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Performance Improvement of the single slope Solar Still Using Sand

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Abstract

Desalination could be a sustainable solution for responding to the ever-rising demand for water and the scarcity of freshwater resources. But given the substantial energy consumption of conventional desalination methods, greater use of renewable energies such as solar in this area seems inevitable. This study investigated the effect of placing sand within the basin of a simple basin-type solar still on its performance. For this purpose, two solar stills one with a sand-containing basin and the other without sand, were designed and constructed. The stills were then tested in Sabzevar (latitude: 36.20; longitude: 57.67), Iran, to determine the effect of sand. The tests were carried out over three days in early July 2019 for 13 hours each day. The results showed that the presence of sand within the basin of the still increased its water productivity and thermal efficiency by 21.16%. Considering these results and the low cost and high availability of sand, placing sand inside the basin of the solar still appears to be a good solution to increase its efficiency.

Keywords: desalination, solar still, sand, productivity, efficiency

1. Introduction

Although water covers about three-quarters of the Earth's surface, only a small percentage of the world's waters are potable. Today, many of the world's freshwater resources are strained by rising demand, irresponsible consumption, and global warming, which, the water deficit crisis is one of the major problems in human societies. One of the sustainable solutions to this problem is the desalination of seawater or brackish waters. Over the years, several different water desalination technologies have been introduced and used in different parts of the world. However, most of these technologies consume high a mounts of energy, which mostly come from non-renewable fossil fuels with well-known adverse environmental effects [1].

Because of concerns about the environmental effects of fossil fuels and their scarcity and non-renewability, there has been a growing interest in desalination systems that utilize renewable energies[2]. Freshwater production with renewable energy-based desalination technologies seems to be the most sustainable solution for responding to the water shortage crisis, especially in remote areas without potable water and power grids [3]. One of the major renewable-energy-based desalination approaches is solar desalination, which, given the broad scope of water scarcity problem, has been the

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subject of much interest to many researchers around the world. Solar desalination is believed to be a good solution for freshwater production in arid and semi-arid areas where it is difficult to access freshwater in the usual ways [4].

Solar desalination systems have been designed and built in various sizes and shapes. One type of solar desalination system is simple basin-type solar still. In a simple basin-type solar still, which is one of the oldest types of solar desalination systems, saline water is placed inside a solar heat absorber reservoir to evaporate and the resulting water vapor condenses on an inclined wall above the reservoir, thus turning into freshwater. The main drawback of simple solar stills is their fairly low performance. Therefore, most of the studies on these stills have been mainly focused on improving their performance through a variety of methods.

Some studies on simple solar stills have explored the idea of using heat storage materials to store heat for use during the night or non-sunny hours. In a study by Tabrizi and Sharak (2010), where they investigated the use of a sandy heat reservoir under the simple solar still as the heat-storage component, it was reported that heat reservoir increased the unit's productivity by 75% [5]. Faegh and Shafi (2017) performed an experimental investigation on a solar still with an heat storage system consisting of phase change materials and heat pipes and found that it can have up to 66% higher product than a conventional still [6]. Using phase change materials, Al-Harashe et al. (2018) succeeded to achieve a 40% improvement in the night product of a solar still [7]. In a theoretical study by Kabeel et al. (2018), they compared the use of different phase change materials in solar stills [8]. Musa et al. (2019) conducted an experimental study on the effect of different phase change materials on the performance of solar stills and reported an increase in the night product and a decrease in the day product of these stills [9].

Some studies have investigated the use of nanomaterials in the structure of solar stills or for the production of nanofluids. For example, Chen et al. (2019) studied the use of carbon nanotube containing Nano fluid in a solar desalination system and observed an increase in thermal efficiency from 24.91% to 76.65% [10]. Kabeel et al. (2014) investigated the impact of using copper oxide and aluminum oxide containing Nano fluids on solar desalination and reported a 90-94% improvement in the performance of simple solar stills[11]. Sharshir (2017) studied the effect of graphite and copper oxide nanomaterial containing Nano fluids on desalination with solar still and observed 44.91% and 53.95% improvement in the performance of solar still respectively [12].

As the above review suggests, improving the performance of solar stills through different methods has been a popular subject of research worldwide. The present study investigated whether using sand aggregates within a simple solar still basin can improve its performance. The presence of sand can improve the absorption and storage of solar heat and, since sand is abundant and inexpensive, the method can serve as a simple economical solution to improve desalination performance. Note that the studies of Tabrizi et al. (2010), Madhu et al. (2017) [13], Kabeel et al. (2018) [14], and Dumka et al. (2019) [15] have already investigated the use of sand as heat storage material, but they have placed it in a compartment separate from saline water. This study, however, examined the effect of placing a porous layer of sand within the saline water basin and in direct contact with water. It should also be noted that while other researchers including Rashidi et al. (2017) [16] and Mohamed et al. (2019) [17] have studied the use of porous materials within the basin of solar stills, they have used materials other than sand for this purpose.

Materials and Methods

For this research, two solar stills with the designs displayed in Figure 1 were constructed. The body of both basins was fabricated with composite sheets and their inner surface was painted black after sealing. Considering the latitude of the test site (Sabzevar, Iran), the inclination angle of the glass cover was set to 36°. This cover was made with a simple 6-mm thick glass. Despite the use of composite sheets in the basin walls, glass wool was used to further insulate the body of the units. Two valves were installed on the body and bottom of the units to serve as inlet and outlet of saline water. A channel with a diameter of 1.5cm and a slope of 40° was installed at the bottom of the glass to collect the condensed water and transfer it to a container outside the unit.

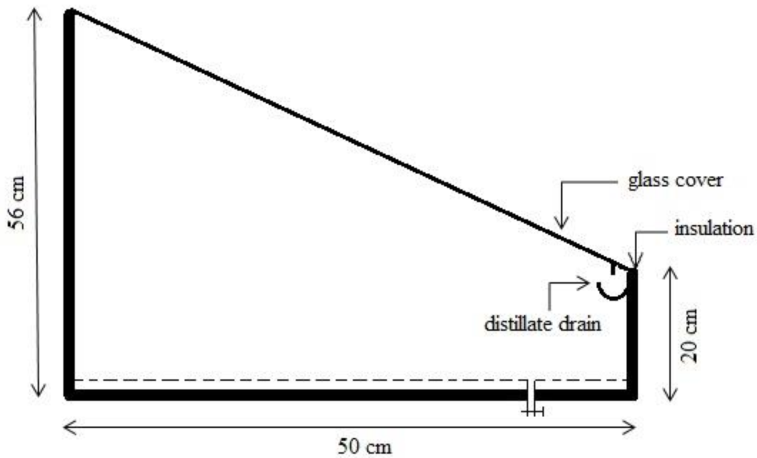

Figure 1. Schematic diagram of the fabricated solar stills

Experiments were performed in two treatments: control and sand (Figure 2). In the first treatment (control), there was no sand in the basin of the solar still. In the second treatment (sand), a layer of sand was placed inside the basin to investigate its effect on the still's output. Both stills were tested in the batch mode. For both stills, 2.5 liters of saline water with an initial concentration of 35 g/L, which was prepared by adding sea salt to drinking water, was poured in the basin. Water depth in the control treatment and the sand treatment was 1cm and 2 cm respectively. The surface of the sand layer was matched to the water surface. The fineness modulus and uniformity coefficient of the sand were 2.83 and 4.5, respectively. The sand was made saturated surface dry sand before being placed in the basin.

Figure 2. Image of the solar stills used in the experiment

The experiments were carried out in Sabzevar, Iran, from 8 A.M. to 9 P.M. of three summer days in early July 2019. Air temperature at the site was measured with a mercury thermometer. Wind speed and Sunlight radiation data were obtained from the records of the Sabzevar Meteorological Office. Temperature of the air and the water inside the basin was measured by TMP-10 digital thermometers. The volume of water produced by the still was measured at one-hour intervals.

To investigate the effect of sand on the thermal efficiency of the still, the following equation was used to calculate this parameter for different hours of each day and for each day in its entirety:

$$\eta_d = \frac{\sum m_{dss} \times h_{fg}}{\sum I \times t \times A} \qquad (1)$$

In this equation, m_{dss} is the cumulative mass of distilled water (in grams), h_{fg} is the latent heat of evaporation of water (2335 J/g), I is the solar radiation intensity ($\frac{W}{m^2}$), t is time (s), and A is the area of the basin (m^2).

Results & Discussion

Experiments of this study to investigate the effect of sand on the performance of a simple passive solar still were performed on 3 summer days on July 6, 7, and 8, 2019 in Sabzevar, Iran (latitude: 36.20; longitude: 57.67). Wind speed is one of the parameters affecting the efficiency of simple solar stills, as wind can increase condensation by reducing the temperature of the glass cover. Wind speed at the test site was obtained from the reports of Sabzevar Meteorological Station. These wind speed data are plotted in Figure 3. This chart shows the average wind speed over the three days of testing. As can be seen, average wind speed in these three days fluctuated between 4.5m/s and 8m/s, with two peaks at the hours 13:00 and 19:00.

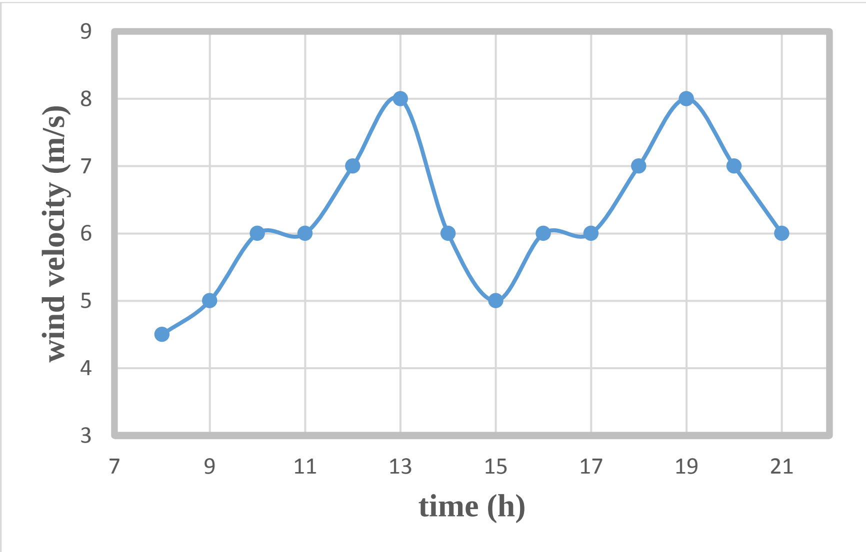

Figure 3. Wind speed at different hours of experiment days (average of three days)

Solar radiation is the most important determinant of the performance of a solar still. Solar radiation data were also obtained from Sabzevar Meteorological Station. Figure 4 shows the average solar radiation over the three days of testing. This parameter directly affects the temperature of the water, glass and ambient air. As this figure shows, the peak solar radiation in these three days was 950 w/m2, of which occurred at 13:00. Changes in ambient temperature at the test site are plotted in Figure 5. These three days had an average daily temperature of 32.5, 33.6, and 34°C, a maximum daily temperature of 37, 38, and 38°C, and a minimum daily temperature of 29, 28, and 30, respectively. As these solar radiation, wind speed, and ambient temperature values suggest, the area had a fairly stable climate during the three days of testing.

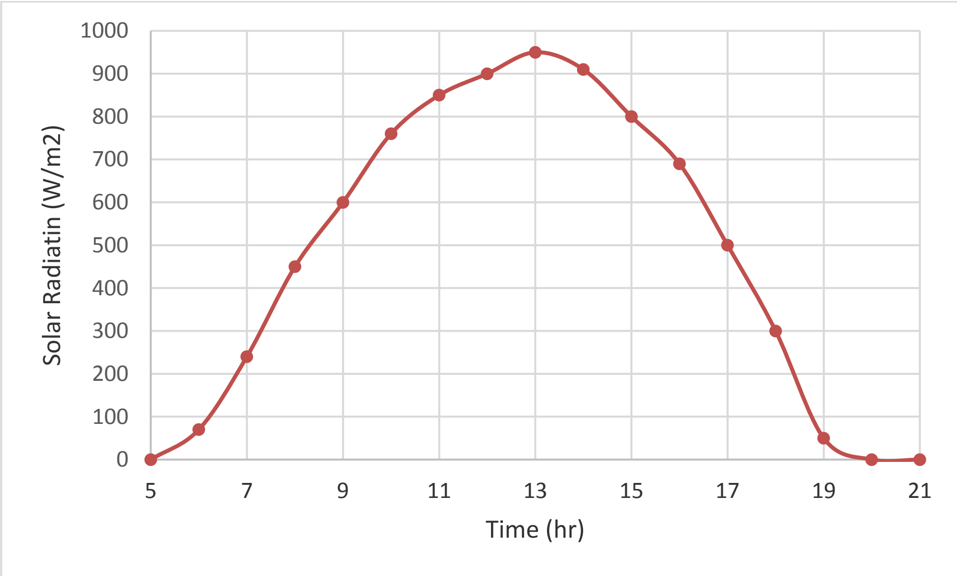

Figure 4. Changes in solar radiation during day (average of three days of experiment)

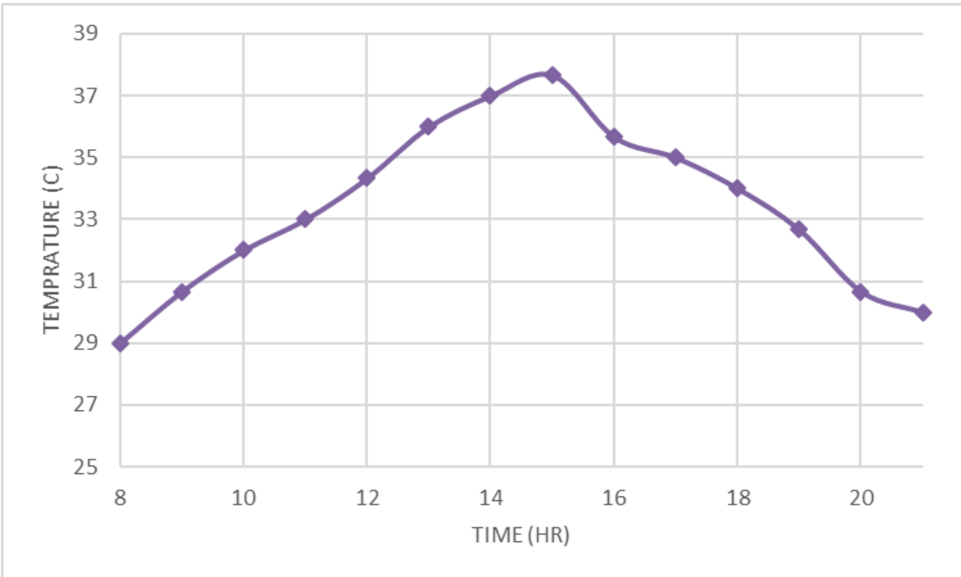

Figure 5. Changes in ambient temperature at the test site

In addition to ambient temperature, air temperature inside the stills (under the glass cover) and water temperature inside the basins were also measured. Changes in the temperature of air and saline water inside the still are plotted in Figure 6. The values presented in this chart are the average hourly temperatures during the three days. As can be seen, the average air temperature inside the sand-containing solar still varied between 28.3 and 73.7°C and in the control still it was between 28.3 and 71.8°C, and in both cases, peak temperatures occurred in the middle of the day, i.e. at 12:00 and 13:00. Peak air temperatures inside the sand-containing solar still were about 3% higher than in the control still. The average saline water temperature inside the sand-containing still was 27-67.7°C and in the control still it was 27-65.3°C, with the highest temperatures occurring in the noon hours, i.e. 12:00 and 13:00. Peak water temperatures inside the sand-containing still were 3.7% higher than in the control still.

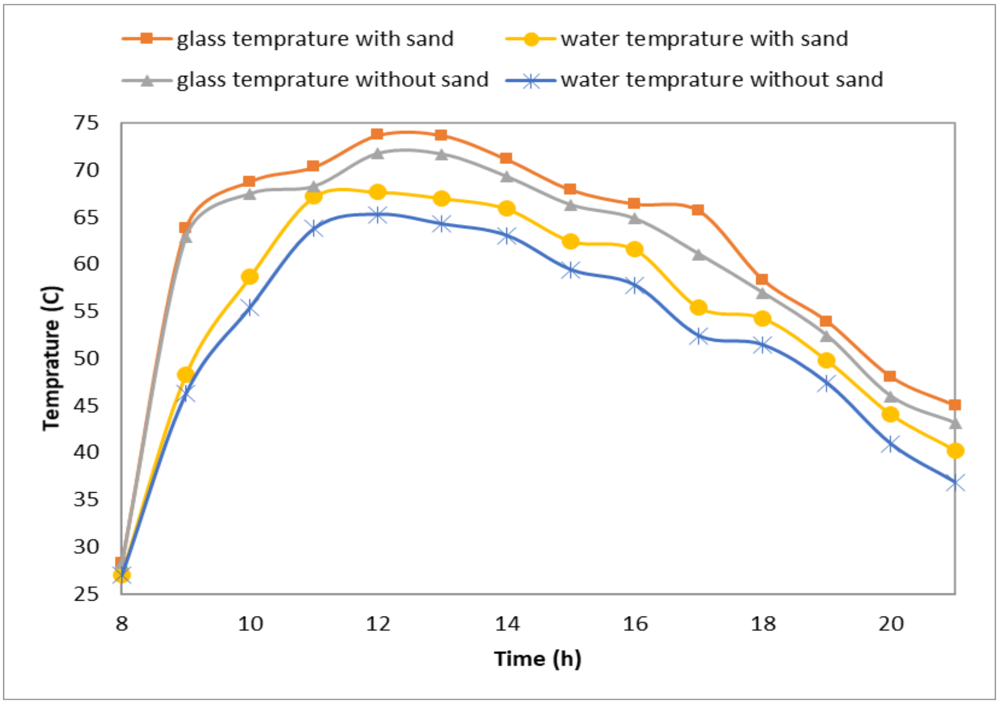

Figure 6. Changes in air temperature (under the glass cover) and water temperature inside the stills

Figure 7 shows the hourly water production of the stills at different hours between 8:00 and 21:00. The values presented in this figure are the averages for the three days. As this figure shows, the hourly output of both stills has an increasing trend in the morning, reaches a peak at 13:00, and then declines in the afternoon. The maximum hourly water production of the sand-containing still and the control still was 120 ml and 104 ml respectively, and the average hourly production of these stills was 67 ml and 55.4 ml, respectively.

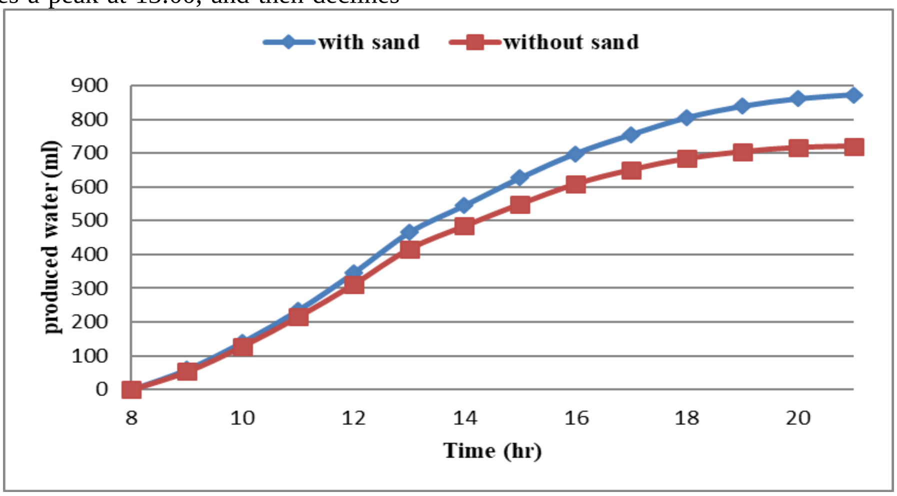

Figure 8. Cumulative water production of the stills

The thermal efficiency of the two stills was calculated based on the solar energy received and the cumulative water produced during the test hours. The calculated thermal efficiency values are presented in Figure 9. As this figure shows, the total thermal efficiency of the still with the sand was

29.28 % and without the sand was 24.17 %, which means a 21.16 % improvement in thermal efficiency because of the presence of sand.

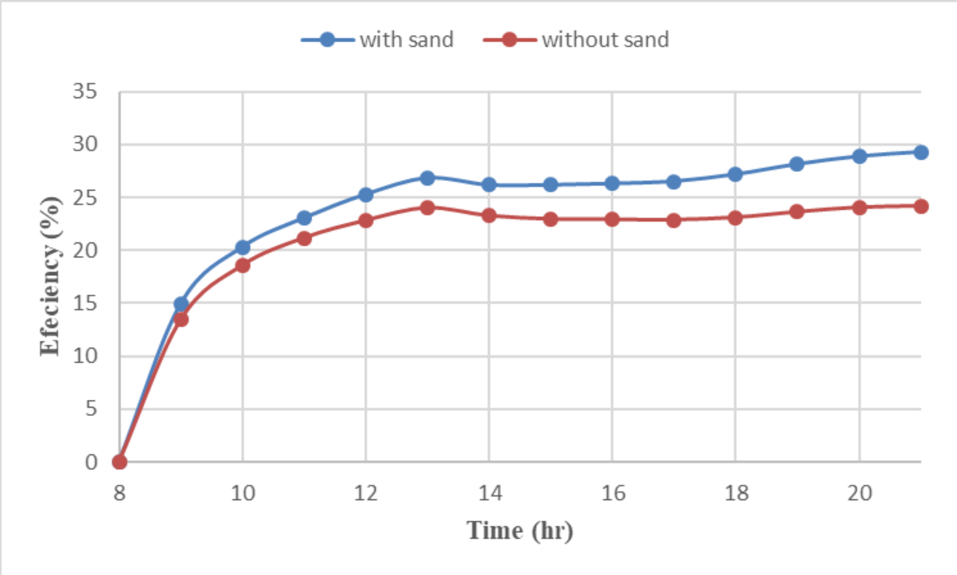

Figure 9. Thermal efficiency of the sand-containing still and the control still

The results of this study seem to be in good agreement with those of similar studies. The productivity values reported by Tabrizi et al. (2010) for the still with sandy heat reservoir, by Rashidi et al. (2017) for the still with porous materials, and by Dumka et al. (2019) for the still with sand bags are 3000 g/m2, 3829 g/m2, and 3490 g/m2, which are repressively 86 %, 109.7 %, and 100 % of the productivity that obtained in this study. Also, the thermal efficiency values obtained by Rashidi et al. (2017) and Dumka et al. (2019) are 26.9% and 28.8%, which are respectively 91.9 % and 98.4 % of the corresponding value in this study. it seems that using sand within the basin of simple solar stills can be suggested as a viable method for improving the yield and thermal efficiency of these stills, especially since sand is easy to acquire and inexpensive.

Conclusions

This paper presented the results of an experimental study carried out to determine whether the performance of simple solar stills can be improved by placing sand within their basin. For this purpose, the performance of two solar stills, one with a sand-containing basin and the other without sand, was measured. The goal of this measurement was to determine the effect of sand on freshwater production and thermal efficiency of the still. The results of this study showed the effectiveness of placing sand in the basin of the solar still, as it increased the productivity and the thermal efficiency by 21.43%. Therefore, using sand in the basin of simple solar stills seems to be an easy and inexpensive solution to improve their performance. Given its simple and economical design, this still can be used in remote arid and semi-arid regions. Further research on the impact of water-sand surface difference and sand grading on freshwater production is recommended.

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