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Study of Different Parameters Affecting the Productivity of Solar Still for Seawater Desalination under Djiboutian Climate

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Abstract

Experimental studies were carried out to determine the influence of solar radiation, temperatures variations, basin water amount, wind speed, glass cover thickness and salinity on the daily production of the distillate output using solar desalination process, namely single slope solar still to produce fresh water from seawater in the context of Djibouti. The temperatures variations increase in relation to solar radiation. Consequently the hourly distillate output increases and reaches a maximum around noon when the solar still receives maximum intensity of solar radiation. An inverse relation is found between glass cover thickness, basin water amount and distillate output production. The variation wind speed has an effect on the daily production; which increases in relation to wind speed. In order to assess the effect of salinity on the daily production, the solar still is provided with brackish water to compare the daily production obtained from seawater. Experimental results show that the cumulative productivity decreases when there is an increase of salinity. In addition, the quality of the distillate output was tested by measuring TDS, EC, pH, hardness water and chlorides and was compared to WHO standards. The values obtained for these parameters were in accordance with the requirements of WHO and good removal efficiency for four parameters.

Keywords

Solar Still, Glass Cover Thickness, Salinity, Solar Radiation, Djibouti

1. Introduction

Access to clean drinking water is vital and is a fundamental right to human dignity. 11% of the world's population, 844 million people, did not have access to safe drinking water in 2015 according to the 2017 report on progress in sanitation and water supply from the World Health Organization (WHO) and United Nations International Children's Emergency Fund (UNICEF) [1]. The shortage in supply of this valuable water around the world is considered a great challenge.

Located in the northeast of the African continent, the Republic of Djibouti is between the Aden Gulf and the Red Sea. The climate is hot and dry. Annual rainfall is low 150 mm/year on average and irregular. People in the rural areas of Djibouti suffer a shortage of clean water, especially during the dry season [2]. One of the reasons for water supply shortages in Djibouti is the high salinity of the water due to over-exploitation of aquifers and the high pumping rate. Moreover, Djibouti receives a high level of sunshine on its territory throughout the year, and solar desalination has been considered as an important option to obtain potable drinking from impure water and the instrument which is required to do this process is known as solar still. However, this is the best suitable solution to solve the problem of fresh water supply for small communities in arid regions with lack of drinking water [3].

In general, there are several factors affecting the rate of solar still productivity such as solar radiation, ambient temperature, water depth in the basin, thickness glass cover, cover angle, wind velocity, material coated on the basin, salinity, etc [4]. However, various research works were carried out to improve the performance of the solar still base on these parameters [5]. The solar radiation is the main parameter that affects the productivity of the solar still. Velmurugan *et al.* [6] studied the effect of solar radiation on productivity in stepped solar still. It was found that productivity increased with solar intensity.

Glass cover is the most used and efficient material for the design of solar still. Glass cover is transparent to short wavelength radiation and is therefore more effective in reducing radiated heat losses from the absorber plate [7]. A comparative study on the impact of different condensing cover material conducted by [8] showed that glass cover gives higher yield due to higher thermal conductivity compared to plastic. However, the effect of glass thickness on solar still performance has been investigated in many studies [9] [10] and [11]. Edeoja *et al.* [12] conducted an experimental study on three identical size solar stills, having three different thicknesses of glass cover of 4 mm, 8 mm and 12 mm in winter climatic conditions of Mehsan. A result shows that, 4 mm glass cover thickness increases distillate output compared with 8 mm as well as 12 mm glass cover thickness inside the solar still. The same study was carried out by [13] on three different thicknesses of glass cover to determine the optimum thickness of glass cover for the effective distillate output from solar still. He found that 4 mm and 5 mm glass cover thickness increased average distillate output of 27% and 12% compared with 6 mm glass cover thickness.

The basin water depth is one the most important parameters that affects the yield of solar still. Experimental investigations were carried out by [14] in a triangular pyramid solar still varying water depth from 0.02 m to 0.08 m. Their experimental results showed that the accumulated fresh water is more than that of a water depth of 0.02 m at 4.3 kg/m^2 while that of a water depth of 0.04, 0.06, 0.08, and 0.1 m are 2.3, 1.2, 0.9, and 0.5 kg/m^2 respectively. Layek [15] has studied the impact of water depth in basin on the rate of solar still with variables values (0.02 m, 0.03 m, 0.04 m, 0.06 m, 0.08 m and 1 m) and found similar results with accordance in the literature [16]. The low in basin water depth leads to an augmentation the yield of solar still [17].

Many authors studied the effect of wind speed on production of fresh water of solar still. They concluded that when the wind speed increases the productivity goes up accordingly [18]. Sathyamurthy *et al.* [14] have found when wind speed increases from 1.5 m/s to 3.5 m/s and to 4.5 m/s the productivity of solar still increasing by 8% and 15.5%. Dimri *et al.* [8] have studied the effect of wind velocity on the yield of an active and passive solar still. They have observed that the yield increases when the wind velocity increasing in both cases.

The effect of water salinity on the productivity of a solar still has been investigated in many publications [15] [19] and [20]. Hoque *et al.* [21] investigated the effect of salt concentration on the productivity of solar still. They prepared synthetic solutions with total dissolved solids of 2000, 5000 and 8000 ppm by adding sodium chloride. They found that the distillate output drops by 7.28% with the increase in TDS from 2000 to 8000 ppm. In another research work conducted by [22], with different salt concentrations (0%, 10% and 20% of salt), showed that the lower salt concentration conducted a higher productivity to distilled water.

Many researchers have analysed the quality of distillate output in various solar still with different environmental condition, design, and operational parameters [23]-[29]. The majorly parameters of the water quality mainly studied are pH, EC, TDS, Total hardness, chloride and salinity or alkalinity before and after distillation. The physical and chemical water quality examination revealed that the distillate output was acceptable according to the WHO-2017 standard [30].

It is clear that there are not scientific studies conducted on the different parameters affecting the Productivity of Solar still under Djiboutian climate. This is why it seemed important to us to determine the impact of these parameters under Djiboutian climate. However, there is only one study conducted by [3] which consists of the construction of the solar still and its possible use under the arid climate of Djibouti.

The objective of the present paper is to study the effects of different parameters, namely solar radiation, water amount in the basin, glass cover thickness, water salinity and wind speed on the daily production of fresh water from seawater under Djiboutian climate. In order to assess the effect of salinity, the solar still is provided with brackish water to compare the productivity obtained from seawater. After wards, water quality parameters, such as electrical conductivity (EC), pH, Total Dissolved Solids (TDS), hardness water and chloride, were analysed before and after distillation in the solar still. The results obtained of various parameters are compared with the World Health Organization (WHO) standards for drinking water.

2. Materials and Methods

Figure 1 represents the schematic diagram of single slope solar still used in this work, which is made mainly of a wooden box equipped with thermal insulation, where a still basin in galvanized iron black painted is inserted. The wholer's covered by transparent glass inclined at an angle of 32˚C to transmit the maximum solar radiation. This solar still is a passive solar still and conventional design.

Experiments were carried out in Djibouti city particularly within Campus Balbala of the University of Djibouti (GPS coordinates are of longitude 43˚07.045' and latitude 11˚32.256'), Republic of Djibouti. The experiments have been conducted during the month of May-June 2021. The prototype of the solar still was placed on the terrace of Doctoral school building to get the maximum of solar radiation from 8:00a.m. to sunset (5:00p.m.). During 9 h of direct experiment, the measurements of the ambient temperature, glass cover temperature, vapour temperature, water temperature in basin, solar radiation, wind speed and absorber plate temperature are recorded each hour.

The solar still is oriented towards East direction up 12p.m. and then orientation is changed towards West direction in order to receive most of the available solar radiation. The temperatures at various locations in the solar still and the intensity of solar radiation were measured using respectively K-type thermocouples and pyranometer. The data of wind speed and the glass cover temperature were measured using respectively anemometer and pyrometer during the five days. The distillate water is measuring by graduated cylinder tube each hour and collected in a polyethylene terephthalate (PET) bottle during experiments. A sample, with a capacity of 250 mL, is collected at the end of the experiment for water quality analyzes.

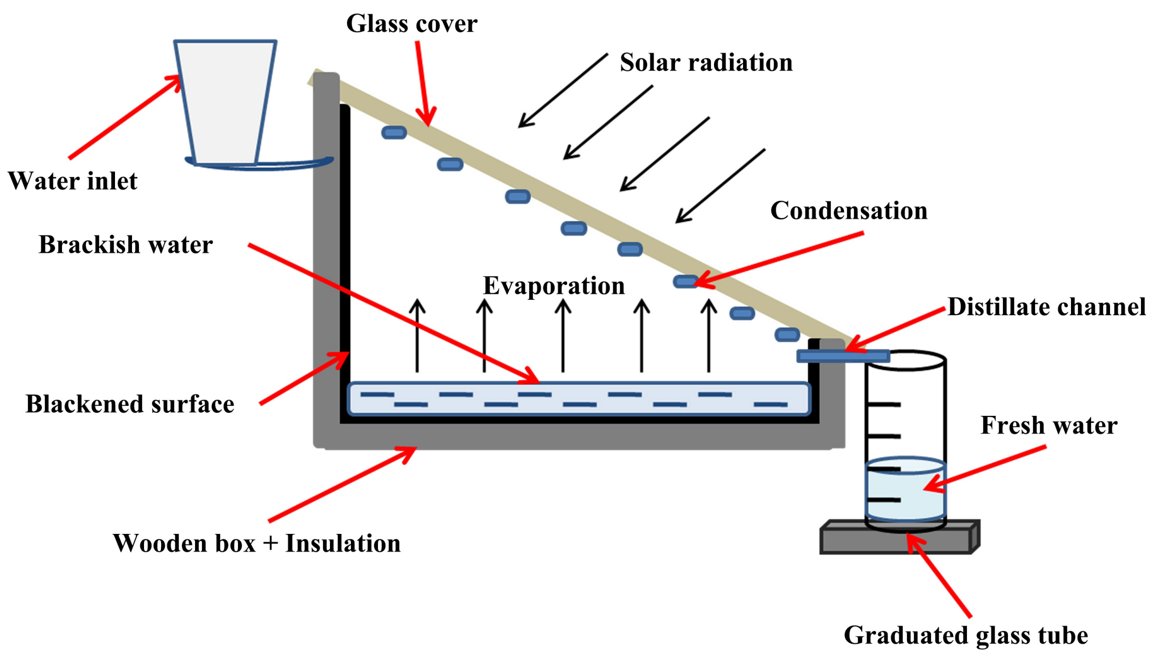

Figure 1. Schematic diagram of single slope solar still [3].

Seawater in the Red Sea with 31,000 mg/l TDS was used for this study. Chemical analyses of all samples for distillate water and brackish water which were used for the study was carried out for electrical conductivity, total dissolved solids using EC/TDS/Temperature portable meter (HANNA instruments). As for the analyzes, of EC and TDS, of sample of seawater we are used the Palintest Micro 800 Multiparameter. The values of pH for all the samples were measured with pH-meter (HANNA instruments), Chloride and Hardness water using respectively method of Mohr and titration complexometric by EDTA (ethylenediaminetetraacetic acid). The accuracies and error limits for the various measuring apparatus are given in Table 1.

3. Results and Discussion

3.1. Variation of Various Solar Radiation

The intensity of solar radiation is the one of the most important parameter of which depends of the productivity and thermal performance of solar still [31] [32] and [33]. Figure 2 represents the variation of solar intensity for the five days of manipulations (27.05.2021, 03.06.2021, 05.06.2021, 07.06.2021 and 09.06.2021)

Table 1. Accuracy and error limits for apparatus used in this work.

Apparatus used	Accuracy	Range	%Error
Thermocouple	0.1˚C	−40˚C/+120˚C	1.5%
Pyrometer	2˚C	−50˚C/600˚C	2%
Pyranometer	2 W/m^2	0 - 2000 W/m^2	<10%
Anemometer	0.1 m/s	0 - 30 m/s	5%
Graduated cylinder tube	10 ml	0 - 1000 mL	10%

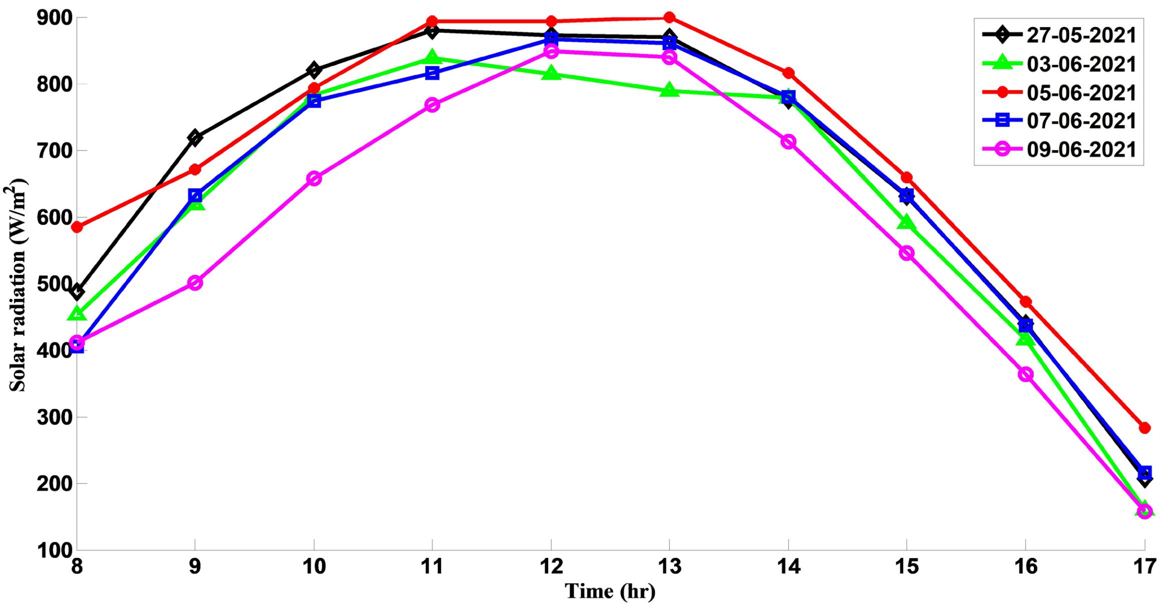

Figure 2. Hourly variation of solar radiation during the five days operating of solar still.

during the period from 8:00a.m. to 5:00p.m. All curves of the variation of solar radiation have the same profile for all the experimental days. The maximum was observed between 11:00a.m. and 1:00p.m. and was obtained 900 W·m^{-2} average values in mid-noon. The difference observed between the values of solar radiation intensity is due to the change climatic conditions during the five days.

3.2. Thermal Performance of Solar Still within Water

Figures 3-5 show the hourly variation of the temperature (*i.e.* ambient temperature, water temperature in basin, absorber plate temperature, glass cover temperature and vapor temperature) during the period from 8:00a.m. to 5:00p.m. for the 5 operating days (27.05.2021, 03.06.2021, 05.06.2021, 07.06.2021 and 09.06.2021).

Here we can say that all temperatures are having similar variation during of 5 days of experiments. They increase in relation to intensity of solar radiation except for the ambient temperature. As can be seen in these figures, the ambient

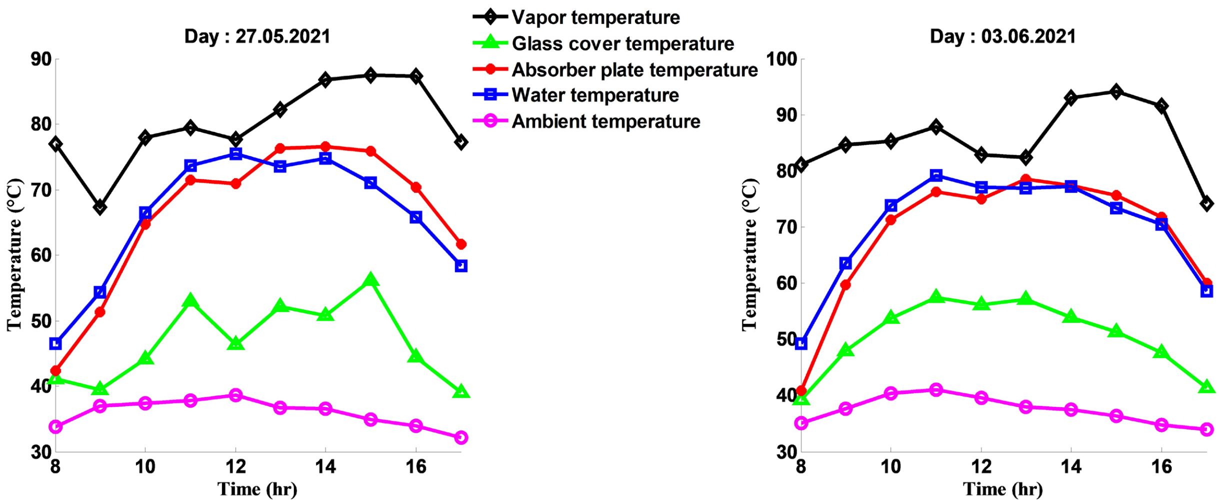

Figure 3. Variation of different temperatures with each hour for operating days, 27.05.2021 and 03.06.2021.

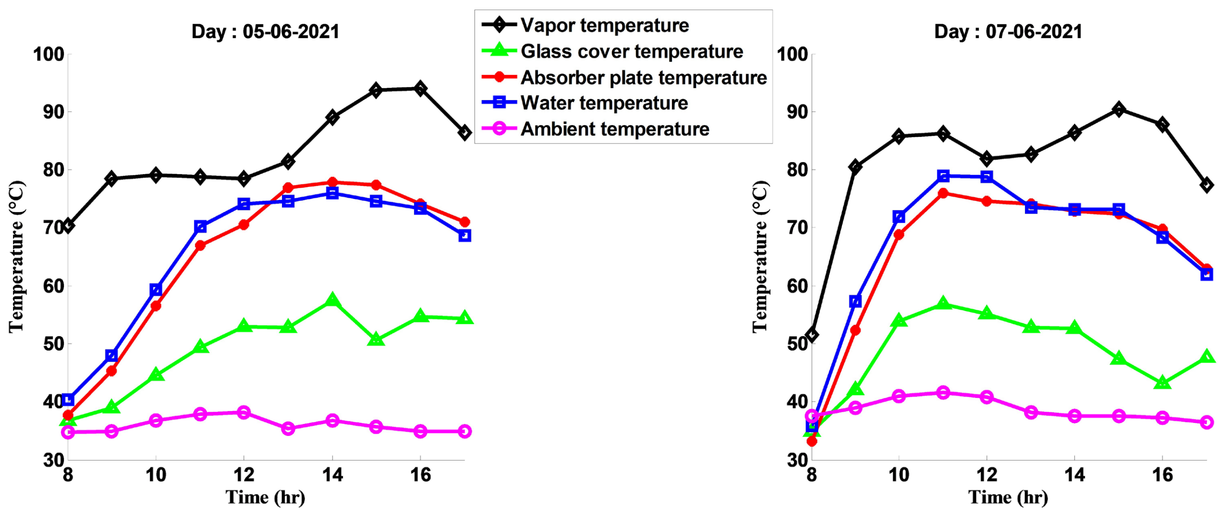

Figure 4. Variation of different temperatures with each hour for operating days, 05.06.2021 and 07.06.2021.

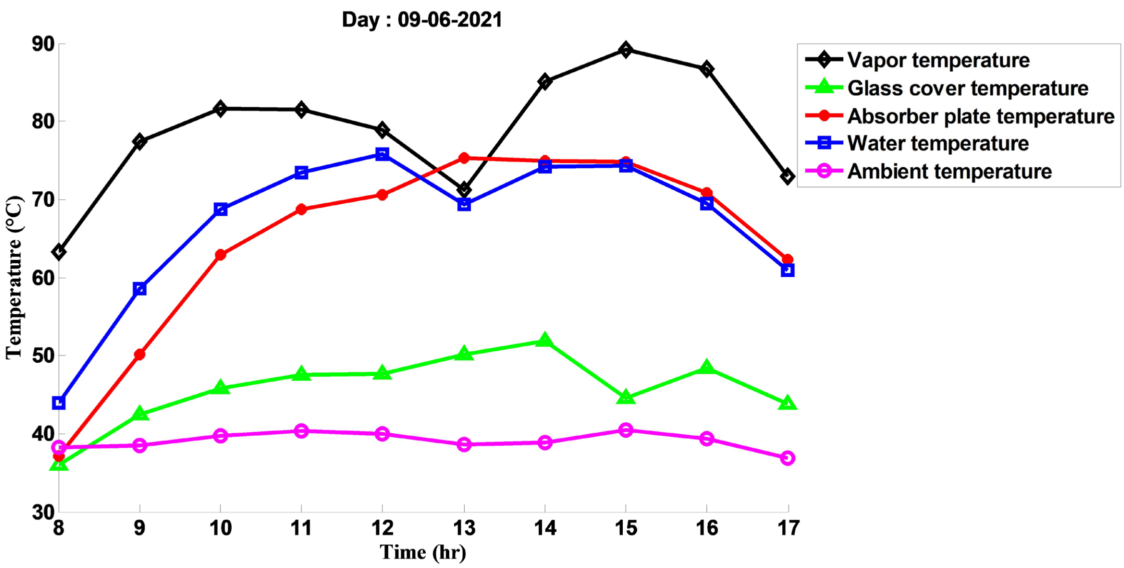

Figure 5. Variation of different temperatures with each hour for operating day, 09.06.2021.

temperature is less than all other temperature measured. The water temperature in basin and absorber plate temperature are having similar variation, of course with a slight difference. The variation absorber plate temperature is mainly due to her high ability of basin material to absorb the solar radiation as a form of heat energy and to diffuse this energy to water in basin. A change of state takes place from liquid to vapor as the water evaporates, as such the temperature of vapor is increased. The maximum temperature that can be observed is that of vapor during of 5 days of experiments. The maximum was observed at 3:00p.m. for all days. The day 03.06.2021 has a higher value at 94.2˚C while the minimum value was obtained for 27.05.2021 at 87.3˚C. These observations are consistent the results obtained in the literature [34].

3.3. Effect of Glass Cover Thickness on Water Production

The experiments were carried out in single slope solar still by varying glass cover thickness of 8 mm and 6 mm , from 8:00a.m. to 5:00p.m. during 2 days, 27 May and 3 June 2021, respectively. The water amount in the basin was maintained as 6 L.

Figures 6-8 show a comparison of the hourly distillate output, cumulative productivity and hourly variation of the basin water temperature for 6 mm and 8 mm glass cover thicknesses. The variation of hourly distillate output of solar still having two different thicknesses is shown in Figure 6. It can be seen during the experiment, that 6 mm glass cover thickness gives higher distillate output in comparison to 8 mm glass cover thickness. It is also found that the maximum of hourly distillate output is obtained between 11:00a.m. and 3:00p.m. for both glass cover thicknesses, coinciding with peak the solar radiation. It can be concluded that the thinnest glass thickness has higher transmittance and less reflectivity, that is why high distillate output production is obtained in this case. Similar

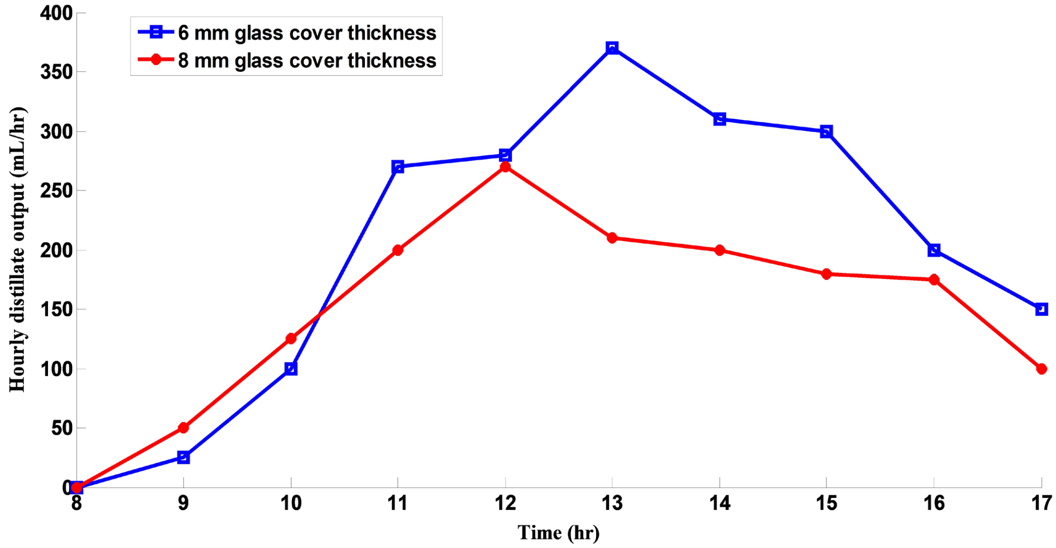

Figure 6. Variation hourly distillate output of single slope solar still with both different glass cover thicknesses.

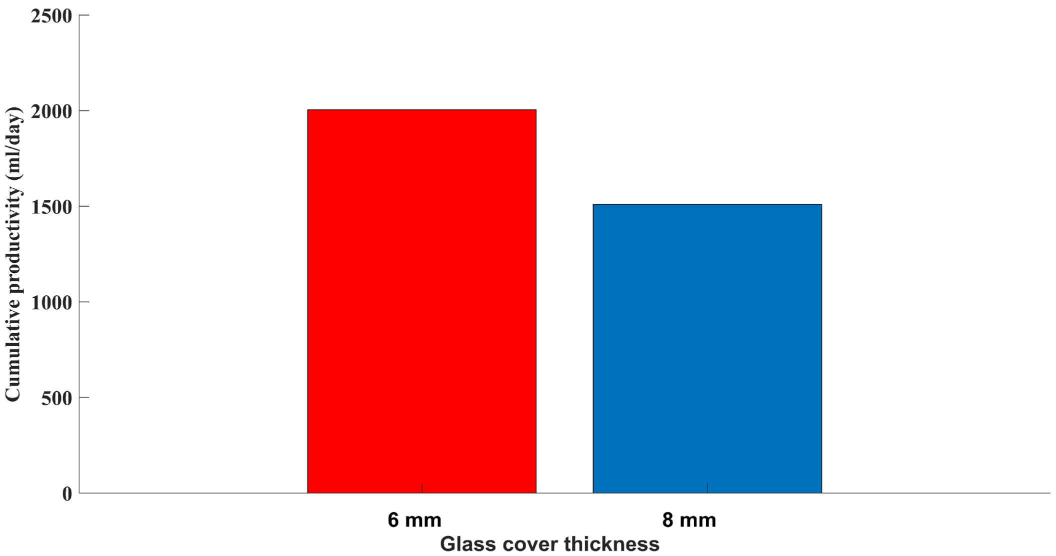

Figure 7. Variation cumulative productivity of single slope solar still with both different glass cover thicknesses.

experiments have been conducted by [11]. They found that 4 mm glass cover thickness increases the distillate water output compared to 6 mm glass cover thickness.

Figure 7 shows the cumulative productivity of solar still for two different glass cover thickness 6 mm and 8 mm, respectively. From the experimental results, the total accumulated distillate output obtained is 2005 mL and 1510 mL with 6 mm and 8 mm thicknesses, respectively. It can be noticed that, a solar still with glass cover with 6 mm thickness gives 24.7% more production than the glass cover with 8 mm thickness. Therefore, it can be concluded that thin glass cover thickness enhanced the performance of solar still as compared to thick glass thickness.

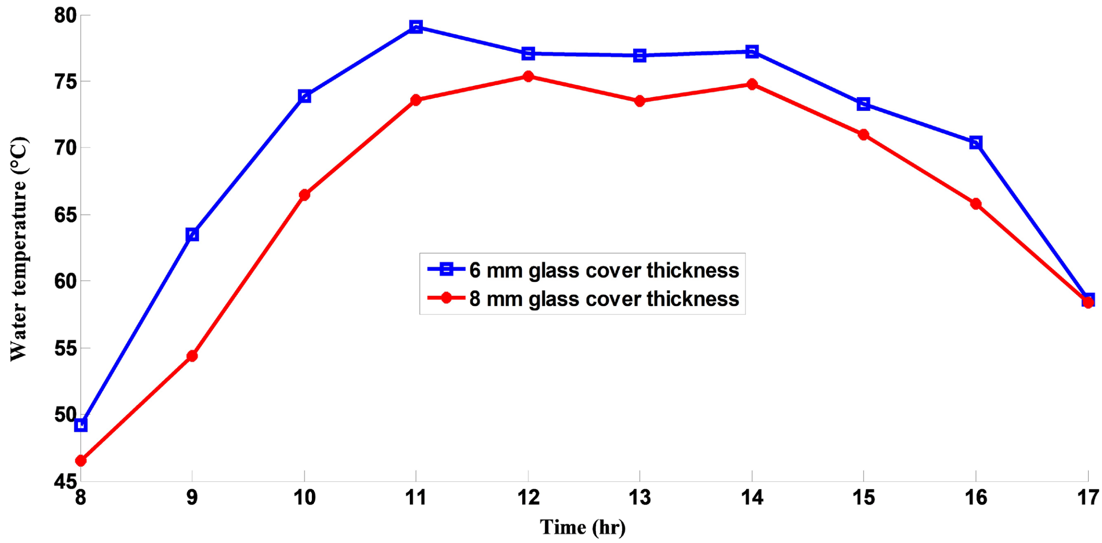

Figure 8. Variation water temperature in basin of single slope solar still with both different glass cover thicknesses.

The hourly variation of the water temperature in basin of solar still by varying glass cover thickness of 6 mm and 8 mm is presented in **Figure 8**. As shown, the water temperature follows the same trend for the two thicknesses. It was also observed that water temperature with 6 mm glass thickness is greater than water temperature with 8 mm glass thickness during the experiment. The reason behind this difference of water temperature in basin could be attributed to the thin thickness of glass cover which allows the incident solar radiation to penetrate into of the absorber plate resulting in rising its temperature and the temperature of water. The results obtained are a good agreement with the experimental studies conducted by [35] and [36].

3.4. Effect of Basin Water Amount on Water Production

Figure 9 shows the variation of cumulative productivity for both water amount in the solar still basin (*i.e.* 6 L and 12 L) for seawater of electrical conductivity (EC) having 59,900 μS/cm the basin keeping all other operating variables same during the operating days of 3 and 5 June respectively. From the experimental results, it found that the minimum cumulative productivity is obtained from a high water amount (12 L) in the basin of solar still and maximum for a low water amount (6 L). It can be seen that with increase in basin water amount the hourly cumulative productivity reduces. Other authors found similar results [37] and [38]. **Figure 10** represents the variation of basin water temperature and distillate output each hour from both water amount (6 L and 12 L). Therefore, the basin water temperature and distillate output increases with time of the day and reaches its maxima between 12:00a.m. and 2:00p.m. and 1:00p.m. respectively, also follows the same pattern of the variation of intensity of solar radiation (**Figure 2**). This can be attributed that at mid-noon the thermal losses minimizes and increases the thermal performance proportionately, increase in yield and

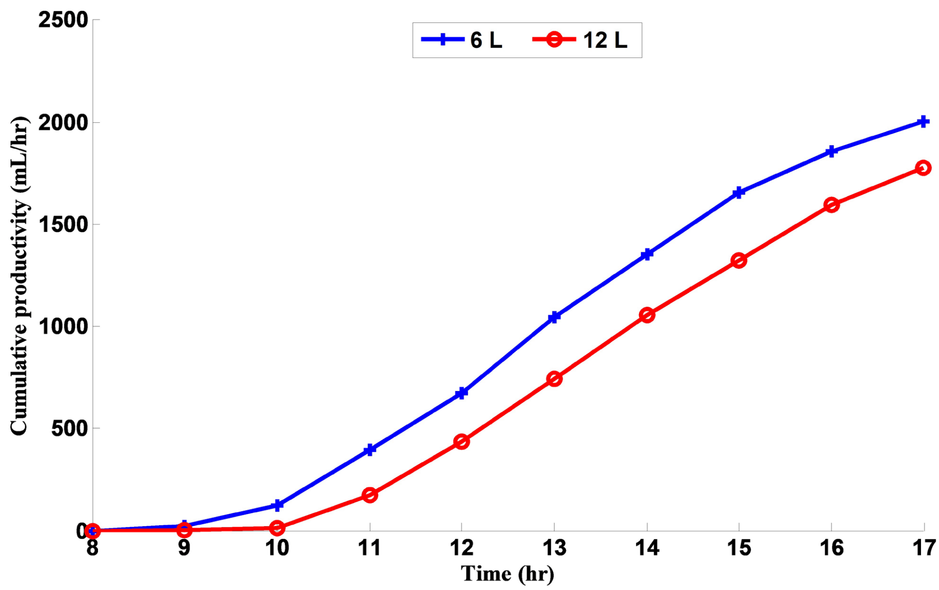

Figure 9. Variation of cumulative production each hour with 6 mm glass cover thickness, 3 and 5 June 2021.

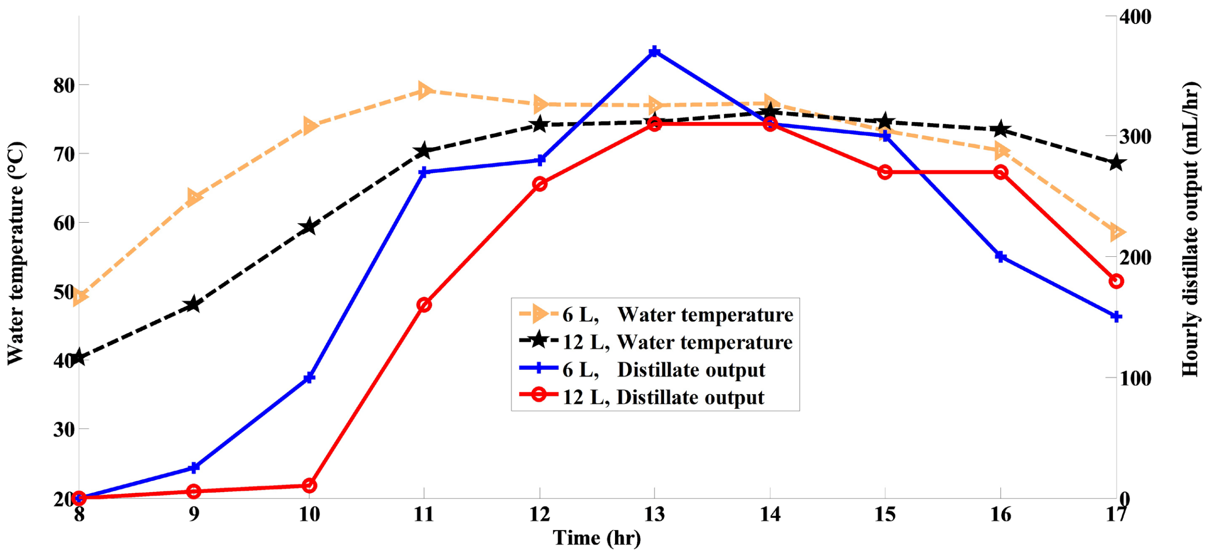

Figure 10. Variation of hourly productivity and water temperature each hour with 6 mm glass cover thickness, 3 and 5 June 2021.

instantaneous efficiency with lower water amount in basin of the solar still [15]. On other hand, with the increase in basin water amount from 6 L to 12 L, the yield from solar still reduces by 11.47%.

3.5. Effect of Wind Speed on Water Production

Figure 11 represent the variation of cumulative productivity and hourly distillate output with both average daily wind speed for 3 and 9 June 2021. In Figure 11(a), at the minimum cumulative water productivity of 1675 mL/day, average wind speed was obtained as 1.93 m/s. The average wind speed of 2.04 m/s

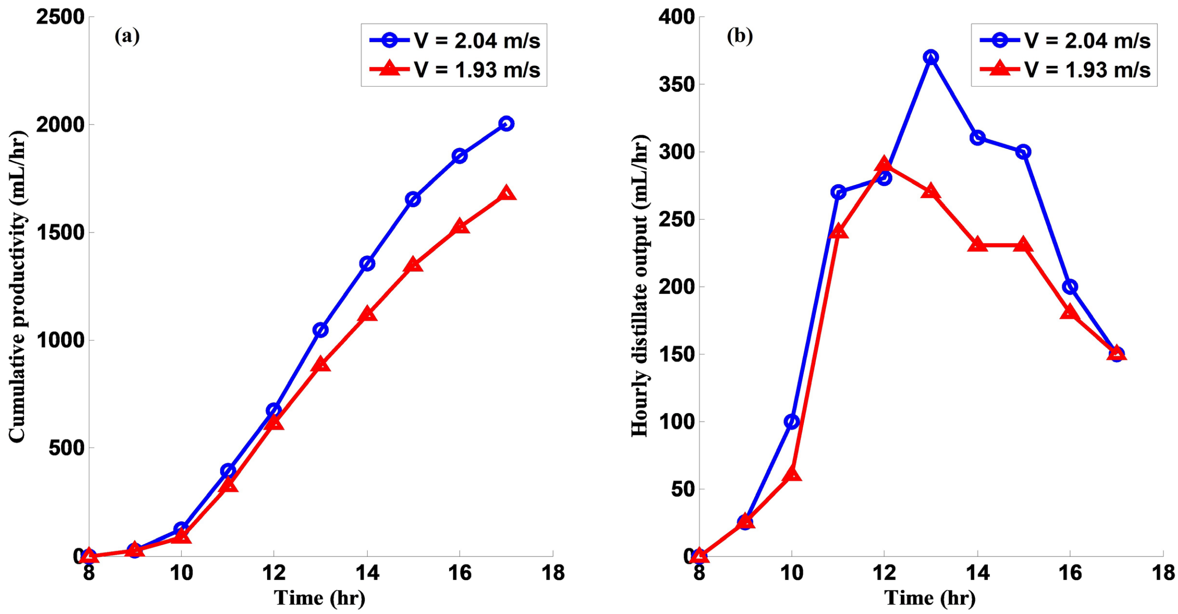

Figure 11. Variation of cumulative (a) and hourly distillate output (b) each hour with 6 mm glass cover thickness, 3 and 5 June 2021.

was occurred at the maximum cumulative water productivity of 2005 mL/day. As in **Figure 11(b)**, it is observed that the hourly distillate output curve with the highest average wind speed remains higher than that corresponding to the lowest average wind speed. On other hand, with the increase of average wind speed from 1.93 m/s to 2.04 m/s, the yield from solar still increases by 16.46%. We concluded that the average wind speed increase in relation to the yield.

Many authors conducted some research the effect of wind speed on the performance of solar still and found similar observations [4] and [15]. They concluded when the wind speed increase the convective heat transfer coefficient from glass cover to ambient air also increases, which, in turn, leads to a decrease in glass cover temperature. The difference between glass cover inner and water temperature increases which results in the daily production of solar still [39].

3.6. Affecting of Salinity Water on Productivity

The experiment was carried in single slope solar still with 6 mm of glass cover thickness, from 8:00a.m. to 5:00p.m. during 2 days, 3 and 7 June 2021, respectively. The effect of salinity on the solar still productivity is studied with brackish water and seawater which have a TDS value of 3670 mg/l and 31,000 mg/l, respectively, having 6 L of water in basin. It can be observed from **Figure 12** that the cumulative productivity obtained is 2125 ml and 2005 ml for basin water TDS value of 3670 mg/l and 31,000 mg/l. We notice with the increase TDS value from 3670 mg/l to 31,000 mg/l, water cumulative production from solar still reduces 5.65%. The results revealed that the cumulative productivity decreases when there is an increase of salinity. The reason for this is that evaporation rate of water decreases when there is an increase of salinity, which leads to a fall in

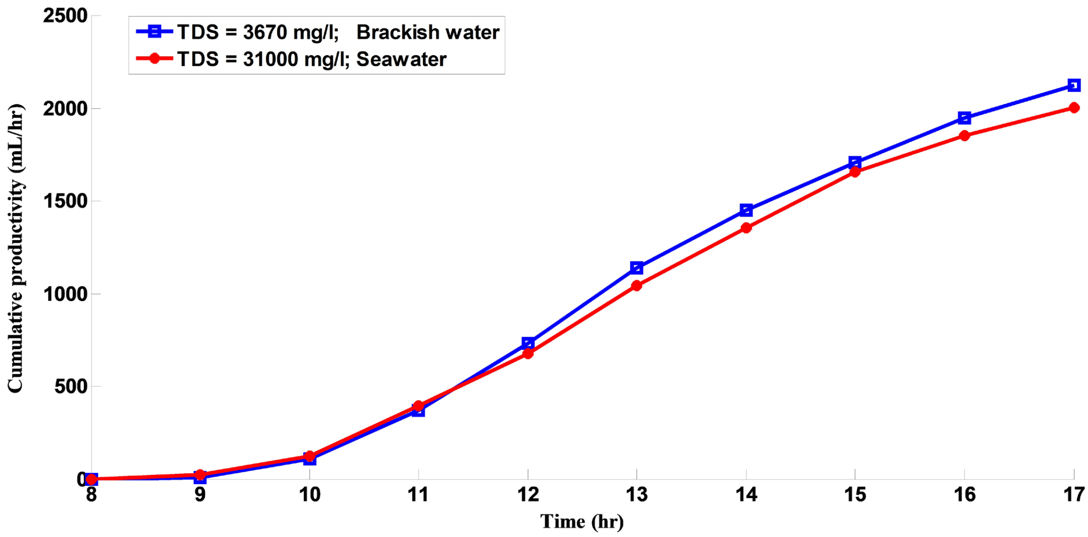

Figure 12. Variation of cumulative productivity each hour with different TDS of water used.

Table 2. Water quality parameters of product water from seawater and brackish water.

Samples	(TDS, mg/l)		(EC, µS/cm)		pH		Hw (mg/l $CaCO_3$)		Chloride (mg/l)	
	before	after	before	after	before	after	before	after	before	after
Seawater	31,000	61	59,900	0.12	8.36	4.46	4485	27.5	21,655	15.53
Brackish water	3670	27	7050	0.053	8.20	4.34	1745	30	2254.25	17.75
WHO standards	<600		<250		6.5 - 8.5		200		250	

Note: Electrical conductivity (EC); Total dissolved solids (TDS); Hardness water (Hw).

the distillate output. The results obtained are consistent with good with experimental studies carried out by [20] and [40]. The results obtained in this experiment showed that the salinity of the water has an effect on the water productivity.

3.7. Water Quality Analysis

The different water samples water used during the distillation with single slope solar still were tested. Table 2 shows that the distilled water quality before and after distillation seawater and brackish water. The parameters such as TDS, EC, Hardness water and chlorides is well widely within the desirable limits as prescribed by WHO standards for drinking water [41]. Furthermore, a good percentage (>98%) of removal was observed for four parameters such as TDS, EC, Hardness water and chloride. Similar results found by [25] [42] and [43].

The pH values for distillate water of both samples (Brackish water or seawater) were reduced to value average of 4.5. These values of pH of distilled waters are not within the WHO limits of drinking water (Table 2). According to the literature, many authors found that the pH of distilled waters is acid with different design of solar still [44] [45] and [46]. Flendrig *et al.* [45] and Gorjian *et al.* [46] explained that acidity of the distillate result from dissolution of carbon dioxide transforming into carbonic acid and hydronium ions.

4. Conclusions

In the present study, the effects of various parameters, such as solar radiation, glass cover thickness, basin water amount, salinity and wind speed, on the productivity of single slope solar still and water quality examination results are discussed. Following points are concluded in this work:

- The performance thermal increases in relation to solar radiation.
- The productivity of single slope solar still decreases when there is an increase in basin amount water. The maximum productivity was obtained from the smaller basin water amount. The dependence of distillate output on basin water amount is a strong function of the performance thermal in solar still (mainly water temperature in the basin).
- In addition, it is concluded that the distillate output production of solar still is inversely related to glass cover thickness and salinity of water amount.
- On other hand, it is obtained that when there is an increase of average wind speed from 1.93 to 2.04 m/s, the daily productivity increases by 16.46%.
- Single slope solar still can produce water quality which is within the acceptable range of the WHO for four parameters (TDS, EC, hardness water and chlorides).

The production of distillate from this single slope solar still is very encouraging. But this productivity requires to be compared, under the same climatic conditions, to the productivity of various designs of the solar still (such as double slope solar still, triangular solar still, hemispherical solar still, pyramid solar still, tubular solar stills, etc.).

However, the use of the solar still, especially for rural and coastal populations, offers an economically advantageous alternative while desalination of seawater in fresh water by producing good quality water.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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