NTU Journal for Renewable Energy (2024) Vol. 6 (1): 68 - 77
DOI: https://doi.org/10.56286/ntujre.v6i1

IRAQI
Academic Scientific Journals

JRE NTU

EISSN: 2788-9920
NTU Journal for Renewable Energy
Available online at:
https://journals.ntu.edu.iq/index.php/NTU-JRE

Effect of square and perforated fins on improving the efficiency of the classic pyramidal solar still, A review

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Article Information's

Received: 12 – 03 - 2024
Accepted: 16 – 04 - 2024
Published: 23 – 04 - 2024

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Key words:
solar stills, solar still classification, solar still efficiency and performance.

ABSTRACT

A practical study was conducted to improve the performance of traditional pyramidal solar stills by using fins with square shapes and a circular diameter on the inside, as well as an internal mirror with a pyramid angle of 55 degrees for the improved and 45 degrees for the traditional. The fins were inserted into the base of the solar still, and a glass mirror was installed on each of the still's four sides to compare its performance to that of a typical device. The experimental findings acquired from the pyramidal and enhanced solar systems revealed the following for the first system: Combining the classic pyramidal with the inner-mirror pyramidal demonstrated the results of traditional distillation at 1250 ml/hour with a 47.6% efficiency. Regarding the modified pyramidal still, distillation data revealed an increase of up to 1500 ml/hour with an efficiency of 56.9%. The second system consisted of a traditional pyramid with a 45-degree angle and an enhanced one with a 55-degree angle, square fins, and an internal mirror, which generated more distillate products than the traditional one under all conditions tested. The daily productivity of the enhanced pyramid was 2200 ml/hour, with a 90% efficiency, whereas the original pyramid's daily output was 1675 ml/hour, with a 59.5% efficiency. Furthermore, the use of fins enhanced daily distillate production.

Introduction

Water is said to be the most essential element needed for life to exist on Earth. Although water covers roughly 71% of the planet's surface, only 2.5 percent of that water is fresh water, with the remaining 97.5 percent being salt water [1].

There are three ways to desalinate seawater: electrical, thermal, and reverse osmosis. Salt and water are separated using electric current in the electrical method. Generally, the dissociated salt ions are pushed through a selectively permeable membrane by the ions themselves. This method's crucial feature is that the amount of energy used varies depending on the water's salinity level. The desalination process purifies polluted water by removing contaminants. This method involves removing dissolved pollutants from water using a range of thermal, electrical, or mechanical methods. The basic principle of solar distillation is to evaporate brackish water by using solar radiation as a heat source, condense the vapor on a surface, and then collect the condensed water as pure water. These technologies have been around for a very long time. They will also function effectively in the current situation [2].

The radiant energy that the sun produces when nuclear fusion produces electromagnetic energy is known as solar radiation. With a temperature of about 5800 K, the solar radiation spectrum is similar to a black body in the visible short-wave portion of the electromagnetic spectrum, which comprises almost half of the energy. The near-infrared region makes up a larger portion of the second half of the spectrum, which also contains some ultraviolet light. The measurement units are watts per square meter. The impact of solar radiation on living things and the possibility of practical applications are making it increasingly valuable. It is an endless supply of naturally occurring energy that holds great potential for a variety of applications, in addition to other renewable energy sources, due to its abundance and accessibility [3].

The cost of energy is a major factor in the economics of desalinating water, and conventional fossil fuels have historically been the primary source of energy. However, recent worries about greenhouse gas emissions have prompted efforts to develop and implement cleaner energy sources and energy minimization techniques globally. Furthermore, because of strict discharge limitations, the rejection of certain components by reverse osmosis membranes in salt water, including boron, has recently become an issue. As a result, solar stills that run on renewable energy from the sun could be a useful tool for conserving fossil fuels and protecting the environment from dangerous substances [4].

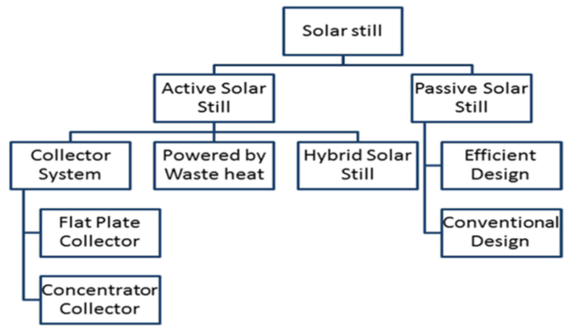


Figure (1) shows the detailed diagram for dividing the solar still [5]

The concept underlying employing different designs for solar water distillation processes shown in Figure 1 to produce pure water from saline water is the same as shown in Figure 2. The briny water in the trough absorbs most of the sunlight that comes through the lid. The cover and trough absorb the remainder. Thus, the briny water is heated until it evaporates. The density of water vapor in the humid air rises due to evaporation from the lake's surface. The water vapor that builds up on the inside surface of the cover evaporates, releasing its latent heat. The condensed water eventually flows downward and gathers in a collector due to gravity [6].

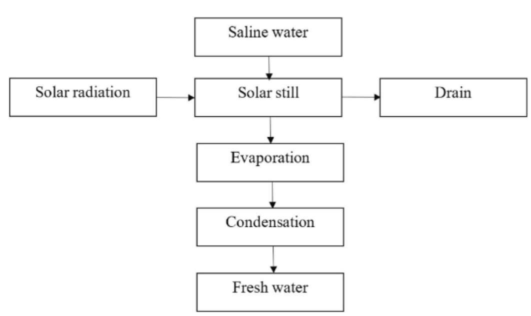


Figure (2) shows the pure water production mechanism

There are many solar energy technologies Integrated with pyramid stills for increased efficiency the device. The three solar distillers is used widely with a special configuration of absorber surfaces painted with CuO nano black paint, PCM with pin fins, and reflecting mirrors. On the other hand, Nanocomposites, Hollow Cylindrical Perforated Fins, and Inclined Rectangular Perforated Fins Used in Pyramidal Solar Stills. It is mainly used to increasing the condenser, reflectors, absorber, and thermal storage material's efficiency in the pyramid solar distiller. Combination of Multi-effect stages of PV panels and solar stills are used to enhance productivity by utilizing a water heater and cooling fan.

A novel configuration for modifying the pyramid solar still (PSS) was presented in 2022 by Fadi and others [7]. .To increase the surface area available for evaporation, a pyramidal absorber was installed in the distiller to replace the previous flat absorber. Cotton wick and jute cloth were also used as wick materials, which were spread out across the top of the pyramidal absorber. Additionally, the efficiency of the modified pyramid solar still (MPSS) was examined by increasing the input solar energy using exterior mirrors and condensers. Finally, paraffin wax and silver nanoparticle phase change material (PCM) were inserted beneath the MPSS pyramidal absorber for testing. The results showed that after implementing the enhanced absorber, MPSS's evaporative surface area increased by close to 40%. In addition, jute fabric is recommended for use with the MPSS because it is more functional than cotton cloth. To top it all off, we used mirrors and a condenser to boost productivity and distiller efficiency by 142% and 52.5%, respectively, for the best MPSS performance.

In the one-sided impact, first, an effective illustration would be a solar heater coupled with a solar concentrator, a solar pond coupled with photovoltaic panels, cooling equipment coupled with a solar collector, biomass coupled with a solar dish, wind energy coupled with an evacuated tube, and renewable solar energy. Secondly, those that are ineffective include the following: basin and diffusion, wick and plug, pyramidal, tubular, rectangular, and spherical.

In 2021. Mohammed and a few others Using a novel combination of functional enhancements, the absorber surface was covered with CuO nano black paint, reflective mirrors, and phase-change material with pin fins. To show how this novel combination influences the overall production of a pyramid still. Both a standard pyramid sun distiller (reference case) and a modified pyramid solar distiller (MPSD) with a novel mix of helpful adjustments were built and tested under identical environmental conditions. Experimental, energy, and exergy assessments are also analyzed in this paper. The results of the trials show that this novel approach to making efficient improvements is an excellent strategy for maximizing performance. The cumulative yield achieved by CPSD ranged from 4085 to 4171 mL/m2/day, but after applying this unique combination of efficient modifications, it increased to 9885–10015 mL/m2/day, an increase of 140.1–142%. Additionally, MPSD's daily thermal and exergy efficiencies were improved by rates ranging from 138.1 to 140.1% and 243.6 to 252.9%, respectively, as compared to CPSD[8,9].

In2023. Haider A. Dhahad and others are still investigating the possibility of a pyramidal solar system. The productivity of pyramid stills can be increased by as much as 35% and 88%, respectively, according to several studies, because of the increased heat storage capacity of PCM and corrugated absorber plates. Distillate output can be increased by as much as 48% with mirrors and 53% with reflectors. Because of their increased capacity to absorb solar radiation, some nanoparticles have been shown to boost solar productive yield by as much as 72%. Based on this analysis and other studies, we can say that the effectiveness of the pyramid distributer is significantly affected by environmental, structural, and operational variables. Suggestions for further work are also provided[2].

K.A. Hamoodi and colleagues in the year 2023. I am researching a solar still with a pyramidal shape. Multiple studies have demonstrated the importance of improving pyramid SSs in many ways, such as by incorporating storage materials, which can significantly increase productivity by around 35%. The yield can be increased by about 87.4 percent by using a v-corrugated absorber with PCM. The use of wicks can increase freshwater production by as much as 122%, with jute wicks being superior to cotton wicks. By using evacuated tubes and carbon black nanofluid, a pyramid solar still can boost freshwater production by roughly 57.1%. Using a combination of nano and wick materials, a pyramid distiller's output might improve by as much as 176%, while thermal efficiency would climb to 60.44 percent. The daily production of a pyramid distiller equipped with revolving cylinders and electrical heaters can rise by 214%, reaching 9100 ml/m2 per day[10].

In the current study A practical investigation was conducted to improve the performance of traditional pyramidal solar stills by using fins with square shapes and a circular diameter on the inside, as well as an internal mirror with a pyramid angle of 55 degrees for the improved and 45 degrees for the traditional. The fins were inserted into the base of the solar still, and a glass mirror was installed on each of the still's four sides to compare its performance to that of a typical device.

1- Methodology

The experimental system is located in the city of Kirkuk, Iraq, at latitude (35.46° north) and longitude (44.39° east). A system consisting of two distillers, one improved and the other traditional, was designed and manufactured with different cover angles and moving fins. Mirrors were used to increase the reflection of solar rays.

With technical specifications as shown in Figure (3), two models of the pyramidal solar still were designed and manufactured, of the regular and improved pyramidal types used in the current research. Galvanized iron sheets with a thickness of 3 mm were used. The length of the base dimensions of the solar stills is (60 ˣ 60 cm, with a height of 30 cm, and the other 55 ° and a height of 42.8 cm, where silicone was placed on the bent edges at each end of the glass (the transparent cover) to ensure complete confinement of the steam inside the still, and to prevent its leakage to the outside. At the base of the pyramid there are square-shaped fins (Steel) with a length of 4 cm and a diameter of 5.5 mm. The number of fins is 25 in one still, the distance between the fins is 10 cm, and the height of the still from the ground is (55 cm). A glass mirror was used on the four edges of the improved solar still and the other regular still, so it is free of improvements (inner mirror and fins) A group of sensors were connected to measure temperatures and humidity inside and outside the solar distiller.

A raft was used to determine the amount of water inside the distiller. A tube was used to collect water from the inside. It was made of galvanized iron and its length is as long as the base of the distillers. There are two large water tanks to supply the distillers with water. It is connected via a soda connected to a copper pipe with a length of 7 cm, where the height of the water inside the distillers is 8, 7 and 6 cm, which was determined by the raft. Water is exited from the two devices through a copper tube with a length of 7 cm connected to a transparent plastic tray that is placed inside a bottle to collect the water coming out, and the amount of production is measured using a graduated tester. The inner surfaces of the two metal basins containing water were painted with a matte black dye to increase the absorption of solar rays and prevent them from being reflected outside the distillery. As for thermal insulation, the distillers were completely insulated from the bottom and sides with panel sandwich material, and a valve was placed at the bottom of the base of the distillers for the purpose of cleaning them and preventing the accumulation of limescale materials in them. It is closed and opened using a tight stopper.

A hose links the tank and the two devices, distributing water between them. They are filled early in the morning and emptied in the evening.

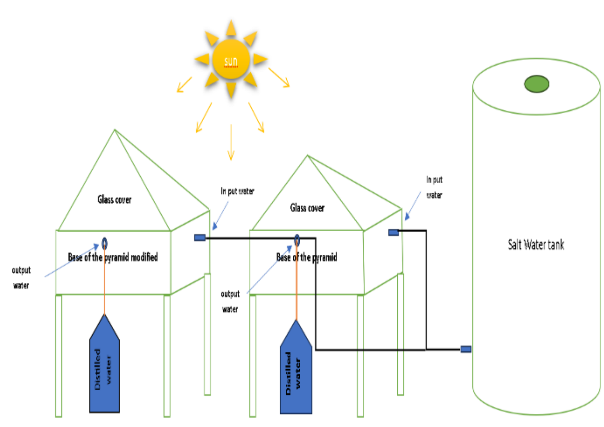
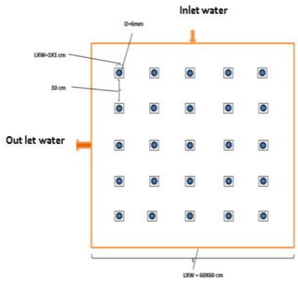
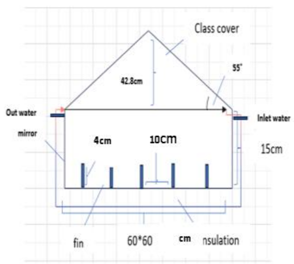


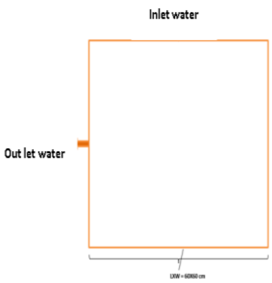
Figure (3) shows the detailed diagram of the traditional and improved solar stills

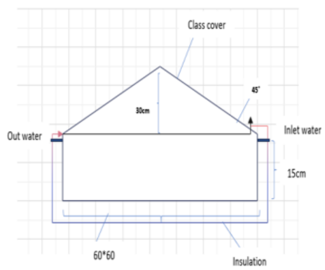




(A) (B)

Figure (4) :(A) shows the detailed diagram of the base of the improved solar still, (B) shows plan of what the device looks like from the outside.





(A) (B)

Figure (5): (A) shows the detailed diagram of the base of the traditional solar still, (B) shows outline of what the device looks like from the outside.

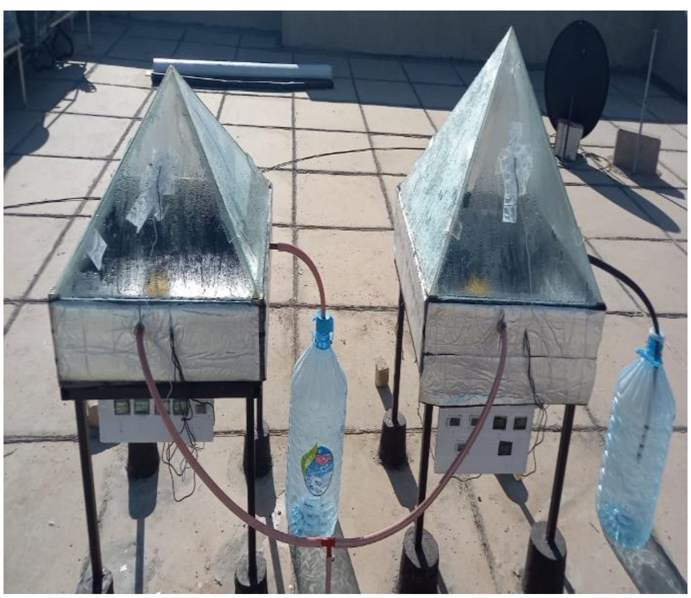


Figure (6): The external appearance of the two devices.

TABLE (2) Materials for the trough and lid of the new and old TSS.

No.	materials	Items	Old TSS	New TSS Cover
1	Cover	Cover material Thickness of cover (mm) Height of the pyramid Transmissibility (%) Density (kg/m3) Angle	the glass 3 mm **30**cm 90% ----- 45˚	the glass 3 mm 42.8cm 90% ----- 55˚
2	Trough	Trough material Trough wrapped by Thickness of trough (mm) Fin material Fin shape mirror	galvanized iron Sandwich panel **3**mm **-----** ------- --------	galvanized iron Sandwich panel 3mm Estelle Square with circular diameter in side L=4cm, D=5.5mm L x w=60*15

TABLE (3) Temperature readings in glass and water, productivity gains and decreases for PPS-IPRF with and without nanocomposites.

No.	Parameter	Ordinary pyramid still Without glass mirror	Improved pyramid distiller With glass mirror
1	Water temperature	0 to9 ◦C	0 to7 ◦C
2	Glass temperature	0 to8 ◦C	0 to7 ◦C
3	Daily productivity	1500 mL/m2/day	2000mL/m2/day

2- Mathematical model and data collection

Kirkuk, Iraq, is home to the experimental system, which is situated in a workshop at latitude 35.4655 N and longitude 44.38039 E. Because Kirkuk has the sunniest days of the year, it is a popular choice for solar energy experiments due to its advantageous geographic position.

Solar stills are [2] almost always permanent. Cleaning the basin to prevent particle accumulation is part of solar system maintenance. In dynamic mode, a solar still drives water-dissolved solids through the solar still basin and into the overflow channel. Cleaning the solar is only required on a regular basis because no dissolved particles accumulate in the trays. Solids and pollutants, on the other hand, sink to the bottom of each tray and are exposed to the sun's rays. This allows the sun's heat to reach them. As the temperature rises in the basin, an unappealing, pigmented, hard coating forms that is difficult to remove.

Because the production of fresh water by solar stills is highly dependent on many variables, these variables are extremely difficult to manage. In addition, for each explanation, the variables are measured and annotated. Dropwise condensation was detected on the inner surface of the glass cover, as expected. Droplets are shown to have radius sizes ranging from infinity to 3 mm for the largest droplets. The large droplets are concentrated near the top of the glass cover, while the little droplets are concentrated near the bottom. These variables are very hard to control because the production of fresh water by solar stills depends heavily on a wide range of factors. Furthermore, the variables are measured and documented for every explanation. As anticipated, dropwise condensation was found on the glass cover's interior surface. The radius sizes of the droplets are shown to range from infinity to 3 mm for the largest droplets. The top of the glass cover is where the huge droplets are concentrated, while the bottom is where the small droplets are concentrated.

Figure (7) shows the condensation process in the device

It is commonly recognized that the daily production rise, thermal efficiency, and energy efficiency of the solar system still determine its performance. The following formula yields the daily productivity increment[11,12].

Daily productivity rise,% = $\frac{(\textbf{productivity of modified distiller} - \textbf{productivity of conventional distiller})}{\textbf{productivity of conventional distiller}}$ × 100 (1) ....(1)

Connection between water output and temperature differential [13]:

$$\mathbf{P = 0.052\ (\mathit{T}w - \mathit{T}c)} \quad \text{...............(2)}$$

The following formulas were used to determine the exergy and thermal efficiencies of the modified pyramid solar distiller (MPSD) and the conventional pyramid solar distiller (CPSD)[8].

$$\boldsymbol{\eta}_{\textbf{daily,exe}} = \frac{\sum EX\ out\ put}{\sum EX\ in\ put}, \times \mathbf{100}\ ;\ \% \quad \text{...............(3)}$$

$$\mathbf{EX_{in\ put} = As\ \ I\ (t) \times [\ 1 - \frac{4}{3}\left(\frac{Ta+273}{6000}\right) + \frac{1}{3}\left(\frac{Ta+273}{6000}\right)^4\ ];\ \times .\ w} \quad \text{...............(4)}$$

$$\mathbf{EX_{out}\ put = \frac{\dot{m}ev\ \ hfg}{3600}\ [1 - \frac{Ta+273}{Tw+273}] \times w} \quad \text{...............(5)}$$

Daily thermal efficiency, th, is determined as[8] :

$$\eta\ \text{daily,th} = \frac{\sum \dot{m}ev\ \ hfg}{\sum \text{I (t) As} \times 3600} \times 100\ ,\%\ \text{c.........(6)}$$

Latent heat $\mathbf{h}fg$ is measured by:

$$\mathbf{h}fg = 10^3\ [2501.9 - 2.40706 \times Tw + 1.192217 \times 1\bar{0}^3 \times Tw^2 - 1.5863 \times 10^{-5} \times Tw^2\ ] \text{......(7)}$$

Hourly solar distiller efficiency[13]

$$\eta_h = \frac{P \times \text{hfg}}{I \times \text{A}} \quad \text{...............(8)}$$

Daily solar still efficiency

$$\eta d = \frac{\sum P \times \text{hfg}}{\sum I \times \text{A}} \quad \text{...............(9)}$$

2- Results and discussion

Based on the tow design factors and in months, 12, 1, and practical results were produced for the regular and upgraded pyramidal solar stills. During the two test days, the weather will be sunny. The wintertime radiation and wind speed are depicted in the image below. On December 10, 2023, the outside temperature varied from 12 to 24 degrees Celsius. On January 19, 2024, the outside temperature varied from 10 to 23 degrees Celsius. Under winter circumstances, the total solar radiation ranged from 0-800 watts/m2, with around 12 hours of sunshine each day. During the test days, there was a shift in wind speed of 0 to 9.2 m/s.

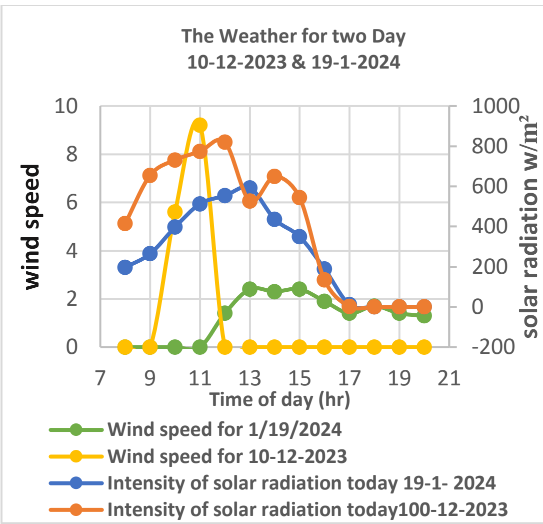


Figure (8) shows weather conditions.

The first system (A1) compares the productivity of two solar stills with the normal distiller at an angle of 45 degrees and the still's interior at 55 degrees, respectively, under the same meteorological circumstances.

Figures (9) and (10) show the distribution of temperatures and solar radiation intensity over time on December 10, 2023, at a water height of 3 cm within the distillery. The greatest solar radiation intensity was 819.9 watts/m2 at 12:00, while the lowest was at sunrise and sunset, with values of around (415.3 and 2) W/m2. The greatest temperature of the base and surface of the salt water was at 14:00 inside the improved pyramid still, with a value of (38 and 38.9) degrees Celsius, while the highest temperature of the inner and outer glass was at 13:00, reaching (34.6 and 30.7) degrees Celsius, respectively. While the temperatures of the base and surface of the salt water inside the conventional pyramid remained at 40.8 and 45 degrees Celsius, the inner and outer glass reached 37.7 and 30.5 degrees Celsius, respectively. The temperature of the salt water declines faster in the ordinary pyramid still, reaching 15.5 degrees Celsius at eight o'clock in the evening, than in the improved still, which reached 19.9 degrees Celsius, since the improved still frequently retains heat**.**

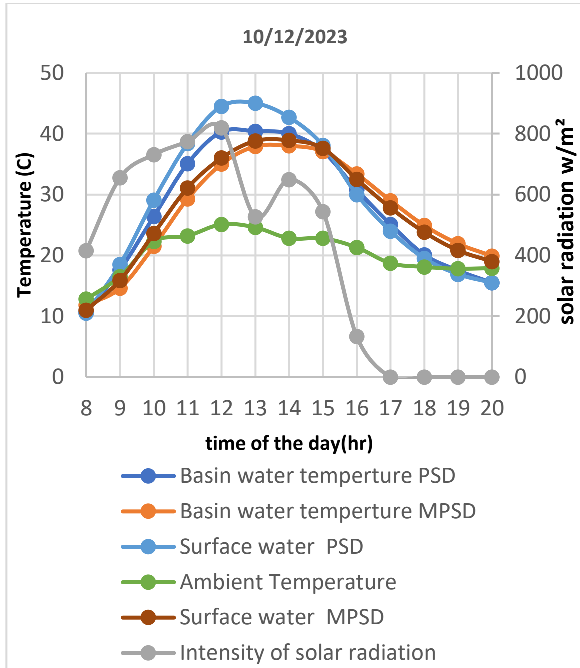
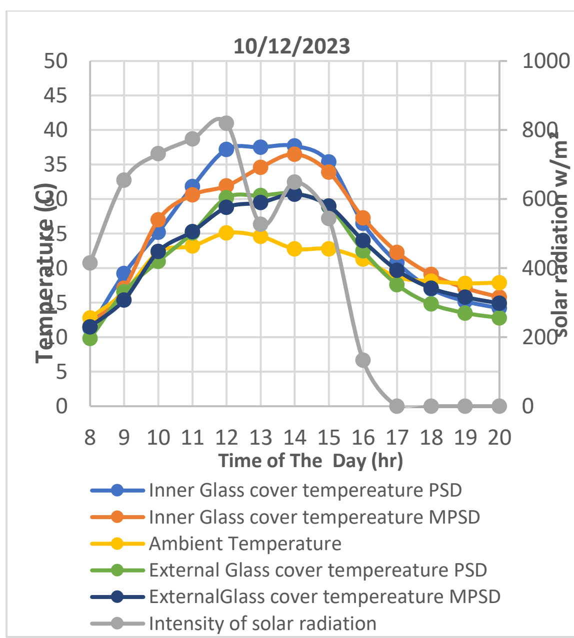


Figure (9) shows the temperature difference between the water surface and the base of the two regular and improved pyramid devices with the intensity of solar radiation and the ocean temperature for to day 12/10/2023.



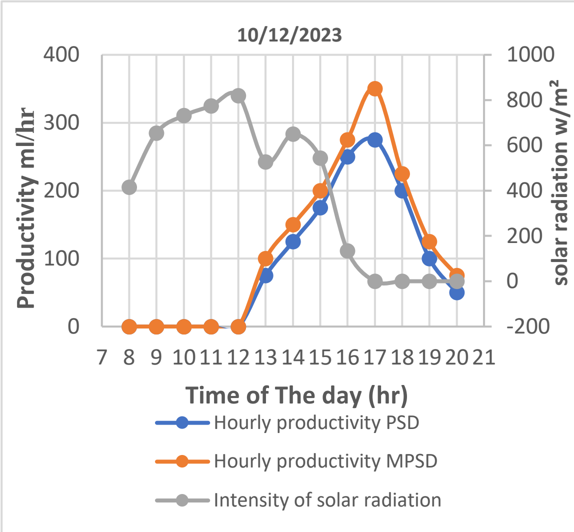


Figure (10) The temperature difference between the inner and outer glass covers with the intensity of solar radiation and the ambient temperature for today 12/10/2023.

Figure (11) depicts the distribution of steam temperatures, humidity, and hourly solar radiation intensity across time on December 10, 2023, with a water height of 3 cm within the still. The greatest value of solar radiation intensity reached 819.9 watts/m2 at 12:00, while the lowest value measured around (415.3 and 2) W/m2 in the morning and at sunset. At 12:00, the greatest steam temperature within the enhanced pyramid was still 45.9 degrees Celsius, while the steam temperatures and humidity in the regular pyramid were still 46 °C. It is noticed that the steam temperature and humidity steadily fall at night, which speeds up the condensation process, and the relative humidity reaches 99%.

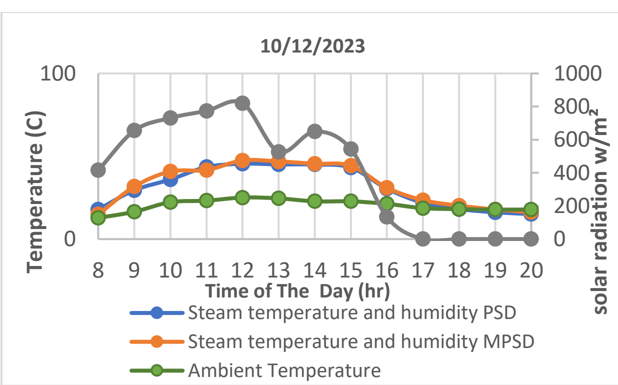


Figure (11) The difference in steam temperatures and humidity with the intensity of solar radiation and the ambient temperature for today 12/10/2023.

Figures (12) and (13) depict the volume of distilled water generated over time in practice on the same day indicated above. At a depth of 3 cm of salt water inside the improved and regular pyramid stills, the highest hourly productivity values at 15:00 in the afternoon reached 275 mL/min, while the highest productivity of the improved pyramid reached 350 mL/min, so productivity became low in the improved. Because there was no auxiliary component to absorb the most heat and promote the condensation of the evaporated water, and because the wind speed was changeable on that day, with the wind being very strong at first but decreasing or becoming non-existent by midday. Thus, the night gives As a result, the enhanced distillate had a night output of 1500 ml/hr, as did the still. The traditional daily intake is 1250 ml/hour.

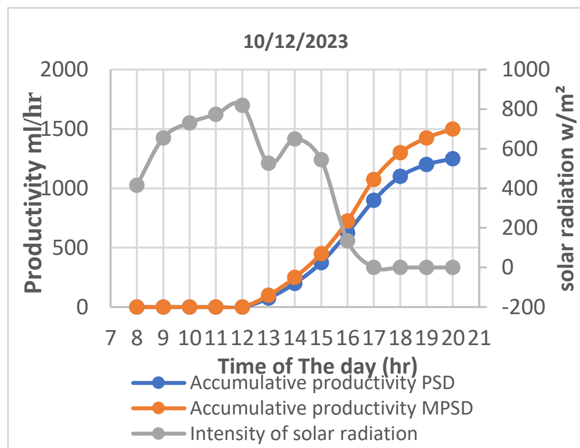


Figure (12) shows the fresh water production variation with respect to time with Intensity of solar radiation

Figure (13) shows the Hourly fresh water production variation with respect to time with Intensity of solar radiation.

Figures (14) and (15) show the daily and hourly efficiency for today and tomorrow (10/12/2023) at a water depth of 3 cm for the regular and upgraded solar stills. It is found that the efficiency grows over time, peaking around 15:00. The normal pyramid had the best hourly and daily efficiency (14.5% and 47.6%, respectively), followed by hourly and daily efficiency (18.5% and 56.9%, respectively). We notice that the presence of indoor women contributed to higher temperatures and consequently boosted production.

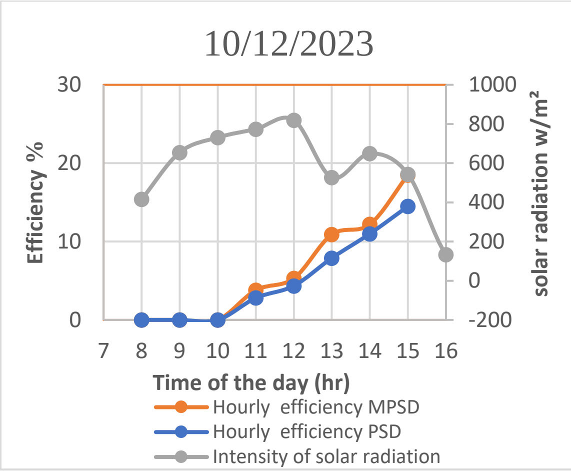


Figure (14) shows the Hourly efficiency variation with respect to time with Intensity of solar radiation.

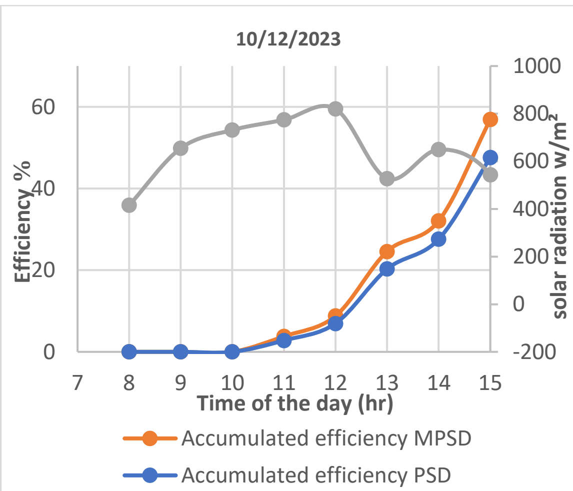


Figure (15) shows the efficiency variation with respect to time with Intensity of solar radiation.

Conclusions

The use of square and perforated fins to improve the efficiency of the classic pyramidal solar still (CPSS). Its productivity is further increased by the employment of a glass inside mirror; hence, the suggested improved solar energy technology for saltwater desalination is both simple and cost-effective. The experimental findings acquired from the pyramidal and enhanced solar systems revealed the following for the first system: Combining the classic pyramidal with the inner-mirror pyramidal demonstrated the results of traditional distillation at 1250 ml/hour with a 47.6% efficiency. Regarding the modified pyramidal still, distillation data revealed an increase of up to 1500 ml/hour with an efficiency of 56.9%. The second system consisted of a traditional pyramid with a 45-degree angle and an enhanced one with a 55-degree angle, square fins, and an internal mirror, which generated more distillate products than the traditional one under all conditions tested. The daily productivity of the enhanced pyramid was 2200 ml/hour, with a 90% efficiency, whereas the original pyramid's daily output was 1675 ml/hour, with a 59.5% efficiency. Furthermore, the use of fins enhanced daily distillate production.

List of Symbols/Acronyms

(MPSD)	modified pyramid solar distiller
(PSS)	pyramid solar still
(CPSD)	conventional pyramid solar distiller

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