PERFORMANCE ENHANCEMENT OF WATER OUTPUT VIA LATENT HEAT STORAGE SYSTEM WITH SINGLE SLOPE SOLAR STILLS

by

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The purpose of this study was to design, build, and assess the performance of a latent heat storage system in tandem with a single slope solar still. Using a solar accumulator to transfer hot water to a shell and a spiral finned tube filled with 30 kg of paraffin wax – 1.2 wt.% of Al_2O_3 *nanocomposites, latent heat was stored. To test the effect of the storage system's performance, two trials were conducted, with and without storage, under as similar of conditions as could be arranged. The proposed storage system design eliminates any potential issues with usage of paraffin wax as the storage system in conjunction with the solar still. An outcome indicated that daily fresh water output was enhanced by 4.63% when the solar still was used in conjunction with the storage system.*

Key words: *solar desalination, latent heat storage system, finned tubes, solar still,* Al_2O_3

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Introduction

The single slope solar still (SSSS) was the simplest technology for delivering water to remote locations with limited resources. Research on using PCM with a SSSS to boost efficiency. The PCM attachment and steel wool fibre variants were also examined, along with a variety of other permutations [1]. Evaluating the efficacy of solar still designs that use PCM. Methods are discussed to progress heat transmission in PCM solar still. Improvements in distillate output and thermal efficiency have been seen in a variety of lay-outs [2]. In-depth analysis of how PCM may be used to increase solar still output. Significant gains in output are seen with both passive and active solar stills when PCM is used. Most PCM are organic, and research on inorganic and eutectic varieties is scant [3].

The effectiveness and efficiency of various designs and combinations are compared and contrasted [4]. Sustainable development discussion centering on the value of renewable energy. Solar power and thermal energy storage (TES) get the most attention [5]. Latent heat thermal energy storage (LHTES) unit with vertical multitube shell and spiral-finned tube thermal performance studied experimentally. A paraffin PCM with a water heat exchanger [6]. The findings of a cycling test on an absorption heat storage device are reported. Both sodium hydroxide and water are excellent solvents. A heat and mass exchanger with a spiral finned tube was used for the cycles [7].

Temperature of drying air and its relation weather are examined. Experiments with drying under different settings have shown that some sort of oversight is required [8]. Using a hollow finned absorber basin embedded in paraffin wax as a phase transition material, researchers hope to boost the drinkable water production of a single-slope solar still [9]. Ricinus communis leaf extracts PCM (paraffin wax) and Ag nanoparticles in experimentally designed single distiller [10].

Solar still with a single slope, simulated numerically using PCM with and without nanoparticles. The Al_2O_3 nanoparticles distributed in 1 kg of paraffin wax have been shown to increase daily production by 20%. [11]. To investigate the effects of employing paraffin wax and a solar driven electric heater on the efficiency of a single-slope solar still, an experiment was conducted. The CO_2 mitigation and the results of an economic analysis are reviewed [12]. Energy storage efficiency of a conventional solar still (CSS), a solar still with a hollow finned absorber, and a solar still with a solid finned absorber [13]. A single-slope solar still paired with a solar air heater is discussed in terms of its energy, exergy, and economic viability [14]. Improving the efficiency of a tubular solar still through experimentation with copper hollow fins and a PCM reservoir [15].

Absorber plate with block-shaped fins and a PCM chamber with slender-shaped fins are used to enhance the efficiency of a SSSS [16]. Attempts were made to improve the efficiency of a pyramid solar still by combining a PCM tank with hollow circular copper fins [17]. The purpose of incorporating hollow cylindrical pin fins into PCM is to enhance the heat transfer properties of PCM storage units [18]. Designing a solar still glass dome that combines a cylinder in the vertical orientation with a sphere for the top. Modifications to the design result in increased output and reduced energy use [19]. Modelling the behavior of a solar still with a single slope to examine the parametric performance of a basin filled with salt water. Modelling the solar still in two and three dimensions with ANSYS FLUENT [20].

The GPBMSS thermodynamic study *vs.* CSS. Research was done in both the warm and cold seasons [21]. A flat plate solar water heater with an integrated shell and finned tube latent heat storage system was designed, built, and tested. The parafin wax is used as a phase change material by being sliced thinly and then melted to increase thermal conductivity [22].

An insulated cylindrical tank filled with paraffin-filled spheres is the subject of this experimental study of a combined sensible and LHTES unit. The use of water as a sensible heat storage (SHS) and heat transfer fluid is commonplace [23]. Cascading solar water heaters with PCM integrated into the base of the absorber plate. Different flow rates were used in the experiments with and without PCM [24]. Solar water heating at night: a feasibility study of storing energy in PCM [25].

Latent heat storage, SHS, and hybrid heat storage are all discussed as potential options for thermal solar collectors and TES [26]. The MXenes are special 2-D materials with interesting physical and chemical properties. A variety of photovoltaic PCM, solar water heater, solar greenhouse, thermal building, cold storage, and air conditioning applications are discussed [27]. Prototype development, production, and experimental study of a LHTES device. A unique horizontally oriented multitube heat exchanger contained within a rectangular tank uses PCM RT62HC and water as the working fluid [28].

Differential thermal analysis, differential scanning calorimetry, and calorimetry are only few of the techniques discussed here that may be used to ascertain PCM thermophysical characteristics [29]. The PCM are discussed in relation their usefulness in solar-powered appliances such as air heaters, water heaters, greenhouses, cookers, troweled walls, wallboards, and refrigerators [30]. Analyzing the relationship between inlet water temperature, PCM thicknesses and characteristics, and mass-flow rates and the resulting output water temperature and melt percentage was the focus of this parametric investigation [31]. Evaluating the energy and exergy performance of an integrated PCM solar collector under transient settings, taking into account the impacts of natural-convection, the effect of PCM thicknesses, and the effect on heating needs and exergy efficiency [32].

The results of this study demonstrate the widespread use of parafin wax in solar stills as a thermal storage medium. According to the numbers, the solar still combined with a thermal storage system (TSS) yields the greatest outcomes. The PCM was also found to be widely used in the area immediately below the solar still basin's absorber, as evidenced by the study's findings. Several problems, such as PCM leakage and a low allowable PCM usage, were uncovered during the melting process. In addition, there are not a lot of ways to improve PCM heat transmission by design. Issues that emerge with a solar still that has an integrated PCM are addressed in this work for the first time by combining the SSSS with a separate LHSS. The independent LHSS provides a large amount of energy storage and is an excellent answer to the PCM leakage problem. Furthermore, it offers many design possibilities to enhance heat transmission, such as the use of spiral fins in this work. Additionally, the heat conductivity of paraffin wax may be increased by using Al_2O_3 nanoparticles without worrying about any leakage.

Experimental work

The architecture and construction of LHSS and SSSS are dissected here. In addition, the testing protocol and experimental set-up are detailed.

The suggested system comprises primarily of three components: SSSS; low temperature solar collector and solar water heating system. The LHSS was coupled in a closed loop to the SWH during peak solar activity, while the SSSS took over during nighttime and low solar activity.

Stainless steel was used in the construction of the solar still basin, which measures a bottom length and breadth of 0.7 m × 0.7 m and north and south heights of 0.55 m and 0.2 m, respectively. Foam was used to insulate the basin's bottom and sides at a thickness of 0.05 m, and 0.004 m of transparent glass was used to cover the top. As may be seen in fig. 1(a), the south-facing interior was where the water distillation system's collecting channel was situated. Insulation was provided by two layers of foam, with painted galvanized iron sheets acting as a screen against the still sides and bottom.

The TSS depicted in fig. 2 was developed, built, and evaluated with the PCM consisting of varying concentrations of parafin wax/Al_2O_3 (0, 0.6, 1.2, 1.8, and 2.4%). The spiral finned tube's potential impact is also investigated. Additional information on the prototyping process and its subsequent testing may be found in theory.

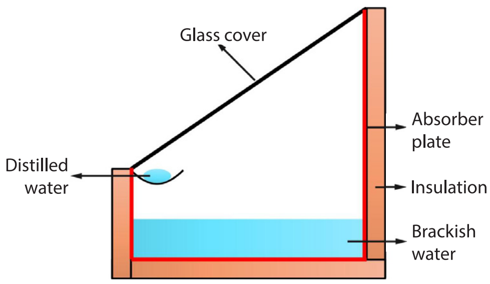

Figure 1. Schematic diagram of the SSSS

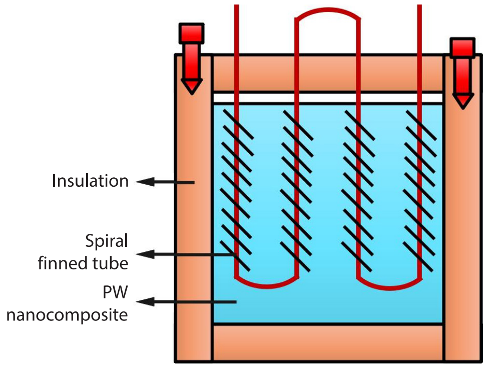

Figure 2. An outline of the SSFT storage unit

To improve upon the TSS, engineers developed a SSFT-LHSS. A parafin wax-Al_2O_3 nanocomposite with a 1.2% $Al_2O_3$was heated by-passing hot water through the finned tubes while 30 kg of it was being charged (optimal concentration). The Al_2O_3 was utilized for the tubes, whereas iron was used for the connected spiral fins. Figure 2 depicts the LHSS's elaborate lay-out. In the LHSS configuration, the spiral finned tube is a detachable component that is nailed into place on the top of the shell for convenient removal. The outside is a stainless-steel cylinder that is 30 cm in diameter on the inside. Foam insulation measuring four centimeters thick and a barrier of painted galvanized iron protected it.

The absorber was a plane sheet of galvanized iron combined with rectangular Al_2O_3 tubes, and the insulation for the walls and floor was 6 cm of foam. The SWH top glass was 4 mm thick. When there was a lot of solar light, water would flow in a closed loop within the rectangular tubes and into the SWH, but the flow would stop when the Sun went down. Here, the LHSS was linked to the solar still with the help of several manually operated valves. Figure 3 showsthe diagrammatic representation and an image of the suggested system.

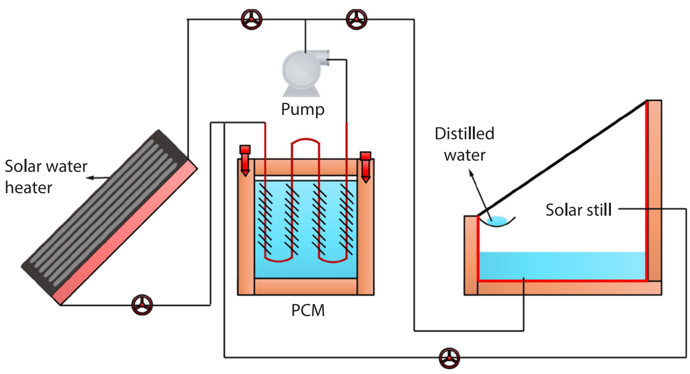

Figure 3. Schematic diagram of the SSSS with SSFT storage system heated by SWH

Experimental process

Two tests were carried out under almost identical weather conditions to monitor how the LHSS might affect the performance of the SSSS. Initially, 6 kg of water was stimulated into the basin in order to test the standard solar still without the usage of the storage system throughout the day. The temperatures of the solar still's absorbing plate, T_p, glass cover, T_g, and water basin, T_{b-w}, were recorded for each 60 minutes with a K-type thermocouple. The output collects in a graded cone on an hourly basis, and then weighed on a digital scale. Every hour, prynometer and a thermometer was used to measure the amount of solar radiation, I, and the temperature of the surrounding air, T_a. The LHSS, SWH, and SSSS were all combined for the second round of testing. The SSSS and the LHSS inside the SWH operate independently from 9:00 a. m. to 6:00 p. m. From 6:00 p. m. until 9:00 a. m. the following day, the LHSS is switched from its connection the solar water heating system to its connection the SSSS, allowing basin water to be recycled between the two systems. Note that the system temperatures and production were monitored hourly right up to 11:00 p. m. In this scenario, additional readings of the water temperature in the storage tank, T_{sw}, and at the SWH output, T_{o-h}, was recorded. Five K-type thermocouples were used to take readings from a variety of locations within the PCM, and these readings were found to be uniformly distributed with depth. The mean PCM temperature was then determined, $TPCM_{(av)}$. At 9:00 a. m. the next morning, the cumulative output from 10 p. m. to 9 a. m. was evaluated.

Results and discussions

Enhancement of the LHSS

The LHSS was improved utilizing a combination of methods, including the use of spiral finned tubes inside the heat exchanger and the addition of Al_2O_3 to the paraffin wax at varying weight percentage.

The average PCM temperature during melting and solidification wasshown in figs. 4 and 5. Do not forget that all the trials went on until the ice had melted. Figure 4 shows unequivocally that a 1.2% weight fraction of Al_2O_3 nanoparticles added to parafin wax is the optimal concentration for reducing PCM melting time and increasing PCM temperatures. Both 1.8 wt.% and 2.4 wt.% concentrations yield the similar melting duration at a significantly minimum average phase change temperature. Since just a small quantity of nanoparticles was em-

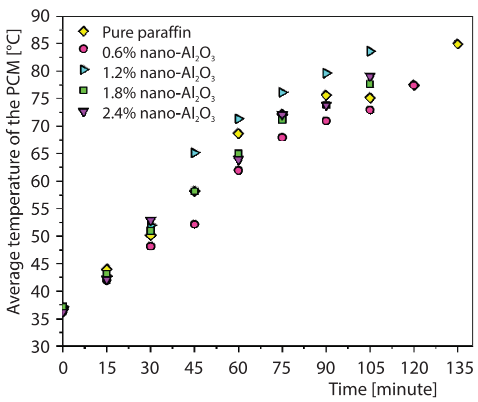

Figure 4. Evaluationof average temperature of the PCM and the timethrough the melting procedure

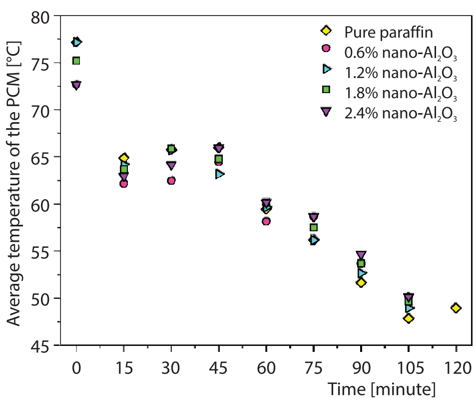

Figure 5. Evaluation of average temperature of the PCM and the time through the solidification procedure

ployed, a concentration of 1.2% by weight is recommended for cost-effectiveness. The solidification process had similar findings, with a time of 45 minutes being found in three of the cases studied. Compared to 60 minutes with either pure paraffin wax or Al_2O_3 added at a concentration of 0.6%, fig. 5 displays the results of adding Al_2O_3 at weight fractions of 1.2%, 1.8%, and 2.4%. To get a ballpark figure for how long it will take for the solid to form, one need just determines how long the flat section of the curves seen in fig. 5. When the PCM average temperature hits 56 °C, its melting/solidification point, this flattening process begins in every scenario.

Figures 6(a) and 6(b) show the mean temperature of the phase change material during melt and solidify process to highlight the impact of employing the SSFT in the TSS. Figures 6(a) and 6(b) show that by using the SSFT within the TSS at the optimumattention of nano-Al_2O_3, melting time is cut by 42.85% and solidification time is cut by 66.66%. The TSS was evaluated in a controlled environment, and the findings informed the design of the LHSS, which included the addition of Al_2O_3 nanoparticles to the process water at a weight fraction concentration of 1.2% and the use of spiral finned tubes.

Figure 7 as hows the solar intensity and ambient air temperature on April 14, 2023. Figure 7(a) shows that peak I values, ranging from 725.5-1010 W/m^2, were recorded between 9:00 a. m. and 3:00 p. m. The average solar intensity for the day is 696.3 W/m^2, and the day's air temperature ranged from 31-37 °C between 9 a. m. and 11 a. m., before remaining steady at 33 °C until 6 p. m.

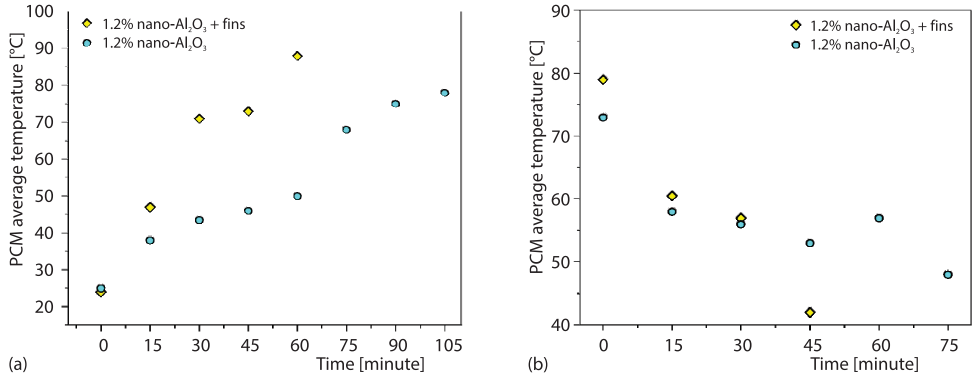

Figure 6. (a) Melting time and (b) solidification time in the LHSS as a result of utilising spiral finned tubes

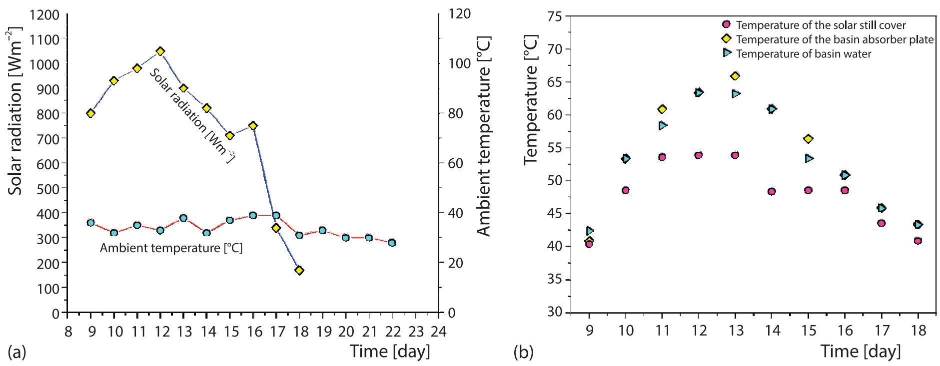

Figure 7. (a) Hourly values of variant temperatures and (b) climate conditions were recorded on April 14, 2023

On April 14, 2023, the SSSS was put through its paces with only 5 kg of water in the basin and no storage system. Temperature of glass cover, absorbing plate, and water basinare shown in fig. 7(b) along with their corresponding measured values. The highest T_{p} and $T_{\mathrm{b\text{-}w}}$ temperatures recorded are 65.9 °C and 63.4 °C, respectively. Figure 7(b) shows that between 11:00 a. m. and 3:00 p. m., significant temperature variations (between 5-25 °C) were seen among the basin water and the cover of glass. Figure 8(a) indicates that this is also when hourly production reaches its highest levels. After 3:00 p. m., SSSS production drops significantly, highlighting the need for an appropriate energy storage system. The requirement for an energy storage system is demonstrated by the fluctuations in the observed temperatures between 2:00 p. m. and 4:00 p. m. owing to gloomy weather, fig. 7(b), and its detrimental influence on hourly production.

Figure 8 shows the total output of SSSS-during the test on April 14, 2023, which did not involve the energy storage device. The tested SSSS produced 575.36 g after 10 hours of operation, but only 142 g throughout the night, as measured at 9:00 a. m. on April 15, 2023.

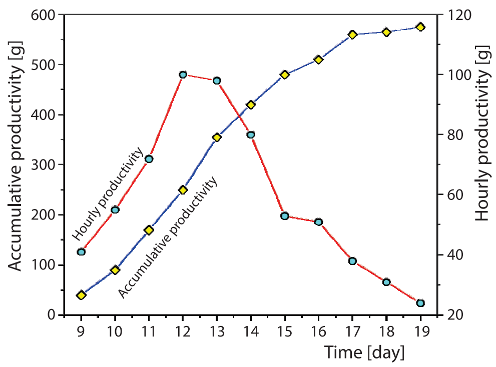

Figure 8. Hourly productivity and accumulative productivity of the SSSS without the storage system on April 14, 2023

On 23 May 2023, the SSSS was put through its paces with the LHSS and the SWH. From 9:00 a. m. to 6:00 p. m. the SSSS and LHSS ran independent of the SWH. In order to allow the basin water to be cycled between the two systems overnight, the LHSS was disconnected from the SWH between the hours of 6:00 p. m. and 9:00 a. m. The entire production was evaluated the next morning at 9:00 a. m., even though the temperatures and outputs of the system were recorded hourly until 11:00 p. m. The 23 May 2023, I and T_{a} values observed, fig. 9(a) were quite close to the values recorded during storage-less SSSS testing, fig. 8(a). In this scenario, solar intensitywas typically 744.8 W/m^2, and Ta ranges from 31-37 °C throughout the day, before decreasing to 28 °C around 10:00 p. m.

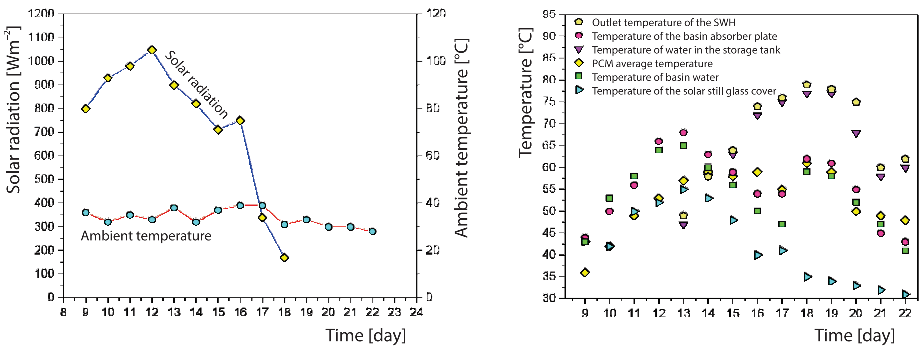

Figure 9. (a) Climatic conditions and (b) temperature of various elements of the SSSS and the PCM

Various temperature elements and T_{PCM} are some of the SSSS and storage system temperatures that were measured and plotted hourly in fig. 9(a). Figure 9(b) shows that between 4 p. m. and 5 p. m., the PCM melted entirely because its average temperature was higher than the melting point (59 °C). The PCM stored heat energy is transferred to the basin water that flows among the SSSS and latent heat storage system around 6:00 p. m., when the LHSS is reconnected to the SSSS after being detached from the SWH. The PCM average temperature lowers to 55 °C after integrating the LHSS with the solar still for 1 hour, suggesting a discharge period of less than 1 hour. Due to the enormous amount of heat transmitted to the basin water throughout the discharge operation, the temperature of the water remained rather consistent (57-59 °C) between 6:00 p. m. and 7:00 p. m. The LHSS spiral finned tube and Al_2O_3 nanomaterial allowed for a rapid discharge rate. It is not possible to keep the basin water at a constant temperature using only the sensible heat stored in the parafin wax after 7:00 p. m.

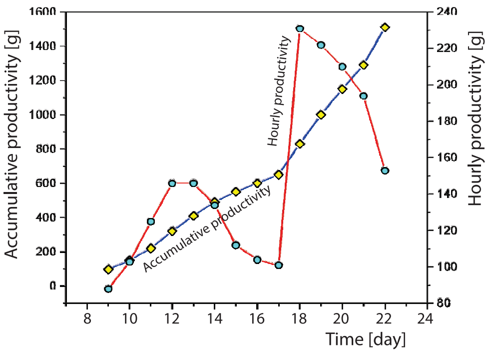

Figure 10. Hourly productivity and accumulative productivity of the SSSS-LHSS

The temperature of the basin's water plummeted to a refreshing 30 °C around 11:00 p. m. So, additional tanks that can be linked to the still in stages over the night are recommended. As the day progresses and the temperature differential among the $T_{\text{b-w}}$ and its $T_{\text{st-g}}$ increases from 3.5-14.95 °C, the LHSS is merged with the SSSS. The difference in temperature grows to between 5-25 °C after night falls. Using the storage system at night increases productivity, as shown in fig. 10(a), although this is best explained by the substantial disparity between overnight and daytime production. When the water temperature in the basin is between 52 °C and 53 °C, maximum hourly output is reached about 6:00 p. m., followed by 173.5 g around 7:00 p. m. As shown in fig. 10(a), production gradually drops to 98.6 g by 10 p. m.

Figure 10 depicts the cumulative output of the SSSS combined with the LHSS. Total output was 1452.8 g between 9:00 a. m. and 10:00 p. m., but only 530 g between 10:00 p. m. on May 23 and 9:00 a. m. the next day (May 24, 2021). Based on these results, a combination of a solar-collecting array (SSSS) measuring 0.3 m^2 and a solar-concentrating array (SWH) measuring 0.5 m^2 may generate 1982.8 g/day, whereas the comparable figure for a solar field of 1 m^2 is 2478.5 g/daym^2. The daily output rise by 4.63% when the LHSS with SSSS.

Conclusion

The LHSS was used throughout construction and testing of the SSSS, both in conjunction with and independently of the LHSS. The results of the trials revealed several significant findings. All problems that have arisen from employing parafin wax as storage material in the SSSS have been solved by the projected design of the LHSS. The integration of the LHSS with the SSSS resulted in a 4.63% increase in daily production. After 1 hour of circulating basin water to theLatent heat storage system, the greatest hourly productivity is instantly realized. To maximize operational duration and fresh water productivity, many storage tanks should be merged with the SSSS one by one throughout the nocturnal period.It is also suggested that several forms of PCM augmented by high conductivity nanoparticles be tested.The use of solar reflectors in conjunction with the solar water heating and SSSS is also advised for future development.

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