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Investigating the Performance of Solar Still System Integrated with and without Solar Trough Collector Using PCM Basin –An Experimental Study

Hazim Jassim Jaber [1], Qais. A. Rishack [2], Qahtan. A. Abed [3]

[1]Department of Mechanical Engineering, College of Engineering, University of Basrah, Al Basrah, Iraq.

[2]Department of Material Engineering, College of Engineering, University of Basrah, Al Basrah, Iraq.

[3]Technical Institute/Al-Rumaitha, Al-Furat Al-Awsat Technical University, Al-Muthanna, Iraq.

E-mail : hazimj.altalqani@uokufa.edu.iq , qais.rashck@uobasrah.edu.iq , qahtan.abed@atu.edu.iq.

Abstract. The performance of two solar still systems has been investigated experimentally by taking the effect of parabolic trough collector (PTC) and phase change material (PCM). The effect was investigated under different environmental conditions. The productivity of the solar still was the main factor that was considered as a criterion for comparison. One day was taken under the investigation; 22-December 2020. Results show that a solar still using PTC with PCM has better productivity and temperature than without using PTC, And the additive PTC unit with the PCM basin causes an increase in temperatures of the system, and also an increase in rate productivity by 0.72 % than the solar still system without PTC.

Keywords: Productivity; double slope solar still; single slope solar still; parabolic trough collector.

Introduction

As the population grows, there are fewer sources of drinking water available per person. The most significant problem in developing countries is the persistent lack of potable water. In daily living, there is a need for fresh water. Freshwater shortages are increasingly being caused by man-made water pollution of natural water sources. Using sun energy to filter water is a popular practice. [1][2][3]. Design, use, and surrounding climatic variables all have an impact on how much water the solar still can generate. Humans are unable to regulate the climate because it is based on meteorological factors. Humans may simply adjust the design settings, including the controller of the assembly materials, in order to affect the manufacturing pace.[4][5][6]. One popular renewable energy source is solar energy. In spite of water constraints, solar energy is still regarded as one of the most promising sustainable solutions for desalinating water. Indeed, compared to other active desalination methods, adopting such sustainable systems is more practical in areas with highly concentrated sun irradiation. [7][8]. Trying integrating a PTC (Parabolic Trough Collector) unit and

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not integrating it. It was discovered that adding PTC to the PCM basin boosts the still's productivity and efficiency by roughly 30%. The researcher looked at an experimental analysis of using micro ZnO-enhanced paraffin wax as a thermal energy storage medium to improve thermal performance. [9].The impact of thermal storage on the productivity of the desalination system at various levels was discussed. Solar systems without PCM were compared to solar systems that still had PCM in order to assess the impact of PCM. In addition to measuring the air and water temperatures, the temperatures of the inner and outer glass surfaces were also recorded. They found that the single slope solar system with a parabolic concentrator still had a 62% improvement in productivity due to the effect of thermal storage.[10][11]. Researchers discovered that solar stills with glass covers effectively transmit solar energy compared to those with plastic coverings. Additionally, a portion of the solar energy that is received is still absorbed and reflected by the inside surfaces of the walls onto the water's surface. The effective insolation on the basin's salted water is still influenced by the reflectance of the solar walls. [12][13]. investigated the impact of water depth on the efficiency of active solar stills using experimentally various collecting areas. They discovered that while productivity increases with larger solar collecting areas, productivity declines with smaller water depths. [14] a test to ascertain the impact of water depth in the solar still. The specifications of the length and height of the stairs were created to make an angle of 20°, which was identical to the inclination angle of the glass cover. They note that lower water depths result in increased solar still productivity [15]. By combining the shallow solar pond with the double slope solar still, productivity was increased. It was discovered that, in comparison to stills without combining, the productivity of solar stills with shallow solar ponds was higher. The productivity of the solar still with the shallow solar pond and without it was determined to be 5.09 l/m^2 per day and 3.17 l/m^2 per day, respectively. The theoretical results and the actual results were in good agreement. [16][17]. The productivity of solar stills was studied experimentally to determine the impact of design factors such as water surface to glass cover distance and water depth. They discovered that the best productivity is achieved at water depths of 2 cm and a water surface to glass cover distance of 9 cm, respectively [18]. Fuzzy sets can be used to study the effects of different meteorological variables on the solar distillation system. The study found a relationship between sun intensity, water depth, ambient temperature, wind speed, sprinkler, integrated collector, and solar concentration and solar still productivity. [19]. A flat plate collector and active single slope solar still were integrated experimentally under operating conditions, and the highest productivity gain was found to be up to 33% [20].

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Experimental System Components

The experimental system in operation was set up at Kufa University in the Iraqi city of Najaf (latitude 32.026°N and longitude 44.37°E).

Two double-slope solar still with similar specifications are used in the experimental system, one of which is connected to PTC and the other is not, as illustrated in Fig (1), Solar still The two basins have the same measurements of 1.0 m in width and 1.5 m in length but differ in height because they are made of galvanized iron sheet. Microcrystalline wax is employed in one basin as a phase change material (PCM) to store heat; the wax's qualities are given in Table (1) [1]. The 0.04 m-high wax basin, almost contains 42 kg of PCM. As seen in Fig (2-a). it covers a heat exchanger submerged in it. The heat exchanger pipe was constructed from a copper tube with a diameter of 11.28 mm and a length of 16 m, and it is positioned 1 cm above the wax basin's surface. A second 0.10 cm high water basin was installed over the wax basin and in order to stop any heat leakage silicone was used to seal it. The basin is filled with salt water, and to boost the basin's ability to absorb solar energy, all of its interior surfaces have been painted black as shown in Fig (2-b). Thermal insulation has been used to prevent heat loss from the bottom of the basin and the side walls to the environment. In the current work, glass wool insulation has a 25 mm thickness and a thermal conductivity of 0.040 (W/m.k.). The choice of insulation type is important to improve thermal performance. The surface bottom and side walls of the basins were also installed inside a 0.03-meter-thick timber frame with dimensions of 1.70 meters in length and 1.15 meters in breadth. In order to reduce heat loss to the environment, the space between the basins and the wooden frame is filled with an insulating polyurethane foam layer that is resistant to heat and cold (-50 to +90). Two 4 mm thick glasses are used to cover the top, which is supported by a wooden frame on both sides and is angled at 32° to represent the latitude of Najaf, Iraq. Silicone sealant was used to stop any leaks from occurring between the basin box and the glass cover. To collect the condensed freshwater, a reinforced plastic tube was placed within the solar at the base of the still glass walls. The condensed water is continuously drained through a flexible hose and kept in a measuring jar. To get incident solar energy maximum falling on still was oriented in the south-north direction of Najaf city. Also for compensating for the daily condensed freshwater in the basin with salty water at the beginning of each daily experiment, a saline water tank is positioned 0.5 m above the basin. As shown in Fig. (3) the reflective stainless steel sheet used to create the parabolic solar concentrator has dimensions of 2 m, 1.06 m aperture, 0.5 mm thickness, and 0.266 m focal length. Additionally, the PTC's receiver tube is made up of an absorber type SUS304 (carbon steel or stainless steel) pipe that is 2 meters long, 0.04 meters in diameter, and 3 millimeters thick. It is covered with an anti-reflective coating to absorb the most solar energy that is incident upon it.

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Figure (1) Photograph of the experimental system

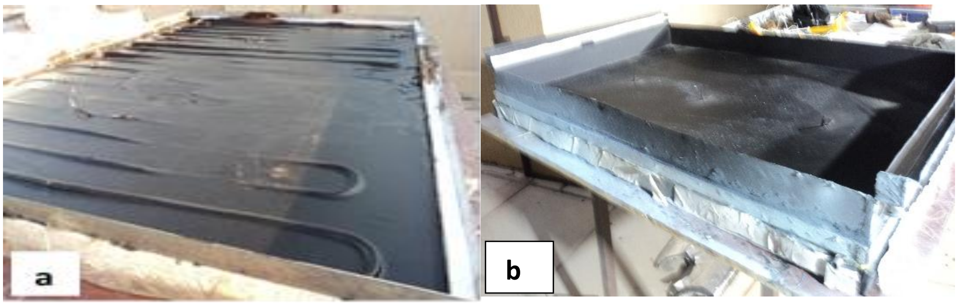

Figure (2) a) Basin wax with heat exchanger, b) Basin wax without heat exchanger and Water basin.

Table (1) Properties of used Microcrystalline wax [1].

Wax Type	Congealing point (°C)	Liquid density (kg/m^3)	Solid density (kg/m^3)	Melting temp (°C)	Thermal conductivity (W/m.K)
Microcrystalline	**60-66**	**900**	**930**	**70-75**	**0.26**

And a covered by an Evacuated Tube Made of High Borosilicate Glass 10 cm in diameter and 1.9 m long. The steel and glass tube's evacuated area is utilized to reduce convective heat losses and boost the receiver tube's ability to absorb solar radiation. For stationary PTC, the orientation is south with a tilt angle corresponding to Najaf, Iraq's latitude. The absorbed solar radiation by the receiver tube is transmitted to water passing inside this tube where this water is used to transfer the heat gain to the microcrystalline wax in double slope solar still connected with PTC. Plastic tubes are used to transmit the heated water from the receiver tube to the wax basin in a solar still. To reduce heat loss from the heated water, the plastic tubes are manufactured of a material with low thermal

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conductivity and are insulated on the outside. A heat exchanger is still used to transfer the heat that the water at the still input was carrying to the wax basin. The employed system (PTC with solar still) uses a tiny pump to move hot water through its tubes at a flow rate of 0.75 L/min.

Figure (3) A photograph to parabolic trough collector.

Experimental measurements

The experimental measurements were carried out from 9:00 am to 4 pm on 22-December 2020. Measuring the temperature at different positions of the solar still gives good information and explanation on the still performance, During the experimental work, temperatures of ambient air (Ta), the temperature outside glass cover of south and north (T_{gs}),(T_{gn}), saline water (T_w), water basin surface (T_{sb}), water steam (T_s), and wax temperature (T_{wax}), wax basin surface (T_{swax}) were measured simultaneously. The glass temperature was measured on the glass wall facing the south and north because it has a great effect on the solar still performance compared to other sides. The saline water temperature was measured at a distance of 1cm from the bottom of the basin. These temperatures were measured by using K-type thermocouples and the outputs of the thermocouples were registered on a digital temperature device of type Mult-Channel Temperature Meter (AT4532) modular programmable logic control. Tracking system to the solar tracker (Model WST03-2T) using to be suitable for solar tracking from south to north to collect as much solar radiation as possible, Also The intensity of solar radiation (I) was measured by using Digital Solar Power Meter type (TENMARS TM-207). The water flow rate was stated constantly at 0.75 L/min during all experimental measurements. The condensed fresh water was collected in a calibrated flask. The measurements were carried out at saline water depths of 20 mm. The previous temperatures and solar intensity were measured and recorded at the same time every 30 minutes.

Results and discussions

Some practical experiments were conducted for both distillates used in the research for December of 2020. All experiments were almost similar in terms of thermal behaviour, so some

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experiments were chosen to be represented graphically. The results of the present experimental work are carried out for the studied two solar still systems double slope solar still with PCM and double slope solar still with PCM and tracked PTC and for the depth of saline water in the basin, D_w (20 mm). The measurements are measured and recorded every 30 minutes from 9 AM to 4 PM and are carried out on a day 22- December 2020. The productivity of the solar still increases with an increase in the rate of evaporation of the saline water in the basin and the rate of condensation of the evaporated water in the humid air region. So, in this work, we aimed to augment the evaporation rate of the saline water by adding extra heat supplied by PTC to a heat exchanger tube immersed in a wax basin coupled with the solar still.

Solar Still Temperatures

Measuring the temperature at different positions of the solar still gives good information and explanation on the still performance, so all temperatures are measured. Fig. (4-a) shows the evolution of the temperatures of ambient air (T_{amb}) and solar intensity (I) with time for solar still without PTC at water depth 20mm.Also indicates that the solar intensity and the temperature ambient air increases with time from the morning until about 12 PM and then the solar intensity decreases with the time. It is noted that the maximum value of the solar intensity is around 12 PM. While temperature ambient air increases until about 1:30 PM and then it becomes semi-stable and gradually decreases with time. Fig. (4-b). Shows the hourly temperature variations of basin water (T_w), basin surface (T_{sb}), PCM (T_{wax}), and basin surface to wax (T_{swax}) for the solar still without PTC.

It is observed that all the temperature values follow an upward trend as the time and reaches the maximum value for (T_w),(T_{sb}) at 2:30 pm, and the maximum value for (T_{wax}), (T_{swax}) at 3:30 pm, and then gradually decreases. At the starting of the experiment Microcrystalline wax (PCM) takes heat from the absorber plate to the solar radiation fallen and its temperature gradually increases with time. After the solar radiation decreases, its temperature starts to decrease. PCM provides its stored heat to basin water and keeps the water warm during the sun goes down period and the distillation process continues to the next day. Fig. (4-c). Shows the evolution with time of the temperatures of water steam (T_{s1},T_{s2},T_{s3},T_{s4}) where distributed vertically in different dimensions, and south glass cover (T_{gs}), north glass cover (T_{gn}).Also demonstrates that the temperatures of water steam with time increased and is greater than the glass covers temperature (T_{gs},T_{gn}) and which accords with the phenomena of the evaporation process.

They also show that the water steam temperatures (T_{s4}, T_{s3}) Near the surface of the southern and northern glass cover are greater than (T_{s1}, T_{s2}) temperature. And greater than (T_{gs},T_{gn}) temperature. The performance of the solar still depends on the temperature difference increase of

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(T_s-T_a) where the condensation increases with the increase of this value. It also depends on the value of saline water temperature (T_w) where its increase raises the evaporation process.

All the parameters gradually decrease with the decrease of solar radiation intensity. This means that the solar still with PTC has a higher evaporation rate than the solar still without PTC. Hence, the evaporation of water is greater than that of solar still without PTC for all studied systems because the humid air has more ability to carry vapor because of its higher temperature. The current system used Microcrystalline wax PCM to absorb heat from the solar radiation falling on the water basin as well as from the parabolic trough collector PTC by heat exchanger immersed of the PCM, and then thereby increasing temperatures (T_{swax}), (T_{wax}), basin surface (T_{sb}), steam (T_s) and water (T_w), Also the PCM has kept the heat of Resulting by the solar radiation and the PTC even with a decrease in the ambient temperature and solar intensity, as seen in Fig. (5-a,b) Subsequently, with a further decrease in solar intensity towards sunset, The PCM begins to release latent heat to the basin surface (T_{sb}) in the still basin. This helps hot the basin water for a longer period Which leads to the continuation of the condensation process even at night and thus leads to an increase the productivity throughout the day and in even at night.

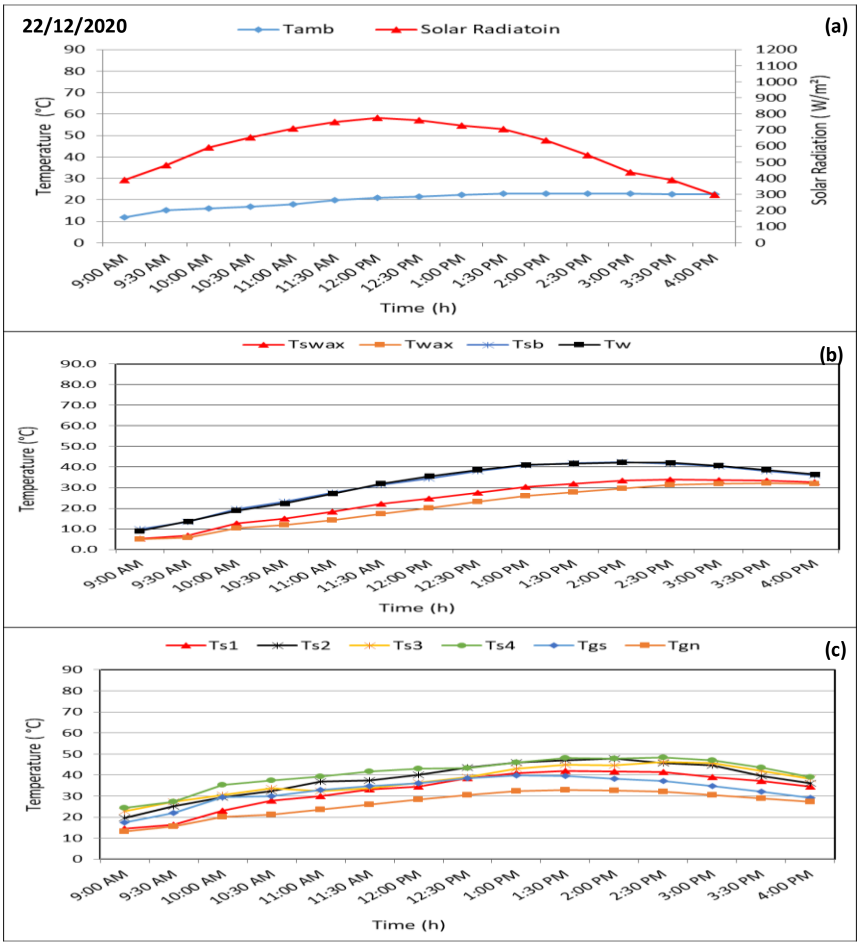

Figure (4) Evolution of temperatures and solar intensity with time for solar still without PTC in Month December-2020.

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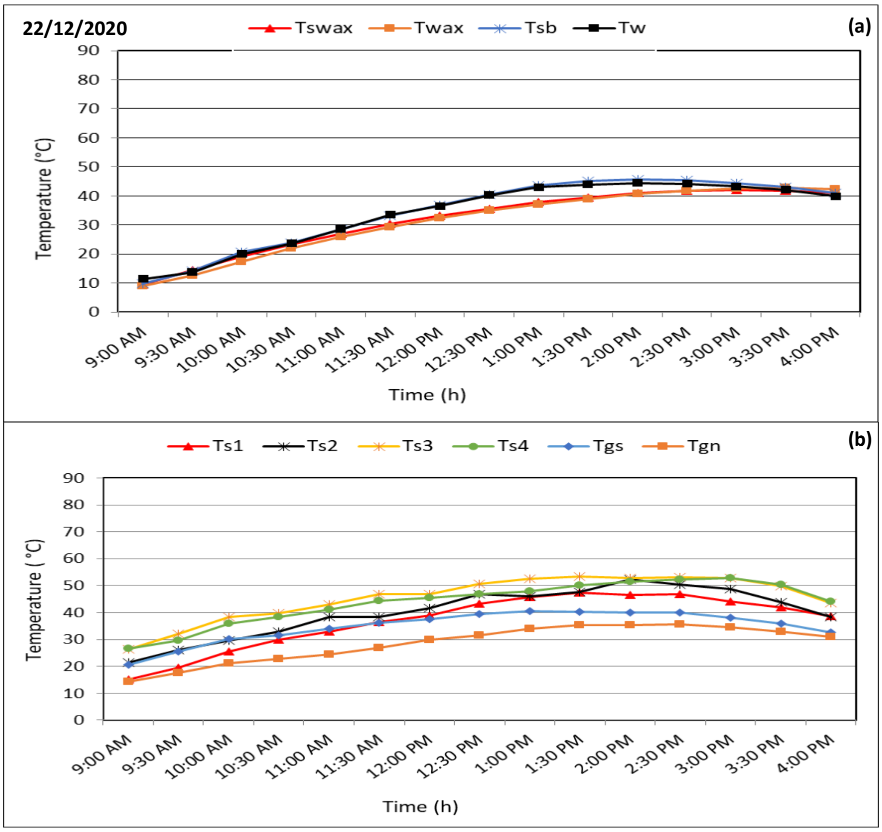

Figure (5) Evolution of temperatures with time for solar still with PTC in Month December -2020.

Total Daily Production

The production of freshwater from double slope solar still with PCM and tracked PTC is the greatest than double slope solar still with PCM and without PTC, where this accords the values of solar still temperatures for these systems as indicated in Figs. (4), (5).

This high operating temperature obtained is because the solar radiation fall and heat stored of the PCM that is transferred by conduction through the basin to evaporate the water at a high temperature. Furthermore, the increase in temperature noticed in the still at 16:00 is due to the effect of heat released by the PCM.

Fig. (6). illustrates that the total freshwater production in solar still with PTC is the greatest than the production in solar still without PTC because of the high solar intensity and the heat added to the PCM by PTC, this leads to higher saline water temperature and thus an increase in the condensation rates in solar compared to solar still without PTC as discussed previously, this leads to an increase the productivity throughout the day and in the evening. In this work, the influence of PCM with different designs of solar still with Phase change materials PCM and thermal energy storage materials play an important role to enhance the internal energy of the system. The PCM is also one of the methods to induce faster condensation inside the solar still. The Microcrystalline wax is kept heat even with a decrease in the ambient temperature and solar intensity. Subsequently, towards

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sunset, the PCM started to releasing latent heat into water in the still basin. The freshwater productivity in the solar still without PTC. It is 1660 ml/day, and the solar still with tracked PTC. It is 2850 ml/day respectively, with an increased rate of Productivity by 0.72%. This means the total production of potable water of the solar still with tracked PTC is greater than the solar still without PTC, which indicates that the performance of the solar still with tracked PTC is greater than the performance of the solar still without PTC.

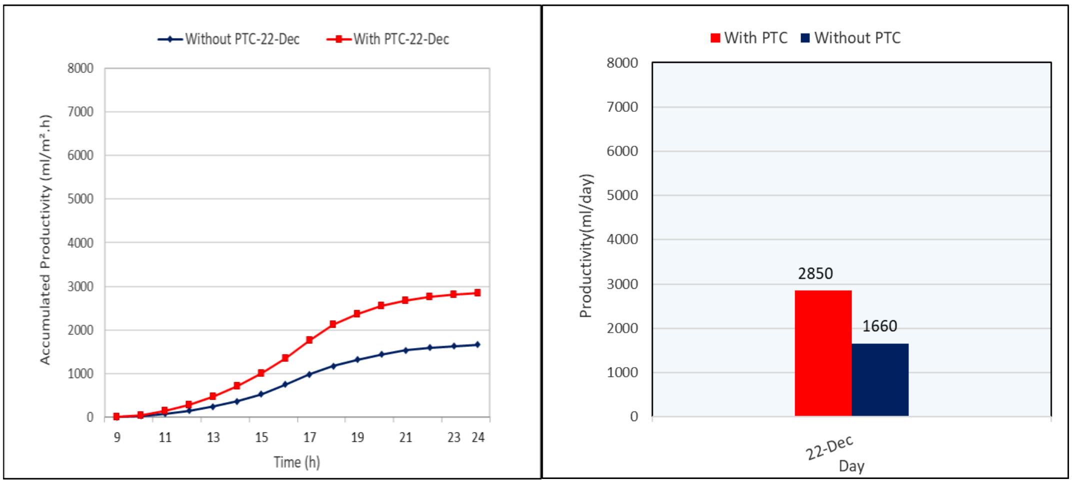

Figure (6) Accumulated freshwater productivity for solar still without PTC and with PTC at 20 mm water depth in Month December-2020.

Conclusion

The performance of double slope solar still with heat exchanger Immersed in Microcrystalline wax (PCM) and coupled with parabolic trough collector (PTC) and solar still with Microcrystalline wax (PCM) and without (PTC) is experimentally investigated. The results showed that.

1. Solar still reaches temperatures in case of adding PTC unit higher than the temperature values in case without PTC unit.
2. Adding PTC unit causes increase in productivity by 0.72%.
3. PTC unit causes continuous increase in the temperature of water and PCM even after the maximum solar radiation time affected by the latent heat of the PCM and water medium mediums.
4. Solar radiation has an impact on the temperatures of the water and wax, but this effect does not happen immediately since the glass warming process has caused latent heat to be stored in the still.

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