http://doi.org/10.25130/ISC-CS.2025.036

The effect of the tilt angles of the single-tilt and single-basin solar still on productivity and efficiency

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ABSTRACT

Researchers are turning to renewable energy sources as a viable solution to the worldwide water deficit and fossil fuel pollution. Solar stills simulate evaporation and condensation in rains. This process removes pollutants, organic and inorganic chemicals, and bacteria from the basin without transport by the vapour, producing high-quality water.

The single-basin, single-tilt solar still was created and implemented in this research. The practical part involved monitoring the amount of distilled water generated at three tilt angles (22°, 28°, 34°) during a month in Tikrit, located at (34.6°N, 43.68°E). We also used experimental data to create a model that relates water production to solar radiation, maximum ambient temperature, and wind speed. The highest yield of 4.5 litres per day and 45% operational efficiency was achieved at 28° tilt angle. Local manufacturing at low cost made the gadget economically viable.

Keywords: Single Slope Solar Still; Tilt Angles; Productivity; Efficiency; Solar Energy

1. Introduction

Water is the most important element necessary for the survival of living organisms on Earth. It is the primary source for completing vital processes on Earth. In recent years, due to the significant growth in the world's population and the growth of industries, as well as the widespread pollution of fresh water, this has led to a shortage of potable water. This has prompted researchers to explore various methods to obtain freshwater sources to meet a portion of daily freshwater needs. Researchers have relied on the option of producing fresh water using solar energy [1]. Solar distillation is one of the most important methods used in water purification and desalination. The idea is to use solar radiation as a source to increase the temperature of impure (raw) water. The vapor then condenses on the inner surface of the desalination system to produce pure water droplets. A solar desalination system can be easily designed using inexpensive and readily available materials. Freshwater desalination technologies can be classified into three main categories: evaporation, filtration, and crystallization [2]. A single-basin, two-slope solar still was studied using local materials. Measurements were conducted in Salah al-Din Governorate (latitude 34.46° east of the Tigris River). The study included distillation characteristics and heat transfer. Results in March showed a gradual increase in the temperature of the water and glass, and an increase in efficiency over time of up to 40% [3]. Tests were

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conducted on a single-basin solar still in Baghdad Governorate during April and May. The results showed that the daily production of a 20.34 m² still was approximately 0.8 liters [4].

Trend-type solar stills were developed and comprehensively analyzed, focusing on techniques to improve performance and increase water production and efficiency. The study aims to inform researchers and stakeholders about developments in the use of solar energy, particularly since these low-cost systems provide effective solutions for securing fresh water in rural and remote areas. It also highlighted the ongoing want for layout improvements to improve thermal and production performance [5]. Several designs and traits of solar stills had been reviewed, and the outcomes showed that the variation in their productivity is without delay related to their design variations [6].

- The effect of three layout factors on solar still overall performance became studied: glass transmittance, warmth transfer coefficient, and glass absorptivity. Theoretical and experimental effects confirmed that the heat switch coefficient has a large impact, especially at low values. Reducing it from zero (W/m²·K) to 30 (W/m²·K) elevated manufacturing through 64.02%, and performance elevated by way of 23.28% while the glass absorptivity became reduced from 0.1 to 0.01 [7].

- Solar stills with cylindrical and rectangular tanks and numerous top casings have been studied, and it changed into found that cylindrical tanks provided better overall performance and higher water manufacturing. The effects also confirmed that copper metallic is the maximum efficient in generating water the use of sun strength [8]. A solar nevertheless turned into designed that is based on feeding the basin with preheated water to transform infected water into potable water. This changed design contributed to accelerated production of natural water and improved distillation efficiency [9].

A comprehensive assessment of studies on sun-powered water stilling in India changed into carried out, in which sunlight is used to split fresh water from salts and contaminants. The manner relies on evaporating a skinny layer of salt water and condensing the vapor on a transparent cowl to acquire it as natural water. This technique is effective at putting off salts and microbes, making it appropriate for desalinating seawater and imparting ingesting water in sunny regions [10].

-Modern technology used to enhance the overall performance of sun stilling structures have been reviewed, with new answers proposed to growth efficiency and productivity. The effect of several factors on overall performance became analyzed, and technologies that decorate thermal efficiency had been developed. The study proposed future directions for improving system performance under standard operating conditions [11].

-A solar still was designed that relies on radiation, convection, and thermal conduction to remove contaminants from water. The model produces 1.5 liters of purified water from a 14-liter capacity in 6 hours, with an efficiency of 64.37%. [12]. The performance of a single-basin solar distillation system with a double 45-degree angled cover was tested in Indonesia under rainy conditions, with an average distillation efficiency of 34.3%. Condensers demonstrated five times greater efficiency at night than during the day, due to the higher water temperature in the basin compared to the glass cover. Therefore, using materials as a thermal energy storage device during the day and releasing them at night significantly enhances condensate production [13]. In the current research, a single-basin, single-inclined solar still was manufactured and tested at different inclination angles. The productivity was (3L) at angle (22°) and the efficiency was (30%), the productivity was (4.5L) at angle (28°) and the efficiency was (45%), the productivity was (2.44L) at angle (34°) and the efficiency was (24.40%), it was proven that the still has the best angle and productivity at (28°).

2. Theoretical Section

1- Internal Heat Transfer

Several heat transfers occur within the solar still: convection, radiation, and evaporation. Convection and evaporation heat transfers occur simultaneously and do not depend on radiative heat transfer.

http://doi.org/10.25130/ISC-CS.2025.036

2-Convective Heat Transfer from Water to Glass

The energy transfer by convection between the water and the cover, measured in W/m², is given by the following equation [14]:

$$q_{cw\text{-}g} = [h_{cw\text{-}g}\,(T_w - T_g)] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where

T_W represents the surface temperature of the brine.

T_g is the temperature of the inner surface of the glass cover, measured in Kelvin.

hcw-g is the convective heat transfer coefficient, measured in W/m² (K). It depends on the temperature difference between the evaporating and condensing surfaces, the physical properties of the fluid, the flow properties, and the geometry of the condensing surface.

3- Convective heat transfer from the basin to the brine.

Convective heat transfer between the black surface of the basin and the water is given by the equation [15]:

$$q_{cb\text{-}w} = [h_{cb\text{-}w}\,(T_b - T_w)] \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where (T_b) represents the temperature of the black surface.

4-Heat transfer by radiation from the salt water to the glass cover. Heat transfer by thermal radiation ($q_{rw\text{-}g}$) is expressed by the equation [16]:

$$q_{rw\text{-}g} = [h_{rw\text{-}g}\,(T_w - T_g)] \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$q_{rw\text{-}g} = [0.96\,\sigma\,(T_w^4 - T_g^4)] \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where σ represents the Stefan-Boltzmann constant and is equal to 5.99×10-8 W/m2.k4

$h_{rw\text{-}g}$ is the radiation heat transfer coefficient.

5- Evaporation

Evaporation is the mechanism by which water is separated from the salt inside a solar still, and it is the primary purpose of the still. Evaporation involves the transfer of mass and heat. The heat transfer of evaporation per unit area is expressed by the equation [17].

$$q_{ew\text{-}g} = [h_{ew\text{-}g}\,(T_{W50} - T_g)] \ldots\ldots\ldots\ldots (5)$$

$q_{ew\text{-}g}$ represents the evaporation heat transfer from water to glass.

hew-g represents the evaporation heat transfer coefficient.

6- Efficient Solar Distillation

Efficiency is a measure of the efficiency of heat transfer during various processes within the distillation. It is also defined as the ratio of the heat used in the evaporation process to the actual energy absorbed by the water. It can be expressed using the equation [18]:

$$\eta = \frac{(\boldsymbol{m} \times \boldsymbol{L_w})}{(\boldsymbol{G} \times \boldsymbol{A} \times \Delta \boldsymbol{t})} \ldots\ldots\ldots (6)$$

m: The mass of condensed water in a given period of time, measured in gm.

L_W: The latent heat of vaporization of water, measured in J/gm.

A: Area (m2)

Δt: The time interval (sec).

Daily efficiency (η_d) can also be given in the following formula [18]:

$$\eta_d = \frac{\Sigma\, m \times L_w}{\Sigma\, A \times G \times t} \ldots\ldots\ldots (7)$$

3. Practical Part

A single-slope solar still was constructed from 2mm thick wood of varying lengths. The lower base of the still was 130cm long and 150cm wide. The rear side of the still was 90cm high and 150cm wide. The sloping sides on the right and left sides were 90cm high and 130cm wide. All internal parts were coated with a solar reflector to maximize the amount of radiation inside the still. Three angles (34°, 28°, and 22°) were used. Therefore, side edges were designed inside the still to secure the glass portion. These edges were 3cm wide. At the end of the sloping section, there is a channel to collect the water produced by the still into a water collection cylinder located at the end of the channel. The inclined upper cover of the still (the glass part) used in this research is made of regular glass with a thickness of (6 mm) and different lengths depending on the angle used. This part allows the penetration of solar rays into the still. As for the basin placed inside the still and used in this research, two basins were used. The first is an aluminum basin. The inner surface of which, containing the water, was painted with a matte black dye to increase the absorption of solar rays and prevent their reflection outside the still. The length of this basin was (70 cm), its width was (70 cm), and its height was (8 cm). As for the second basin, a glass basin was made, and the inner surface of which, containing the water, was painted with a matte black dye to increase the absorption of solar rays and prevent their reflection outside the still. The length of the basin became (a hundred cm), its width changed into (one hundred forty cm), and its height become (11 cm). The outer part of the still was covered with cork to isolate it from the external environment Figure (1).

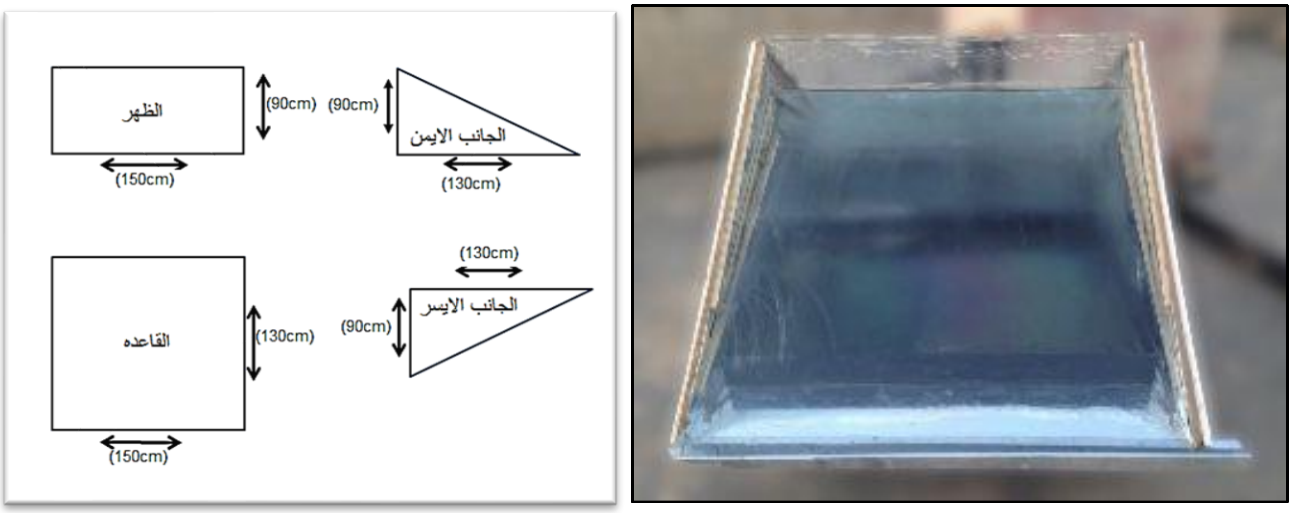

Figure 1. shows each part of the distiller and their lengths.

4. Results and calculations

Figure (2) represents the temporal relationship between solar radiation and the solar still's productivity at three glass cover tilt angles: 22°, 28°, and 34°. The figure shows that solar radiation begins to gradually increase from 8:00 AM, reaching its peak between 12:00 PM and 2:00 PM, exceeding 850 W/m². It then gradually declines until the end of the day. This behavior is consistent with the natural daily cycle of the sun and is a key factor in determining the performance of solar thermal systems [19].

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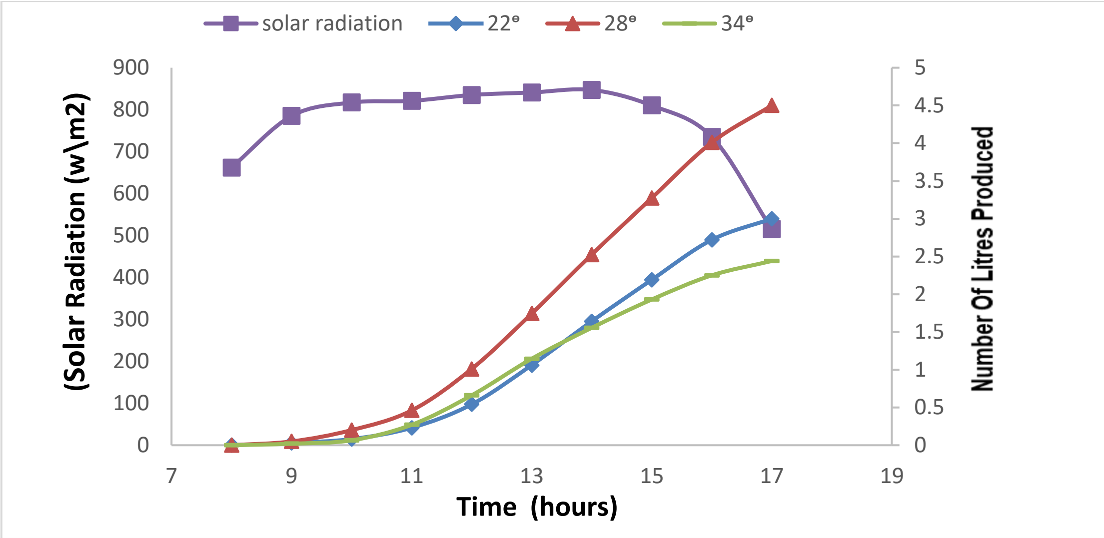

Fig. 2: represents the relationship between productivity, solar radiation and time for each angle at each hour.

We note that the 28° angle showed the highest water productivity of the still, exceeding 4.5 liters during the peak period. The 34° angle followed with moderate productivity, while the 22° angle showed the lowest performance throughout the day. This behavior can be explained by the effect of the tilt angle on the amount of solar radiation absorbed: the optimal angle achieves a greater match between the angle of incidence of solar rays and the glass surface, which enhances thermal energy absorption [20]). Condensation efficiency also matters: Larger angles (such as 34°) increase the velocity of distilled water droplets sliding across the glass, reducing surface shading and increasing collection efficiency [21], but at the same time, they reduce the amount of incoming radiation compared to the 28° angle.

A clear match is evident between the solar radiation curve and the yield curve at the 28° angle, indicating that this angle maximizes the use of available radiation during daylight hours. Recent studies support that the optimal angle should be proportional to the local latitude, often ranging between 25° and 30° in semi-arid regions [22].

The graph illustrates the relationship between the efficiency of a Single Slope Solar Still and time during different daytime hours for three different tilt angles (22°, 28°, and 34°). It is observed from the graph that the efficiency increases over time at all angles due to the rising solar irradiance as the day progresses, which enhances the evaporation of water inside the still and increases the distilled water output [23].

The 28° tilt perspective suggests the very best performance in comparison to the opposite two angles, accomplishing about 45% at 17°. This suggests that setting the lean perspective toward 28° allows for most efficient solar radiation reception on the nevertheless surface, growing the surface temperature and therefore the evaporation charge [24]. The 22° tilt perspective comes in 2d, even as the 34° tilt perspective facts the lowest performance. This can be defined via the reality that the improved tilt reduces the attitude of direct prevalence of daylight, leading to a discount in the quantity of thermal strength absorbed [25]. In trendy, this variation in performance with the tilt angle emphasizes the significance of fixing the solar still's surface perspective in step with its geographical area and time of year to obtain the best efficiency in sun desalination [26].

Figure (3) illustrates the relationship between the inner temperature in a solar nonetheless and sun radiation at specific tilt angles at some point of the day. Solar radiation depth begins to increase in the morning and reaches its top between eleven and 3 p.M., then steadily decreases as nighttime strategies, a herbal pattern reflecting the movement of the sun across the sky throughout the day [27]. The inner temperature within the nonetheless immediately follows this sample, growing with growing sun radiation, indicating that the quantity of power absorbed by means of the nonetheless normally influences its inner temperature. At a tendency angle of 28°, the temperature registers its highest fee, drawing close to 80C, indicating that this attitude makes the first-rate use of sun radiation, increasing the performance of strength absorption and conversion into internal heat [28]. In comparison, an inclination attitude of 22° suggests the bottom internal temperature in comparison to other angles, which means that the nevertheless at this perspective absorbs much less energy and is consequently less green at heating and evaporating water. The tilt attitude of 34° additionally shows a higher temperature, but it's miles decrease than 28°. This can be explained by using the truth that a larger tilt can also reduce the perspective of direct radiation prevalence on the floor of the still, affecting the amount of absorbed strength [29]. Therefore, these consequences spotlight the significance of exactly adjusting the lean perspective to improve the overall performance of the sun nevertheless and increase its internal temperature, which enhances the performance of desalination the usage of sun electricity.

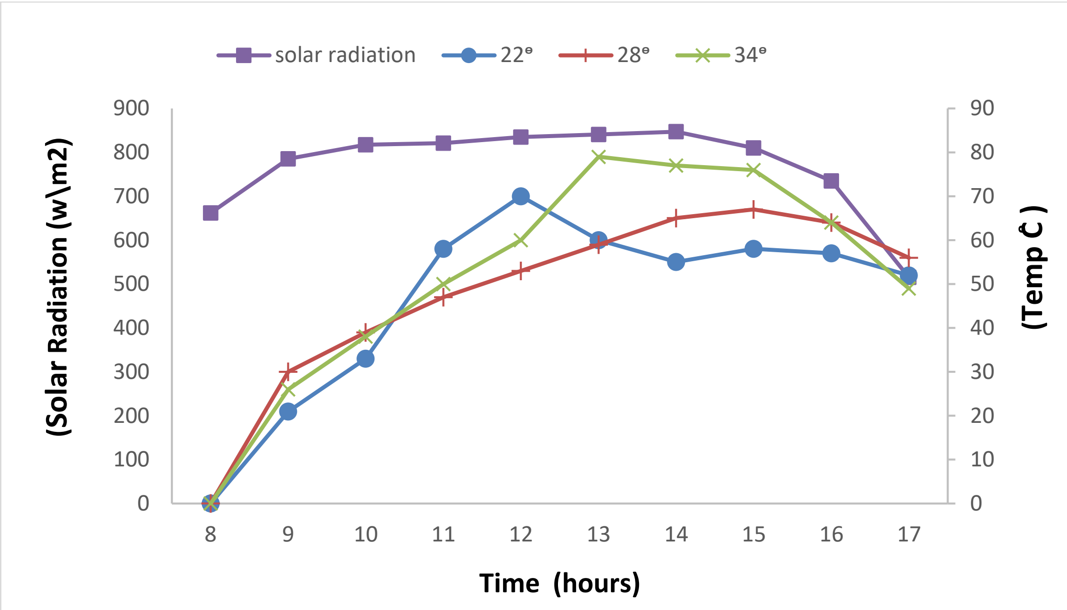

Fig. 3: shows the relationship between the internal temperature and solar radiation for each angle at each hour.

Conclusions

The experimental results showed that the productivity of a solar nonetheless depends notably on numerous operational and environmental elements. First, it become proven that decreasing the depth of the water within the tank will increase evaporation efficiency, ensuing in a higher extent of distilled water. The inner strain of the nonetheless became additionally found to play a key function in its efficiency; defective sealing and air entry cause a drop in internal temperature and for this reason reduced productivity, as found at the 28° perspective. Furthermore, adding water at some stage in operation can negatively impact performance, as the delivered water is commonly at a lower temperature, requiring overtime to heat it, as a result temporarily decreasing the evaporation charge. Furthermore, sun radiation turned into shown to play a pivotal position, with productivity and efficiency increasing because the radiation intensity will increase and decreasing because it decreases. Finally, measurements performed at 3 different inclination angles confirmed that the

28° perspective become the most green, with a maximum productiveness of four.5 liters per day and an efficiency of forty-five.%

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