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TESTING THE TRAYS SOLAR STILLS WITH YELLOW SAND BEDS AND REFLECTORS

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ABSTRACT. Solar still (SS) are systems powered by solar energy that can provide drinkable water, however it has a low production issue. A solar distiller's production is influenced by a variety of factors. The water depth and thermal storage beds are the most influential factors. During rainy or cloudy days (sunlight is not available) a SS cannot work in its original state. During daylight hours, the SS can be powered utilizing energy saved in thermal storage materials. This paper aims to increasing water production from brackish water or seawater using renewable energies via a system of solar desalination. An experimental work for sand beds trays solar still (TSS) was performed to enhance performance of TSS, the yellow sand used as thermal storage materials. The effects of sandy bed height (1, 2 and 3 cm) and reflectors on the TSS performance were studied. Results revealed that the sandy layer (heat storage beds) improves the TSS productivity. The maximum increase in accumulated production of sandy TSS with internal and external reflectors was reached at sand beds height of 1 cm. In this case the daily production of TSS was improved by 112% over CSS.

KEYWORDS: Trays solar still; Solar still; Sand; Thermal storage material.

1. INTRODUCTION

A worldwide shortage of drinkable water has resulted from the rapid rise of population and industrialization, which has led scholars to look for a different approach to fulfil this demand. Solar stills are systems powered by solar energy that can provide fresh water, however it has a low productivity issue. So, scientists have studied the various variables that affect the performance of SSs to increase its output by reducing the basin's water depth [1, 2], increasing the sun energy incidence on the SS by adding reflectors [3], utilizing solar water heaters to raise the temperature of the feed water [4]. Additionally, in an effort to increase the amount of fresh water distillate, the researchers tried to modify the conventional solar distiller [5]. Solar stills with fins, corrugations, and wicks made up the majority of these modifications. [6], stepped SS [7], Utilizing rotating components to enlarge the evaporation surface area, sun energy exposure, and break basin water surface tension, tubular drum SS [8], blades SS [9], rotating wick SS [10], discs distiller [11], rotating-drum distiller [12], half barrel [13], and convex SS [14].

The traditional SS was modified to include internal trays as well as exterior and internal reflectors at the bottom and top, which led to the creation of the trays solar still design. Trays and reflectors can be used on TSS vertical walls to lower their temperature and lessen heat leakage to the environment. So, Abdullah et al. [15] investigated experimentally trays type SS to study a few performance enhancing measures. Three techniques have been tested: basin walls and trays coated with mixture of black paint and nanoparticles, paraffin wax - CuO nanoparticles, internal mirrors. A theoretical model was presented in addition to the experiment. A 108 % improvement in daily productivity was obtained when all of these tactics were combined.

Solar irradiation is at its peak between 12:00 and 13:00, as we all know. The thermal efficiency of SS is dependent on the sun's energy. As a result, between 12:00 and 13:00, SS should produce more fresh water. However, due to the increased amount of solar rays' incident on the basin water during this time, water temperature inside the SS remains higher, and water vapor generation is also higher. So, the temperatures of the mixture of vapor air increased which increases the temperature of glass. So, thermal energy storage materials are employed in order to make use of extra thermal energy; they store the extra thermal energy and release it at non-sunny times, allowing for an increase in production and thermal efficiency. According to Nafey et al. [16], some of the substances used to store heat include rubber, glass balls, and gravel. Sand, rubber, sawdust, sponge and gravel are examples of basin materials that absorb and store solar energy in varied proportions.

They enhance the surface area exposed to water evaporation, Murugavel et al. [17]. Velmurugan et al. [18] utilized pebbles, sponges, sand and black rubber in the fin type single-basin SS for improving the daily fresh water productivity. They indicated that, as a result of this modification, daily production has increased significantly. They also indicated that sand in the SSs improves the SS production by about 14%. They also discovered that adding sand to the SS improves SS production by about 14%. Srithar [19] utilized pebble, sand and sponge to improve the daily distillate of the traditional SS. Results indicated that maximum daily production of 32.3% improvement was found by sponge and sand. Sunirmit and Ranjan [20] indicated that, when sunshine is not available, an energy source for a solar still can be a packed bed thermal storage tank. While thermal storage materials can be utilized to prevent heat losses while solar radiation is at its peak, these substances also have the ability to store energy and release it at night, when solar radiation is not present. Omara and Kabeel [21] investigated solar distillers with sand beds, taking into account sand type and sand depth. They found that black sand was the most efficient of the various sands tested.

From the previous review, the effect of adding sand to the trays SS as thermal storage material is not recognized. In this research, we aim to improve the performance of the tray's SS via yellow sand as thermal storage material. In light of the preceding literature, this work's originality can be summed up as follows:

1. The yellow sand beds with TSS were investigated.
2. Three height of the sand beds (1, 2 and 3cm) were investigated.
3. How adding internal and external reflectors affects sand TSS performance.

2. METHODOLOGY

2.1. SETUP FABRICATION

Two SSs were fabricated; CSS, and trays SS to evaluate and compare the performance of tested solar stills and estimate the effect of install trays to the solar still vertical walls, internal mirrors, two type of sand. Fig. 1 and Fig. 2 present 2D-shematic drawing and a photograph of the experimental test rig. The setup involves two solar stills and a feed tank; CSS and TSS. The tested SSs were constructed using galvanized steel. Both SSs had the projected area of 1 m × 0.5 m (0.5 m^2). The lengths of front and back sides of SSs were 15 and 35 cm. Three circumference trays have been installed on the internal sides of the TSS, Fig. 3. The lower, middle, and upper trays were 10, 8, and 6 cm wide, Fig. 2. In Fig. 3a, the varied colors were used to make the installed trays inside the TSS clearly visible. Besides, a 3 mm thick glass sheet was also used to cover the basin structure. To maximize the SSs' ability to absorb the solar radiation, matt black paint was applied to the examined SSs. To maximize the amount of incident solar irradiation, the entire system was positioned on an East-West axis and pointed south.

2.2. TESTING PROCEDURES

To evaluate the distiller's performance, all variables that have an impact on it were measured. In order to measure the solar radiation, temperatures, velocity of wind, and productivity, all measuring instruments were then attached to the setup. While the production of the tested SS was aggregated over 24 hours to achieve the output of the entire day, the tests were conducted during the day from 8:00 am to 8:00 pm. The following elements serve as a summary of the experimental testation procedures: (a) Effects of yellow sand on the performance of TSS were investigated, (b) three height of sand (1, 2, 3 cm) with zero water height above the sand beds level were investigated, (c) the influence of adding external and internal mirrors on the sand TSS performance.

2.3. MEASURING DEVICES

The tested SS thermal performance is a function of the sun irradiation, glass and water temperature, temperature of ambient, velocity of wind, and water productivity. For instance, the solar energy was hourly recorded through the use of a solarimeter. Also, the water, glass, and ambient air temperatures were hourly reported utilizing K-type thermocouples. The signals of thermocouples are transformed into numbers by an Arduino unit. As well, an anemometer is employed to quantify the air velocity. This helps to report the environmental conditions where the tests were conducted. Furthermore, the distillate yield of distillers was hourly recorded with graded bottles. Table 1 provides the unit, accuracy, resolution, and range characteristics of the measuring equipment.

2.4. UNCERTAINTY ANALYSES

The experimental uncertainty of the devices and calculations' errors were approximated utilizing the technique achieved by [22]. The result errors can be estimated by:

$$W_R = \sqrt{\left(\frac{\partial R}{\partial X_1}W_1\right)^2 + \left(\frac{\partial R}{\partial X_2}W_2\right)^2 + \cdots + \left(\frac{\partial R}{\partial X_n}W_n\right)^2} \quad (1)$$

Where W_R is the result uncertainty, and W_1, W_2, W_3, ………, W_n are the independent parameters uncertainties. The errors in the measurements of the devices are tabulated in Table 1. Moreover, the hourly productivity can be written as a function of basin water depth; m=f(h). So, the uncertainty for the productivity is:

$$W_m = \sqrt{\left(\frac{\partial m}{\partial h_1}W_h\right)^2} \quad (2)$$

Additionally, the uncertainty in thermal efficiency (η) is:

$$W_{\eta_{th}} = \sqrt{\left(\frac{\partial \eta_{th}}{\partial m}W_m\right)^2 + \left(\frac{\partial \eta_{th}}{\partial I_R}W_{I(t)}\right)^2} \quad (3)$$

Therefore, the errors of daily productivity and efficiency of solar stills are around ±1.4% and ± 2.5 %, respectively.

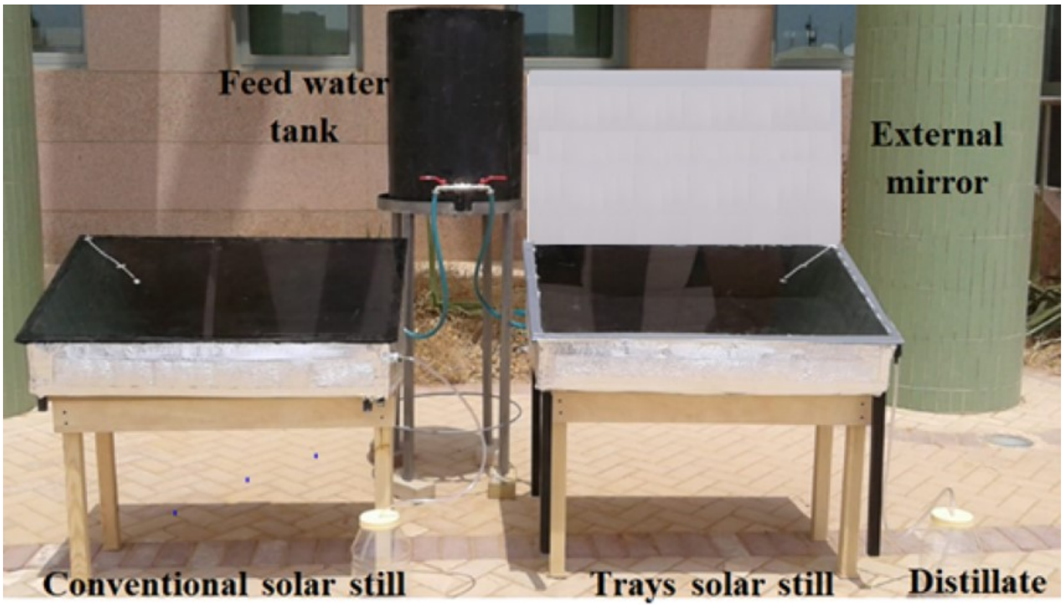

Fig. 1. Experimental setup photograph.

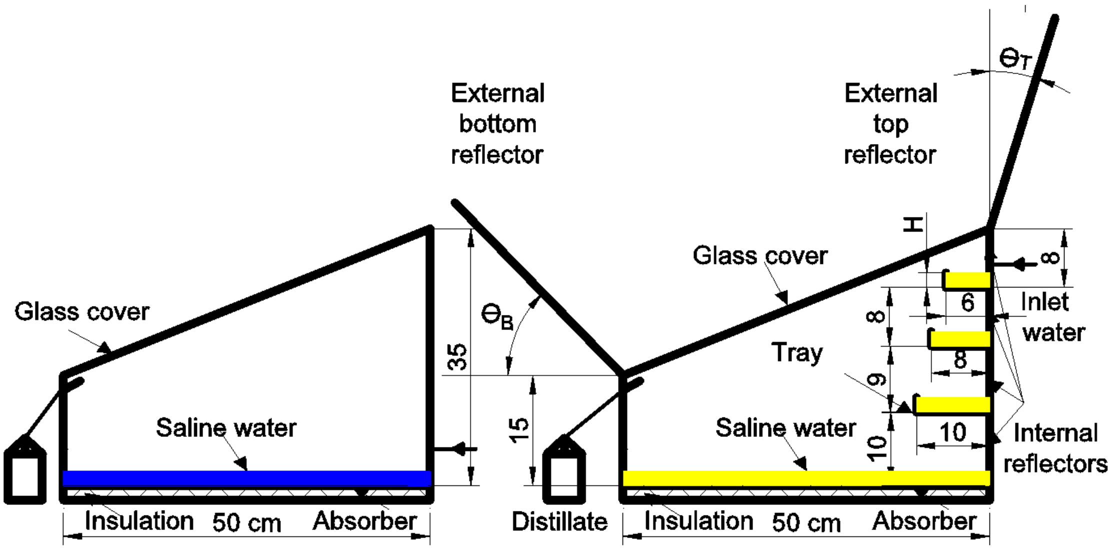

Fig. 2. Schematic drawing of setup.

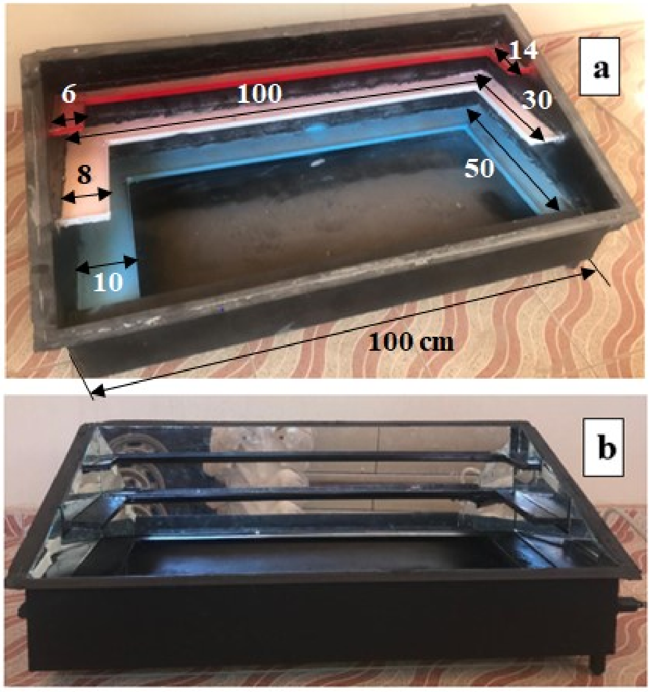

Fig. 3. TSS (a) without black paint, (b) with black paint with internal mirrors.

Table 1. The properties of the measuring devices.

Device	Parameter	Unit	Resolution	Accuracy	Range	Error
Solar power meter	Solar radiance	W/m^2	0.1	± 1	0 – 5000	1.6%
K-type thermocouple	Temperature	°C	0.1	± 0.5	0 – 100	1.3%
Anemometer	Air speed	m/s	0.01	± 0.1	0.4 – 30	1.1%
Graded bottles	Yield	L	0.01	± 0.2	0 – 25	1.3%

3. Results and Discussions

The experiments were conducted at various type of sand, different sand height. In addition, effects of internal and external refractors are investigated. The sandy trays SSs and conventional SSs were examined under identical circumstances with a constant water level of 1 cm.

3.1. Performance of TSS and CSS at 1 cm height of water

When compare the performance of TSS (at 1 cm trays height) and CSS at 1 cm water height the results indicated that, the average water temperature of the tray's SS was less than that of the CSS by 0 – 1.5 °C as the TSS has more saline water than the conventional SS. The highest value of sun radiation was achieved at 12:00 of 1070 W/m^2. Additionally, the highest water temperature was 62.5 for TSS, while the water temperature of conventional SS was 64 °C at 13:00. The glass cover temperature of for trays SS was found to be more than that of the CSS by about 0 – 1 °C. This is brought on by an increase in the TSS rates of evaporation and condensation relative to the CSS. Moreover, the maximum glass temperatures were observed at 13:00 where the glass temperatures of TSS and the conventional SS were 44 and 43 °C.

The water production for TSS is higher than in CSS. In comparison to CSS, which has an evaporation area of 0.5 m^2, TSS has an area of roughly 0.865 m^2. For the upper, intermediate, lower trays, and basin liner, the evaporation areas of TSSs are separated into 0.0696, 0.1152, 0.18, and 0.5 m^2. In comparison to CSS, the area of TSS evaporation was almost 72.8% larger. The production of the CSS and TSS were 3050 and 4450 mL /m^2. day, with improvement of 46%, for the TSS higher than CSS.

3.2. Performance of CSS and sand TSS at 1 cm sand height

The average sand–water mixture temperature of in STSS, saline water temperatures of TSS and CSS, and productions increase with sun irradiation. They rise until the afternoon when they reach their peak, then fall during the rest of the day as the sun's irradiance and ambient temperature fall, Figs. 4 and 5.

Glass and water temperatures of conventional SS and STSS and solar climatic conditions were measured at 1 cm height of trays, as shown in Fig. 4. From Fig. 4, it can be indicated that the sand-water temperature (average value) of yellow STSS is higher than that of the CSS by a range of 0–1.5°C. This is owing to the fact that sand has a large capacity for storing sensible heat. The highest value of sun radiation of 1070 W/m² was achieved at 12:00. Additionally, the highest sand-water mixture temperature was 65 and 63.5 °C for yellow TSS and conventional SS.

The glass cover temperature of for yellow STSS was found to be more than that of the CSS by around 0 – 2.5 °C. This is brought on by an increase in the TSSs' rates of evaporation and condensation relative to the CSS. Moreover, the maximum glass temperatures were recorded at 13:00 where the glass temperatures of TSS, yellow STSS, black STSS and the conventional SS were 45 and 42.5 °C, respectively.

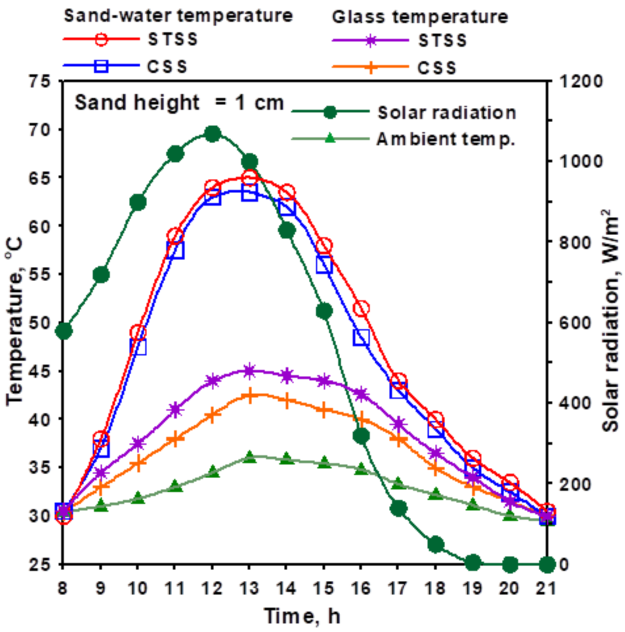

Fig. 4. Solar radiation and temperatures profiles for tested SSs at sand height 1 cm.

Fig. 5 displays the changes of instantaneous hourly productivity and accumulated yield for the tested solar distiller from 8:00 to 21:00. From Fig. 5, the daily production of yellow TSS was higher than that CSS. This is because STSS evaporate at higher rates than ordinary SSs do due to their higher evaporation area. Also, from Fig. 5 the water production for sand TSS is superior to that of the CSS. The growth of both sensible heat and the area that absorbs sun irradiation increases the output of fresh water. Additionally, Sand in TSS reduces the amount of time needed to pre-heat the water in the basin until it evaporates, where the specific heat of saline water (average value 4050 J/kg °C) is approximately five times than that of sand (average value 830 J/kg °C), Therefore, compared to the CSS, the STSS requires less time to preheat before production for the same depth. At 1:00 pm, the tested SS have a maximum hourly fresh-water production of 490, and 800 mL /m².h, for CSS, and yellow STSS. Additionally, Fig. 5 shows the productivity of the CSS and yellow STSS were 3000 and 4950 mL /m². day, with improvement of 65, for the yellow STSS higher than CSS.

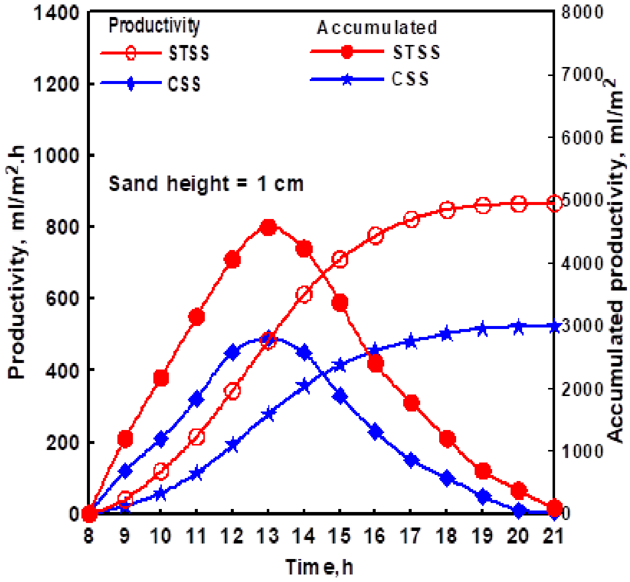

Fig. 5. The accumulated and hourly output production for tested SSs at sand height 1 cm

3.3. Effect of Height of Sand Beds on the STSS Performance

According to Fig. 6, the measured variations in the daily production increase's percentage (productivity rise, %) for TSS and yellow STSS over the CSS with different sand heights. According to Fig. 6, the greater amount of heat that is stored as sensible heat and transported within the tested sand beds trays, results in a drop in daily production rise when the height of the sand beds is increased. Previously, [21] had achieved the same outcomes. The STSS has a higher production for all heights of sand bed, as shown in the figure, because it has the highest heat capacity. From Fig. 6 at sand beds height of 1 cm, the daily production rises of freshwater of the TSS and yellow STSS were 46%, and 65 over CSS. While at 3 cm sand beds height, the daily production rises of freshwater of the TSS and yellow STSS were 40%, and 61% over CSS.

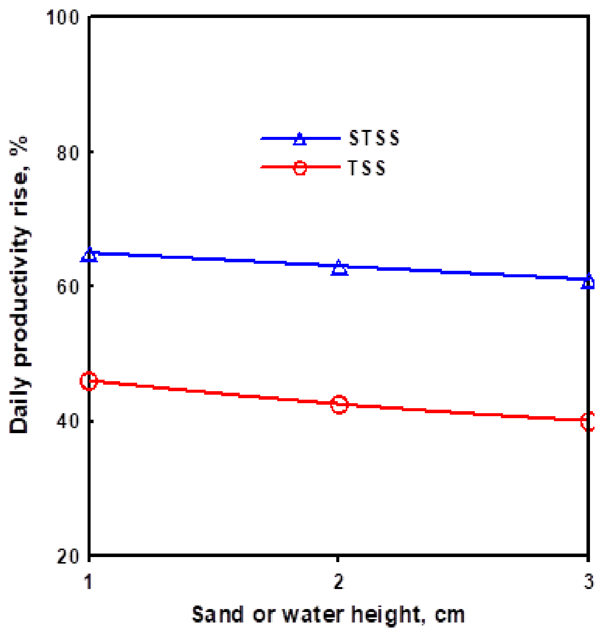

Fig. 6. The daily production rise of trays solar stills

The formula used to compute the daily thermal efficiency, (η_d), for the examined distillers is as follows;

$$\eta_d = \frac{\sum \dot{m} \times h_{fg}}{\sum A \times I(t)} \quad (4)$$

Where h_{fg}, $\dot{m}$, A, and $I(t)$, and are vaporization latent heat, hourly distillate productivity, system area projected area of distiller and daily average solar radiation.

Table 2 shows the daily thermal efficiency of the tested distillers at varying sand bed height, based on the given relationship. Without sand, Table 2 displays that the lowest and highest thermal efficiencies of TSS we discovered at 3 and 1cm, with thermal efficiency of 40 % and 41.1 %. Table 2 indicated that the daily thermal efficiency reduces with increasing the height of sand beds for the tested STSS similar to the productivity rise. The thermal efficiency of the yellow STSS at 1 cm and 3 cm was 44 % and 43.1 %. The CSS's efficiency was also between 33 and 34 %.

Table 2. Tested solar stills efficiency at different sand bed height.

Sand height	CSS	TSS	Yellow STSS
1	33.5	41	44
2	34	40.4	43.45
3	33.1	40	43.1

3.4. Effect of Reflectors on STSS Performance

For further improvement of STSS performance, STSS has been tested with bottom and top external mirrors and internal reflectors. Mounting top and bottom external reflectors and internal reflectors showed greater performance as a result of the TSS's increased energy input. The experimental results showed that the water and glass temperatures of STSS with mirrors are superior to that of conventional SS by around 0 – 7.5 ˚C and 0 – 8 ˚C, respectively at 1 cm sand height. Where bottom and top mirrors reflect a large amount of sun irradiation onto the STSS. Thus, improve the rates condensation and evaporation. The results shown that daily production reaches 3300 and 7000 mL/m² for CSS and STSS. In this instance, STSS's improvement in fresh water productivity is approximately 112% greater than CSS's.

4. Conclusions

The tray's SSs production is enhanced by adding sand beds above the basin plate and trays of TSS. Sand is thought to be an effective heat-storage medium, so the water production increases due to the increase in the sensible heat. The aforementioned findings and justifications lead to the following conclusions;

1. The daily distillate of the sandy TSS is inversely related to the sand beds heights.
2. The highest daily production of STSS is obtained at 1 cm height of sand beds.
3. At 1 cm height of sand beds the daily yield for TSS and STSS were improved by 46% and 65%, over CSS.
4. Employing internal and external mirrors, at 1 cm height of sand beds the production for STSS was enhanced by 112% over CSS.

Recommendations and Future Work

1. A numerical study to determine the optimal dimensions of the trays
2. Conducting a numerical study to determine the distance between the trays that gives the best performance
3. Studying different types of sand

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