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Research Article

Enhancement of the Performance of a Solar Still Using a Vibrator

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ABSTRACT

Solar distillation is an effective way to generate fresh, potable water in areas with abundant sunlight and sufficient water unfit for human consumption or other activities. Therefore, the current work introduces vibrator technology to improve the performance of a single-slope solar still (CSS) that uses solar energy to evaporate salt water. The new still was introduced as CSS-V. The effect of the water level inside the basin was studied for a level of (1,2) cm. The results showed that lowering the water level by 50% increases productivity by 9%. The use of a vibrator was found to increase productivity by 9% to a water level of 1 cm.

1. INTRODUCTION

The determinant of freshwater needed by the population and the breadth of agriculture and industry is the cost, as most distillation plants currently use fossil fuels, wood, coal, or any kind of fuel, which are exhausting, expensive, and polluting to the environment. Therefore, using solar energy as an alternative and clean in the distillation process has a great economic return because it is available in most countries. Also, it can be used in arid and desert areas with abundant solar radiation and salt water, especially noting that the cost of transporting freshwater to desert areas is high. Many studies have emerged to develop solar distillation devices, but few have been successful due to inefficiency and low production. Single-slope solar stills have a simple design, low cost of operation and maintenance, and acceptable performance[1-5].

Many researchers have investigated the enhancement of the yield of solar stills. Phadatare and Verma [6] studied theoretically and experimentally the effect of the materials of the cover of the solar still on the yield of the solar still. The model consists of two solar stills made of plastic with similar geometry to preserve a correct comparison under Malegaon, India, weather conditions. The cover of one still was a glass of 3 mm thickness, and the other still had an acrylic (plastic) cover of 3mm thickness. The consequences showed that the productivity of solar still with glass covers was more than that with plastic lids by about 30-35%.

Murugavel & Srithar [7] studied the improvement in the productivity of solar distillates. A wicking layer in the basin is used to increase the evaporation area and thus increase distill productivity. Wick materials work as sponge sheets, light cotton cloth, pieces of waste cotton, and coir mate fitted in the trough of double slope solar still. The still is also tested with the aluminum rectangular fin, which is covered with different wicks. Consequences showed that the highest productivity was for a light black cotton cloth for wicked type still. The aluminum rectangular fin covered with cotton cloth was more effective than the light black cotton cloth. The theoretical results were close to the experimental. Abujazar et al. [8] evaluated experimentally and theoretically the efficiency of inclined copper-stepped solar still. To raise the efficiency of the system, the inclined steps with 28 steps are used. The inclined copper-stepped solar still is tested under meteorological conditions in Bangi, Malaysia. The experimental results coincided with the theoretical results well, where the total productivity was (4353 ml/m^{2}d). Khalifa [9] studied theoretically the influence of tilt and latitude angles on the productivity of solar stills. The survey was performed widely, and experimental and numerical studies were performed for simple solar stills. A relation between the optimum tilt angle and the latitude angle and a relation between simple solar still productivity and the cover angle are obtained. The cover tilt angle was ideal when approaching the latitude angle of the place. To increase the productivity of the solar still, the angle of inclination of the cover should correspond to the latitude angle of the place.

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Abbas [10] evaluated experimentally the effect of the preheating entrance water on the still efficiency and productivity with the strength of the solar radiation. The model was a single slope single effect horizontal basin type solar still. Solar still is connected with the thermal tank which is insulated with thermal insulation. The tank is supplied with hot water from a flat solar thermal collector, which heats the water using solar energy. The transparent surface is cooled by subjecting an air current over it at a constant speed to increase the external heat convection between the glass cover and the atmosphere. The productivity is increased by (30 – 40 %) for a still with a solar water heater when air is used to cool the transparent lid. Panchal and Shah [11] presented experimentally double basin solar still to test the optimum water level, including (30, 40, and 50 mm) inside the upper and lower basin. The model consists of a double-basin solar still; the lower basin is connected to a solar collector of evacuated tubes. The daily productivity of the solar still is about (11.064 kg) which was obtained for a water depth of (30 mm). Amori and Hilal [12] investigated the performance of a single-slope stepped solar still with floating perforated absorber wicks (cotton ribbons). The results showed that the stepped still daily efficiency and productivity are 30% and 36.19% higher than those of the conventional solar still. The thermal efficiency and daily productivity of stills with floating absorbers are 16% and 26% higher than those of conventional solar stills. Rashidi et al. [13] experimentally improved the performance of single slope solar still by inserting a reticular porous layer in it. The inserted porous layer (from black sponge rubber) is used for its capability to absorb water due to the wicking property. The porous media increased the surfaces of convection and radiation heat transfer and increased the evaporation surface. Results showed an increase in the yield by 17.35% of freshwater. Saadi et al. [14] experimentally studied the productivity improvement of the conventional still under climatological conditions for Adrar-Algeria. In the rear wall of the solar still, a Multi-Tray internal evaporator has been incorporated to increase the evaporation area. Results showed that modified solar still was more efficient than ordinary solar still. The evaporation area for the still of the Multi-Tray Evaporator is more than the evaporation area of the conventional still by about (30%).

The objective of this research is to examine several solar still designs experimentally in order to determine their thermal efficiency and production. So, in order to determine their efficiency and productivity, we put a conventional single-slope sun still with a vibrator and a conventional single-slope solar still in Baghdad, Iraq (Lat. 33.3° N, Long. 44.4° E) through comparison tests.

2. EXPERIMENTAL SETUP

The solar water desalination system has been designed and fabricated to investigate the influence of using a vibrator and water level on its performance. Outdoor tests were conducted on the 21st and 22nd of April, 2023, at Baghdad climate conditions (33.27° N, 44.37° E). The experimental setup is a single-slope basin-type solar still, as shown in Figure (1). The basin is fabricated from a galvanized iron sheet of 1.6 mm thickness, (0.9x0.6) m^2 base area, welded joints, and the inner surface of the still was painted with matt black dye to enhance its absorptivity. The water is supplied through an electric valve, which opens and closes according to the signal from the water level control circuit. The supply valve is shown in figure (2). The volume of the basin of the still is (100 liter). To minimize the heat loss from the still to the ambient, the still is isolated from the sides and the bottom by thermal insulation. A vibrator is placed inside the basin water in order to mix the water, as shown in figure (3). The vibrator is driven by a DC motor, and its speed is controlled by a regulator, as shown in Figure (4). The tilt angle of the cover was chosen as 31°, which is close to the latitude of the Baghdad city (latitude 33.3° N) conventional. The cover is fabricated from a conventional glass of 4mm thickness. Double adhesive foam tape of 18 mm thickness is used as a sealant between the glass cover rim and the basin frame. The glass frame dimensions are shown in Figure (5). Three distillate channels are fixed at a small inclination angle along the edges of the south, east, and west sides of the galvanized body to collect the condensed water and deliver it out into the collection flask.

Fig. 1 . The experimental setup

Fig. 2. Feeding valve.

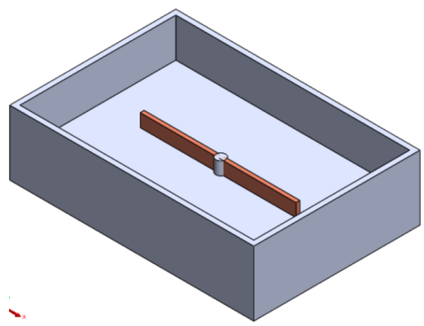

Fig. 3. The vibrator

Fig. 4. The DC motor and its speed regulator.

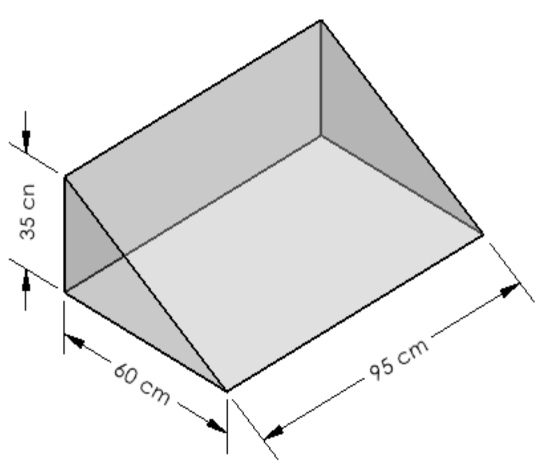

Fig. 5. Schematic of glass cover.

3. INSTRUMENTATION

In the present work, temperature, solar radiation, and collected distilled water volume have been measured. Temperature data logger, solar radiation data logger, and graduated beaker are used. Three thermocouples (type K) are used to measure the temperatures inside and outside the stills. A digital thermometer and data logger of model BTM-4208 from Lutron company is used to read and record the temperature as shown in figure (6). The range and accuracy of its measurement are (-55 to 999 ^{o}C) and 0.4%. The temperatures of the water, glass, and ambient are measured.
The solar radiation is measured using solar power meter SPM 1116 SD from Lutron company as shown in figure (7). Its range, resolution, and accuracy are (0 to 2000 W/m2), 0.1 W/m2, and 5%, respectively. The probe of the meter is fixed horizontally.
The collected distilled water volume was measured using a graduated glass cylinder. The volume of the cylinder is 500 ml with 5 ml resolution.

Fig. 6. Temperature data logger and thermocouples

Fig. 7. Solar power meter

4. CALCULATIONS

The daily efficiency (ηd)is given by the summation of the hourly condensate production (mc) multiplied by the latent heat, so the result is divided by the daily average solar radiation I(t) over the basin area (A) **[15]** :

$$\eta_d = \frac{\sum_{i=1}^{24} m_c h_{fg}/3600}{\sum A\, I(t)} \tag{1}$$

5. RESULTS

5.1 Effect of water depth

Two experiments were conducted on the 21st of April in 2023 under Baghdad's clear sky to investigate the effect of water level inside the still (h) on the performance of the conventional single slope still (CSS). Figures (7) and (8) show the measured temperatures (water, glass) for the conventional single slope solar still with a flat absorber plate (CSS) along with weather conditions of solar radiation and ambient temperature for the water levels of 1 cm and 2 cm, respectively. The maximum and average solar intensities are 809 W/m^2 and 529 W/m^{2,} respectively. The maximum and average ambient temperatures are 23 ºC and 20 ºC, respectively. The water and glass average temperatures are 45 ºC and 36 ºC, respectively, for water level of 1 cm. At the same time, the water and glass average temperatures are 42 ºC and 33 ºC, respectively, for a water level of 2 cm. The water temperature is higher by 7 %, as shown in figure (9). This behavior is due to the lower water quantity inside the still when the water level is 1 cm, which requires a lower heat quantity to heat up.

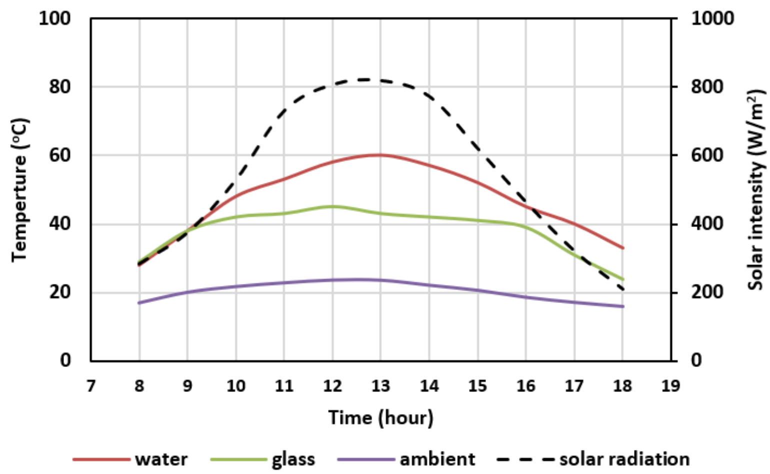

Fig. 8. CSS water and glass temperatures and weather conditions (h=1cm)

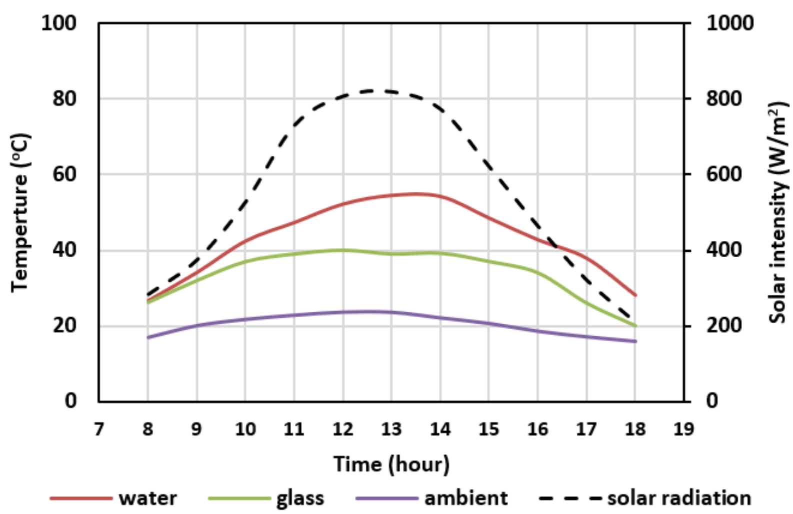

Fig. 9. CSS water and glass temperatures and weather conditions (h=2cm)

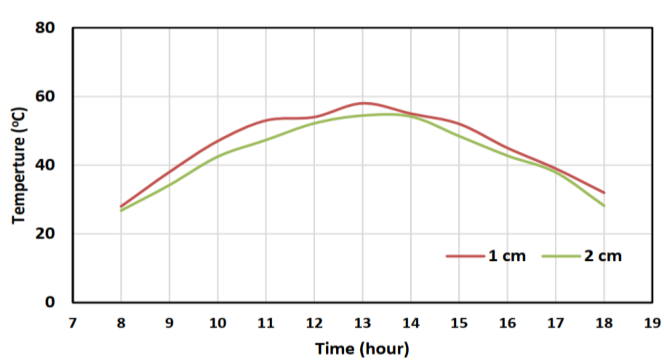

Fig. 10. water temperature inside the CSS for different water levels.

Figure 10 illustrates the cumulative output of freshwater from CSS at 1 cm and 2 cm water levels. The total yield from 8:00 AM to 6:00 PM is 1.36 liters at a water level of 2 cm and 1.5 liters at a water level of 1 cm. The collected yield increases by 10% at a water depth of 1 cm. This behavior is ascribed to the decreased volume of water, necessitating a reduced amount of heat for evaporation.

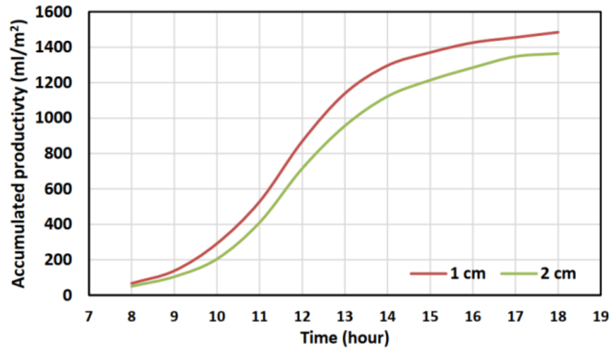

Fig. 11. Accumulated water productivity of CSS for different water levels.

5.2 Effect of the Vibrator

Two experiments are conducted on the 22nd of April to examine the performance of the single-slope solar still with the vibrator (CSS-V). The presence of a vibrator inside the basin leads to a better mixing between the fluid layers, which results in faster water heating that augments the evaporation. Figure (11) shows the water temperature inside the basin in the presence of the vibrator. The water temperature is higher by 8.5 % in the case of CCS-V.
Figure (12) shows the effect of the vibrator on the accumulated yield of freshwater of CSS for water levels of 1cm. The accumulated yield from 8:00 am to 6:00 pm is 1.6 liter and 1.5 liter for CSS-V and CSS, respectively. The accumulated yield is increased by 9.4%.

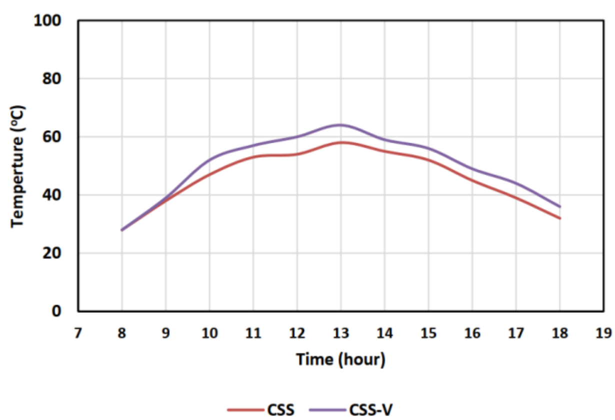

Fig. 12. Effect of the vibrator on water temperature (h=1cm).

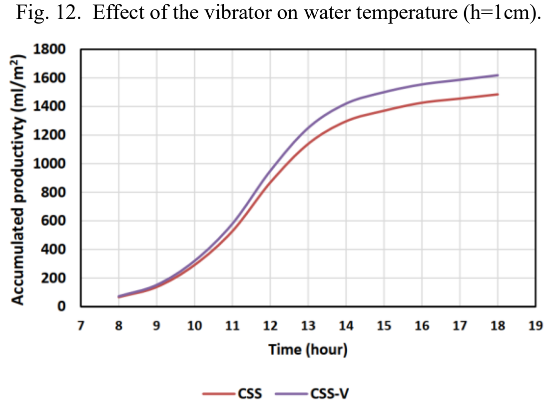

Fig. 13. The accumulated productivity of the CSS and CSS-V(h= 1cm).

5.3 Thermal Efficiency

The hourly and average thermal efficiency of the conventional solar still (CSS) and the conventional solar still with the vibrator (CSS-V) are shown in figure (13) and figure (14). In general, the efficiency increases from the sun shine to reach its peak at solar noon and then decreases gradually following solar radiation intensity. The average efficiency is decreased by 11% when the water level is increased from 1 cm to 2 cm. The efficiency of the CSS-V is higher than that of CSS by 7.5%.

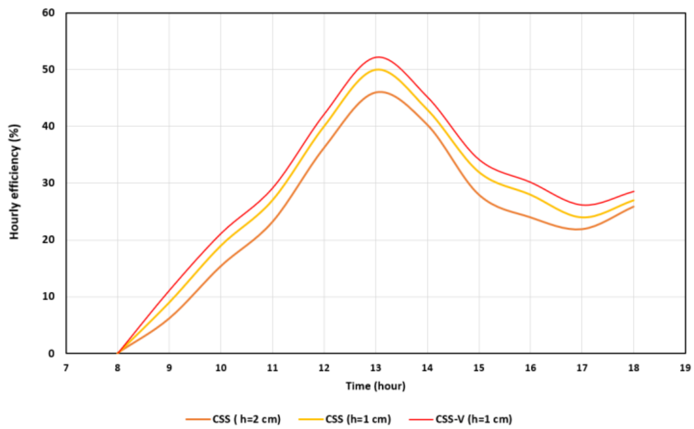

Fig. 14. Hourly efficiency of CSS and CSS-V.

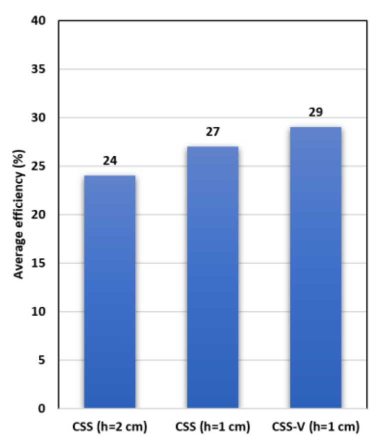

Fig. 15. Average efficiency of CSS and CSS-V.

6. CONCLUSIONS

The present investigates experimentally the performance of a conventional single-slope solar still in the presence of a vibrator inside the basin. The effect of water depth for the values of:1cm and 2cm is also tested. The main findings can be summarized as:

1. Increasing the water level from 1cm to 2cm decreases the water temperature by 8%.
2. Decreasing the water level from 2 cm to 1cm increases the productivity by 8% and the efficiency by 12.5%.
3. Using the vibrator increases the productivity of CSS with water level of 1 cm by 10% and the efficiency by 7.5%.

Conflicts of Interest

The author asserts that there are no conflicts of interest that could have affected the study design, methodology, or results.

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