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Original Research Article

Toward Eco-Friendly Solar Still: Enhancement of Solar Still Productivity Using Ground Tire Rubber

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ABSTRACT

In the present study, the experimental investigation was conducted to evaluate the effect of adding recycled ground tire rubber in the basin of a single-slope solar still unit with a paddle wheel device to improve its performance. A single-slope solar still unit was used and investigated under the extreme climate of Basra in southern Iraq. Compared to the conventional type, the results of the developed solar still indicated that using recycled tire rubber granules increased the still's water productivity by approximately 95%. Using the paddle wheel device in the presence of recycled tire rubber granules increased water productivity to about 172%. The results also indicated that increasing the proportion of recycled granules of tire rubber impacts the unit's energy efficiency and water productivity. The energy efficiency achieved a maximum value of 38% for the improved solar still with 100% filling of recycled granules tire rubber and a paddle wheel device at a rotational speed of 30 rpm, while its value was reported to be about 46% at a rotational speed of 90 rpm. According to the energy and productivity analysis, these units can be reliable in remote areas and have good productivity compared to conventional solar stills.

KEYWORDS

Modified solar still, Ground tire rubber, Solar energy, Desalination, Fresh water, Productivity improvement.

INTRODUCTION

Due to the massive global energy demands and the simultaneous shortage of energy supplies resulting from the depletion of traditional energy resources, numerous studies have been conducted over the past years to increase the efficiency of alternative energy sources to

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replace conventional energy [1], [2]. Alongside increasing awareness of the environmental damage caused by traditional energy sources, experts and engineers are seeking alternative ways to utilize renewable energy sources such as solar, wind, geothermal, wave, and others [3], [4]. Solar energy is one of Earth's cleanest and most abundant renewable energy sources, making solar systems more cost-effective in industrial and residential thermal applications. In addition to global energy shortages, another critical challenge significantly impacts the Earth's inhabitants: the shortage of freshwater resources. Although water covers nearly two-thirds of the Earth's surface, freshwater accounts for only 3%, and even less is readily available for use, as only about 0.5% of the freshwater is accessible for practical use [5], [6].

Iraq in general, and southern Iraq in particular, including the city of Basra, face significant environmental challenges, such as the availability of freshwater resources, so it encourages sustainability and recycling studies [7], [8]. This densely populated city faces a pressing challenge in ensuring an adequate supply of drinking water and significant water treatment problems particularly during summer [9]. These problems were attributed to the lack of spare parts, water treatment chemicals and qualifies service staff [10]. Other challenges face water treatment plants in Basra are the bad quality of water provided by Shat Al Arab river which is considered one of the main tourist destinations in this city [11]. Despite the abundance of seawater along its coastline, the availability of renewable energy sources such as solar energy, and the high temperatures throughout most of the year, Basrah needs more fresh water [12]. Countries experiencing freshwater shortages can also use integrated renewable desalination systems to address the deficiency and provide fresh water [13], [14]. Consequently, this lessens reliance on conventional energy-produced freshwater sources, adversely affecting climate and environmental shifts. Numerous studies have explored using seawater as a substitute source for providing fresh water to the city through various desalination technologies [15], [16]. As a coastal city, Basrah has significant potential and capacity to produce fresh water by desalinating seawater. Solar energy and the city's climatic conditions create an ideal environment for improving the efficiency of desalination technology.

Studies indicate that desalination processes require substantial amounts of energy [17]. It is estimated that producing one million cubic meters daily requires 10 million tons of oil annually [18]. Desalination can be defined as removing and eliminating the total dissolved solids (TDS), such as minerals and salts, from water [19]. The distillation technique is one of the most important processes used for water desalination. Most water distillation devices and systems rely on fossil fuels or electrical energy [20]. However, using electricity or fossil fuels in distillation devices is highly energy intensive [21]. Air pollution, acid rain, global warming, and climate change are some of the results of using fossil fuels [22]. Solar stills are an important water desalination technology that uses solar energy to produce fresh water. This technique mimics the Earth's water cycle's natural evaporation and condensation process [23]. The energy efficiency of the solar stills is based on the amount of useful energy utilized as a percentage of the total incoming solar radiation. Solar energy is free and non-consumable, but its instability and irregular availability have some drawbacks. The fluctuation of solar energy depends on the daytime, seasonal changes, and weather conditions. In order to achieve high efficiency in the solar still operation, it is essential to maintain a high temperature for the still basin feed water, which can be achieved by absorbing a high proportion of the incoming solar radiation to pre-heat the feed water. Low-solar absorption glass and a good-solar absorption surface can achieve this. Minimizing heat losses through the floors and walls and keeping the water as shallow as possible reduces heating up energy. The temperature difference between the condensation surface and the feed water affects the solar still efficiency. Increasing the absorption of the condensing surface allows it to absorb a greater amount of solar radiation, which leads to obtaining a larger temperature difference and thus increasing the condensation efficiency [24], [25].

Conventional solar distillation technology generally consists of four main elements: solar heating, evaporation, condensation, and distilled water collection, as shown in **Figure 1a**. In the evaporation stage, the water distilled from any source is placed in a solar distillation tank made of materials that absorb and retain heat. In the solar heating stage, the tank is covered with a transparent layer of glass or plastic to allow the maximum possible amount of solar radiation to pass through to heat the water and evaporate it. It is noted at this stage that a quantity of impurities and pollutants, which are often salts, remain. In the condensation stage, the water vapour rises and condenses on the cooler underside of the transparent cover, as the distillation device's design usually ensures that the angle of the cover allows the condensed water droplets to flow into the collection channel. In the final stage, a separate container collects the impurity-free distilled water, preparing it for drinking or other purposes. Construction of solar stills is relatively simple, and their versatility makes them particularly useful in remote or arid areas with limited access to fresh water. The process is energy-efficient, relying entirely on solar energy, making it an environmentally friendly water desalination method. **Figure 1b** shows a schematic of the conventional solar still technology for water desalination.

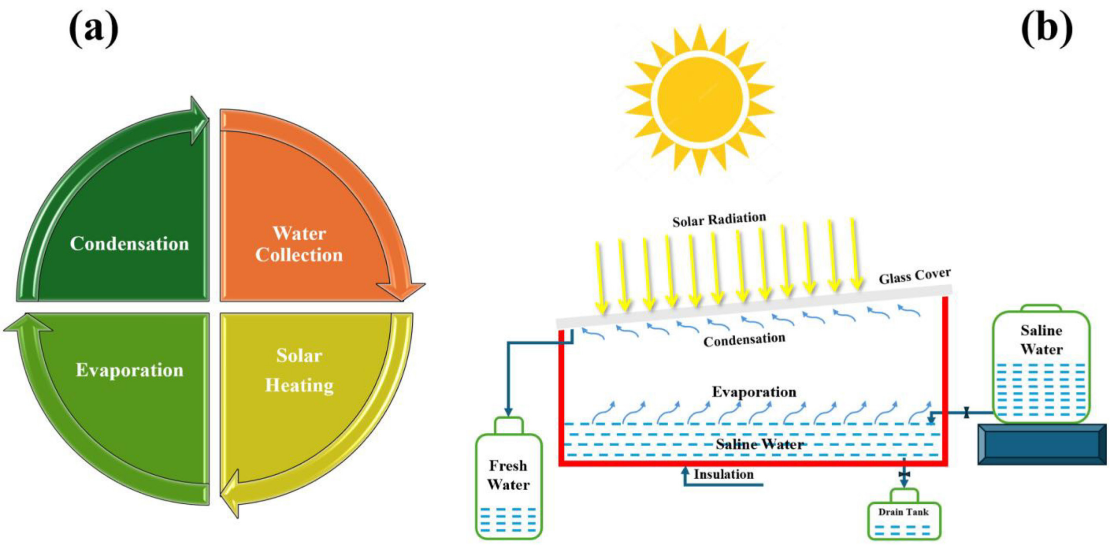


Figure 1. Conventional solar distillation technology: a) four main stages, b) basic components

In the last decade, solar distillation has received much attention, aiming to increase the system's efficiency through the use of various materials and designs. Kabeel *et al.* [26] developed conventional solar stills using storage materials, which resulted in a total accumulated productivity of 7740 ml/m^2 and an energy efficiency of around 61%. Similar results, with efficiencies up to about 60% and productivity up to 7740 ml/m^2, were obtained by El-Said *et al.* [27] using high frequency ultrasound atomizer (HFU). Alaian *et al.* [28] studied the conventional solar still with pin-finned wick and achieved the total accumulated productivity of the solar still, and its energy efficiency was 4872 ml/m^2 and 47%, respectively. Apurba Layek uses qualitative absorbing black dye solution and gets suitable overall energy efficiencies of around 45% [29]. A fundamental modification by Abed *et al.* [30] increased the accumulated production capacity by focusing on the phase change materials using high-frequency ultrasonic waves as an evaporator. Its energy efficiency was 7740 ml/m^2 and 60.54%, respectively. Overall, researchers and investors are still interested in developing solar distillation and exploring more materials that can contribute to increasing its efficiency.

In the present study, recycled granules of tire rubber are used for the first time to enhance solar still productivity and energy efficiency in comparison with conventional solar stills. Three different cases have been studied: Conventional Solar Still (CSS) as a baseline case for comparison and evaluation, enhanced solar distillation using recycled granules tire rubber with varying filling ratios, and enhanced solar distillation using the optimal filling ratio of recycled granules tire rubber (GTR) combined with the paddle wheel tested at different rotation speeds to determine the optimal speed for maximum productivity.

EXPERIMENTAL AND METHODS

The experimental setup of the study system consists of the construction of a conventional solar still (CSS), a photovoltaic (PV) system, a feed water tank, and a freshwater collection tank. **Figure 2** shows the schematic arrangement of the system. A glass basin of 0.54 m × 0.35 m for length and width and 0.43 m and 0.58 m for the height of the shorter and taller sides, respectively, with a thickness of 0.006 m, was fabricated. A glass plate of 0.54 m × 0.39 × 0.004 m in length, width, and thickness, respectively, was utilized as the cover for the still, inclined at 23 degrees to the horizontal. A U-shaped PVC channel was used to collect the distilled fresh water on the inner surface of the glass cover. On the other hand, the proposed integrated solar still (ISS) is similar to the conventional solar still but with the addition of a paddle wheel to induce water and air agitation inside the still. The paddle wheel is driven by an electric motor connected to the PV system as a power source. A power converter was used to control the rotational speed of the paddle wheel, as shown in **Figure 3**. Wooden boards and polystyrene sheets of 0.01 m thickness are used on the outer side walls and bottom of the basin to prevent heat energy loss. The basin lining was painted black to reduce energy loss by preventing the reflection of incoming solar radiation to the feeding water, which increases the temperature while keeping the condensation surface temperature low, thereby increasing the condensation efficiency and thus enhancing the solar still productivity. Additionally, this improves the still's heat absorption properties.

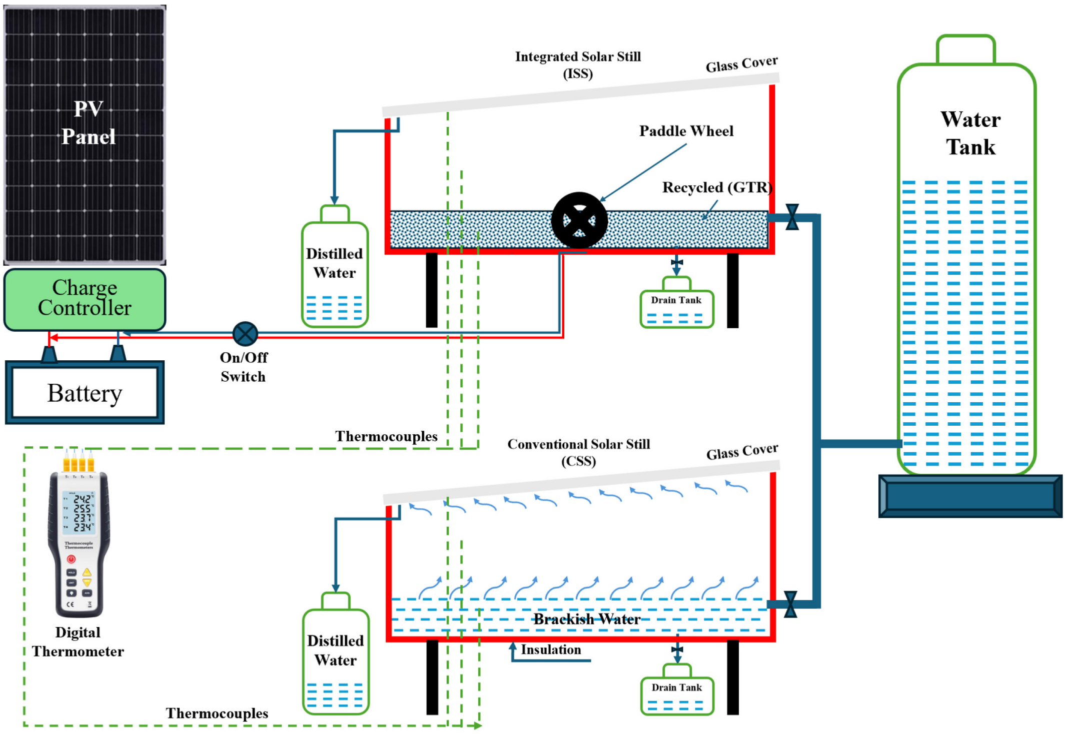


Figure 2. Schematic arrangement of the solar stills system

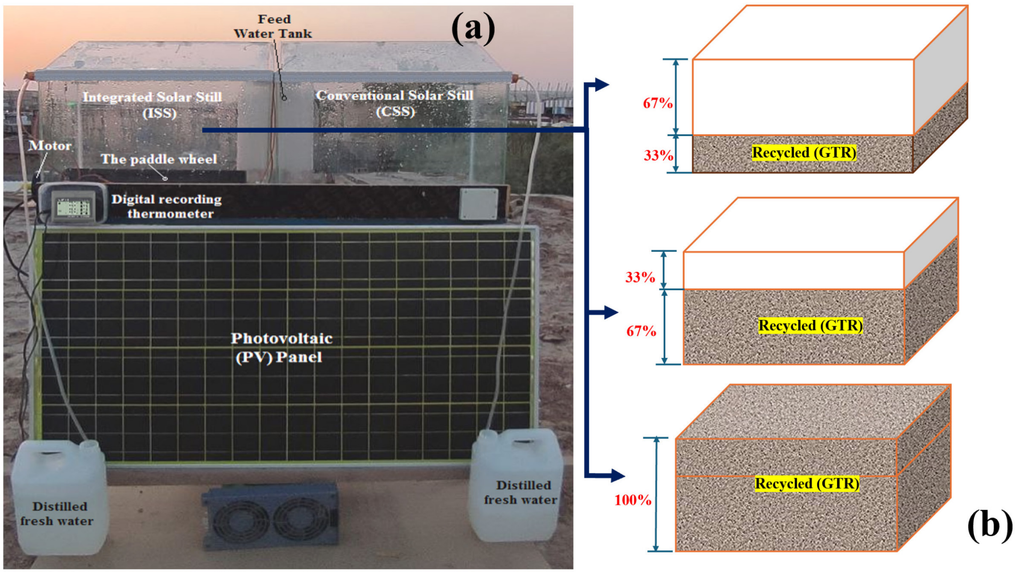


Figure 3. a) Solar stills system setup; b) ratios of recycled tire rubber granules

In this study, recycled granules of tire rubber (GTR) ranging in size from 2 to 5 mm were used in the integrated still to improve the energy absorption properties from solar radiation. Table 1 lists the thermo-physical properties of recycled granule tire rubber [31].

Table 1. Recycled granules tire rubber properties [31]

Properties	Value
apparent particle density	1.15 g/cm^3
Particle size	2 – 5 mm
Thermal conductivity	0.17 W/m×K
Specific Heat Capacity	1.9 J/g×K
water absorption	6% in 24 h

A digital thermometer model (HT-9815) was used to measure and record temperatures in both the conventional solar still (CSS) and the integrated solar still (ISS). Several standard thermometers were installed at selected locations in both stills to measure various temperatures: two thermometers to measure the temperature of the glass cover (both outside and inside), labeled T_g, and the temperature of the air inside the still, T_{ain}. Two thermometers were placed inside the basin to measure the water temperature in the basin T_{win}. One thermometer was installed in the raw water feed tank, T_{wrow}, and one thermometer for ambient temperature measuring T_∞. The speed of wind was measured and recorded using a mini anemometer (UT363) to determine the ambient wind speed, V_a. Additionally, the solar radiation intensity, I_r, was measured and recorded during daylight hours using a solar radiation sensor model (ProtekDM-301).

The experimental study was conducted to test and evaluate the efficiency of the enhanced integrated solar still (ISS) compared to the conventional solar still (CSS) in early July 2024 in Basrah City, southern Iraq. The test site was chosen to be free from any shading obstacles, such as trees and nearby buildings. The experiments were conducted from 6:00 to 18:00, with both solar stills and photovoltaic (PV) panels orientated towards the southeast, which provides optimal exposure to solar radiation during daylight hours. In the three cases, the main goals of experiments were to examine the variation that will occur in the still's energy efficiency and productivity of water throughout the day. In case 1, conventional solar still (CSS) is a baseline case for comparison and evaluation. In case 2, improved solar distillation using recycled granules of tire rubber (GTR) with different filling ratios in the basin was tested to find the best ratio for increasing still productivity. In case 3, improved solar distillation using the best filling ratio of recycled granules of tire rubber (GTR) combined with the paddle wheel was tested at various rotation speeds to find the best speed for increasing still productivity. **Table 2** illustrates a summary of the three cases in this study. The study was conducted over six days to gain a comprehensive understanding of the performance of solar stills under various conditions. The key measured variables were water basin temperature, glass temperatures (inside and outside), ambient temperature, solar radiation intensity, and wind speed. All variables were recorded hourly. The saline water level inside the conventional solar still basin was controlled at 3 cm, equivalent to a volume of 6 liters, using a mechanical float to compensate for evaporated water. In the enhanced still, the same water volume was maintained in the basin but varied the height based on the proportion of recycled tire rubber granules added to it. Three fill ratios were selected: 33%, 66.66%, and 100%, as shown in **Figure 3b**. Additionally, three paddle wheel speeds were tested: 30, 60, and 90 rpm.

Table 2. Solar still cases

Cases	Specification
1	Conventional solar still
2	Conventional solar still + Recycled (GTR)
3	Conventional solar still + Recycled (GTR)+ Paddle wheel

ENERGY EFFICIENCY AND UNCERTAINTY ANALYSIS

For three cases, the solar stills' energy efficiency (η) can be calculated according to the below equations **[23]**, **[32]**:

$$\eta_{\text{daily}} = \frac{\sum m_{\text{w}} h_{\text{fg}}}{3600A \sum I(t)} \tag{1}$$

The variables I, A, m_{w}, h_{fg}, and T_{b} represent the average hourly solar radiation intensity, surface area of the solar still, average hourly production rate of distilled water, latent heat of evaporation, and water temperature in the basin, respectively.

The vaporization latent heat of water (h_{fg}) is calculated as a function of water temperature in the basin (T_{b}) from **[33]**, **[34]**:

$$h_{\text{fg}} = \left(1 - 9.4779 \times 10^{-4} T_{\text{b}} + 1.3132 \times 10^{-7} T_{\text{b}}^2 - 4.7974 \times 10^{-9} T_{\text{b}}^3\right) \times 2.4935 \times 10^6 \tag{2}$$

Eq. (2) allows for calculating the solar still's energy efficiency, indicating how effectively it converts solar energy into distilled water production. As for the integrated solar still (ISS), its energy efficiency generally depends on the amount of energy consumed by the paddle wheel motor during its operation time **[29]**:

$$\eta_{\text{daily}} = \frac{\sum m_{\text{w}} h_{\text{fg}}}{3600A \sum I(t) + W_{\text{motor}}} \tag{3}$$

where W_{motor} is amount of energy consumed by the paddle wheel motor.

On the other hand, uncertainty analysis is of great importance in solar stills experiments because it is considered a correctness and accuracy guarantee of the recorded data, as it is required to be acceptable [35], [36]. The uncertainty analysis was applied to both measured and estimated parameters for the three cases and was conducted according to [37]:

$$E_r = \sqrt{\sum_{i=1}^{i=n} \left(\frac{\partial R}{\partial X_i} E_i \right)^2} \tag{4}$$

E_r denotes the results uncertainty; R = Result Value = R (x_1, x_2,…,x_n); E_1, E_2, E_n denotes the individual variables uncertainties. The required values in this study are indicated in Table 3.

Table 3. Estimating and measuring parameters uncertainty errors

Parameters (Measured)	**Specification**
Temperature	± 0.6 °C
Wind speed	± 0.05m/s
Solar irradiation	± 5 W/m^2
Flow rate of water	0.13 l/min
Parameters (Estimated)	**Specification**
Daily efficiency	± 6.1%

RESULTS AND DISCUSSION

The results will be discussed sequentially, starting from recycled GTR's effect and paddle wheel speed's effect on temperature distribution. Then, their effect on the thermal performance of the solar still will be studied, and the study will conclude with a review of the efficiencies in the various case studies.

Effect of recycled ground tire rubber on temperature distribution

An experimental thermal performance analysis was conducted on a single-slope solar still unit enhanced with recycled ground tire rubber (GTR) and a stirring device. The evaluation included hourly productivity analysis, cumulative productivity, basin water temperature, ambient temperature, still glass surface temperature, and solar radiation density. Concurrently, the thermal performance of a traditional solar still unit was evaluated to serve as a reference for comparison with the current enhanced solar still.

Figure 4a illustrates the variations in solar radiation intensity, basin water temperature, glass surface temperature of the still, and ambient temperature for the conventional solar still unit (case 1). Solar radiation intensity gradually increased, peaking at its maximum value (1120 W/m²) around 13:00, after which it began to decrease gradually. The highest recorded temperatures were 74 °C, 56 °C, and 48 °C for the basin water temperature, glass surface temperature, and ambient temperature, respectively, at 13:00.

Figure 4b-d depict variations in solar radiation intensity, basin water temperature, internal glass surface temperature of the distiller, and external ambient temperature for the enhanced solar distillation device with different filling ratios (33%, 66%, and 100%) in case (2), during the testing period (from 6:00 to 18:00). Analysis and evaluation of these figures reveal that the basin water temperatures are higher than those in case (1). Specifically, temperatures were 81 °C, 84.6 °C, and 87.4 °C at 13:00 for ratios of 33%, 66%, and 100%, respectively. In case (2), the basin water temperature increased by 7.0 °C, 10.6 °C, and 13.4 °C compared to case (1).

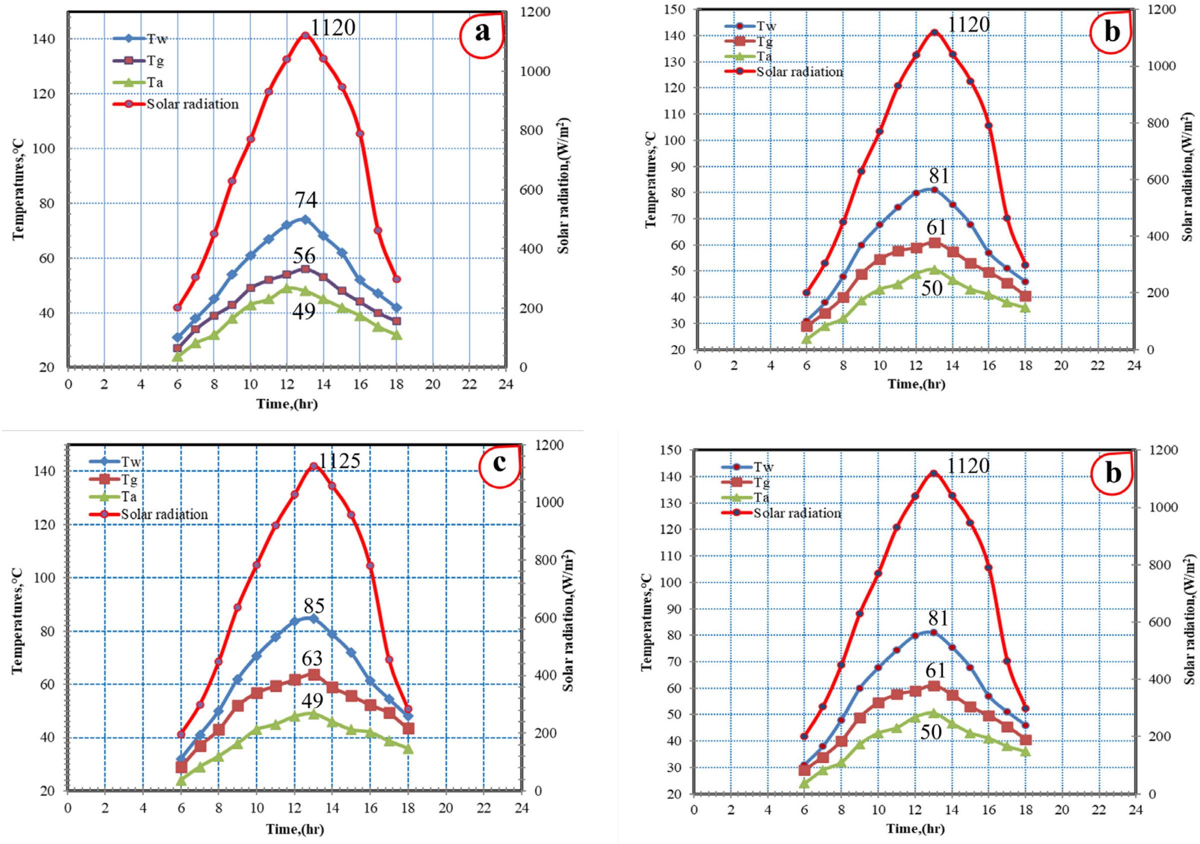


Figure 4. Hourly solar radiation variation and temperature on July 05, 2024, for: a) conventional solar still, b) still with 33% Rubber, c) still with 66% Rubber, d) still with 100% Rubber

The enhanced thermal energy absorption by the recycled GTR in varying filling ratios directly contributes to this temperature increase, and it subsequently transfers this energy to the basin water during daylight hours. After 13:00, as solar radiation gradually decreases, the recycled (GTR) retains a portion of the absorbed heat as stored energy, which continues to supply it to the basin water. This results in the basin maintaining higher water temperatures for a longer duration during daylight hours than case (1), thereby increasing the evaporation rate and, consequently, the water productivity, as anticipated.

It is noteworthy to mention that the inner glass surface still experienced a significant increase in temperature during daylight hours compared to the case (1). At 1:00 PM, 61 °C, 63.8 °C, and 66 °C were observed for filling ratios of 33%, 66%, and 100%, respectively. In case (2), the water basin temperature increased by 5.0 °C, 7.8 °C, and 10.0 °C compared to case (1). This increase is attributed this increase to the enhanced thermal energy absorption by the recycled (GTR) and their respective filling ratios, which boosted the water evaporation rates. Consequently, this led to higher condensation rates on the inner surface of the distillation glass, which in turn resulted in increased temperatures due to heat transfer from the condensed water (the latent heat of evaporation) during daylight hours, compared to the glass surface under case (1).

The evaluation and analysis of the previous experiments for the enhanced solar still with recycled (GTR) at 100% filling ratio (case 2) revealed that this configuration yielded the best thermal performance and productivity compared to other cases.

Effect of paddle wheel speed on temperature distribution

The experiments were conducted on July 10, 2024, with the addition of the paddle wheel inside the still (case 3) to induce stirring of the recycled (GTR) and water, as well as to create air currents inside the still at rotation speeds of (30, 60, and 90 rpm), while maintaining the recycled (GTR) filling ratio at 100%.

Figure 5a-c illustrates the variations in solar radiation intensity, water basin temperature, internal glass surface temperature of the still, and ambient outside temperature for the enhanced solar still with a 100% recycled (GTR) filling ratio (case 3) during the testing period (from 6:00 to 18:00). Furthermore, these figures indicated that the water basin temperatures were lower than those in case 2 at the same immersion ratio. Specifically, temperatures were recorded at 85.3 °C, 83.6 °C, and 81.8 °C at 13:00 for 30, 60, and 90 rpm rotation speeds, respectively. The decrease in water basin temperature in case 3 was 2.3 °C, 4.0 °C, and 5.8 °C compared to case 2. The stirring and mixing process of rubber granules and water increases the surface area for evaporation, which directly contributes to this decrease. Additionally, the transformation of heat and mass transfer from the convective load to the forced load results in increased latent heat loss from the basin water, known as latent heat of evaporation, which lowers its temperature during daylight hours. The magnitude of this temperature drop depends on the rotation speed.

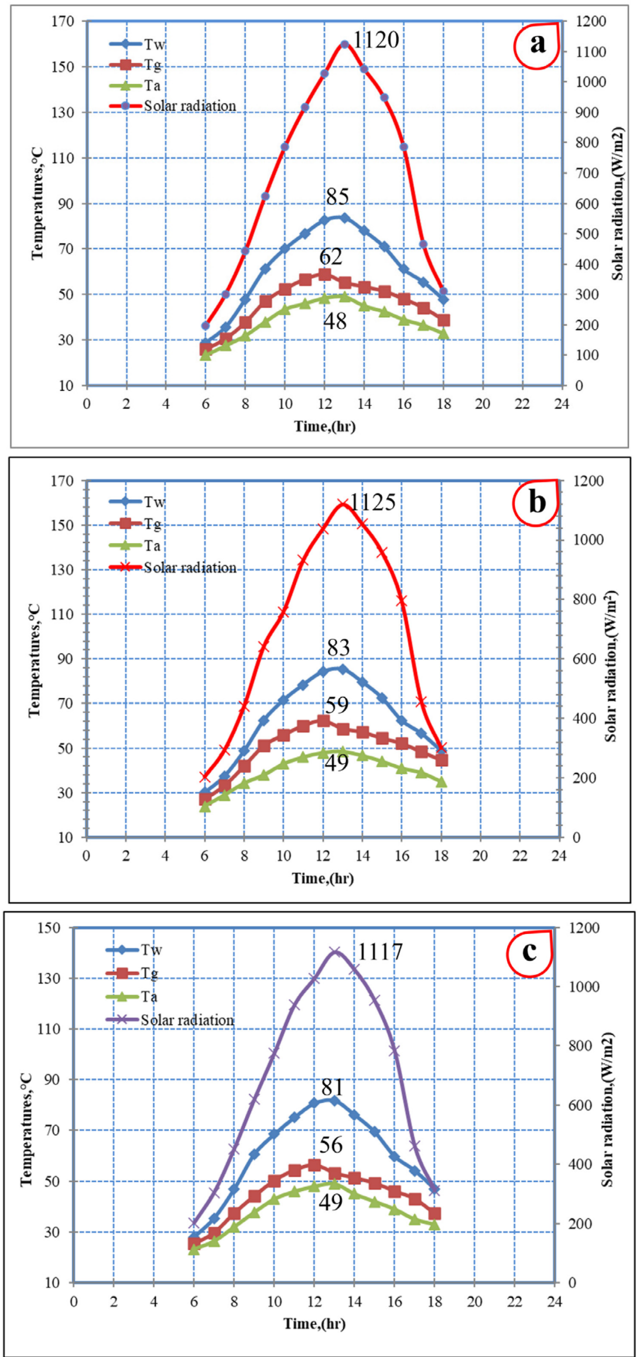
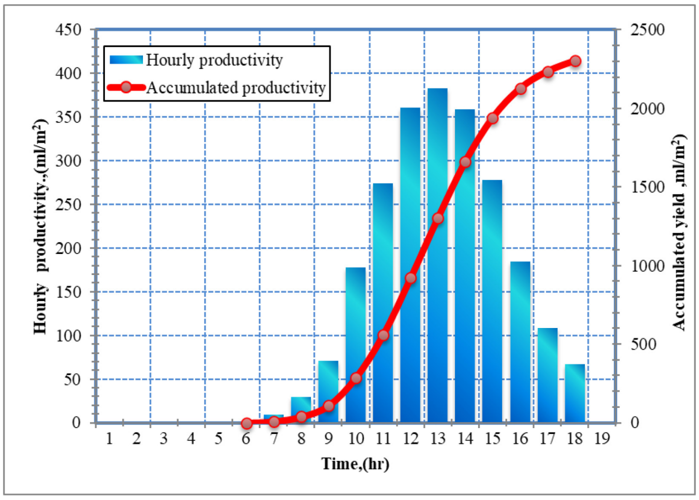


Figure 5. Effect of paddle wheel rotational speed on the hourly solar radiation and temperature for solar still with Rubber (100%) on July 10, 2024, at: a) 30 rpm, b) 60 rpm, and c) 90 rpm

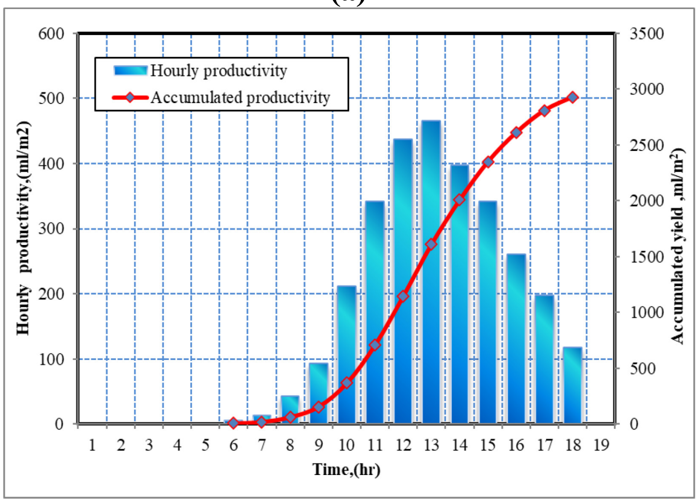
Effect of recycled ground tire rubber on energy performance

Energy performance is a crucial factor in evaluating solar stills because it gives an impression of the manufactured model's effectiveness and the product's quality [38], [39]. Hourly cumulative water productivity was recorded for cases 2 and 3, and then they were compared with case 1 to conduct a rigorous assessment of energy performance. **Figure 6a** shows that the maximum hourly productivity for case 1 was approximately 383 ml/m² at 13:00, with a cumulative productivity of 2302 ml/m² over the testing hours. The experimental findings show that hourly productivity is directly related to the temperature change between the glass cover and the water basin. Therefore, the period from 6:00 to 9:00 shows no productivity due to the low-temperature difference between the glass and water. This analysis underscores the critical role of temperature differentials in enhancing water productivity in solar stills, highlighting the impact of design modifications such as recycled (GTR) filling and speed paddle wheel (case 3) on improving overall energy efficiency and water production rates.

Figure 6b demonstrates that the hourly productivity of case 2 is greater than that of case 1 during the testing periods from 6:00 to 18:00 due to the presence of recycled (GTR). These granules enhance the absorption and direct energy transfer to the basin water, raising its temperature. This positive effect leads to higher basin water evaporation rates. Additionally, temperatures significantly differ between the basin water and the internal glass surface, enhancing distilled water's productivity. **Figure 6a-c** indicates a linear relationship between the recycled (GTR) filling ratio and hourly and cumulative productivity. At 33%, 66%, and 100% recycled (GTR) filling ratio, hourly productivity peaked at approximately 466 ml/m², 582 ml/m², and 699 ml/m² at 13:00, and cumulative productivity reached 2929 ml/m², 3690 ml/m², and 4491 ml/m² for the respective testing hours.



(a)



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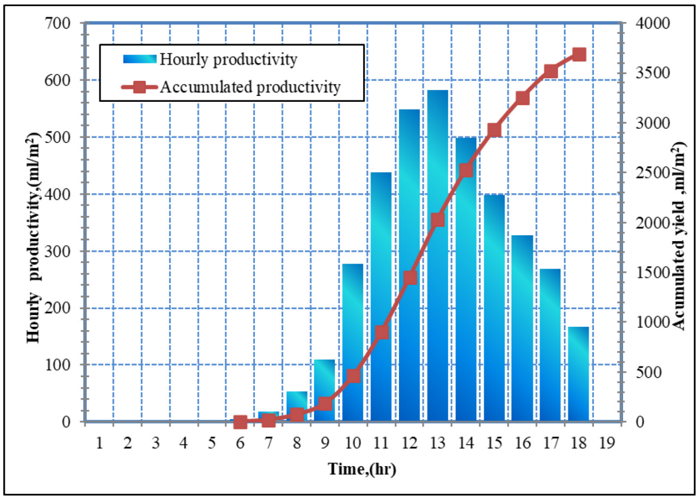

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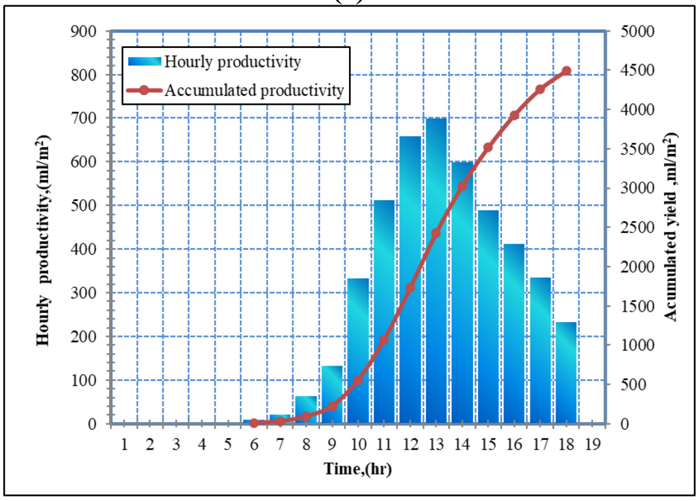


(d)

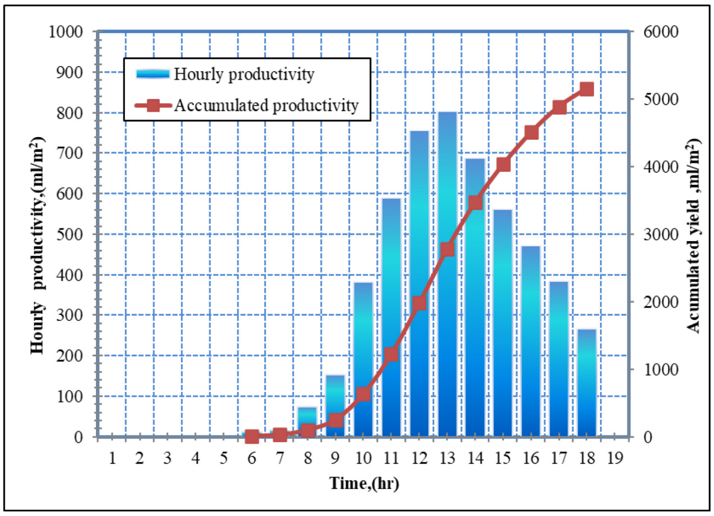
Figure 6. Hourly and accumulated productivity of water for solar still on July 05, 2024: a) conventional solar still, b) with 33% GTR, c) with 66% GTR, d) with 100% GTR

Moreover, the presence of rubber granules, compared to case 1, improved evening hourly productivity across all filling ratios. This improvement can be attributed to recycled (GTR) acting as an energy reservoir in the basin, providing additional heat for a longer period during the evening hours. Consequently, there was a significant increase in daily cumulative productivity, with improvements of approximately 27%, 60%, and 95% compared to case 1 for filling ratios of 33%, 66%, and 100%, respectively. This increase is attributed to enhanced evaporation processes within the basin, leading to increased vapor accumulation in the water and glass area, thereby improving water productivity. Separate experiments were conducted on July 10, 2024, to illustrate the effect of using the paddle wheel on productivity improvement. It was evident that hourly and cumulative water productivity increased with the rotational speed of the paddle wheel. The current results can be explained by the increased surface area for mass and energy transfer inside the still due to stirring and mixing, as well as saturation of the internal air with water vapor and the creation of vortex currents that enhance the spread rate of water vapor inside the still and its arrival at the internal glass surface over a shorter period which resulted in higher hourly and cumulative productivity of water than cases 1 and 2.

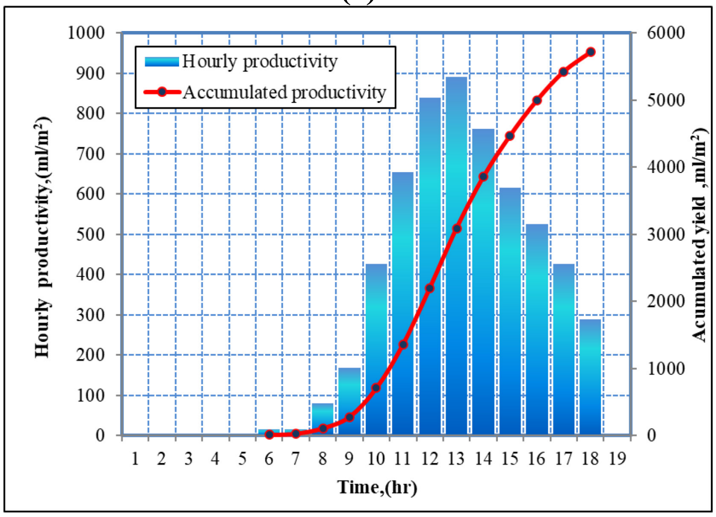
Effect of paddle wheel speed on energy performance

Regarding effect of paddle wheel rotation speed on the solar performance, **Figure 7a-c** indicates that at rotational speeds of 30, 60, and 90 rpm with 100% recycled (GTR) filling ratio, maximum hourly productivity was approximately 804 ml/m², 892 ml/m², and 973 ml/m² at

13:00, and cumulative productivity was 5158 ml/m², 5714 ml/m², and 6266 ml/m² for the respective testing hours. Based on the discussions and analysis of the above results, it can be concluded that the distillate productivity of the solar still has been significantly improved in case 3.



(a)



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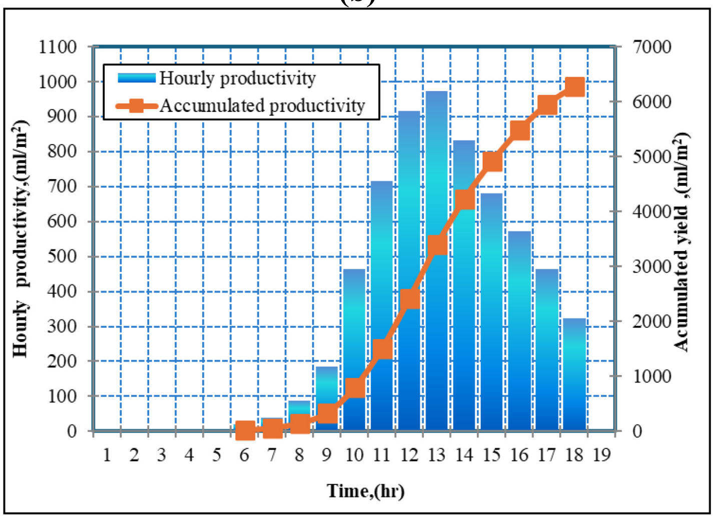

(c)

Figure 7. Hourly and accumulated productivity of water for solar still with Rubber (100%) on July 10, 2024, at: a) 30 rpm, b) 60 rpm, and c) 90 rpm

Average energy efficiency

Here, it is necessary to make the necessary comparisons and analyze the results for solar energy efficiency in the three cases described in equations 1 and 3. **Figure 8** illustrates the average energy efficiencies for all tested cases in the study. The maximum energy efficiencies for filling ratios of 33%, 66%, and 100% were approximately 22%, 33%, and 33%, respectively. In contrast, the energy efficiency for the conventional solar still (case 1), used as a reference, was 17%. In case 3, the energy efficiency of the enhanced solar still using a paddle wheel with a 100% recycled (GTR) filling ratio increased significantly compared to cases 1 and 2. The maximum energy efficiencies for rotational speeds of 30, 60, and 90 rpm were approximately 38%, 42%, and 46%, respectively. This increase can be attributed to the substantial increase in water vapor generated inside the water and glass area due to agitation and mixing and the increased surface area for energy and mass exchange, positively affecting the rate of vapor condensation and heat transfer on the condensing surface.

In case 3, despite the additional energy consumption from the motor power supplied to the stirring device, it achieves high daily water productivity compared to cases 1 and 2. The energy efficiency of case 3 significantly increased, reaching approximately 170% when compared to energy efficiency of the conventional solar still.

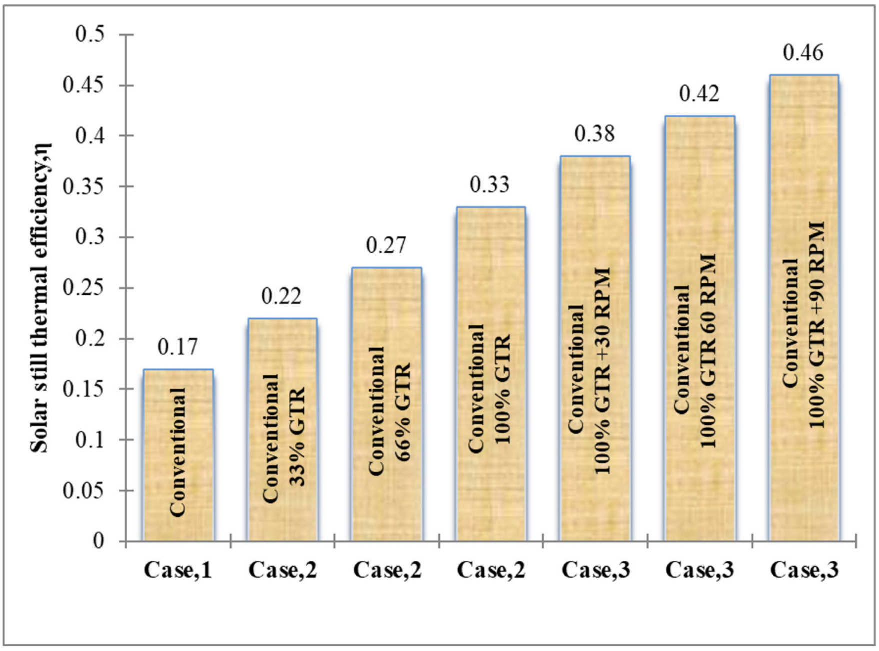

Figure 8. Average thermal efficiencies for the three cases in the study

CONCLUSIONS

An experimental investigation was conducted on an improved solar still unit by adding recycled granules of tire rubber and integrating an agitation device under the harsh climatic conditions of Basrah city to enhance the unit's energy efficiency and water productivity.

The study concludes with the following key findings:

1. Using recycled tire rubber granules with the paddle wheel in the still basin positively impacts thermal performance and water productivity.
2. The solar still's total accumulated productivity and energy efficiency for case 3 were 6266 ml/m² and 46%, respectively, 172% and 170% higher than the conventional solar still in case 1.
3. It was also observed that increasing the proportion of recycled granule tires has a sound on energy efficiency and water productivity, as increasing the proportion from 33% to 100% increased productivity from 2929 to 4491 ml/m², respectively.

4. Increasing the stirring speed has an impact on energy efficiency and water productivity, as increasing the speed from 30 to 90 rpm increased productivity from 5158 to 6266 ml/m^3, respectively.
5. Adding recycled granules of tire rubber and using the paddle wheel significantly improved the unit's energy efficiency and water productivity. By evaluating energy efficiency and water productivity, this unit can be reliable in remote areas and have good productivity compared to conventional solar stills.

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