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Experimental Research on Improving the Performance of Solar Still by Changing the Shape of Base

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Abstract. Improving the productivity of solar distillers is of great importance because of its dependence on solar energy, which is available to all, environmentally friendly, free of pollutants and at a low cost. An experimental study of more than one solar distiller at one time was carried out in order to find out the effect of changing the shape of the base of the distiller on the amount of fresh water produced by the solar distiller. The experiment was conducted in Najaf (32.0107º N, 44.3265º E), Iraq. Two forms of the base were used, the square-shaped base solar still (SSS) and the all-new pentagonal base solar still (PSS). The results showed that the productivity of the new pentagonal base solar distiller is higher than that of the conventional solar distiller. As the rate of increase in daily production at a water height of 1 cm for PSS1 increased by 30.952% and 14.285% for PSS2.

Introduction

Due to the salinity of the world's oceans and seas, pure water is scarce. As more than two-thirds of our planet is covered in water, but the majority of this water is saline seas and oceans, only 0.014% of the total water on Earth is drinkable. [1]. So, there is a pressing need to clean water and get water that can be used for people, industry, and other things.

The development that takes place annually in all parts of the earth in terms of industry, agriculture, increase in population density in addition to the environmental pollution that occurs and industrial waste in rivers led to an increase in the shortage of fresh water suitable for use and the urgent need appeared to obtain fresh water suitable for drinking, agriculture and industry.

Solar stills are characterized by the simplicity of their installation and components, their cheapness, and their freedom from environmental pollution, but one of their most important problems and negatives is their low productivity of distilled water, in addition to the fact that they require large areas [2], so the research aims to increase productivity in the least area possible.

The working principle of solar stills is very simple, they work in the same principle as rain formation. The working principle is evaporation and condensation, the water inside solar still at a certain height.

Many experimental and theoretical studies have been conducted by many scientists and researchers on solar distillates in order to develop its work and increase its efficiency and production of fresh water. Mohammed and Hashim [3] were able to increase the productivity of the solar still by using a

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black cloth made of cotton and also a reflective mirror, as the cloth was used to cover the base of the solar still. The reflector was used externally to increase the solar rays falling on the base of the solar still. It was found that this research increased the efficiency of the solar still by 38.2% . Badran [4] carried out an experimental study where he painted the solar still basin with asphalt and black paint and obtained an increase in the productivity of fresh water by 29%. Manokar et al, [5] made experimental study to find out the effect of thermal insulation on the rate of water production by the solar still, where it was found that the use of insulator leads to an increase in the amount of fresh water produced daily, as the production increased by 28.5%. Aljubouri [6], did an experimental research to find out the effect of changing the angle of inclination of the glass cover and the effect of changing the height of the water inside solar still on its productivity, the result of this practical research was that the highest productivity of the solar distiller was obtained at a height of 1 cm, an angle of inclination of 20 degrees. Ramanathan et al, [7] made an experimental study on the conventional solar still, where they modified it by adding a flat mica plate to the solar still basin in order to increase its efficiency by increasing the water evaporation rate inside the solar still. The result of this research was to obtain a higher productivity by 25%. Sathyamurthy et al, [8] carried out an experimental study to find out the effect of adding cubic boxes filled with sand and these boxes are placed inside the solar still basin. These boxes act as a heat storage medium, and the result of this research was that the productivity of the solar still increased by 145% compared to the ordinary solar still. Al-Madhhachi and Smaisim, [9] studied an experimental and theoretical study of a pyramid solar distiller with a square-shaped base and found that the productivity of the distiller is 60% higher compared to the normal solar distiller, where the average daily production was 2.2 liters per square meter. Abdullah et al, [10] conducted an experimental study to know the performance and productivity of rotating-wick solar distiller compared with conventional solar distiller and the results showed that the productivity of rotating-wick solar distiller has increased by 300% compared with conventional solar distiller. Ayoub et al, [11] did an experimental study by comparing two solar distillers, one of which contains a rotating drum used to circulate water inside the solar distiller slowly, and the results were an increase in productivity by 200% per day compared to a solar distiller free of a rotating drum. Abdullah and Badran [12], carried out an experimental study to improve the performance of solar distillers using a solar ray tracking device, which is used to move solar distillers with the movement of solar rays, and the result of this experimental research was to increase the productivity of solar distillates by 22%. Abdullah et al, [13] did a practical study to know the effect of adding absorbent materials on the productivity of solar distiller, where they used black painted metal sponge, unpainted metal sponge and black rocks, and the result of the research was to increase the productivity of solar distilled water by 28% when using painted metal sponge, by 43% when using uncoated metal sponge, and by 60% when using black rocks. Ismail [14] carried out an experimental study by manufacturing a transportable hemispherical solar distiller, and the production rate of solar distiller of water reached 33% during the day with a production quantity ranging between 2.8-5.7 l/m². Abdullah [15] did an experimental study where he used a stepped solar distiller and added to it a solar air heater used to pass hot air under the base of the solar distiller to heat the water inside the distiller, and the productivity of the stepped solar distiller was 112% compared to the conventional solar distiller. Chen et al, [16] carried out an experimental and numerical study using a floating solar distiller where the glass and cellulose fabric are the materials used in condensation and evaporation respectively, and the maximum productivity of distilled water during the day was 1.5 kg / m². Abdullah et al, [17] have studied an experimental and theoretical study by comparing two distillers, one of which is the conventional distiller and the other is a modified distiller, which was modified by adding sheets on the inner sides of the solar distiller, which increases the area of the inner surface that collects solar radiation, and then internal and external mirrors were added to the modified solar

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distiller, and the experiment was done at different water heights the results of this research were that the productivity of the modified solar distiller without mirrors is 1.5 times more than the conventional solar distiller and with the presence of mirrors, the productivity of the modified solar distiller increased by 58% of the productivity of the conventional solar distiller. Mohammed [18] did an experimental study on a stepped solar distiller, reflective mirrors were added to the inner surface of the solar distiller, and the efficiency of this solar distiller in producing distilled water ranged between 40.6% and 75%. Khare et al, [19] conducted an experimental study to improve the performance of a gradient distiller by adding multiple wicks to the solar distiller, and the productivity was increased by 20.5% compared to the solar distiller without wicks.

There are many parameters that effect on the performance of the solar still and the amount of water it produces. These factors are the area of the solar still, height of the water inside the solar still, shape of the base of the solar still, the location of the solar still, climate condition, temperatures, type of solar still active or passive, angle of inclination of the cover glass, type of material from which the solar distiller is made, and other influencing factors [20].

The aim of this research is to improve and know the effect of changing the shape of the base from quadrilateral to pentagonal on the efficiency of solar distiller in producing fresh water and at a variable height of water inside the distiller.

Nomenclature		
Symbols	**Description**	Units
A	Surface area	m^2
H	Enthalpy	J/k.kg
I	Solar Intensity	kWh/m^2
T	Temperature	C
K	Thermal Conductivity	W/m.K
L	Length	m
$\dot{m}$	Water Production	kg/s
Q	Heat Transfer	W
T	Time	s

System description

The shape of solar distillers were designed and drawn in the AutoCAD program, where a new shape was designed for the solar distillers and compared with the conventional solar still. The new design is to change the shape of the base of the solar distiller from the square shape (SS) to the pentagonal shape (PS) in order to study the effect of the base shape on efficiency of the solar distiller in the production of fresh water.

Conventional solar still it is represented by single-slop solar still with a square base solar still (SSS), the front side is 10 cm high, the back side is 50 cm high, and the base area is 2500 cm^2 it is the first model of the experiment as shown in Fig. 1. The second model its pentagonal base solar still (PSS1), pentagonal base is equilateral the length of the side of the base is 38.12 cm, the base area it is 2500 cm^2 the height of the front side of the solar still is 10 cm, and the height of the rear edge of the solar still is 50 cm as shown in Fig. 2. As for the third model (PSS2), it also has a pentagonal base and the same dimensions as the base of the second model, but it differs from it in that the back side is 50 cm high and front edge is 10 cm high as shown in Fig. 2.

Each solar distiller was made from aluminum material and thermally insulated by wood 1.5 cm thickness and foam material, solar still was placing inside an open wooden box from the top and using foam material as a thermal insulator as well, it was placed between the wooden box and the solar distiller, and a glass cover of 5 mm thickness was used.

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As for the glass cover area for each solar distiller, it is equal to 3100 cm², 3147.705 cm² and 3126.418 cm² for each of SSS, PSS1 and PSS2 respectively.

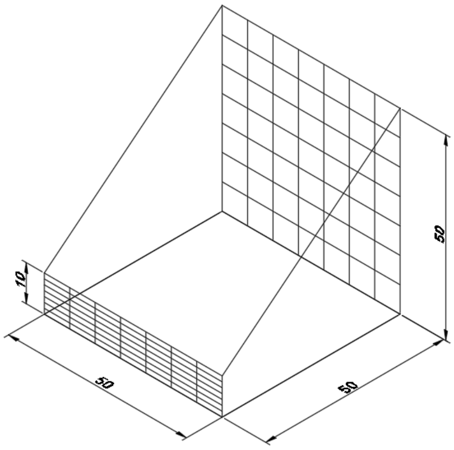

Figure 1: Square solar still (SSS)

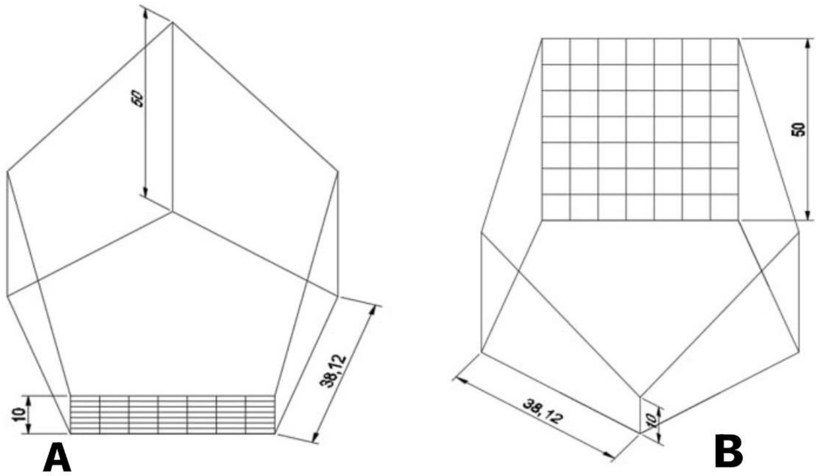

Figure 2: Pentagonal solar still (PSS), a) PSS1 and b) PSS2

Theoretical analysis

According to theoretical calculations, the exterior glass surface's energy balance is as follows:

$$\frac{Kg}{Lg}\,(Tgin - Tgout) = h_2\,(Tgout - Ta)\ldots\ldots\ldots.[9] \qquad (1)$$

The inside and outside glass temperatures are denoted as Tgin and Tgout, respectively. Kg represents the thermal conductivity of the material for glass material, while Lg represents the length of the glass.

The equilibrium of the energy within the internal surface for the glass is:

$$h_1\,(Tw - Tgin) = \frac{Kg}{Lg}\,(Tgin - Tgout)\ldots\ldots\ldots.[9] \qquad (2)$$

By combining equations (1) and (2), we can derive the equation for Tgout:

$$Tgout = \frac{\frac{Kg}{Lg}\times Tgin + h_2 Ta}{h^2 + \frac{Kg}{LG}}\ldots\ldots\ldots.[9] \qquad (3)$$

By combining equations (3) and (2), we can derive the equation for Tgin:

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$$Tgin = \frac{h_1\,Tw + Ugout\,Ta}{Ugout + h_1} \qquad (4)$$ ....[9]

The solar still's typical thermal efficiency is:

$$\eta = \frac{\dot{m}h_{fg}}{IA_{basin}} \qquad (5)$$ ....[9]

The quantity of water produced by the solar still:

$$q_t = \dot{m}\,L_v \qquad (6)$$ ....[20]

To find the amount of heat transferred by conduction through the glass, the following equation is used:

$$Q = -Kg\,\frac{Tgout - Tgin}{L} \qquad (7)$$

In the given context, the symbol " η " represents the thermal efficiency for the solar still, "$\dot{m}$ " denotes the rate at which water is produced in kg/s, "h_{fg}" represents the latent heat of water in kj/kg, "I" signifies the average daily intensity in w/m² of solar radiation on the basin, "Q" denotes the heat transferred.

Experimental part and measurements

The experiment was conducted and measurements were taken in Iraq, Najaf (32.0107º N, 44.3265º E), On January 7th, 8th and 9th, 2023. three water heights, 1 cm, 3 cm and 5 cm, were used to find out which is better for production distilled water, K-type thermocouples were used to measure temperatures, water temperatures (Tw) and water vapor temperatures (Tv) were measured inside solar distillers, as well as measuring the temperatures of the inner and outer glass (Tgin, Tgout) of each solar distiller, and also the ambient air temperatures (Ta) were measured, Data logger was used to save and show temperatures.

The amount of water produced by the solar distillation process was measured by solar distillers by a volume measurement cylinder, as for the water used in the experimental research, it is the water of Al-Kufa River, which needs to be desalinated because it contains many impurities, the readings were taken on the 7th, 8th and 9th of January, 2023 and from 9:00 to 16:00 as the water height on the first day was 1 cm and on the second day it was 3 cm and on third day it was 5 cm. The figure below shows the system that was used in the experiment, which includes all the devices and materials that were mentioned previously.

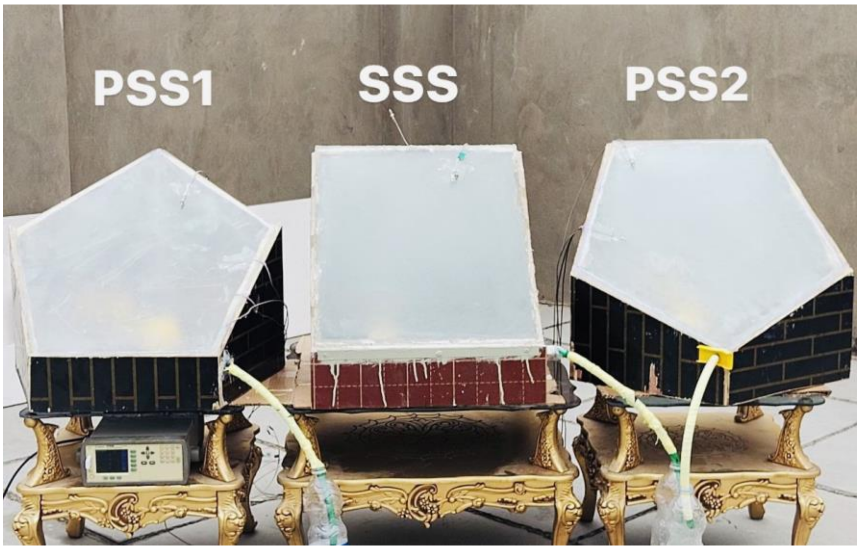

Figure 3: Solar stills system

Results and discussion

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On January 7th, the experiment was carried out on the three solar distillers under the same conditions and at a water height of 1 cm, meaning that the amount of water was equivalent to 2.5 l, and the amount of distilled water produced by each distiller was equal to 210 ml, 275 ml and 240 ml for SSS, PSS1 and PSS2 respectively. Fig. 4, shows the temperature difference for each of the three solar distillers on January 7th, and from observing the difference in temperature, the highest difference between (Tv) and (Tgout) is in PSS1 and after it in PSS2 and the smallest difference in SSS. As the difference between (Tv) and (Tgout) of the solar distiller increases, the rate of vapor condensation on the inner surface of the glass increases and thus the production of distilled water increases. The increase in (Tw) and (Tv) inside the solar distiller is due to the increase in the amount of solar radiation received by the solar distiller, meaning that the solar distiller that receives the most amount of solar radiation is the most productive. From the calculation of the area of each glass cover for all solar distillers, the area of the glass cover of SSS is 3100 cm² while the area of the glass cover of PSS1 and PSS2 is 3147.705 cm² and 3126.418 cm² respectively. Solar distillers with a larger glass cover are more likely to receive solar radiation and therefore have more distilled water productivity, which explains why PSS1 has higher productivity than other distillates. As for PSS2, its productivity of distilled water is higher than SSS and less than PSS1, because the difference between (Tv) in it and (Tgout) are higher than what it is in SSS and less in PSS1, due to the area of the glass cover, which is larger than the area of the glass cover of SSS and less than the area of the glass cover of PSS1, and therefore it is the second in terms of receiving solar radiation and producing water. As for the percentage of increase in daily production (DPR), it can be calculated through the following equation [21]:

$$DPR\% = \frac{PSS\ Production - SSS\ Production}{SSS\ Production} \quad (8)$$

Fig. 5, shows the percentage of daily production per solar distiller on the days of the experiment, and by observing Fig. 5, the highest increase in daily production is for PSS1 on January 7th and by 30.952%.

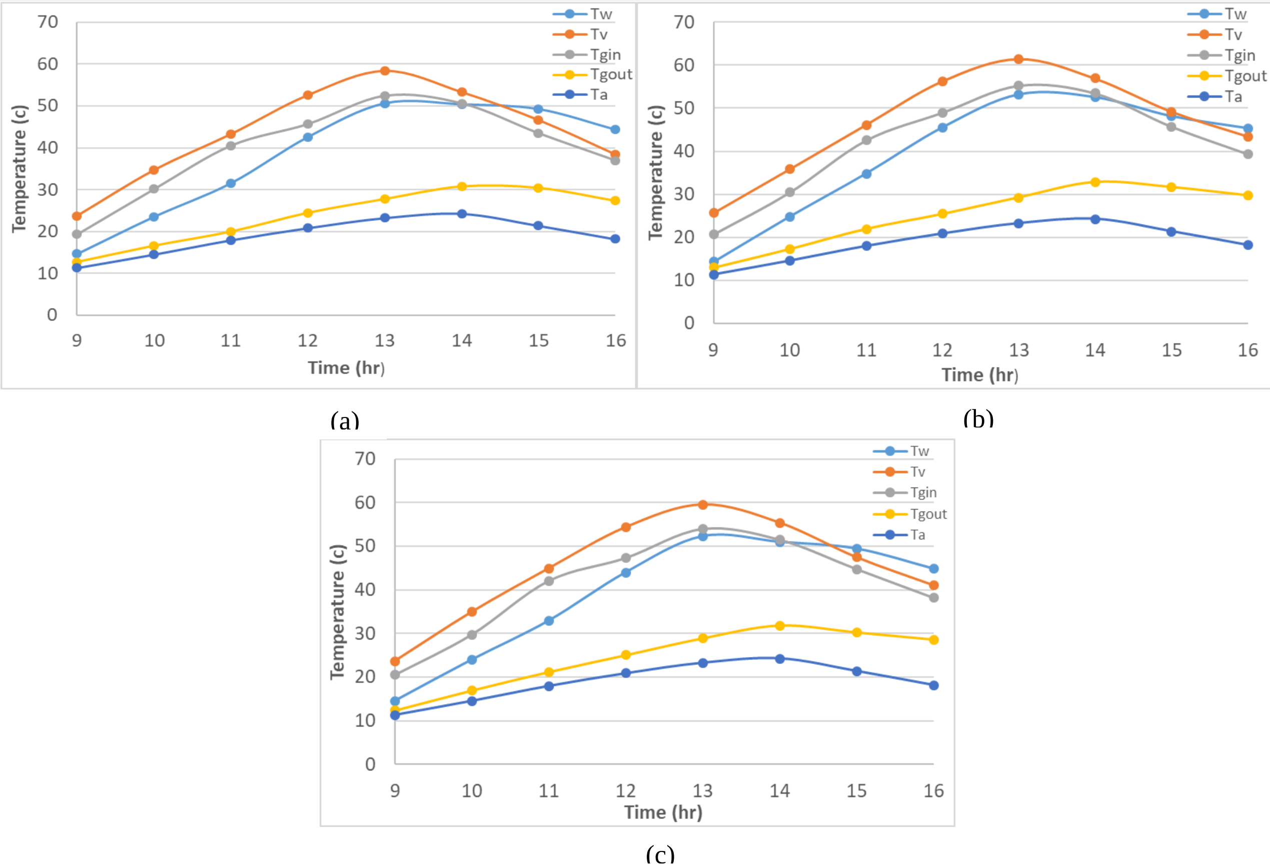


Figure 4: Temperature change of solar stills in January 7th, a) SSS, b) PSS1, c) PSS2

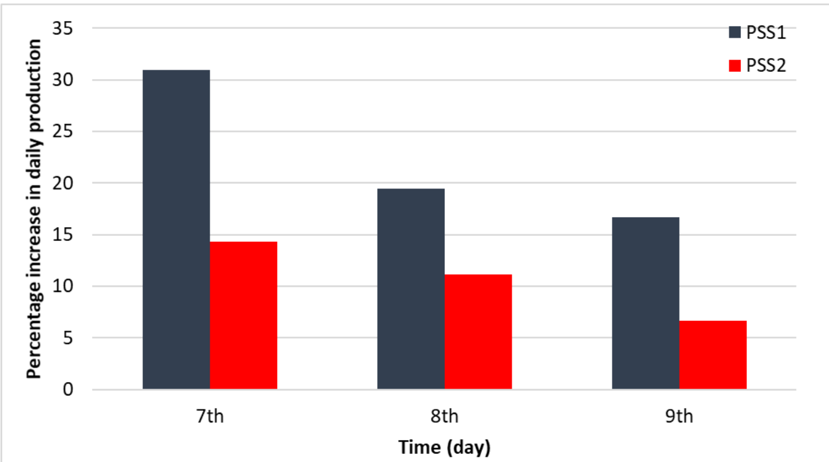
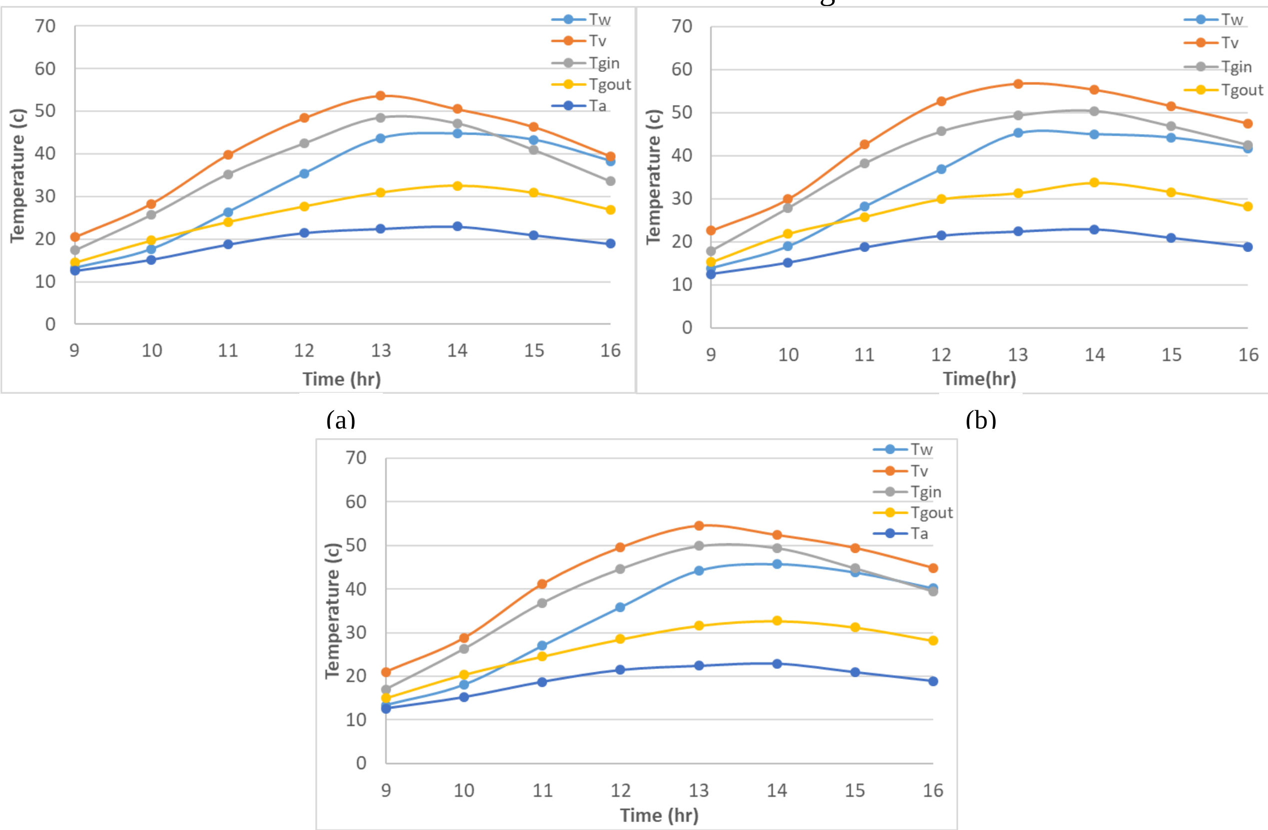


Figure 5: Percentage increase in daily production of solar stills

On January 8th, the experiment was conducted at a height of 3 cm for water, meaning that the amount of water is equivalent to 7.5 l, and the amount of water produced by each solar distiller was equal to 180 ml, 215 ml and 200 ml for each of SSS, PSS1 and PSS2 respectively, meaning that the highest amount of distilled water production on January 8th is using PSS1, because it is the most receiving of solar radiation compared to other solar distillers. This is due to the large size of the glass cover for it. When comparing the amount of water produced by each distiller on January 7 and 8, we notice that solar distillers have higher productivity of distilled water when the height of the water inside them is equal to 1 cm and not 3 cm, and the reason for this is that the less water inside the solar distiller, (Tw) will increase faster and higher, and therefore the water will evaporate faster and its temperature increases inside the solar distiller, which leads to an increase the difference between the temperature of the steam and the temperature of the glass cover of the solar distiller thus, the process of condensation of water vapor on the inner surface of the glass cover increases and the amount of water produced increases. Fig. 6, shows the change in temperature and temperature differences of the three solar distillers, as for the percentage increase in daily production on day 8 of January, the highest increase is 19.444% for PSS1 and 11.11% for PSS2 as shown in Fig. 5.

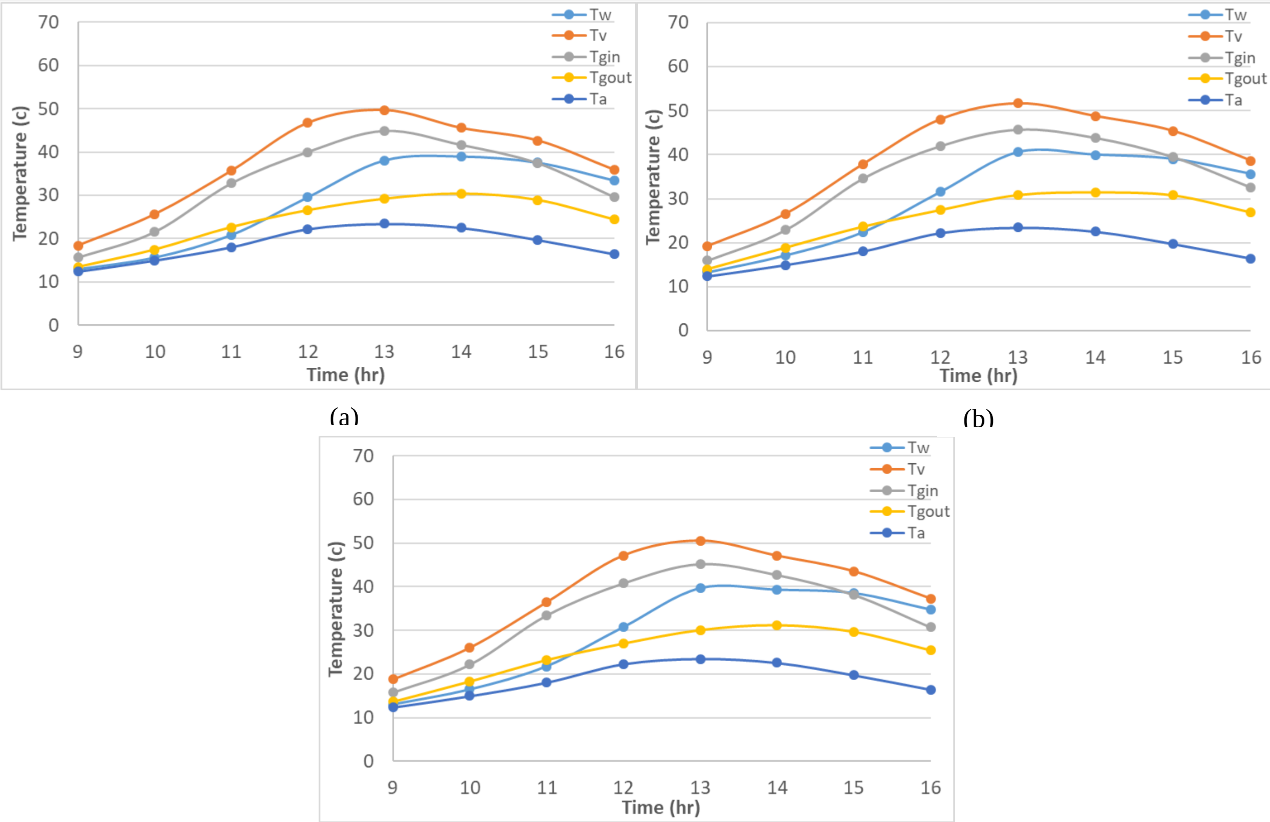


(a) (b)

(c)

Figure 6: Temperature change of solar stills in January 8th , a) SSS, b) PSS1, c) PSS2

On the 9th of January, the amount of water produced by each solar distiller was equal to 150 ml, 175 ml, and 160 ml for each of SSS, PSS1, and PSS2, respectively, and at a height of 5 cm for the water inside the solar distiller, meaning that the amount of water used in the experiment was 12.5 Liters, and this proves that the higher the water inside the solar distiller, the more this leads to a decrease in the amount of water produced by each distiller. Fig. 7, shows the change in temperature for each solar still. Through comparison with the temperatures in Fig. 6, and Fig. 4, it can be noted that the temperatures of water and water vapor decrease with the increase in water height, and thus the productivity decreases. The rate of increase in daily production on this day is 16.666% and 6.666% for pss1 and pss2, respectively. Through Figure 5, it can be seen that the daily production rate of each distiller decreases with the increase in the height of the water inside the solar distiller. As we mentioned earlier, the reason for this is the slow process of heating the water inside the distiller as its quantity increases, and thus the rate of evaporation and condensation is lower, and as a result, the rate of water production decreases.



(a) (b) (c)

Figure 7: Temperature change of solar stills in January 9th , a) SSS, b) PSS1, c) PSS2

Summary

The new design of the pentagonal base of solar still has a higher efficiency in producing fresh water than a conventional square-base solar distiller because it receives more solar radiation and thus the temperature of the water and water vapor inside it is higher compared to the conventional solar distiller. This experimental research has resulted in an improvement in the performance of the solar distiller at no cost, and this is one of the most important advantages obtained. It has also been proven that the lower the height of the water, the greater the productivity of the solar distiller of fresh water this is due to the increase in the temperature of water and water vapor inside the solar distiller and thus increase the rate of evaporation, adaptation and production of fresh water.

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