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Enhancing the solar still performance using solar photovoltaic, flat plate collector and hot air

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HIGHLIGHTS

- Hybrid of solar still with PV system, condenser and solar water and air collectors
- Evaluation of solar still with spraying hot water in passive and active modes
- Enhancing the solar still performance using hot water jet
- Solar still coupled with hot air collector

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ABSTRACT

This work aims to enhance the productivity of a single slope solar still for remote communities facing electricity problems and a shortage of good quality water. The single slope solar still was equipped with a flat plate solar collector, spraying unit, perforated tubes, external condenser and solar air collector. The developed solar still (DSS) was evaluated in passive and active modes and compared with the conventional solar still (CSS). The circulated water was either sprayed into the DSS or pumped from the bottom upward forming fountains. A hot dry air was forced at the bottom of the DSS which constituted air bubbles to burst at the water surface. The DSS was powered by photovoltaic (PV) system and evaluated at different operating modes. The CSS productivity ranged from 3 to 4 l/m^2. The DSS productivity was more than the CSS by 51–148% depending on the type of amendment. The use of external condenser with solar still increased the productivity by 51%. The use of circulated hot water in passive and active sprays without condenser led to increase the DSS productivity by 56% and 82%, respectively. The DSS has demonstrated its suitability for the desalination process when weather conditions are suitable and water demand is not too great.

1. Introduction

Clean water is essential for socio-economic development. Nevertheless, there is limited access to water that meets standard limits of water quality, especially in the African region. The quality of saline/brackish water can be improved through solar desalination. The distillation system can be classified under two categories: Passive and active. Murugavel et al. [1] reviewed the work on passive solar distillation and concluded that, the usage of different materials in the basin improved the productivity significantly. Sampathkumar et al. [2] reviewed the active solar distillation which needs external energy to improve the performance of the system. Tiwari et al. [3] carried out a study on both passive and active solar distillation systems. They have recommended that only passive solar stills can be economical to provide potable water. The active solar distillation system can be economical from a commercial point of view.

In active type basin stills, some external sources are used to increase the temperature of water in the basin such as a flat plate collector, a concentratic collector, a hybrid PV/T system, a heat exchanger and a solar pond. The solar still coupled with flat plate collector works either in forced circulation mode or natural circulation mode. Riffata et al. [4] analyzed the performance of a solar still coupled with a flat plate collector. They found that the solar thermal device under thermosyphon mode (natural circulation mode) had more advantage than the forced circulation mode in terms of simplicity, reliability and cost effectiveness. Zaki et al. [5] investigated the integration of active single sloped solar still with flat plate collector and found that the maximum increase in the yield was up to 33%. While, Badran et al. [6] found that integration of flat plate collector with single basin solar still, increased the productivity of potable water by 52% as maximum.

An external condenser was attached to a solar still to enhance the productivity of the solar still. The effect of adding an outside passive

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condenser to a single-basin-type solar still with minimum inclination (4°) was investigated experimentally by E1-Bahi and Inan [7]. The results showed that, the daily yield reached 7 l/m^2 and 75% efficiency during the summer months. Nijegorodov et al. [8] studied the effect of adding passive condenser on the performance of the single sloped basin solar still. The air saturated with water vapor was removed from the basin still by using low power exhaust fan and then passed through the condenser. The thermal efficiency of the still was twice more than the thermal efficiency of the conventional still. A passive solar still with separate condenser has been modeled and its performance was compared with that of a conventional solar still by Madhlopa and Johnstone [9]. Results showed that the productivity of the still was 62% higher than that of the conventional still. Kabeel et al. [10] enhanced the solar still productivity by using nanofluids and integrating the still basin with an external condenser. The effect of vapor suction at different speeds was also investigated. The results showed that integrating the solar still with external condenser increased the distillate water yield by about 53.2%. The use of nanofluids and external condenser improved the solar still productivity by about 116%.

El-Zahaby et al. [11] studied the enhancement of corrugated stepped solar still performance using a reciprocating spray feeding system. Feeding of the saline water in the form of fine droplets into the still was controlled by a transverse reciprocating spraying system. The recorded accumulated productivity in 10 h and efficiency were 6.36 l/m^2 and 77.35%, respectively.

Pandey [12] reported the effect of dried, forced air bubbling and cooling of glass cover in solar still. Results showed that, the simultaneous bubbling of dry air and glass cooling gave the highest increase followed by bubbling of dry air alone. Mink et al. [13] presented the performance test of air blown, multiple effect solar still with thermal energy recycle consisted of an upper evaporation chamber and lower condensation chamber. The results indicated that the still performance can be enhanced further by increasing the liner air stream velocity in the lower chamber through decreasing its cross-sectional area. El-Agouz [14] investigated the performance of single stage bubble column using air bubbles passing through seawater. The influence of water temperature, saline water level in the humidifier and the airflow rate on the humidification efficiency was studied. The results showed that, the productivity of the system increased with the increase of the water temperature and when decreasing the airflow rate.

2. Objective of the work

The objective of this research work is to improve the basin solar still productivity through the following:

i Connecting a suction (vacuum) blower with the developed solar still (DSS) from the top back side to withdraw water vapor and pass it to the external condenser.

ii Coupling a flat plate solar collector with the DSS, to increase the temperature of feed water to the solar still. This can be achieved through the following:

a) Circulating the water through the flat plate solar collector by natural circulation (Thermosyphon) and forced circulation using a pump.

b) The circulated water could be sprayed or atomized into the DSS and also, pumped from the bottom upward in the form of fountain in order to increase the rate of evaporation.

iii A hot dry air could be suctioned from solar air collector and forced at the bottom of the DSS which constituted air bubbles to burst at the surface of the saline water. Therefore, it could break the surface tension and increase the evaporation rate.

iv In addition, a hybrid of different modifications or augmentations was studied.

The DSS was powered by solar photovoltaic (SPV) system. To decrease the cost and effective use of power to drive the DC suction blower, AC water pump and AC air pump (compressor), the size of PV module was kept to 60 W in the fabricated system.

3. Materials and methods

This section describes the materials and methods used for conducting the experiment on the augmentation of solar photovoltaic, flat plate collector and hot air with solar still for brackish water desalination.

3.1. Setup design and fabrication

The experiments were carried out in the premises of Kafrelsheikh University, Egypt which lies at latitude 31.07°N and longitude 30.57°E during summer 2013.

A schematic diagram of a symmetrical single sloped solar still is shown in Fig. 1, which explains different components of the experimental setup. A photograph of the fabricated hybrid developed solar still (DSS) as well as conventional solar still (CSS) is depicted in Fig. 2.

As shown in Fig. 2, both of the solar stills are in single slope. Each single basin has a basin area of 0.50 m^2 (1.0 m × 0.50 m-inside dimensions). The basins of solar stills were made of galvanized steel sheets of 2 mm thickness. The lower and higher wall heights (south–north) have been kept at 0.16 m and 0.45 m, respectively. Interior surfaces of the basins were coated with matt black paint to increase the

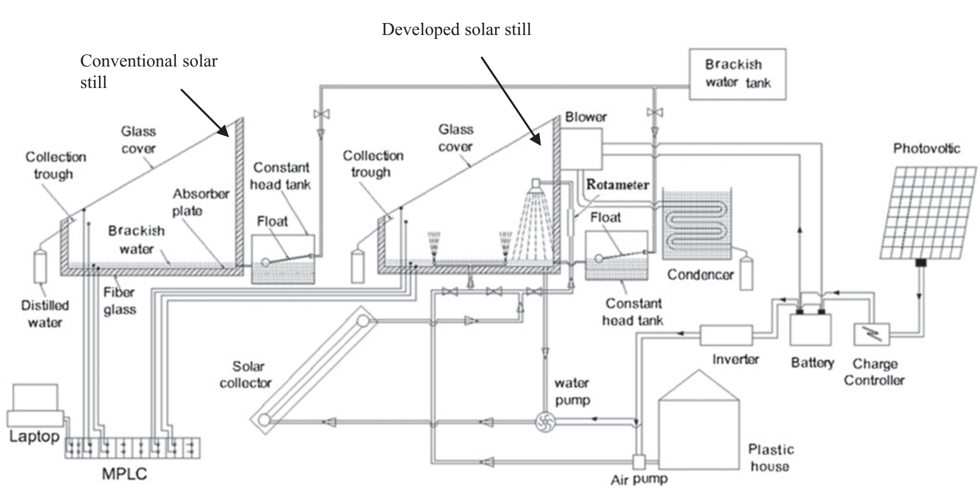

Fig. 1. A schematic diagram for the hybrid experimental setup (conventional solar still and developed solar still).