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Experimental Study of a Solar Still Desalination System

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Abstract: Solar still is a simple equipment for the fresh water production in the regions where water is scarce and is rich in solar energy sources. In this paper, a solar still unit was built and tested in the south of China to investigate its water production. The test results show that the fresh water production is affected by average solar irradiation intensity, the production of the unit averaged at 6.27 kg/day, the water production decreased to 1.9 kg/day when the daily average solar radiation decreased to 236 W/m^2. At the same time, the test result show that because of the difference between the ambient and seawater temperatures, the solar still could produce water at night, and the daily production could increase to 7.55 kg/day when the daily average solar radiation is 533 W/m^2.

Keywords: Solar desalination; Solar still; Fresh water production

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1. Introduction

Water is the basic need in human civilization, all forms of life cannot live without water. Currently, there is one severe problem which is the shortage in water production. Although water occupies the largest proportion on Earth, only 2.53 percent of water is freshwater which can be directly utilized for agriculture and other industries. Water stress and the risk of water scarcity are now common concerns. As of today, 771 million people (1 in 10 people) lack access to clean water [1]. By the year 2025, it is estimated that 1/4 of the world population will be affected by water scarcity, and 2/3 will experience water-stressed conditions. By 2030, 1/2 of the world population will experience high water stress [2].

In this context, desalination has a growing role to play in meeting the demands for fresh water. There are various methods of desalinating sea and brackish water. These include flash distillation, multi-effect distillation, membrane distillation, reverse osmosis, forward osmosis, ion exchange, and seawater greenhouse technology [3,4]. Many coastal regions around the world such as Bangladesh, and the Middle East and North Africa, are now dependent on treated saline water [5]. In terms of desalination methods, solar stills have several advantages including simplicity, low cost, ease of maintenance, and low environmental impact. However, the main drawbacks of solar stills include the requirement of large installation areas, lower productivity, and higher land cost associated with the larger land requirement [6].

In this case, the primary concern is to increase their productivity and test them out in disparate regions and conditions. According to Abujazar et al., the productivity of a solar still is influenced by ambient conditions (solar radiation, ambient temperature, wind velocity, etc.), operating conditions (brine water depth, saline concentration, and more), and design conditions (cover angle, insulation, etc.) [7]. According to the meteorological data obtained from Bangladesh Meteorological Department (BMD), Bangladesh receives an average of 3.125 kWh/m^2-day solar radiation during the summers (March–June) with a sunshine hour of 4.4 h–7 h; in the winters, there is an average of 2.31 kWh/m^2-day solar radiation (October–March) with a sunshine hour of 6 h–9 h. In addition, it is possible for Bangladesh to apply solar still using local labor and low-cost readily available materials, and even illiterate people can operate solar still due to its very simple operations, thus increasing its productivity, as pointed out in several literature [8-14]. Badran and Abdullah have coupled the sun tracking system to the solar still and have observed a 22% increase in productivity and a 2 % increase in overall efficiency [15]. Srithar et al. has optimized the orientation and inclination of the glass cover and has lowered the condensation loss. Also, they used different materials for basins to improve heat capacity and radiation absorption capacity and enhance the evaporation rate. They suggested rubber as the best basin material to improve absorption, storage, and evaporation [16]. Moreover, many experimental and theoretical studies were conducted to investigate the effect of using phase change materials (PCM) as a storage system on the productivity of the solar still [17,18]. A detailed review of the Nano-enhanced phase-change materials was carried out in which the ideal characteristics of nano-enhanced PCM was discussed, as well as thermo-physical properties, applications, and the challenges and future prospects of nano-enhanced PCM [19]. In this essay, we will not only demonstrate recent prevalent and popular material but also the factor that influences the results of research to a certain extent. For example, the brine depth is studied to select an optimum water depth for the fabricated solar still. With an optimized water depth, the effect of basin water salt concentration on productivity was also studied using synthetic saline water. Subsequently, real seawater was used on the solar still and the productivity was compared to using synthetic saline water. Lastly, the water quality was tested based on several parameters to determine the efficiency in removing dissolved impurities as well as suspended particles and to ensure the quality of distilled water was up to WHO standards.

In a previous work, we built a solar still to investigate the performance of the system in south China, and also the effect of PCM on the variation of temperature of the system subjected to a constant heat rate [20] and variable heat source (mimicking the solar energy) [21]. In this work, the role of PCM on the temperature variation of the water in the still was investigated. Moreover, the effect of PCM on the water production was measured as well [22]. The PCM used was tricosane (candle wax) since it is stable, cheap, safe, and easily available. The melting point and the latent heat of fusion of the PCM are 47.65 °C and 234 kJ/kg respectively [23]. The experiments were conducted from April-August 2018 in Muscat, Oman. The effect of various variables like the amount of PCM, the solar irradiation intensity, the ambient weather conditions, and variation of the water temperature on the unit productivity were investigated.

2. Experiment description

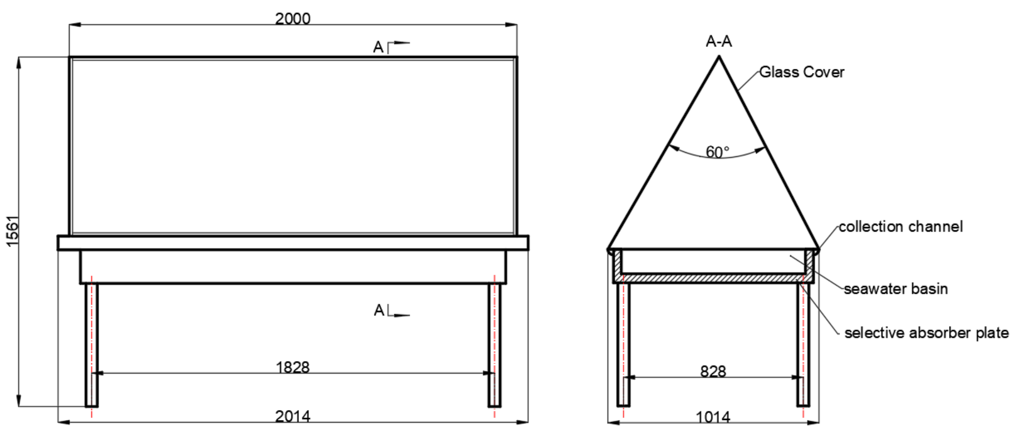

Figure 1. Schematic diagram of solar still

A double slope solar still was designed in this experiment, which was made of rectangular metal basin covered with a 4 mm thick glass panel with a slope of 60°. At the bottom of the basin, a selective absorption plate was installed to absorb the maximum solar radiation, the basin area was 2000 mm × 866 mm. The condensate gets collected through the inclined channel incorporated in the lower side of the glass and collected in the bottle and was measured hourly (**Figure 1**).

In this work, the temperature of the seawater (T_{sw}), the temperature of vapor temperature in the tank (T_{ea}), and the ambient temperature were measured with thermocouples, the solar irradiance was measured using a pyranometer type WXL20-LVRZC-12. The data of all parameters were recorded every 1 min by a data acquisition instrument (Agilent 4970A).

The experiments were carried out from April to November 2020. The experiments typically start from 8:00 to 18:00 or till 8:00 of the next day, and the water produced was tested hourly.

3. Results and discussion

Figure 2 to **Figure 6** shows the seawater, vapor and ambient temperatures, solar irradiation intensity and the accumulated water production in four different days.

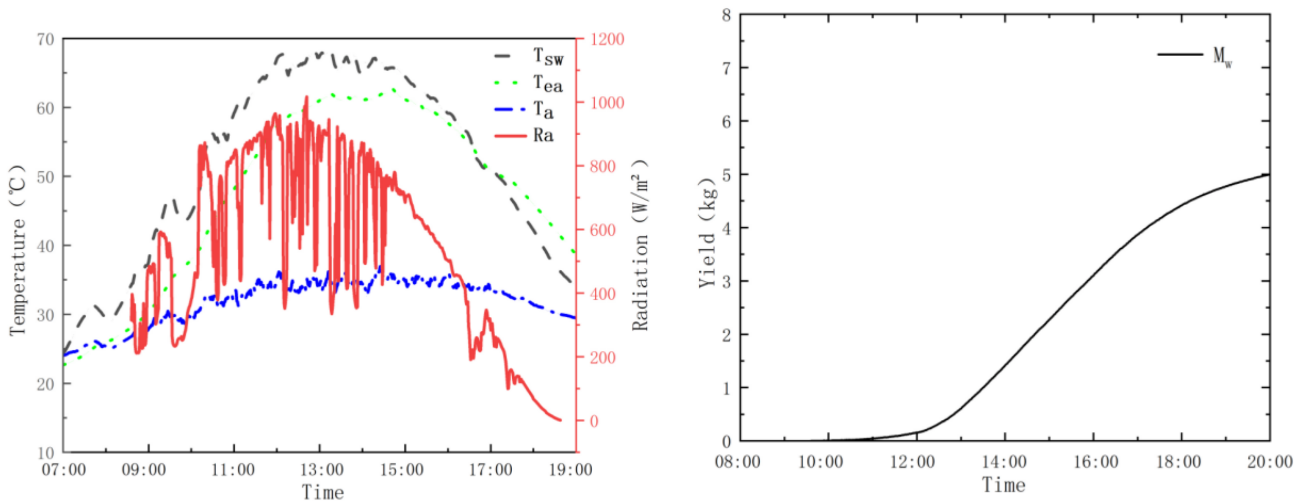

Figure 2. The change in seawater, vapor, and ambient temperatures, and solar irradiation intensity, and the accumulated water produced on April 13, 2020

As shown in **Figure 2**, the average solar irradiation intensity is 534 W/m^2, with the highest irradiation being 900W/m^2, and the average ambient temperature is 28.7℃. Because of the relatively stable solar irradiation, the highest seawater temperature reached 69℃ at 13:00, and the fresh water production increased sharply from 11:00 to 6:00 pm, because of the larger temperature difference between the seawater and the ambient, and the daily accumulated water production reached 6.27kg, which equates to 3.62 kg/(m^2·d).

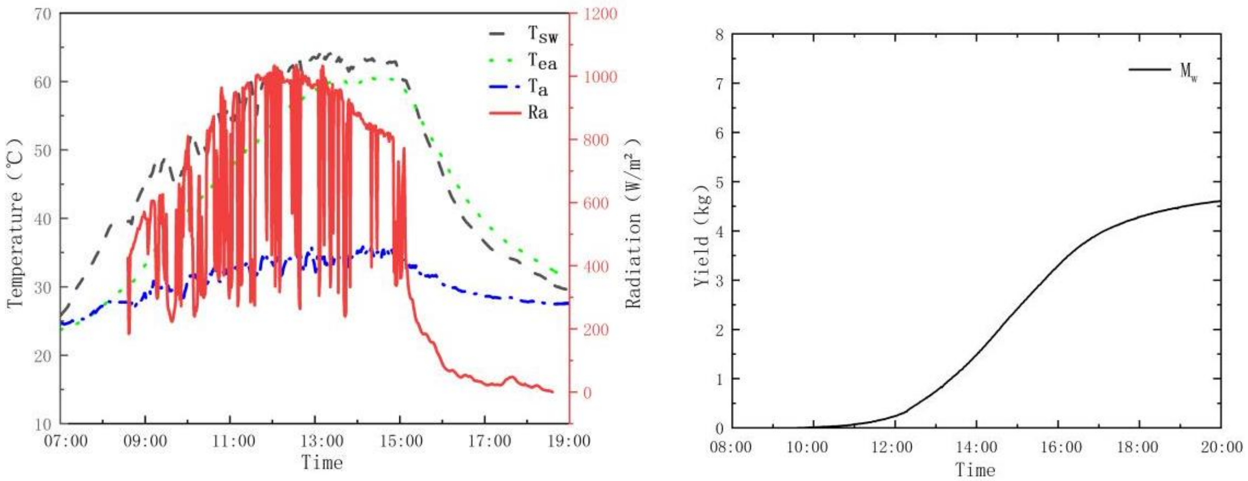

Figure 3. The change in seawater, vapor, and ambient temperatures, and solar irradiation intensity, and the accumulated water produced on April 14, 2020

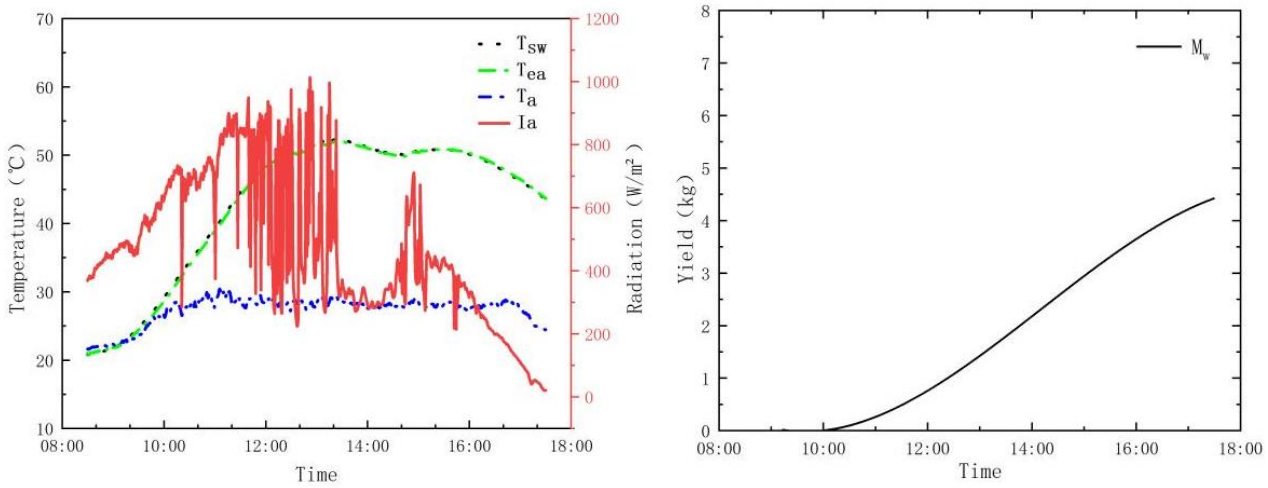

Figure 4. The change in seawater, vapor, and ambient temperatures, and solar irradiation intensity, and the accumulated water produced on October 21, 2020

Figures 3 and **4** showed the test results of April 14 and October 21, the average solar irradiation is 478 W/m^2 and 455 W/m^2, respectively, and the average ambient temperature of these two days is about 27℃; the daily accumulated water production is 5.66 kg and 4.62 kg, respectively; because the solar irradiation decreased sharply in from 13:00 onwards, and the highest seawater temperature was just 50℃, but the highest seawater temperature was up to 63℃.

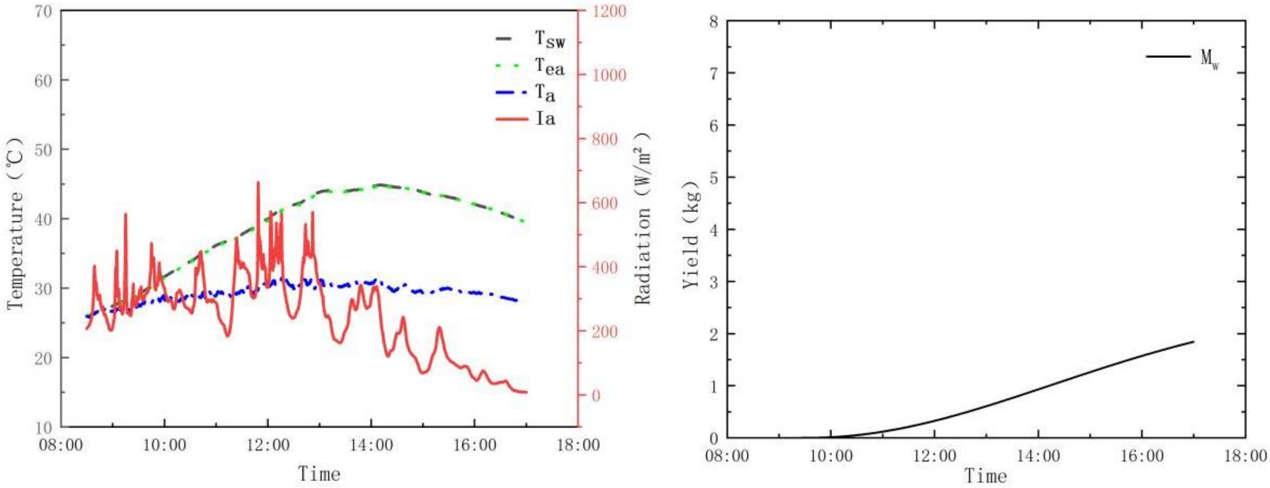

Figure 5. The change in seawater, vapor and ambient temperatures, and solar irradiation intensity, and the accumulated water produced on October 28, 2020

Figure 5 shows the operation of the solar distiller on October 28. It was a cloudy day, the average solar irradiation intensity was 236 W/m^2, the highest seawater temperature was only 45 ℃, and the daily accumulated water production is decreased to 1.9 kg. This indicates that solar irradiation intensity has a great influence on the water production.

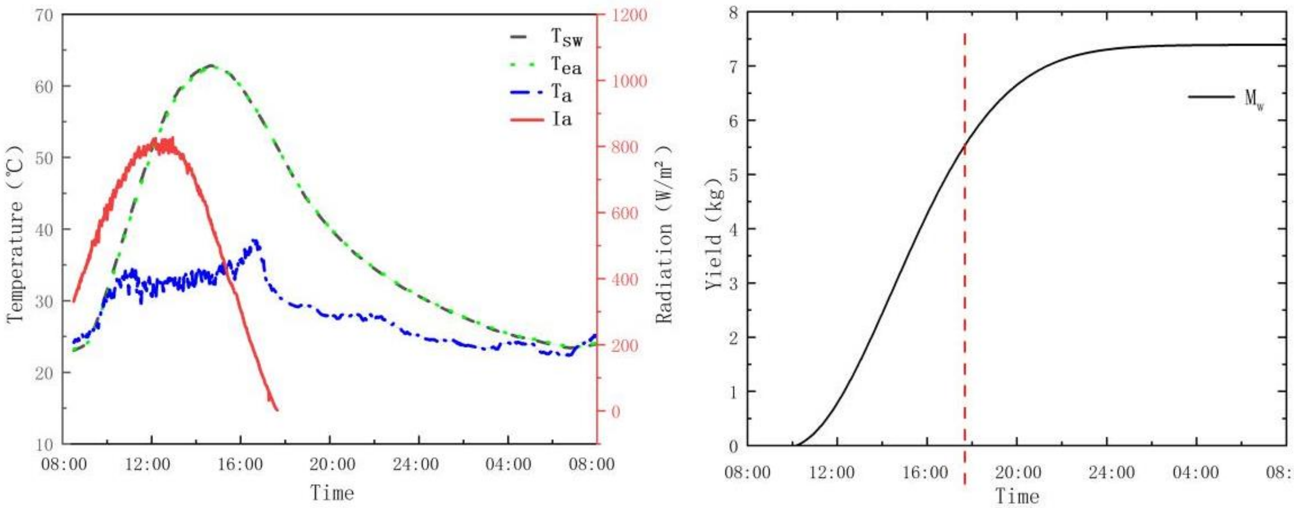

Figure 6. The change in seawater, vapor and ambient temperatures, solar irradiation intensity and the accumulated water produced on Oct 26–27, 2020

As shown in **Figure 6**, the seawater temperature is still as high as 35 ℃ at 18:00, and the temperature difference between seawater and the ambient, the water production after 18:00 pm is test continually on October 26–27, and the result show that the water production was still increasing before 24:00, up to 7.55 kg, which equates to 4.56 kg/(m^2·d).

4. Conclusion

A solar still was built and tested between April 2020 to November 2020, and the test results show that the fresh water production is affected by the solar radiation intensity, the average production of the unit is 6.27 kg/day, the water production is decreases to 1.9 kg/day when the daily average solar radiation decreased to 236 W/m^2. At the same time, the test result show that the solar still could produce water at night, and the daily production could increase to 7.55 kg/day when the average solar radiation per day is 533 W/m^2. The water production could be further improved by the thermal insulation of still basin and the selective absorption material used in the inner wall of the still basin, which will improve solar thermal performance and reduce heat loss. The relative results show that the solar still is an effective method for producing fresh water in coastal areas of low-income countries, where modern desalination techniques are not suitable due to high investment and maintenance cost.

Disclosure statement

The authors declare no conflict of interest.

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