ScienceDirect

Solar Energy
Volume 216, 1 March 2021, Pages 295-302

Enhancement of hemispherical solar still productivity using iron, zinc and copper trays

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https://doi.org/10.1016/j.solener.2021.01.038
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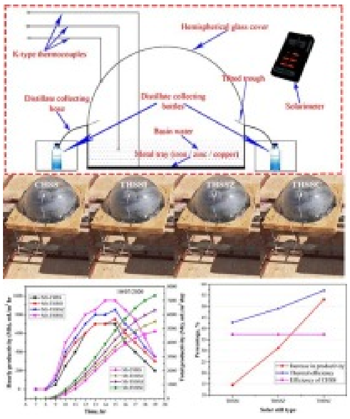
Abstract

In this manuscript, a hemispherical solar still with different metal trays (copper, zinc, and iron) painted with black was studied experimentally. Four hemispherical solar stills were manufactured; the first is the conventional hemispherical solar still which represent the reference case (CHSS), the second, third and fourth were the modified hemispherical solar stills with adding black metal trays of copper, zinc, and iron, respectively. These trays were placed at the bottom of the distiller basin. This modification led to a significant increase in the rate of evaporation of the salt water in the distiller basin due to the improved heat transfer characteristics. The basin water depth in the trays are kept constant at 10 mm in all experiments. The results showed that the accumulative yield of the hemispherical solar still reached to 4.8 kg/m^2/day, while the utilization of iron, zinc and copper trays improved the accumulative yield to 5.5, 6.3 and 7.35 kg/m^2/day, respectively. These results presented that the trays hemispherical solar still of iron (THSSI) was about 1.17 times the daily productivity of CHSS, while trays hemispherical solar still of zinc (THSSZ) showed an increase in productivity by 31.25% compared to CHSS. Moreover, the trays hemispherical solar still of copper (THSSC) gave improved productivity by 53.125% compared to CHSS. The thermal efficiency of CHSS, THSSI, THSSZ and THSSC were 37.4%, 42.8%, 49% and 57.2%, respectively.

Graphical abstract



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Introduction

Desalination of salty or polluted water available in remote areas on a large scale is difficult due to the high cost associated with building and maintenance (Kabeel et al., 2018, Khechekhouche et al., 2020a, Manokar et al., 2018). Solar energy is free natural energy from the sun to convert polluted water into safe drinking water (Kabeel and Abdelgaied, 2019, Kabeel et al., 2016). Solar distillation by solar stills is more economical than other desalination technologies, and is especially suitable for developing countries, especially in remote areas. Solar stills work with two principles, evaporation and condensation (Kabeel and Abdelgaied, 2017a, Kabeel et al., 2017a, Kabeel and Abdelgaied, 2017b). Solar stills are the best way to supply remote areas with potable water without resorting to expensive technology (Khechekhouche et al., 2020b, Khechekhouche et al., 2019, Kabeel et al., 2019, Abdullah et al., 2019). Scientists and researchers are constantly looking for different ways to improve the performance of solar stills, such as increasing distillate output, increasing surface area, using energy storage materials, and creating new designs (Kabeel et al., 2020a, Khechekhouche et al., 2020c, Attia et al., 2020, Kabeel et al., 2020b, Kabeel et al., 2020c).

Ketabchi et al. (2019) studied the effect of several parameters (inclination angle, glass cover cooling, and upper and lower external reflectors) on improving inclined SS performance. The results showed that all of these parameters have a significant impact on the distillation productivity, especially in the spring and winter seasons. When using external reflectors and cooling the glass cover, productivity improved (4.2 kg/m^2) and efficiency (36.7%). Khalifa (2011) conducted experimental and numerical studies of solar stills to optimize the design by investigating the effect of climatic, operational and design parameters on its performance. It was concluded that the cover tilt angle should be large in winter and small in summer. Also, the results suggested an optimum cover tilt angle that is close to the latitude angle of the site. Moreover, it was inferred that (1) the annual yield significantly depends on water depth, inclination of condensing cover and collector as expected for both passive and active solar stills (Singh and Tiwari, 2004).

Mohamed et al. (2019) improved the performance of a CSS through employing basalt stones with different sizes (1, 1.5 and 2 cm). The researchers concluded that a 2 cm stone improves daily productivity and efficiency by 33.37% and 22.6%, respectively, compared to CSS. Rahbar et al (2018) studied the comparison of the productivity of triangular and tubular solar stills. They concluded that the productivity of triangles SS improved by 20% compared to the productivity of tubes SS, with a significant difference in production costs. Okeke et al. (1990) studied the effect of coal and charcoal mixture as absorbers in solar distillate products. The results showed that the coal and charcoal mixture improve the CSS performance. Rajvanshi (1981) used the different dyes (black methylamine, red carnosine and dark green) in a solar still. The researchers concluded that black methylamine is suitable improve the CSS performance. Sodha et al. (1980) performed an experimental investigation various dyes on the thermal performance of the CSS. The researchers found that black and violet dyes had a better rate of production compared to red dyes. Akash et al. (1998) studied the used the different absorbing materials (black dyes, black rubber matt and black ink) in a solar still. Experimental results showed that the use of black dyes is suitable compared of other absorbing materials. El-Sebaii et al. (2000) studied the used the different absorbing materials (mica, aluminum, copper and stainless-steel plates) in a solar still. Experimental results showed that the use of mica plates is suitable compared of other plates. Nafey et al. (2001) investigated the effect of different absorbing materials: black rubber and black gravel on the thermal performance of the solar still. The researchers found that black rubber and black gravel had a better rate of production compared to CSS. Murugavel and Srithar (2011) compared the effect of aluminum rectangular fins (65 mm 45 mm) covered with different cloths (cotton and jute) on the cost-effectiveness of the solar distillate. The researchers concluded that the daily productivity when using covered with cotton cloth on aluminum rectangular fins is higher than the daily productivity when using covered with jute cloth on aluminum rectangular fins. Srivastava and Agrawal (2013) studied the effect of porous absorbers on the performance of a solar still. Experimental results showed that on cloudy days, daily productivity improved approximately 35% when using modified still with Porous absorbers compared to conventional still. Shanmugan (2013) conducted the impacts of concrete stones, pebbles and black granite on single slope and single basin with hot water provision. The authors concluded that the solar still with concrete stones gave 8.40 kg/day total distillate water without hot water, higher performance compared to other energy storage materials, it gives and 9.10 l/day using hot water. Priya and Mahadi (2013) conducted experimental studies used black dye with rocks and ink in water solution on solar still. The researchers concluded that the distillate water productivity improved by 65% and 35% when using black pigment in rocks and ink in an aqueous solution, respectively. Arjunan et al. (2014) conducted experimental studies on black granite gravels, pebbles, blue metal stones and paraffin wax on the performance of solar still. The results showed that the black granite gravels are more effective material various energy storage materials another. Dumka et al. (2019) conducted the impacts of sand-filled cotton bags performance of solar still. They found that showed that the daily production reached to 3140 mL/m^2 for still with sand-filled cotton bags, and 2397 mL/m^2 for without sand-filled cotton bags. Kabeel et al. (2017b) coated the absorber plate with black paint mixed with CuO nanoparticles to enhance its heat transfer characteristics, and hence improve the productivity of the solar still. They improved the distillate of the solar still by 25% at a weight fraction of 40%. Besides, Zanganeh et al. (2019) applied a nano-silicon solution over the condensation surface of the solar still using a dip coating technique. The affirmed that the nano-coating changed the condensation mechanism from film-wise to drop-wise. Balachandran et al. (2020) improved the thermal productivity of solar distiller by utilizing the absorber basin coated with black paint blended with ferric nanomaterial.

The aim of this work is to improve the productivity of the hemispherical distiller by using metal trays. Therefore, we put different metal trays (iron, zinc and copper) on the bottom of the hemispherical basin to enhance the distillate output. The presence of metal trays (iron, zinc and copper) on bottom of the solar distiller increases the heating of the water close to the basin liner. For this, we compared the performance of four hemispherical solar distillers: a conventional hemispherical solar still (CHSS), modified hemispherical solar still with metal tray of iron (THSSI), modified hemispherical solar still with metal tray of zinc (THSSZ), and modified hemispherical solar still with metal tray of copper (THSSC). These experiments were conducted in El Oued city, Algeria on three days in July 2020.

Section snippets

Experimental setup

Algeria is located in the north of the continent of Africa and is the largest country in Africa. It accounts for 80% of the area of Algeria is the Sahara. For this reason, Algeria has a large solar energy reserve (Fig. 1). The average duration of sunlight in the Algerian desert areas ranges from 2000 h/year to 3500 h/year. The total energy received is 169.400 terawatt hours/year (Achour et al., 2017, Nia et al., 2013).

Fig. 2, Fig. 3 illustrates the design 2D and 3D of a conventional…

Instrumental and experimental uncertainty

The uncertainty in the data was approximated using the method found by Holman (2012). Let W_R be the uncertainty found in a result. Also, W_1, W_2, W_3, …, W_n are the uncertainties found in the independent parameters. Then, W_R is counted on as following Holman (2012);

$$W_R = \left[\left(\frac{\partial R}{\partial x_1} W_1\right)^2 + \left(\frac{\partial R}{\partial x_2} W_2\right)^2 + \cdots + \left(\frac{\partial R}{\partial x_n} W_n\right)^2\right]^{\frac{1}{2}}$$

The minimum error is equal to the ratio between its least count and minimum value of the output measured Srithar (2003). The hourly productivity is a function of the flask water depth (m=f(h)). Hence, …

Thermal performance of the hemispherical solar still

The experimentations were conducted on a hemispherical basin distiller with different metal trays (iron, zinc and copper) to improve the distillate output. The main reason for choosing the metal trays (iron, zinc and copper) on bottom of the solar distiller is to increase the heating of the water at the basin. For this, we compared the performance of four hemispherical solar distillers: The first distillation as a Conventional Hemispherical Solar Still (CHSS). The second is the modified solar…

Daily cumulative yield

Table 4 shows the cumulative distillate yield of CHSS, THSSI, THSSZ and THSSC recorded during the days of tests. During the thirteen hours of the days of the experiment.…

Economic analysis

We analyzed the performance of distillers to be able to calculate the cost of distilled water produced from the hemispherical distillers. The details of the costs of the solar distillers are tabulated in Table 5. The analyses are obtained as following (Abdullah et al., 2020, Kabeel et al., 2017c);

The capital recovery factor is…

Conclusions

The current experimental work aims to improve the accumulative yield of the hemispherical basin distillers. To achieve this idea, the modification in the design of hemispherical basin distiller was done by adding metal trays (Iron, Zinc and Copper) and tested at the same weather conditions. We performed a comparative performance analysis of CHSS, THSSI, THSSZ, and THSSC to obtain the better tray metal that achieves the highest performance of hemispherical basin distillers. Among the most…

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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