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An analysis of the productivity of an active solar still vs. a passive solar still over the autumn and winter seasons in the city of Kirkuk, Iraq

Fatima Najaf Ahmed [1], Sami Ridha Aslan [2]

[1]Northern Technical University/ Kirkuk Technical Engineering College, Renewable Energy Research Center Kirkuk, Northern Technical University, Iraq
[2]Northern Technical University/ Kirkuk Technical Engineering College, Iraq.

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Corresponding Author:
Fatima Najaf Ahmed

Email:
Fatimanajaf88@ntu.edu.iq

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ABSTRACT

Solar distillation is seen as a sustainable and practical way to solve water shortages in rural regions, which are experiencing an increase in demand for clean water. Over the course of four months in the autumn and winter, experiments were carried out in Kirkuk, Iraq, located at 35.4666° N, 44.3799° E. We directly inserted eight vacuum tubes into the solar still to boost the passive still's production. The area of it is 1 square meter. The productivity recorded in each month was as follows: 1208 ml in November, 2653 ml in December, 2541 ml in January, and 1794 ml in February. The active still showed a 277.5%, 237.5%, 245.7%, and 233% increase in productivity compared to the passive still, respectively. The active distiller achieved a thermal efficiency of 18.6%, 18.8%, 24.8%, and 36%, respectively. This was higher than the thermal efficiency of the passive distiller, which was only 16%.

Introduction

Currently, water scarcity is a significant global concern, affecting millions of people who lack access to clean and safe drinking water. This issue is escalating because of various aspects such as population growth, climate change, and inadequate water resource management [1]. As per the United Nations World Water Development Report, 26% of the worldwide population, which amounts to 2 billion individuals, lacked access to drinking water services that were safely managed [2]. Polluted water is a major source of global sickness and infection. Improper water use, including drinking, can transmit many infectious diseases. Thus, isolated and dry locations need long-term, safe drinking water [3]. Drinking water with high TDS may be harmful. Water below 600 mg/L of TDS is considered palatable [4].

Fuel, the primary energy source on Earth, is essential for desalination processes. The depletion of fossil fuels puts environmental quality at risk.

Renewable energy sources can replace fossil fuels entirely due to their abundance and lack of pollution [5]. Solar energy is an exceptionally practical and pragmatic energy source when considering sustainable energy. Its quantity is considerable on Earth. It finds applicability in a variety of fields, such as solar distillation [6]. In order to generate potable drinking water, solar distillation is one of the desalination procedures that is both the least expensive and the least energy-intensive [7].

Solar still consistently decreases the release of nitrogen oxide, carbon dioxide, and sulfur dioxide into the atmosphere over time [8]. Solar still is a device that uses the solar energy to desalinate water, providing potable water in isolated places far from urban center [9]. Single-slope solar stills are a common use in this field. Solar stills are popular since they are easy to make and simple in design [10]. Passive solar stills rely on design elements such as basin material, glass cover thickness, glass cover angle, insulation material, and water basin depth. Environmental elements consist of air temperature, solar radiation intensity, and wind speed. Its disadvantages include low productivity [11,12].

To enhance the efficiency of solar stills, we can connect them to vacuum tubes, nanofluid, energy-storing materials, or reflective mirrors to increase the evaporation rate [13]. Solar stills linked to evacuated tubes have been validated in theoretical research as a long-term, eco-friendly solution to the problem of water scarcity in rural area [14]. A solar collector with evacuated tubes enhances daily production by 2,175 kg/m2 to 2.95 kg/m2 (35.63%) on clear days [15]. Connecting evacuated tubes to a solar still with a stepped basin in India increases productivity by 63.8% under local weather conditions [16]. The analysis of the exergy showed that using a pyramid solar still with ETC doubled the highest hourly exergy. This might be because there is a vacuum gap between the two glass surfaces of the evacuated tubes. outcome of decreased heat loss [17].

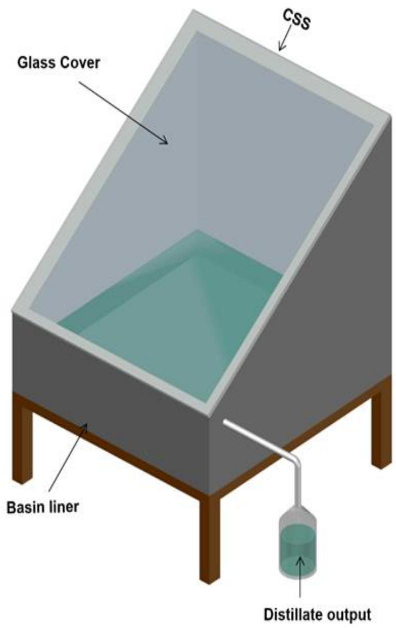
According to the available information above, it's possible that attaching vacuum tubes to a passive solar distiller increases productivity. However, no research has been conducted on directly connecting vacuum tubes to a solar still.

The present study involved an experimental analysis of a single-slope solar still that was directly connected to evacuated tubes. The productivity of this solar still was then compared to that of a passive solar still. The experiment was set up in the autumn and winter conditions of Kirkuk.

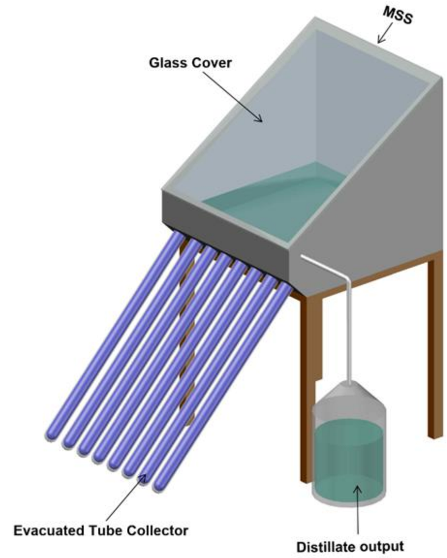
1. Experimental setup and procedures

1.1 Experimental setup

The system consists of two solar stills with a single slope that were placed in Kirkuk, Iraq (latitude: 35.4686, longitude: 44.38933), and their orientation is southward so that they can absorb maximum amount of a solar radiation, as shown in the Fig. 1. The autumn and winter months of November 17, 2023, December 1, 2023, January 26, 2024, and February 10, 2024 were used for the studies. The distillers' galvanized iron construction had a 2 mm thickness and a 1 m2 surface area. They are both solar stills with a single slope. The initial height is 15 cm, while the second is 85 cm. A glass cover with an angle of 35° represents Kirkuk's latitude. Thermal conductivity of 0.76 watt/m k and a thickness of 4 mm [18]. The installation was sealed with silicone rubber to ensure that no steam would leak. To make the water evaporate faster, matte black paint was applied to the inside of the basin to take up more sunlight. To make it easier for water to flow into the collecting container, we set the collection channel at an angle of 5° and used a raft to regulate water level inside basin. The sides and bottom were insulated with 12 mm-thick Armaflex to decrease heat loss to the atmosphere [19]. Solar radiation that enters through the glass cover of a passive solar still heats water in it. To further enhance the water heating process, the upgraded distiller is angled at the base and directly linked to eight vacuum solar tubes. Its 50-degree tilt allows water to easily flow into and out of the solar still. The vacuum tubes have a 150-cm length, an outer diameter of 47 ml, and an inner diameter of 34 ml. There is space between them to reduce heat loss as shown in fig.2. The Table 1. displays the device's dimensions.



a) Passive solar still



b) Active solar still

Fig. 1. Schematic diagram of experimental setup of a) passive and b) active solar still.

Fig. 2. Photograph of experimental setup

1.2 Working and experimental procedure of passive and active solar still

In order to enhance the permeability to sunlight, dust is eliminated from the evacuated tubes and distillers' glass surfaces prior to commencing the experiment. Following this, water is introduced into both the conventional and enhanced distillers via connecting pipes from the tank. A raft measures a depth of 5 cm in both distillers. Solar radiation acts as heat source for water in the basin of a passive still through the glass cover. The water evaporates, steam rises to the top of the cover, and it condenses on the inner surface. Water then descends into a stream and, ultimately, into the collection vessel. When solar radiation heats the water in vacuum tubes in the active solar still, the hot water within the pipes ascends to the collector due to natural circulation, where it is exchanged for cold water via gravity. This process ultimately warms the water in an enhanced distillation basin, as illustrated in Fig. 3. Solar radiation infiltrating the glass cover and hot water emanating from the vacuum tubes both contribute to the water's temperature increase in the basin. Steam rises to the surface of the cover, where it begins to condense before continuing to the collection vessel via the stream. We measure temperatures with a T-type thermocouple in seven places: the water temperature in a tank feeding the stills, the inner surface of the glass cover, and the water surfaces and bottom of the basin in both stills, as shown in Fig. 4. Installed with a data logger. Solar radiation intensity, wind speed, air temperature, and relative humidity in the atmosphere are measured from 8 a.m. to 8 p.m.

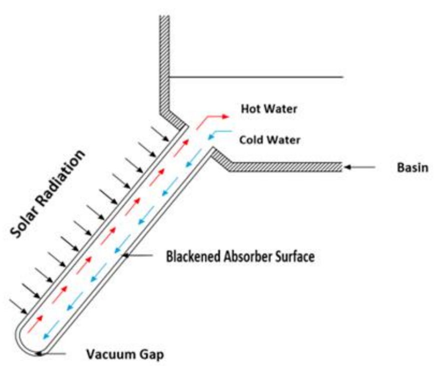
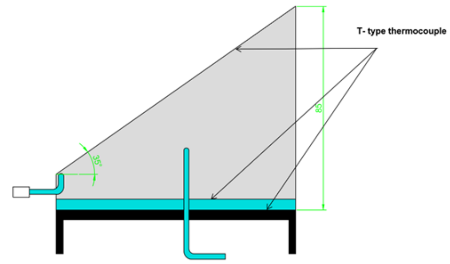
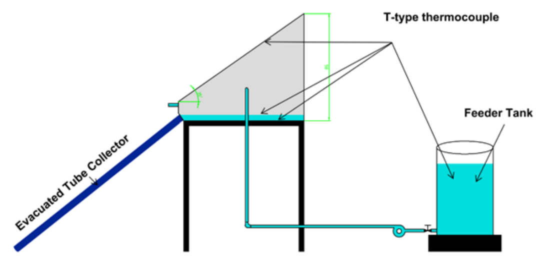


Fig. 3. Schematic of the ETC-solar still thermosyphon process



a) Passive solar distiller



a) Active solar distiller

Fig. 4. A schematic illustrating the location of thermocouples in both a) Passive and b) Active solar distillers.

1.3 Instrumentation

A solar power meter is used to measure the intensity of solar radiation. Its range is between 1-3999 watt / m^2, and its accuracy is ±10 watt/m^2. use Digital Thermo- Hygrometer to measure ambient temperature and relative humidity. An anemometer used to measure wind speed has a range of 0-45 m/sec and an accuracy of ±3 m/sec. T-type thermocouples with a range of -250 to 350 and an accuracy of 1C° are installed with a data logger. A plastic jar for measuring the resulting distilled water has a range of 0-2000 ml and an accuracy of ± 5 ml.

2. Thermal efficiency of solar still

Evaluating performance of passive and an active solar still involves considering their thermal efficiency, which is a crucial factor. An assessment is conducted to determine the thermal efficiency of a passive solar still, as follows [20]:

$$\eta_{passive} = \frac{m_{ew} \times L}{(I(t)_s \times A_s \times 3600)} \quad (1)$$

The thermal efficiency of an active solar still is:

$$\eta_{active} = \frac{m_{ew} \times \mathrm{L}}{(I(t_c) \times A_c \times 3600) + (I(t)_s \times A_s \times 3600)} \quad (2)$$

Based on equations 1 and 2, thermal efficiency of an active distiller was 18.6% on 17/11/2023, 18.8% on 1/12/2023, 24.8% on 26/1/2024, and 36% on 10/2/2024, during a period of 4 months. Furthermore, 16% of the passive solar still.

Table 1. dimension of the experimental setup

Parameter	Value
Area of solar stills	1 m²
The angle of inclination of the glass cover	35°
Glass cover thickness	4 mm
Insulation for basins and walls	Armaflex 12 mm thickness
Material of absorber plates	Galvanized iron
Sealant	Thermal silicon
Number of ETC	8
Length	150 cm
Outer diameter of ETC	47 mm
Inner diameter of ETC	34 mm
Inclination of ETC	50°
Glass material of ETC	Borosilicate glass 3.3

Result and desiccation

This study incorporates two solar stills. The first type is a passive solar still, which does not require any additives. The second type is an active solar still that is directly connected to vacuum solar tubes. These tubes serve to raise the water temperature in the still basin, thereby increasing water evaporation. This leads to higher productivity and the ability to maintain hot water. Even during the time after the sun has set, there are several environmental and design elements that have an impact on the daily output.

a. Effect of ambient temperature and the intensity of solar radiation on a solar still

Environmental factors like ambient temperature and solar radiation intensity have an impact on a solar distiller's performance [21]. Specifically, the temperature at 8 a.m. was recorded at 10.8°C, while the highest temperature reached 22°C at 3 p.m. The sun radiation intensity peaked at 12 p.m., measuring 706 on the surface of the still and 1164 on the surface of the vacuum tubes. Subsequently, air temperature and the magnitude of solar radiation progressively diminished until sunset. Fig. 5. illustrates the fluctuations in temperature and intensity of a solar radiation on December 1, 2023, as per the local time of Kirkuk city.

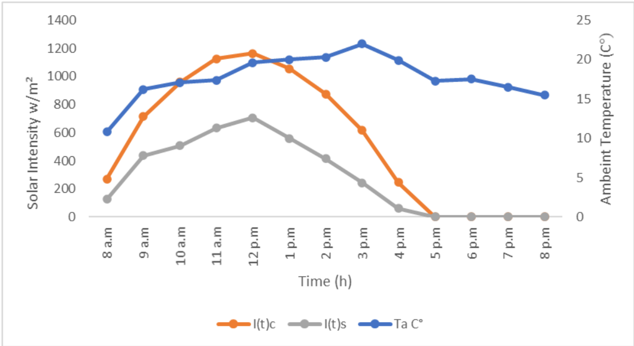


Fig. 5. Hourly fluctuation in ambient temperature and solar intensity.

b. Effect of wind speed and relative humidity on a solar still.

Wind speed and relative humidity are important environmental variables that impact the efficiency of a solar still by reducing the glass cover temperature, resulting in enhanced condensation and consequently improved productivity[3] . The **Fig. 6.** illustrates the fluctuation in temperature and relative humidity over a period of 12 hours in 1-12-2023.

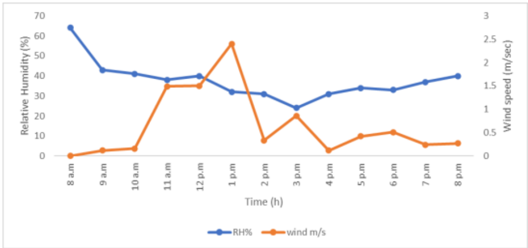


Fig. 6. hourly fluctuation in wind velocity and relative humidity.

c. Effect of adding ETC to solar still

The addition of vacuum tubes directly to the solar still results in a raised water temperature within the distiller basin. This occurs because the vacuum tubes absorb solar radiation, causing the water inside them to heat up. Cold water from the basin replaces the hot water as it rises into the distiller basin. Natural circulation aids in this process. The vacuum between the two pipes acts as an insulator, preventing heat loss to the surrounding environment. This is shown in Fig. On November 17, 2023, the active solar still achieved a productivity of 1208 ml, while the passive still achieved a production of 320 ml. This represents a 277.5% increase in productivity. The productivity of the active distiller was 2653 ml, whereas the passive distiller had a productivity of 786 ml, resulting in a percentage gain of 237.5%. The highest water temperature was 61 °C for PSS, versus 50 °C for ASS. Fig. 7. illustrates a variation in water temperature between passive and active distillers' basins on December 1, 2023.

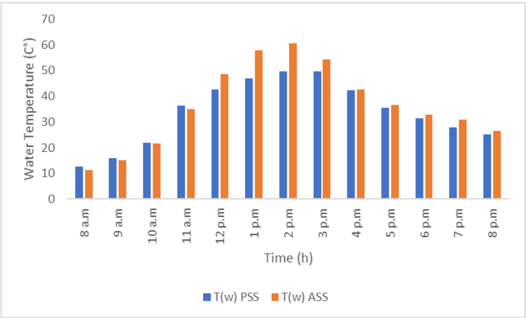


Fig. 7. hourly variation of a water temperature of PSS and ASS.

On January 26, 2024, the production of the active distiller increased by 245.7%, reaching 2541 ml, compared to the passive distiller's output of 735 ml. The **Fig.8.** illustrates the disparity in daily productivity during a 12-hour period between active and passive distillers.

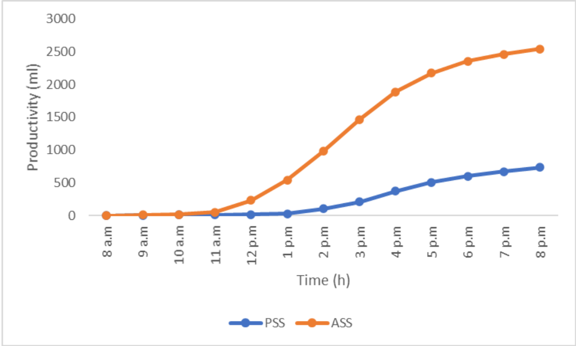


Fig. 8. daily productivity in PSS and ASS.

The productivity improvement percentage reached 233% on February 10, 2024, with the active distiller achieving a productivity of 1794 ml and the passive distiller achieving 538 ml.

The **Fig. 9.** illustrates the temperature variance resulting from the high wind speed between a water's surface and the inner surface of a glass cover of ASS.

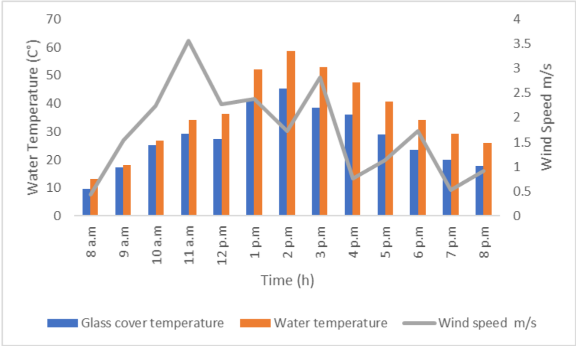


Fig. 9. hourly variation of temperature between a water surface and the inner surface of a glass cover

Based on the above-mentioned data, the active distiller consistently maintains higher production than the passive distiller throughout various weather conditions over a period of 4 months.

Fig. 10. displays the productivity of both active and passive distillers over a period of 4 consecutive months.

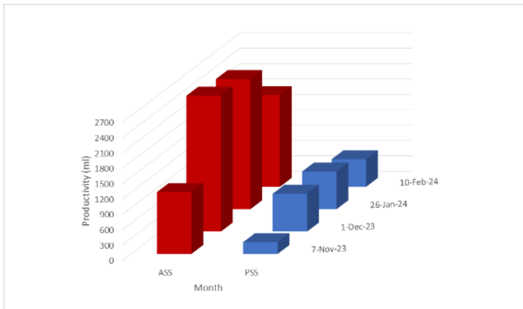


Fig. 10. The cumulative productivity of both active and passive distillers during a period of four consecutive months.

It is seen that the active distiller achieved its optimum level of productivity at 3 p.m. on the experimental days throughout a span of four consecutive months, as depicted in the **Fig. 11.**

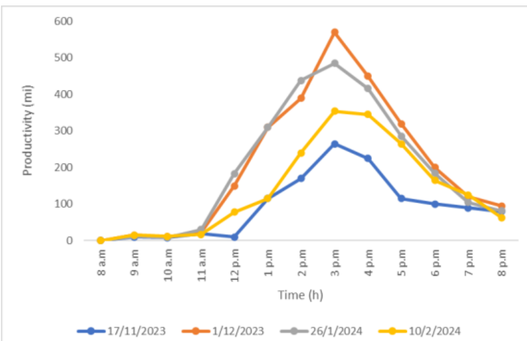


Fig. 11. Hourly variation of active solar still productivity.

Conclusions

In this research, we performed an empirical analysis to estimate the efficiency of a solar still connected with evacuated tube. We then compared its productivity with that of a passive distiller, taking into account the specific meteorological conditions of Kirkuk city. The obtained findings are as follows:

- Intensity of solar radiation and ambient temperature affect a solar still's production because they raise the water temperature in the still basin.
- Wind speed improves solar still carrying out by cooling glass cover, which enhances condensation and production.
- Connecting the ETC directly to solar distiller raises basin water temperature and productivity compared to the passive still.
- Active distiller production improves 277.5% in November, 237.5% in December, 245.7% in January, and 233% in February compared to passive distiller productivity.
- Active distiller thermal efficiency was 18.6% in November, 18.8% in December, 24.8% in January, and 36% in February, while passive distiller thermal efficiency did not exceed 16% during the experiment.

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Nomenclature

A_c	Area of ETC, m^2
A_s	Area of basin, m^2
$I(t)_c$	Intensity of solar radiation on an ETC
$I(t)_s$	Intensity of solar radiation on a solar still
L	Latent heat of vaporization, J/kg
m_{ew}	Hourly distillate output, Kg/m^2

Abbreviations

ASS	Active solar still
ETC	Evacuated tube collector
PSS	Passive solar still
TDS	Total dissolved solids