Effect of water depth, Inlet water temperature, and fins on the productivity of a pyramid solar still – An experimental study

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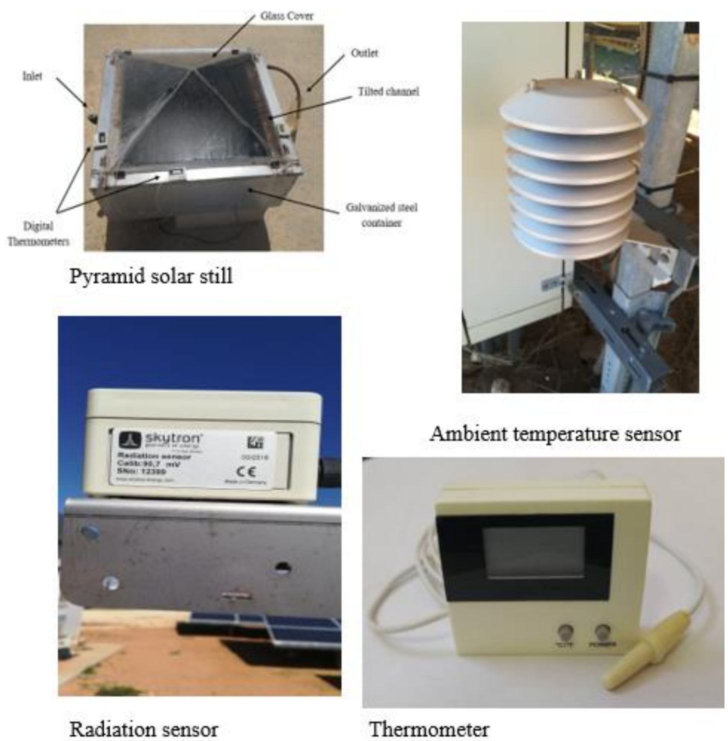
Key words: solar still, water depth, Inlet water temperature, fins, Pyramid, productivity, desalination, freshwater.

Abstract

Many approaches are using to improve the productivity of the pyramid solar still. Pyramid solar still provides a larger surface area than conventional types of solar still. In this research work, three sections have been evaluated. The first section has been studied by changing the water depth from 1 to 5 cm. In the second part of the experiment, increasing the inlet water temperature has been investigated, and finally, adding fins at the bottom of the still at certain inlet water depth has been achieved. The experimental results show that the still productivity could be influenced by the basin depth by up to 40.6% when varying water depth from 1 to 5 cm, The freshwater production from the pyramid solar still was 1230.5, 1045, 998, 901, and 731 ml for the water depth from 1 to 5 cm, respectively. Moreover, it was found that productivity increased by 7.5% when fins were used at the bottom of the pyramid solar still. In addition, the results showed that the still productivity could be influenced by varying inlet water temperature to 15.3% and 21.2% when varying the inlet water temperature from 30 C^o to 40 C^o and from 30 C^o to 50 C^o, respectively.

Graphical Abstract



Experimental Setup Devices

1- Introduction

Freshwater one of the most essential elements in the world and it's important to live. Production of freshwater is still a major problem in several world regions, especially in remote areas. In unsophisticated and sophisticated regions, millions of people capture water from unclear resources approximately, 70% of the world area is covered by water, from this percentage 97% is salty and unclean water founded in the sea and ocean. The percentage of freshwater available is about 3% of the total water in the world. Unfortunately, the distribution of freshwater reservoirs, worldwide, is irregular.

Desert regions (Jordan and all of Middle East regions) complain from difficult freshwater stress which dominated the weaker population. Freshwater reservoirs are limited and finished, yet the need to drinking water is increasing. Such an issue comes about a huge danger that will certainly result in worrying humanity, economic break down, and collapsing of living standards. These problems have drawn our interesting for the need to research and find other sources of freshwater.

Techniques for getting clear water such as: electro dialysis, multi-stage flash desalination, vapor compression, reverse osmosis, and many others are available. However, these options are known of their defects in terms of their need to resources of electric power for producing potable water and cost of installation and operation and maintenance. In addition, a water pipeline circulation system is not founded in coastal and remote areas, the ground network and transportation system are inefficient to carry a huge amount of clear water regularly from desalination plant areas to the consumers regions.

Among many, solar desalination of fresh water is emerging as an inescapable option, mainly in remote desert areas, because its low cost, maintenance and simplicity. Desert regions in North Africa and Middle East are famous of their high intensity of solar irradiation. This makes the direct exploiting of solar radiation for water treatment gives a promising Techniques for these regions.

Solar still is a device that is used to desalinate impure water like saline water and convert it to fresh water by using the solar energy as fuel. The concept behind the use of solar energy to convert the saline or brackish water to fresh water is quite simple. Water left in an open container in an area exposed to the sun will evaporate into the air. The role of the solar still is to capture this water vapor by condensing it onto a cool surface. For capturing and condensing the water vapor, a transparent surface such as glass is needed as it allows the sunlight to reach the water. Solar stills have got major advantages over other distillation systems as follows:

- Produces pure water.
- No prime movers required.
- Non-skilled operator required.
- The possibility of local manufacturing and maintenance.
- Low investment and can purify highly saline water (even seawater).

Moreover, solar still systems are categorized into two classes: passive and active systems. These categories are classified based on the source of energy supply. In the passive solar still systems, the solar energy is the only source of thermal energy. However, the active solar still systems use an additional thermal energy along with solar energy. This additional thermal energy might be obtained by using a solar collector (Badran 2005)[1], or any other source of waste thermal energy such as that from a power plant (Aybar 2007). Many researchers were interested in the sea water and brackish water desalination using solar energy. Till today, many experimental and theoretical studies are undertaken in order to modify the solar still using different configurations and improve its yield (Rubio-Cerda 2002). The study of many researchers undertaken in this context, indicate that the yield of the solar still depends on the different external and internal operating parameters and that the produced water quantity varies according to the type of the solar still.

Ahmed Al-Garni (2012) made an experiment to examine the effect of adding water heater device in the basin water of double slope solar still. The results inferred that the performance of still enhanced by about 370% when adding two water heaters each one has 0.5 kW capacities. A.E. Kabeel et al (2018) conducted a theoretical study to show the effect of using different type of organic and inorganic Phase Change materials (PCMs) on the performance of solar desalination. The results showed the higher productivity in organic PCM and inorganic PCM are A48 (type of PCM) and capric-palmatic respectively. Badran et al (2005)[2] tested the effect of connected conventional flat-water heater collector with solar desalination system using tap and saline water as a feed. The experimental results founded that the performance of proposed technique was increased by 231% comparing with conventional still in case of using tap water and 52% in case of using saline water. Voropoulos et al (2001) designed a single slope solar still system coupled with storage tank and flat plate collector. The experimental results founded that integrating solar desalination system with flat plate collector doubles the productivity value comparing with conventional still. Moreover, the performance of still enhances in the night due to increase temperature difference between water and glass cover of still. Voropoulos et al (2003) conducted an experiment to investigate the effect of integrated hot water storage tank with symmetric solar desalination system using heat exchanger. The results illustrated that the productivity of still increase in the daylight as water temperature increase and is shifted towards the night. Velmurugan et al (2008) conducted an attempt to investigate the effect of adding fins with different types of materials such as black rubber, sand, pebble and sponge between the fins. Their experimental results showed that the daily efficiency of Fin type still, Fin type still with black rubber, Fin type still with sand, Fin type still with pebble, Fin type still with sponge and Fin type still with sand sponge increased 60.2%, 65.1%, 63.4%, 64.1%, 66.4% and 69.1% respectively. Velmurugan et al (2008) studied the effect of integrated fins, wick and sponge on the performance of solar still. The results indicated that, the productivity of fins type, wick type and sponge type increased by 45.5%, 29.6% and 15.3% respectively. Nayi and Modi (2018) pointed out that the inlet water temperature has significant effect on the performance of solar still due to fact that the evaporative and convective heat transfer coefficient will be increased. Jani et al (2019) conducted an experiment to evaluate the effect of integrated circular and square cross-sectional hollow fins on the basin liner still at different water depth (10 mm, 20mm and 30mm). The experimental results showed that the maximum water productivity has been when using circular and square finned solar still at 10 mm water depth. Agrawal et al (2017) conducted a theoretical and experimental study to find the performance of solar still at different basin water depth ranging from 0.02 m to 0.01 m. Their experimental results indicated that the daily distillate output decreased with increase in basin water depth. The theoretical value of daily efficiency for 2 cm and 10 cm basin water depth was around 52.83% and 41.75%, respectively, and for the same basin water depth, experimental daily efficiency was around 41.49% and 32.42% respectively. Arunkumar et al (2012) evaluated the performance of seven solar still designs such as spherical solar still, pyramid solar still, hemispherical solar still, double basin glass solar still, concentrator coupled single slope solar still, tubular solar still and tubular solar still coupled with pyramid solar still on basin water temperature to enhance the productivity of still, the results showed that the compound parabolic concentrator-assisted tubular solar still came true the maximum water temperature and productivity. Salah Abdallah et al (2009) examined effect of three type of absorbing materials (coated metallic wiry sponges, uncoated metallic wiry sponges and black rocks respectively) on the productivity of solar still. The results indicated that the overall average gain of distilled water increased about 28%, 43% and 60% for coated metallic wiry sponges, uncoated metallic wiry sponges and black rocks respectively comparing with conventional one. Manokar et al (2019) conducted an experiment to investigate the performance of pyramid solar still at different water depth with and without insulation material. The experimental results showed that the distilled water without insulated material was about 3.27, 2.93, 2.26, and 1.59 kg/m^2 and with insulated material was about 3.72, 3.40, 2.70, and 2.08 kg/m^2 for water depth of 1, 2, 3, and 3.5 cm, respectively Kabeel et al (2019) tested the effect of tubular solar still (TSS) using various water depth (0.5, 1, 2 and 3 cm) on the performance of solar still. The test founded that the productivity of still reach to about 4.5 L/m^2 at 0.5cm water depth, while at 3 cm the daily productivity gave 3

L/m2. Rajamanickam et al (2012) conducted an experimental setup to investigate the effect of different water depth (0.01m, 0.025m, 0.05m and 0.075m) on the performance of single basin double slope (DSSS) and single slope solar still (SSSS) each one has the same area. The results showed that the maximum water output was 3.07 L/m^2 /day at 0.01m water depth in the DS solar still Phadatare et al (2007) made an attempt to study the effect of water depth (varied from 0.02 m to 0.12 m) on the productivity of single slope plastic solar still. The results showed that the maximum water output was 2.1 L/m^2 /day at 0.02m water depth.

It was noticed that there are absent experiments that study the effect of changing inlet water temperature on the productivity of pyramid solar still. Moreover, most of researches focused on single and double slope solar still to study effect of increasing depth of water and adding basin liner fins on the performance of pyramid solar still. Hence, this research came to explain the behavior of pyramid solar still when varying temperatures of inlet water (30 C^o, 40 C^o and 50 C^o) firstly. The inlet water has been heated by external source before starting experiment**.** Furthermore, it investigates the productivity of still by increasing water depth from 1 cm to 5 cm in the second part. The depth of water has been fixed through days of experiment. Finally, it evaluates the solar still performance by integrated five vertical fins with height, length and thickness 20, 600 and 2.5 mm at specific depth of water, respectively on the basin liner of pyramid solar still.

2- Experimental setup and procedure

The 3D diagram of the Pyramid Solar Still (PSS) is shown in Figure 1. The PSS consists of a glass cover, internal galvanized iron sheet, insulation, and external galvanized iron sheet. The glass cover is 6 mm thick; each glass plate of the glass cover is 60 cm wide, a height of 25 cm, and a slope angle of 30o. The 1.25 mm-thick internal galvanized iron sheets combined forming a closed box with a base area (absorber area) of 0.36 m^2, and a height of 30 cm. Furthermore, the 0.9 mm-thick external galvanized iron sheets combined forming the external surface with a base area of 0.49 m^2, and a height of 30 cm. Moreover, there is a 5 cm Polystyrene insulation between them. Moreover, five fins with height, length and thickness 20, 600 and 2.5 mm, respectively, were used to decrease the preheating time required for evaporating the still's basin water as shown in figure 2. Experiments were carried out from 8 am to 6 pm. The freshwater production by the PSS is collected at the inner surface of the condenser by attaching a small metal piece obstruction. The condensed water is collected every hour by using a flexible hose pipe and the water is transferred into the measuring jar. The thermocouples were used to measure basin, water and glass temperatures. Skytron temperature sensor that was used to measure the ambient temperature, silver color with rang 100^{o}C and ±0.5^{o}C accuracy. Skytron radiation sensor with rang 2000 W/m^2 and ±1W/m^2 accuracy was used to measure solar radiation.

3- Results and Discussion

The experiment was conducted during the period of the end of August to the first of September 2018 at Jordan University of Since and Technology (J.U.S.T). Irbid (Latitude 32.48, Longitude 35.98), Pyramid solar still was assembled and tested. Three parts of the experiments were carried out; the first part was performed by changing the water depth for basin water, the second part was performed by study the effect of increasing inlet water temperature on the performance of pyramid solar still. And the third part was performed by study the effect of fins on the performance of pyramid solar still.

3.1 Changing Water Depth

It has been experimentally investigated the effect of changing water depth on the solar still performance.

3.1.1 Solar radiation, water and ambient temperatures, and freshwater productivity

Figures 3 and 4 show the variation of solar radiation and temperature of the sunshine days during the experimental period. It can be seen that the change in solar radiation was insignificant through the experimental days. In addition, we noticed that the solar radiation increases with time to reach a maximum value between 1:00-2:00 PM. Also, we notice the same trend for ambient temperature which increase with time to reaches a maximum value between 3:00-4:00 PM.

Figures 5 (a), (b), (c), (d), and (e) show the basin water temperature, outer glass cover temperature, ambient temperature, and daily freshwater productivity for pyramid solar still with different water depths during experimental hours. The figures show that the pyramid solar still with the lower basin depth gives a higher daily freshwater productivity and operates at higher basin temperatures during sunshine hours (from 8 am to 2 pm) as shown also in figure 6. The reason behind could be explained in term of high thermal inertia of higher depth of basin water mass according to Agrawal et al (2017) and Phadatare et al (2007)

Figure 6 shows the variation of the basin water temperature of the pyramid solar still with different water depths from 1cm to 5 cm, the maximum basin water temperature was 72.3^{o}C; it was observed in the basin with 1cm water depth at 1:00 PM. On the other hand, the maximum basin water temperature with 5cm water was 57.1^{o}C at 2:00 PM. It is clearly observed that the basin water temperature increases significantly with a decrease in the depth of basin water during the period from 8 am to 2 pm while its decreases with an increased water depth after 2 pm. This is due to that as increasing water depth, the amount of inlet basin water will be increased, So that the water needs more time and more energy to increase its temperature (increase slowly) and it remains hot for long period after 3 pm (decrease slowly) due to amount of heat absorbed is increased over the daylight.

3.1.2 Accumulated Amount of Fresh Water Production

The variation of the hourly freshwater productivity of the pyramid solar still with different water depths from 1cm to 5cm by 1cm step are presented in figure 7. It was noticed that the maximum production of freshwater was 222 ml at a 1cm water depth at 1:00 PM while the maximum production of freshwater was 128 ml at a 5 cm depth at 3:00 PM. We notice that the pyramid solar still productivity decrease with increasing water depth, also we notice that the still productivity during sunset hour for higher depth more than lower depth due to the heat stored during the sunshine hours in the higher water depth.

Figure 8 shows the total amount of freshwater of the pyramid solar still with different water depths. We noticed that the maximum production of freshwater was 1230.5 ml at 1cm water depth, then 1045 ml for 2 cm to reach 731 ml for 5 cm water depth.

The previous figure illustrated that the total amount of freshwater production of the pyramid solar still is increased when the water layer depth in the basin is decreased.

3.2 Effect of Changing Inlet Water Temperature

Figure 9 shows the effect of changing inlet water temperature from 30 C^o to 50 C^o on solar still productivity. it is clearly shown that productivity still increases as inlet water temperature increases up to 14:00 pm, after that the productivity begins to be equal. The reason behind that can be explained in terms of water heat capacity. As increase inlet water temperature, water heat capacity increase, hence the productivity of still increase. But after 14:00 pm, Water temperature becomes equal for different inlet water temperature. Therefore, productivity remains close to each other.

3.3 Effect of Fins

As fins were used at the bottom of the still, the absorber plate can absorb more solar radiation due to the increase in exposure area and preheating time for the basin water decreased. Thus, productivity increased. It was found that productivity increased by 7.5% when fins were used at the bottom of the pyramid solar still. As shown in Figure 10.

Conclusion

The pyramid solar still was designed and constructed to produce distilled water by changing water depth inside pyramid solar still and varying inlet water temperature under the weather conditions of Jordan. In addition, the present study was designed to determine the effect of fins on the amount of distilled water. The results of this study show that:

- increasing the water depth causes to decreases the productivity of the pyramid solar still.
- The daily productivity of the pyramid solar still was measured at five different depths, and the results show that:

1- The maximum productivity of the pyramid solar still was at 1cm depth, and its value was 1230.5 ml.

2- The minimum productivity of the pyramid solar still was at 5cm depth, and its value was 431 ml.

- The results showed that the still productivity could be influenced by depth variation to 40.6% of water depth ranging from 1 to 5 cm.
- From the experimental study, it is found that the varying inlet water temperature increases the productivity by 15.3% and 21.2% when varying the inlet water temperature from 30 C^{o} to 40 C^{o} and from 30 C^{o} to 50 C^{o}, respectively.
- Experimental results showed that the average daily production was higher when fins were used in pyramid still by 7.5%.

Conflict of Interest

The authors declare that they have no conflict of interest.

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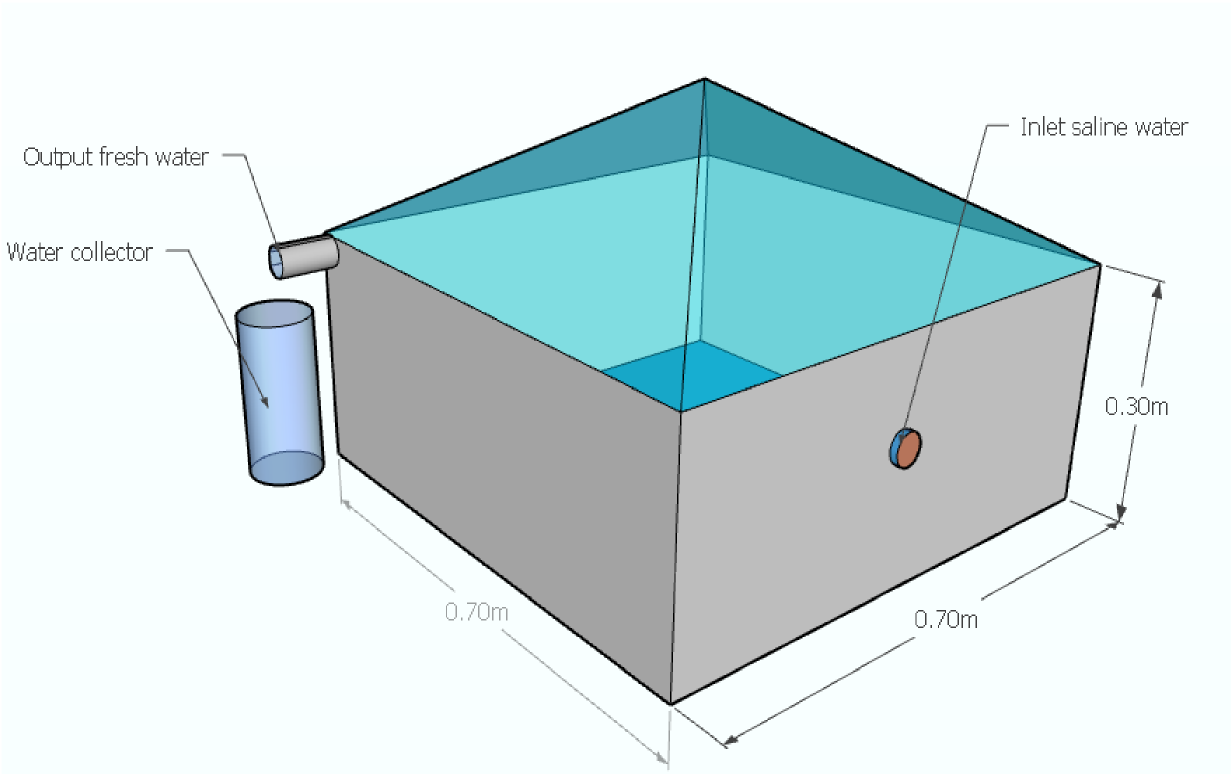
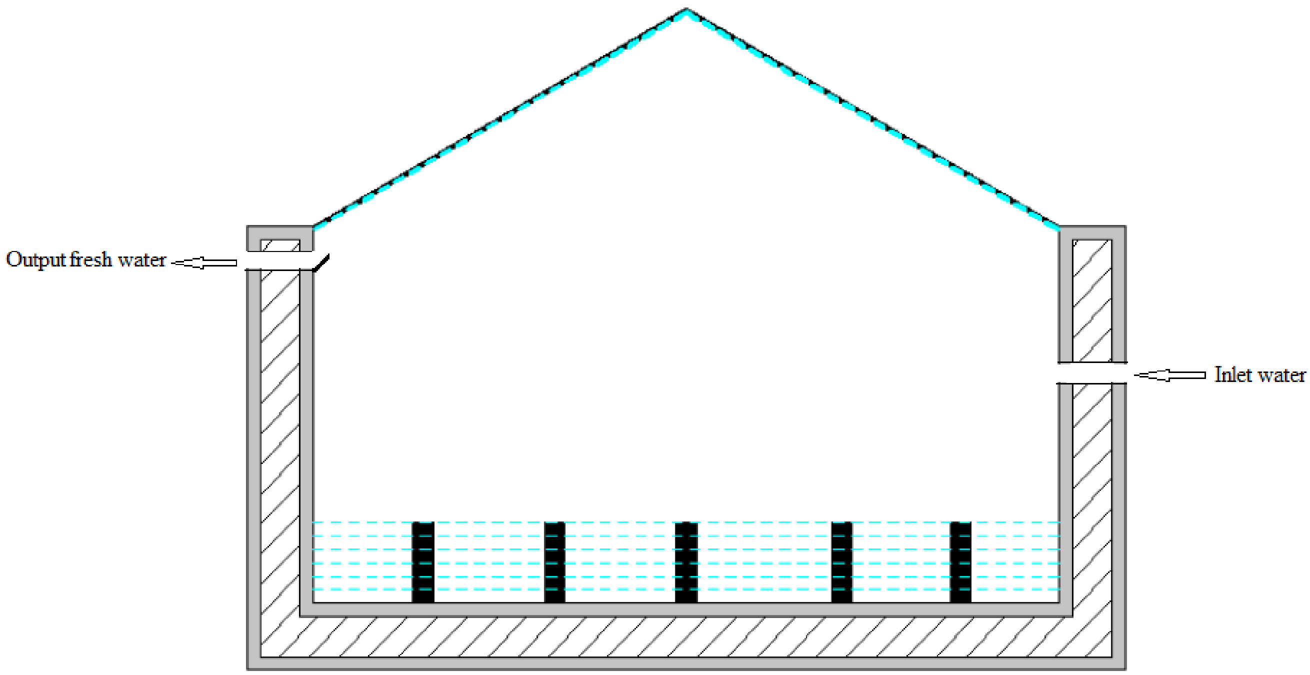
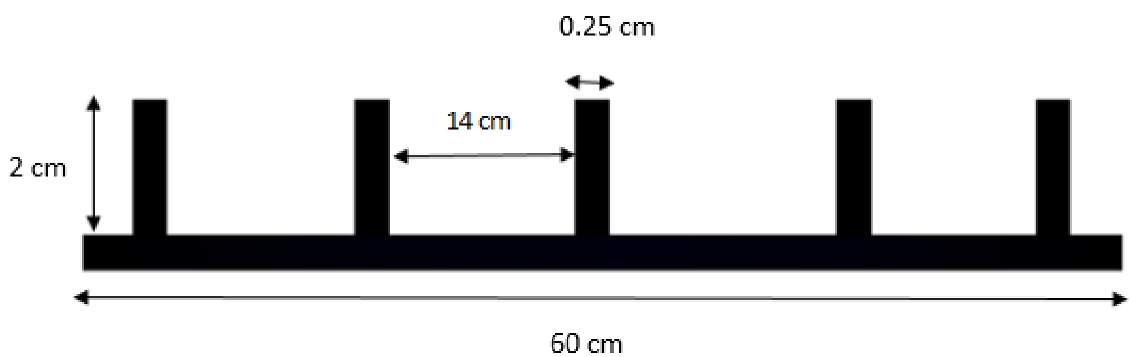


Figure 1: Pyramid solar still that used in the experiment



(a)



(b)

Figure 2: (a) A schematic diagram for pyramid solar still with fins in the basin (b) A detailed dimension of the fins.

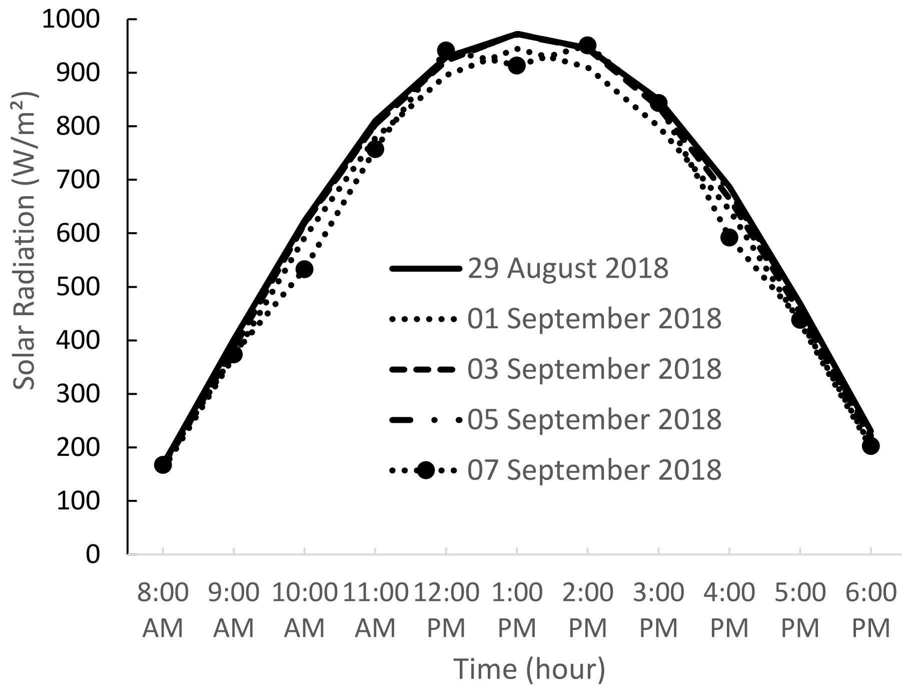


Figure 3: Variation of solar radiation during experimental days.

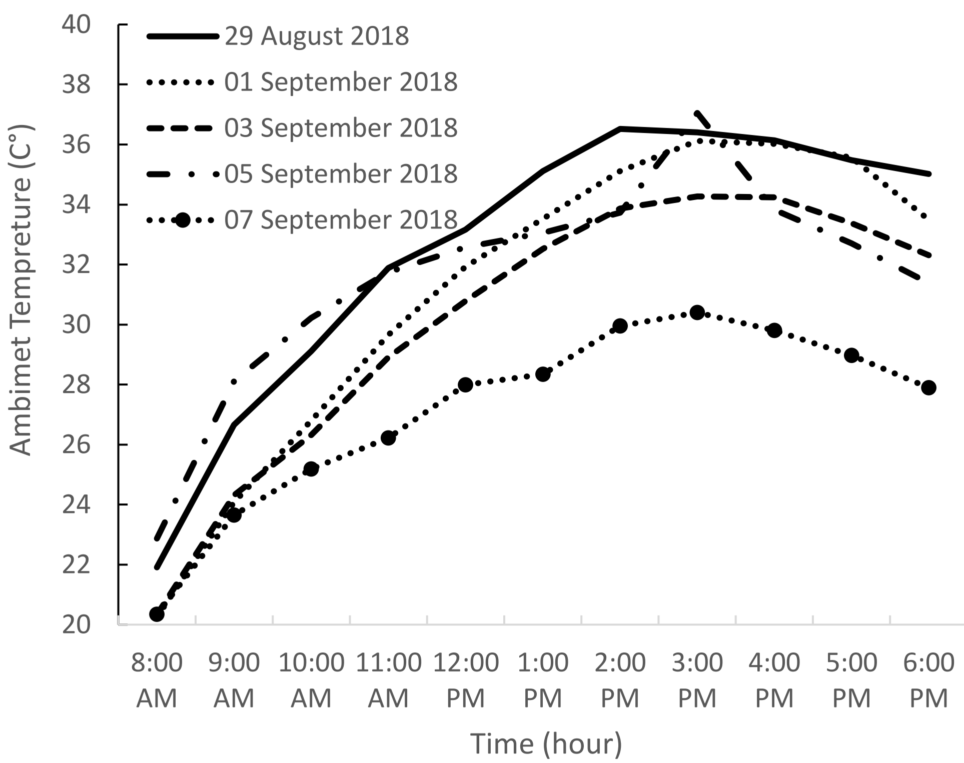
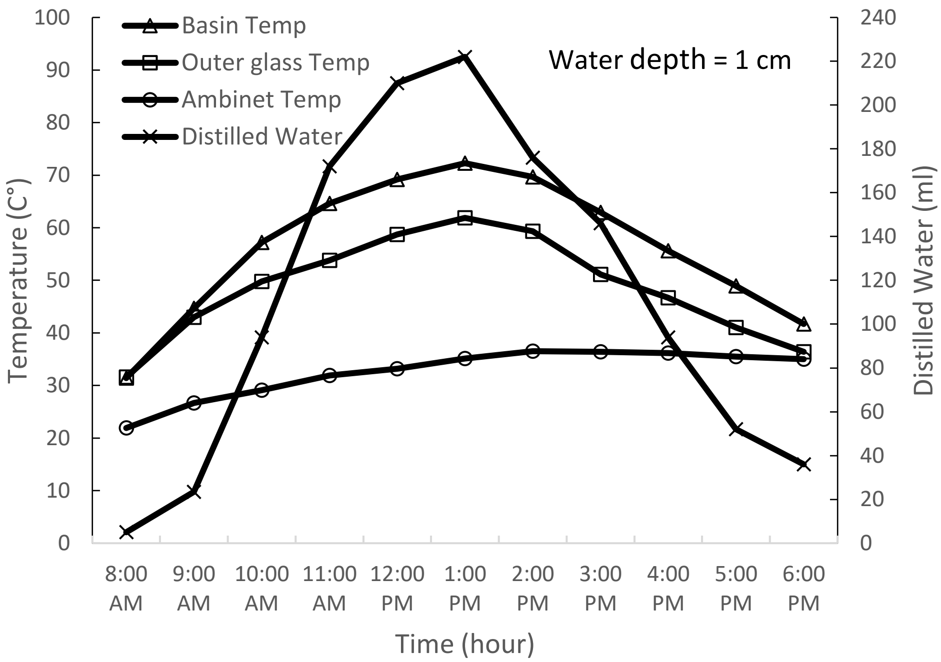
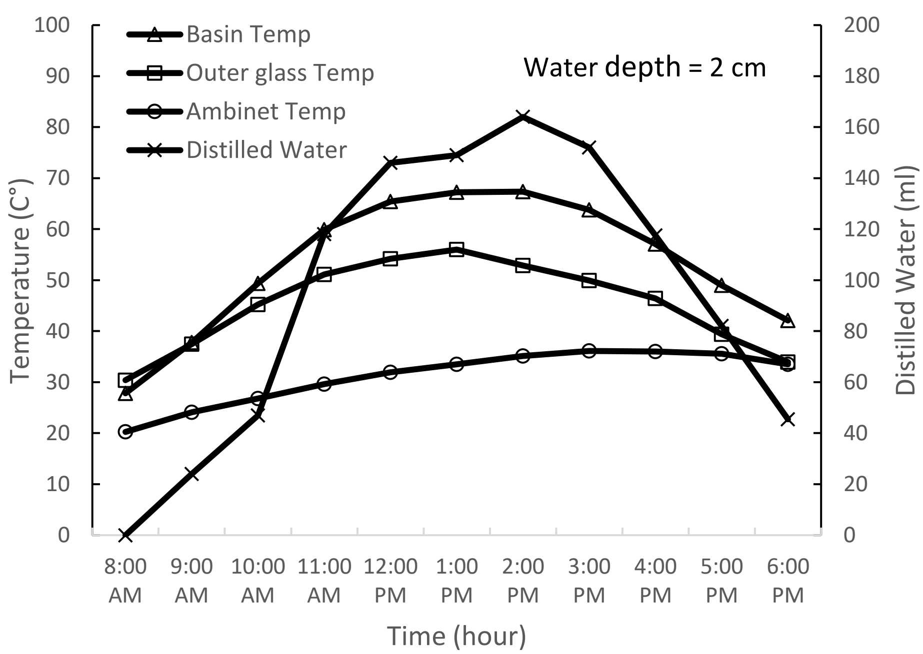


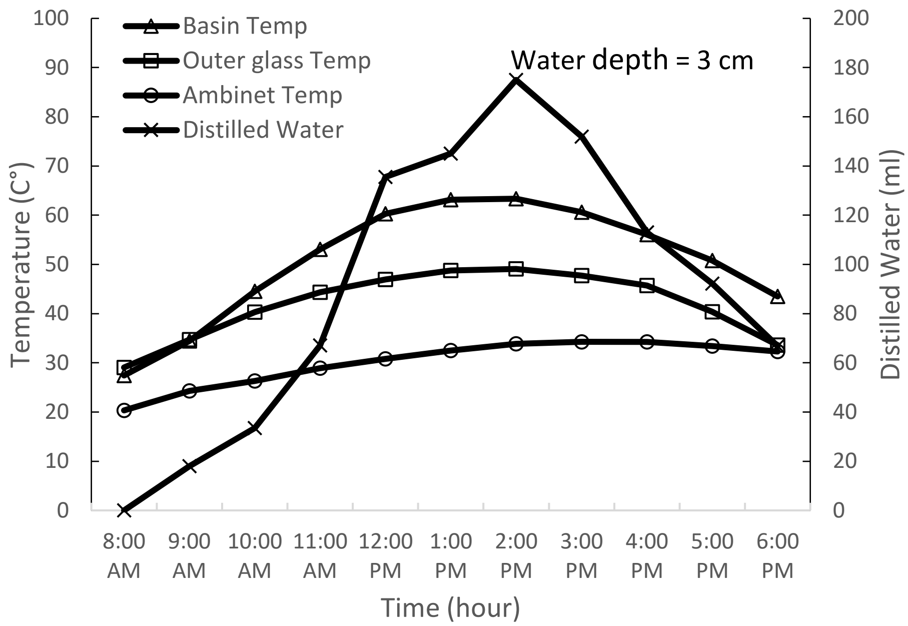
Figure 4: Variation of ambient temperature during experimental days.


Basin Temp
Outer glass Temp
Ambinet Temp
Distilled Water
Water depth = 1 cm
Temperature (C°)
Distilled Water (ml)
Time (hour)
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM

(a)


Basin Temp
Outer glass Temp
Ambinet Temp
Distilled Water
Water depth = 2 cm
Temperature (C°)
Distilled Water (ml)
Time (hour)
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM

(b)


Basin Temp
Outer glass Temp
Ambinet Temp
Distilled Water
Water depth = 3 cm
Temperature (C°)
Distilled Water (ml)
Time (hour)
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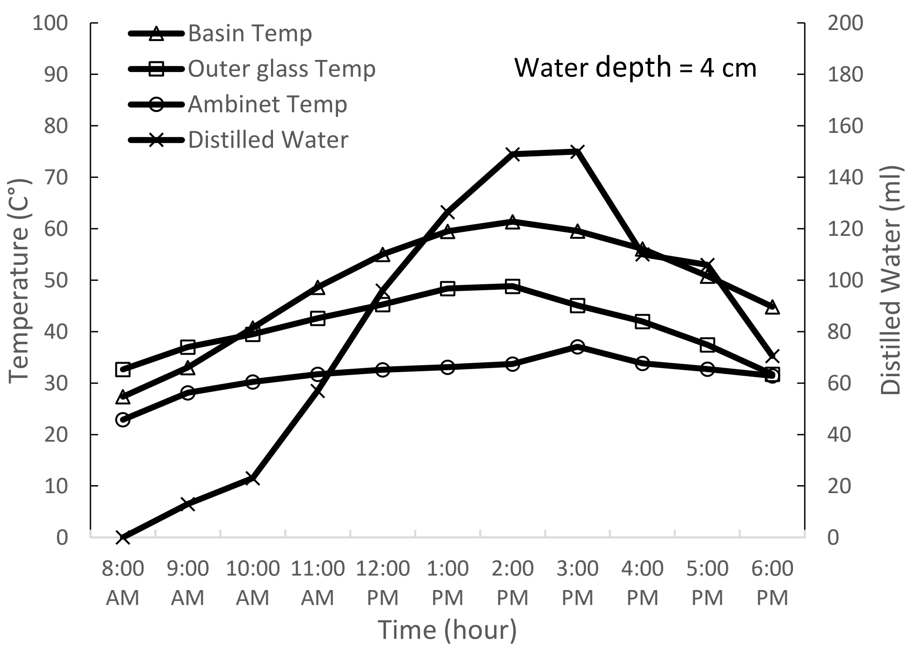
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM

(c)


Basin Temp
Outer glass Temp
Ambinet Temp
Distilled Water
Water depth = 4 cm
Temperature (C°)
Distilled Water (ml)
Time (hour)
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9:00 AM
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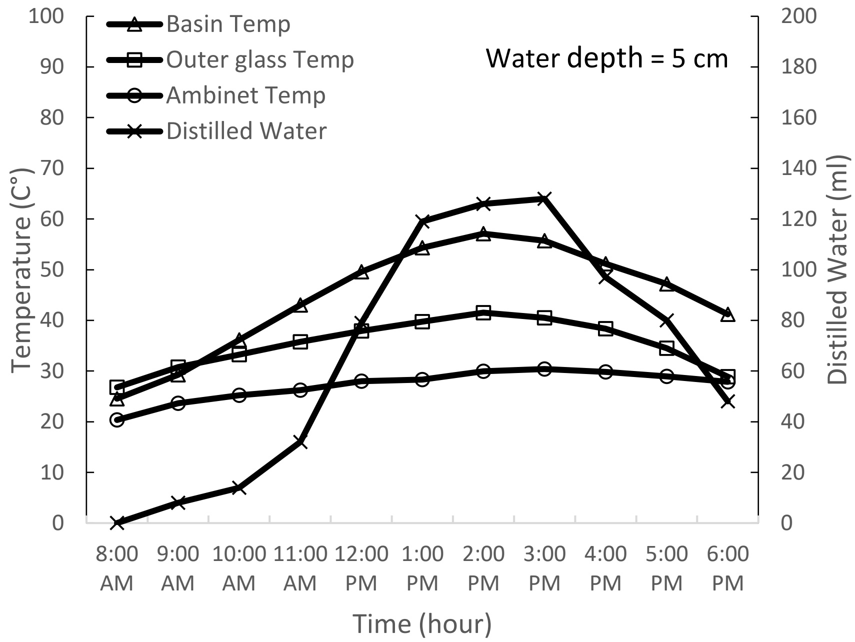
3:00 PM
4:00 PM
5:00 PM
6:00 PM

(d)



(e)

Figure 5: Variation of basin water temperature, outer glass cover temperature, ambient temperature, and daily freshwater productivity during experimental hours.

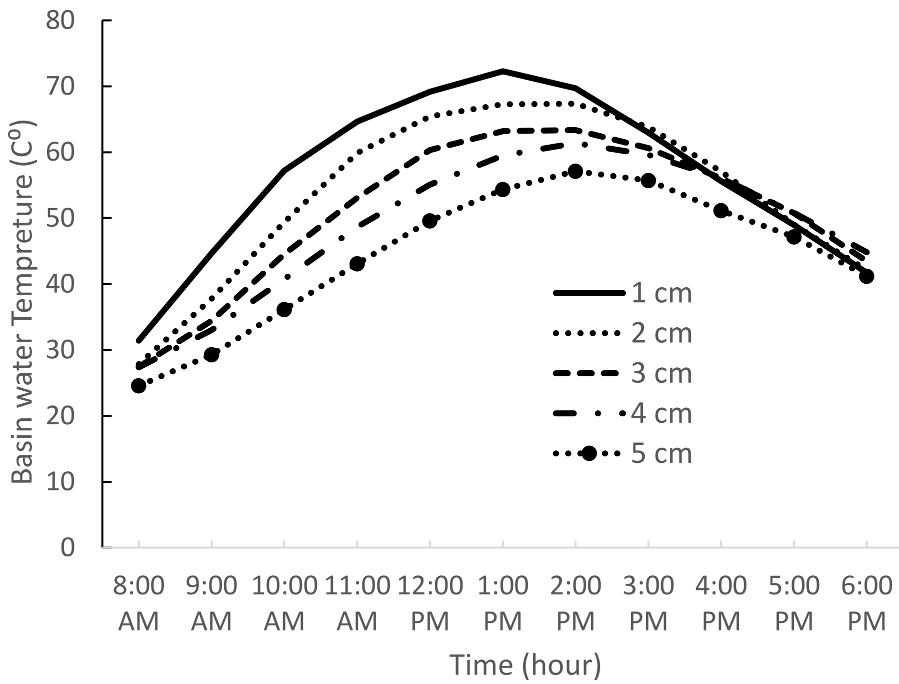


Figure 6: Variation of basin water temperature during experimental hours for different water depths.

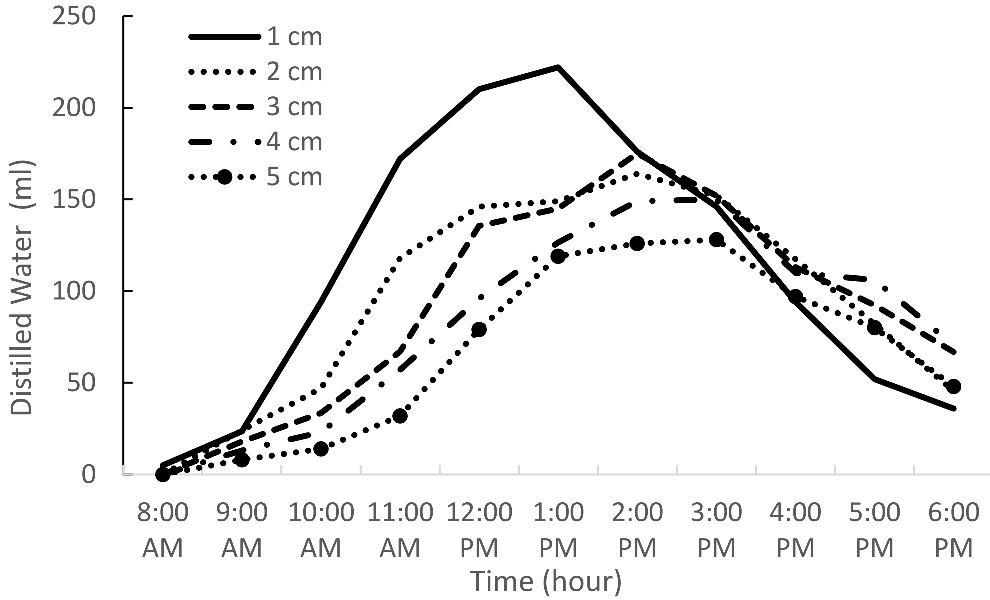


Figure 7: Variation of hourly freshwater productivity for pyramid solar still with different water depths

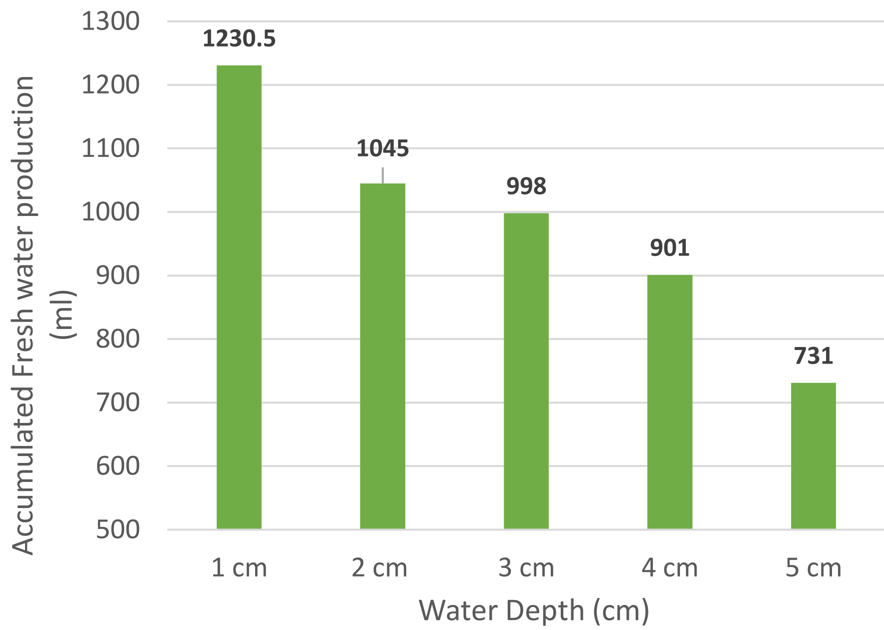


Figure 8: Total amount of fresh water for pyramid solar still with different water depths

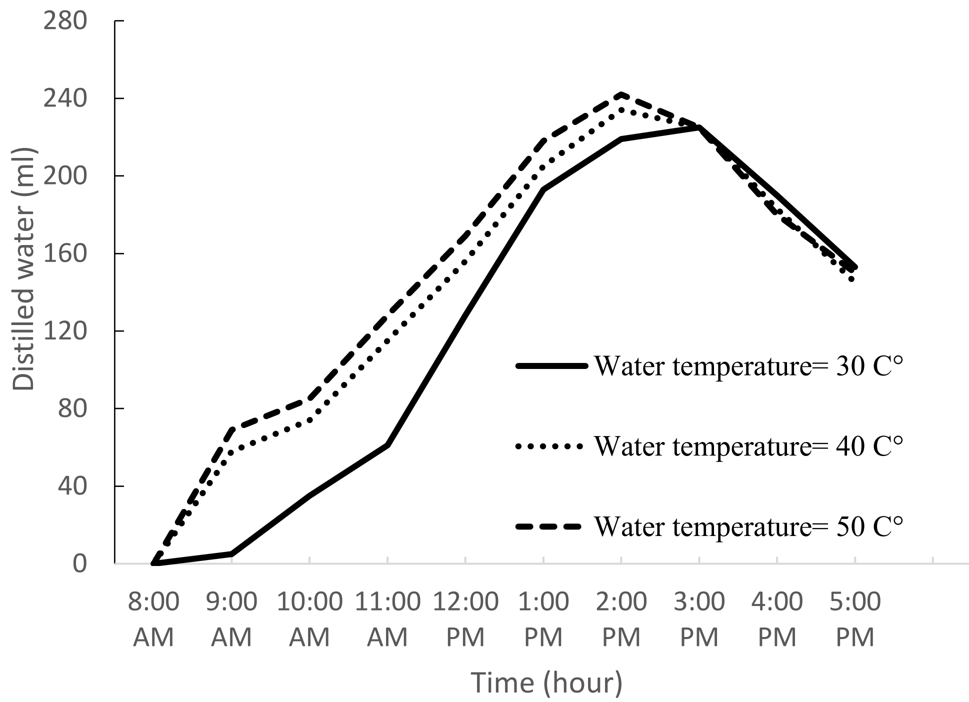


Figure 9: The effect of changing inlet water temperature from 30 C^{o} to 50 C^{o} on solar still productivity.

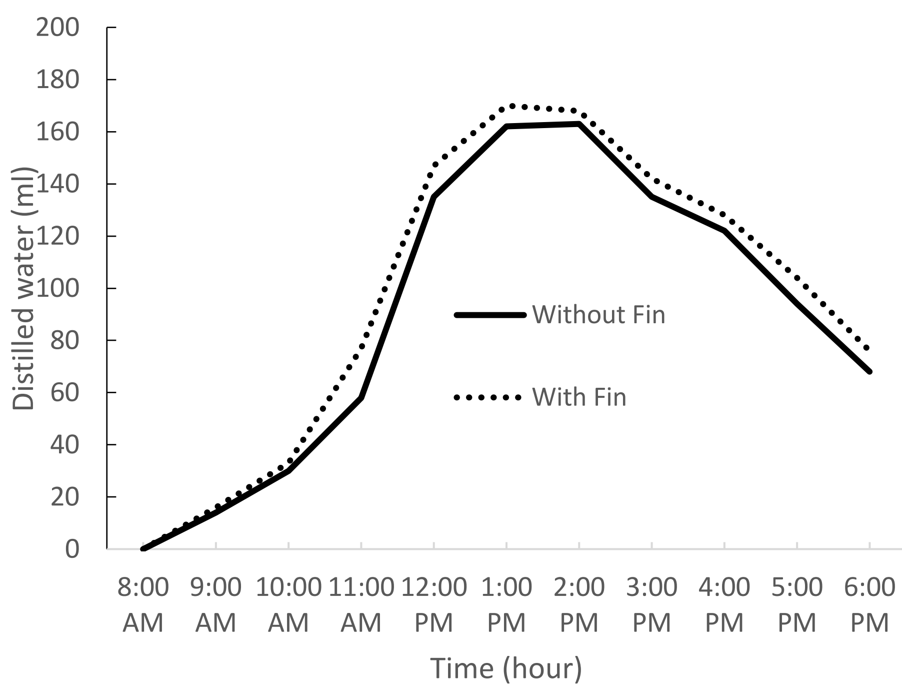


Figure 10: Effect of fins on productivity in the pyramid solar still.