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Improving the performance of solar still by using PCM as a thermal storage medium under Egyptian conditions

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HIGHLIGHTS

- The impact of PCM on the behavior of still was investigated experimentally under Egyptian conditions
- The improvement in the productivity for still with PCM is 67.18% higher than that for conventional still
- The amount of distillate water reaches approximately 7.54 L/m^2 day for still with PCM

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ABSTRACT

The objective of the present work is to improve the performance of a solar still through increasing the productivity of freshwater. In order to improve the performance of a solar still, a phase change material (PCM) was added as a heat storage medium. Two solar stills were designed, constructed and tested in the present experimental study to compare the productivity of the solar desalination system. One of them is a solar still with PCM and the other is the conventional solar still. The experimental results show that, the daily freshwater productivity for solar still with PCM is higher than that of conventional solar still. The daily freshwater productivity approximately reached 7.54 L/m^2 day for solar still with PCM, while its value is recorded 4.51 L/m^2 day for the conventional solar still. The results show that the daily freshwater productivity for solar still with PCM is 67.18% higher than that of the conventional solar still. Also, the solar still with PCM is superior in daily freshwater productivity (67%–68.8% improvement) compared to a conventional solar still in the period from June to July 2015 under the ambient conditions of Tanta city (Egypt). In this case study the estimated cost of 1 L of distillate water reached approximately 0.24 LE (0.03 $) and 0.252 LE (0.032 $) for solar still with PCM and conventional solar still, respectively.

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1. Introduction

Obtaining clean drinking water represents one of the major problems in developing countries. In the last forty years the problem of clean drinking water is one of the challenges facing the world. Clean drinking water is a basic human necessity, and without water life will be impossible. In addition, with an ever increasing population and rapid growth of industrialization, there is a great demand for fresh water, especially for drinking. One of the options used to obtain pure drinking water from saltwater is to use solar desalination plants. Solar stills represent a good option and a simple technique compared to the other distillation methods. The problem facing the solar stills is the low distillate water productivity. To enhance the productivity of the solar still, various research works are being carried out.

Free surface of the basin water is the important factor that affects the productivity of the solar still. Bassam [1] use the sponge cubes in the basin water to increment the free surface of the saline water. This study showed that, using the sponge cubes in the basin water improves the distillate water productivity. Velmurugan et al. [2–4] found that, the use of the sponges in a single basin still and stepped still improved the productivity by 15.3%.

The evaporation rate in the conventional solar still depends only on the solar radiation, but in the active solar still the evaporation rate depends on some additional external sources such as a solar water heater [5–8], parabolic trough concentrators [9], a flat plate reflector [10], solar collectors and a storage tank [11,12] and a pump [13]. These studies showed that, the daily distillate water productivity increases with an increase in the thermal energy in the basin still.

The basin water depth is an important factor affecting the distillate water productivity of the still. Investigations show that the basin water depth is inversely proportional to the distillate water productivity of solar still [14,15]. The effect of several conditions including ambient

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temperature, wind velocity and the intensity of solar radiation for ambient conditions and the angle of the glass cover, the saline water depth, the thermal insulation and the difference in temperature between the basin water and condensation surface for the operating conditions on the productivity of the solar still has been studied Xiao et al. [16].

El-Agouz et al. [17] studied the performance of the inclined solar still with and without water closed loop. They found that, the productivity of the inclined solar still with a makeup water is higher than that of a conventional basin-type solar still by 57.2%.

Another technique that can be used to improve the distillate water productivity of solar still is the use of thermal storage material. The thermal storage material can be classified into the latent heat thermal storage material and the sensible heat thermal storage material. The latent heat thermal storage material has a significant advantage over sensible heat thermal storage material, including a large amount of energy storage per unit mass [18]. A wide range of phase change materials can be used for latent heat storage applications, including salt hydrates, paraffin waxes, fatty acids, and sugar alcohols [19,20]. For use in solar still applications, paraffin waxes represent the most suitable option due to their congruent melting temperatures, availability and low cost. However, they usually suffer from relatively high volumetric expansion ratios and low thermal conductivity values. The poor thermal conductivity can be overcome by using the PCM through geometries with large surface area to volume ratios. A little number of papers studied the use of phase change material (PCM) as a thermal storage material in solar stills. El-Sebaii et al. [21] and Radhawan et al. [22] have theoretically studied transient performances of a single basin still and stepped still with PCM as a thermal storage material, respectively. Mohammad and Farshad [23] studied the behavior of cascade still with latent heat storage material. The mathematical models have been developed to study the behavior of the solar still with and without PCM. The results indicated that, the distillate water productivity of the solar still with PCM was 31% higher than the solar still without PCM. Arunkumar et al. [24] studied the effect of thermal storage material on the productivity of the concentrator-coupled hemispherical basin still. They found that, the distillate water productivity of the still with PCM was 26% higher than the still without PCM.

The objective of the present work is to improve the distillate water productivity of the solar still by using phase change materials (PCMs) as a thermal storage medium. The PCM will act as a latent and sensible heat storage medium. The used PCM in the current work is the Paraffin wax due to its wide availability and low cost. The effect of PCM on the performance of the solar still with PCM is experimentally investigated, and the study results are compared with conventional still, to evaluate the development in the distillate water productivity and the daily efficiency for using PCM, under Egyptian conditions. Also, the estimated cost of the distillate water productivity has been investigated.

2. Experimental work

The present experimental work of this study was carried out in the Faculty of Engineering, Tanta University, Egypt (Latitude 30.47°N and longitude 31°E), during the period from June to July 2015.

In the present work, PCM is used in the solar still as a thermal storage medium to improve the freshwater productivity of the solar still. Two stills were designed, fabricated and constructed to compare the freshwater productivity of the solar desalination system. One of the stills is the conventional solar still and the other is the solar still with PCM as shown in Figs. 1 and 2. Fig. 1 shows the schematic diagram of the experimental work. In addition, Fig. 2 shows a photo of the experimental work.

The conventional solar still (CSS) has a rectangular galvanized iron sheet of 0.72 m^2 (0.6 m $*$ 1.2 m) with 1.5 mm of thickness and coated with black paint to increment the solar radiation absorption. The elevation of the high-side wall of still has been kept at 0.47 m and the elevation of the low-side wall has been kept at 0.12 m. Also, the basin of the conventional solar still is insulated through the side and the bottom by a 5 cm fiber glass insulation to reduce the loss in heat energy from the still to the ambient. The still cover is made of commercial glass, with a thickness of 3 mm, and it is inclined by 30.47° to the horizontal. The condensed water was collected through the lower end side of the glass cover. The silicon is used as a bonding material to prevent any leakage between the basin box and the glass cover. The saline water tank is placed 1 m above the still to feed saline water to the basin still. The saline water tank was connected to the conventional solar still by a water pipe line. A check valve is integrated at the pipe line entrance to regulate the saline water flow rate.

The solar still with phase change materials (SS with PCM) consists of a PCM reservoir, absorber plate, insulation layer, glass cover, saline water tank and K-type thermocouples. The saline water tank is placed 1 m above the still to feed saline water to basin still. The saline water tank was connected to basin still by a feed water pipe line. A check valve is integrated at the pipe line entrance to regulate the saline water flow rate. The absorber plate is made from copper sheet of, 0.615 m^2 (0.54 m $*$ 1.14 m), 0.4 mm thickness and 0.06 m height. It is located inside the basin still, the basin still is made from a galvanized iron sheet of, 0.6 m × 1.2 m, with 1.5 mm thickness. The absorber surface is coated with black paint to increase the solar radiation absorption. The elevations of the high-side and low-side walls are constant at 0.47 m and 0.12 m, heights respectively.

A phase change material reservoir, 3 cm height is installed with the solar still, beneath the absorber plate and filled by PCM. The bottom wall of the PCM reservoir is made from galvanized iron sheet of 0.6 m $*$ 1.2 m, and the upper wall of the PCM reservoir is the absorber plate. The PCM acts as a latent and sensible heat energy storage medium, Paraffin wax with a mass of 17.5 kg is used because of its wide availability and its low cost. The properties of Paraffin wax are indicated in Table 1.

The solar still with PCM is insulated through the side and the bottom by a 5 cm fiber glass insulation to reduce the loss in heat energy from the still to the ambient, and after the insulation the basin box was placed inside the wooden box. The still cover is made of commercial glass, with a thickness of 3 mm, and it is inclined by 30.47° to the horizontal. The condensed water was collected through the lower end side of the glass cover. The silicon is used as a bonding material to prevent any leakage between the basin box and the glass cover.

3. Experimental procedure

The experimental work was designed and constructed in Faculty of Engineering-Tanta University, Egypt. The experiments were carried out from 6:00 am to 10:00 pm during the period from June to July 2015. The following parameters are measured during the experiments, the solar radiation, ambient temperature, glass cover temperature, basin water temperature, absorber plate temperature, PCM temperature and distilled water temperature. The measurements are taken every hour. The collected freshwater productivity is also measured every hour. For both solar still with PCM and conventional solar still the depth of the saline water remains constant at 2 cm during the experiments. All experimental measurements aimed to evaluate the performance of the both stills under the ambient conditions of Tanta city — Egypt. The experiments show the effect of PCM on both daily productivity and daily efficiency for the solar still.

4. Mechanism of heat transfer in PCM

The PCM is used as a heat storage medium. When heating the phase change material, at the beginning, the heat is stored in PCM as sensible heat until the PCM temperature reaches its melting temperature. When the PCM is completely melted, the heat is absorbed again in the form of sensible heat. The PCM will represent a source of heat for the basin water during the night and in the periods of low solar radiation intensity.

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