cost aluminium foil sheet to increase the yield of SS was mentioned in few papers. As a result, the current study aims to increase SS efficiency by using RAFW on the inner surfaces of the HSS. The presence of a RAFW on the inner surfaces of the HSS, raises the water temperature. The following is a summary of the manuscript: The HSS experimentation and theory of operation are presented in Sect. 2; Sect. 3 discusses the findings and discussions; Sect. 4 compares the current research to previously publish related works; and Sect. 5 summarizes the manuscript's conclusion.

2. Experimentation And Principle Of Operation Of Hss

The aim of this paper is to conduct an experimental investigation into the impact of reflective aluminium foil-sheets on HSS results. Two different types of HSS were made and tested. In the first, an HSS was made of wood and coated with black silicon, while the second was made of HSS that had its sidewalls covered with reflective aluminium foil sheets (HSS-RAFW), as shown in Figure 1. Figure. 2 shows the photographic view of the experimental test.

3 Results And Discussions

3.1 Variation of solar intensity [$I(t)$], ambience (T_a), saline water ($T_{s.w}$), and collector cover (T_{cc}) temperatures

The deviance of $I(t)$, T_a , $T_{s.w}$, and T_{cc} for the HSS and HSS-RAFW is shown in Figs. 3 and 4, respectively. From Figs. 3 and 4, it is found that $I(t)$ hike in the before noon and reached the highest of 1010 W/m^2 at 12:00. Also, T_a increases in the morning hours and reached its highest value of 50°C at 15:00. Deviations of T_a , $T_{s.w}$ and T_g are related curves like $I(t)$ because $I(t)$ is the source for variations of T_a , $T_{s.w}$ and T_g . Every day average $I(t)$ and T_a are 636.15 W/m^2 , and 41.69°C , respectively. The peak $T_{s.w}$ of the HSS is 71°C at 14:00; HSS-RAFW is 74°C at 14:00. The peak $T_{s.w}$ of the HSS-RAFW is 3°C higher than the HSS. Every day average $T_{s.w}$ of the HSS is 54.69°C and HSS-RAFW is 56.85°C . Every day average $T_{s.w}$ of the HSS-RAFW is 3.79% higher than the HSS. Due to reflectivity materials attached in walls of the HSS-RAFW, peak and every day average $T_{s.w}$ is maximum than the HSS. From Figs. 3 and 4, it is found that peak T_g of 51 and 52°C was recorded for the HSS-BPW, HSS-RAFW, correspondingly. Every day mean T_g of the HSS, HSS-RAFW are 42.85 and 43.463% , correspondingly. The aluminium foil sheets attached on the walls in the HSS-RAFW is used to enhance the $T_{s.w}$ during the investigational day by reflecting the solar irradiance into the $T_{s.w}$. Therefore, the integration of RAFW in the HSS improves the $T_{s.w}$ by focusing additional heat to the $T_{s.w}$ of the HSS. Whereas in the HSS, input was absorbed by the HSS basin wall surfaces, hence, it has least intensity input to the $T_{s.w}$ as compared to the HSS-RAFW.

3.2 Deviations of Evaporative Heat Transfer Coefficient (EHTC) and hourly distilled water yielding

Figure 5 illustrates the difference of EHTC per hour and hourly yield production from the HSS and HSS-RAFW. The peak calculated EHTC per hour of the HSS and HSS-RAFW are 38.5 and $43.4 \text{ W/m}^2\text{K}$, respectively. Average EHTC per day for the HSS and HSS-RAFW are 22.04 and $24.61 \text{ W/m}^2\text{K}$. Average EHTC per day of the HSS-RAFW is higher than the HSS due to the greater RAFW placed inside HSS. Average EHTC per day of the HSS-RAFW is 10.5% higher as compared average EHTC per day of the HSS. In the HSS-RAFW, RAFW augments the $T_{s.w}$, and so it has highest yield per hour and higher calculated EHTC per day of the HSS.

The hourly yield production from the HSS and HSS-RAFW are increasing for the period of sunrise hours and decreases for the period of sunset hours. The maximum hourly yield of 0.46 and 0.53 kg was produced from the HSS and HSS-RAFW, respectively. Yield production per day from the HSS is 3.36 kg and from the HSS-RAFW is 4.1 kg . While using the RAFW at the wall surface of the HSS, yield was increased by about 22.21% as compared to the HSS. In the HSS-RAFW, use of reflective material, it reflects the concentrated solar energy to the basin of the HSS and thus improves the water temperature so yield from the HSS-RAFW is higher as compared to the HSS.

3.3 Variation of EnE and ExE

Differences of EnE and ExE of the HSS and HSS-RAFW are shown in Fig. 6. The EnE of the HSS and HSS-RAFW were increasing for the duration of the before noon and reached the maximum at 15:00, and then it drops linearly. The EnE of the HSS starts at 3.89% on 08:00 and has an improving tendency and reached 54.42% at 15:00, and then it decreases till 18:00 (28.58%). Moreover, the EnE of the HSS-RAFW starts at 6.85% on 08:00 and has an improving tendency and got 67.55% at 15:00, and then it decreases till 18:00 (39.87%). Average EnE per day of the HSS and HSS-RAFW 26.27 and 32.75%, respectively. The EnE of the HSS-RAFW is 24.66% greater than the HSS. The use of RAFW in the HSS enhances $T_{s,w}$, EHTC, and yield and therefore it produced higher EnE than the HSS. Since EnE of the HSSs are depends on yield and energy input.

The ExE of the HSS and HSS-RAFW was increasing before noon and get its peak at 13:00, and then it has a declining trend. The ExE of the HSS starts with 0.08% at 08:00 and has an increasing tendency and got peak of 1.96% at 13:00, and then it has a declining trend till 18:00 (0.41%). Similarly, the ExE of the HSS-RAFW starts with 0.25% at 08:00 and has an increasing trend and got peak of 3.25% at 13:00, and then it has a declining trend up to 06:00 (0.9%). ExE per day of the HSS and HSS-RAFW 1.04 and 1.71%, respectively. The ExE of the HSS-RAFW is 65.55% higher than HSS. The highest and average ExE per day of the HSS is maximum in the case of HSS-RAFW as ExE directly linked to yield and solar input. For the duration of the evening, the difference among $T_{s,w}$ and $T_{c,c}$ is higher, so ExE of the HSS for the duration of sunset hours is greater as compared to the duration of sunrise hours. Furthermore, it is found that concentrating solar input on the $T_{s,w}$ has enhanced the performance of the HSS-RAFW than the HSS.

4. Evaluation Of Current Study With Available Related Works

Table 1 shows a evaluation of the current findings and previously published related works. The productivity gain of a SS type of "V" with a mirror about 11.92% (Kumar et al., 2008). However, the overall value for the double SS with finned corrugated basin, reflector, wick and black granite is 171.43 % (Omara et al., 2016). The cumulative yield of the HSS with RAFW increases the efficiency by 68.57 percent as compared to the HSS. Using the RAFW, the current study achieved maximum daily productivity 4.1 kg/m².

Table 1: Comparison of yield

Name of authors	Design of SS	Improvement methods	Improvement in Yield (%)
(Kumar et al., 2008)	SS type of "V"	- Mirror	11.92
		- Mirror and charcoal	14.11
(Gnanaraj and Velmurugan, 2019)	DSSS	- Reflector	93.39
		- Finned corrugated basin, black granite, wick and reflector	171.43
(Chandrika et al., 2021)	SSSS	- Reflective glass mirrors	68.57
		- RAFW	48.57
Our results	HSS	- Reflective aluminium foil-sheet	22.21

5. Conclusions

The impact of RAFW on the yield generated by the HSS is highlighted in this experiment. Placing RAFW on the inner walls of the HSS is a simple technique. This method is quick, low-cost, and efficient. It also has no detrimental effects on the climate. In comparison to other studies, this newly proposed approach makes substantial productivity gains.

The following are the findings:

- The aluminium foil sheet with a reflectivity of 88 percent improves the yield and performance of solar stills.
- The HSS produces 3.36 kg/m² of distilled water and the HSS- RAFW produces 4.1 kg/m². The daily accumulation was improved by 22% as compared to the HSS when the reflective aluminium foil sheet was used.
- The HSS- RAFW has a higher thermal and exergy performance than the HSS. The HSS and HSS- RAFW had the highest thermal efficiencies of 54.42 and 67.55 %, respectively.
- The HSS and HSS-RAFW had the highest exergy efficiencies of 1.96 and 3.25 %, respectively.

Nomenclature

CrSS	Corrugated Solar Still
HSS	Hemispherical Solar Still
HSS-RAFW	Hemispherical Solar Still with Reflective Aluminium Foil-sheet Walls
EHTC	Evaporative Heat Transfer Coefficient
[I(t)]	Solar irradiation
T _a	Ambience temperature
T _{s,w}	Salt water temperature
T _{c,c}	Collector cover temperature

Declarations

Ethical Approval

Not Applicable

Consent to Participate

Not Applicable

Consent to Publish

Not Applicable

Authors Contributions

Mohammed El Hadi Attia and Athikesavan Muthu Manokar: Conceptualization, Methodology, Resources, investigation and Writing - original draft preparation

Murugan Kaliyamoorthy, Guruprasad Balachandran, Syed Jafar Kutbudeen: Formal analysis, Writing - original draft preparation, Review and Editing

Ravishankar Sathyamurthy : Software, Review and editing

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Competing Interests

The authors declare that there is no competing interest

Availability of data and materials

Not Applicable

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Figures

Figure 1

Layout of the HSS and HSS-RAFW

Figure 2

Photographic view of HSS and HSS-RAFW

Figure 3

Deviance of $I(t)$, T_a , $T_{s.w}$, and T_{cc} for the HSS

Figure 4

Deviance of $I(t)$, T_a , $T_{s.w}$, and T_{cc} for HSS-RAFW

Figure 5

Hourly deviance of EHTC and yield from the HSS and HSS-RAFW

Figure 6

Hourly deviance of EnE and ExE of the HSS and HSS-RAFW

Supplementary Files

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