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Experimental investigation of the effect of solar collecting area on the performance of active solar stills with different brine depths

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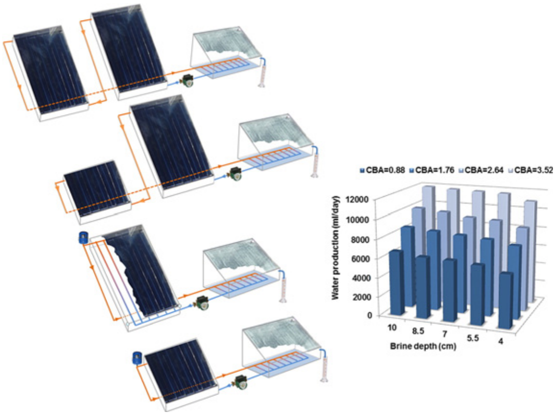
HIGHLIGHTS

- A study was done on the effects of collector area in active solar stills.
- Four parallel active solar stills with different collector areas were fabricated.
- The experiments were conducted for 5 consecutive days to find the actual effects.
- The stills' production increased as the solar collecting area increased.
- For stills with low brine depth and high solar collecting area the brine may boil.

GRAPHICAL ABSTRACT



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ABSTRACT

Solar collecting area is one of the most important operating parameters of active solar stills. No experimental work has been performed to investigate the effect of this parameter to date. Furthermore in all of previous theoretical studies the effect of solar collecting area was examined during only the first 24-hour period of the operation of stills with one specified brine depth. However the present work experimentally studies the long-term simultaneous effects of collector area and brine depth on the performance of active solar stills. For this purpose four parallel active solar stills with different collector areas were fabricated and experiments were conducted for 5 consecutive days during which different amounts of brine depth were considered for active solar stills. The present results indicated that the overall trend of distilled water production and efficiency lessened with decreased brine depth for all solar collecting areas. Moreover, as the solar collecting area increased, water production of stills increased but their efficiency decreased for all brine depths. Furthermore the current results showed that for active solar stills with low brine depth and high solar collecting area the brine may boil and this boiling decreases the efficiency of active solar stills.

1. Introduction

With population growth and development of industry and agriculture, water shortage has become a major problem in most countries

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[1]. Distillation is one of the appropriate methods for supplying safe water. Many sources of energy can be used for distillation of water such as fossil fuel and electricity [2]. Renewable energies can also be used for this purpose to avoid energy and environmental crisis [3–5]. Solar stills use solar energy for distillation of saline water and are divided into two main categories: passive and active. In passive solar stills, the solar radiation is received directly by the brine in the basin and is the only source of energy for raising the temperature of brine thus, these systems produce low amount of distilled water. To overcome this problem various types of active solar stills have been developed [6]. In active solar stills, an extra energy source is used to increase the brine temperature and hence the productivity of still. Solar stills coupled to flat plate solar collectors are one of the simplest active solar stills [7–9] and can work either in forced or natural circulation modes. In forced circulation mode a pump circulates the heat transfer fluid (HTF) but in natural circulation mode the HTF flows by thermosyphon circulation [6].

Many design parameters such as the depth of brine in the basin, type and number of solar collectors, thickness of glass cover, type of condensing cover and the thickness of insulation can affect the performance of active solar stills [10–12]. In addition, climatic parameters such as ambient temperature, solar radiation and wind velocity may affect the performance of these systems [13–15]. Recently Muftah et al. [15] have reviewed the factors affecting the basin type solar still's productivity.

One of the most important operating parameters which can affect the performance of an active solar still is the number of solar collectors or in the other words the solar collecting area. Other important operating parameter is the brine depth which is easily adjustable and a cost-effective way for the improvement of the performance of a still. Several experimental and theoretical studies have been done to investigate the effect of this parameter [16–22]. In our previous work [9] all of these researches and the effect of brine depth on the performance of active solar stills in practical multi-day use have been reviewed. It was shown that unlike the previous researches, the water production and efficiency lessened as the brine depth decreased. This difference in results is primarily due to neglecting the long-term operation of the active solar stills, the operation type that was considered in this work to investigate the effect of solar collecting area.

The effect of solar collecting area has been examined only in three theoretical studies [10,17,20]. Kumar and Tiwari [17] presented a thermal analysis of an active solar still to optimize the collector and basin areas for a given brine depth. They showed that to maximize the yield, the optimum solar collecting area should be 8 m^2 for a 1 m^2 basin area with 15 cm brine depth in the basin. Dimri et al. [20] used an analytical model and investigated the effect of solar collecting area on the productivity of active solar stills. Their results showed that the daily yield enhances with increasing the solar collecting area. However they stated that the increase in yield is marginal due to high value of inner glass cover temperature. They concluded that a 2 m^2 solar collecting area is optimum for an active solar still with 1 m^2 basin area and 15 cm brine depth. In another work, Tiwari et al. [10] conducted a parametric study on active and passive solar stills based on energy and exergy analysis. Their model was similar to the model proposed by Dimri et al. [20] but was based on two assumptions: (a) inner and outer glass cover temperatures are equal and (b) inner and outer glass cover temperatures are not equal. The results of Tiwari and his co-workers showed that the feasible surface area of collectors for 15 cm brine depth is 6 m^2. By increasing this area further, the rise in the daily production of a solar still is reported to be 200 ml for each 2 m^2 of solar collector integrated with the active solar still.

These studies only investigated the first 24-hour of the performance of an active solar still while it is known that in the practical use, the operation of system is more than one day. So far no experimental research has been conducted to study the simultaneous effects of the solar collecting area and brine depth.

The present work experimentally examined the simultaneous effects of the solar collecting area and brine depth for the first time. As for practical uses the long-term operation of active solar stills has been considered. For this purpose, four parallel active solar stills were fabricated and integrated with different solar collecting areas. The experiments were performed for 5 consecutive days and in each day different amounts of brine depth were used in active solar stills.

2. Experimental setup and procedure

As pointed out in the previous section, four similar active solar stills were fabricated and coupled with solar collectors of different collecting areas. The surface area and dimensions of solar collectors integrated with these four solar stills are shown in Table 1. The CBA (Collector to Basin Area) coefficient in Table 1 is the ratio of solar collecting area and basin area.

All solar stills had an effective horizontal surface area of 0.92 m^2 (i.e. 1.25 m by 0.75 m). The inclination of glass cover was 30° and its thickness was 4 mm. The basin liners were covered with black rubber in order to improve the solar energy absorption. Silicon rubber sealant is used to prevent leakage from any gap between the glass cover and the still box. In order to reduce heat losses from the walls and the bottom of the basin, 5 cm of glass wool and 3 cm of polyethylene foam were used as thermal insulation. HTF which was a mixture of water and ethylene glycol was circulated with a pump through a closed loop between solar collectors and heat exchanger installed in the basin. The pipelines were insulated with polyethylene foams of 3 cm thickness. The solar collectors were tilted 40° and the stills and collectors were faced southward to receive maximum possible solar radiation during the day. The pump operated only during sunshine hours when the temperature of HTF was more than brine temperature (around 8:00 a.m. to 4:00 p.m.). A schematic view of the experimental set-up is shown in Fig. 1.

In the present research, 5 days of continuous test was conducted using four parallel active solar stills. In order to simulate the continuous operation of sills, all of them operated for 24 h as a pre-test operation. As a result, the initial temperatures of brines were above the ambient temperature at the beginning of the first day of experiment. In the beginning of the first day of experiment, to compensate the evaporated brine during the pre-test operation, the produced distilled waters during 24 h were heated up to the temperature of the brine and added to the basins. The experiment started at 8:00 a.m. local time and continued for 120 h, until 8:00 a.m. of the sixth day. The depth of brine in the basins was adjusted to a specified value at the beginning of each day; however the initial temperature of brine in each basin (which is the final temperature of previous day) was not changed during this adjustment. These values of brine depth are shown in Table 2.

In order to investigate the performance of solar stills during the experiments, the climatic parameters (solar irradiance and ambient temperature), produced distilled water and temperatures of various parts of stills, were continuously measured and recorded. The temperatures of basin liner, brine, vapour, glass cover, and HTF entering and leaving collectors were measured continuously every 1 s by copper–constantan thermocouples with the accuracy of 0.1 °C and saved in a computer using a data logger.

A Kipp & Zonen pyranometer with an accuracy of 3% was used for measurement of solar irradiance. The produced distilled water was

Table 1
Surface areas and dimensions of solar collectors integrated with solar stills.

Still number	CBA	Collector surface area (m^2)	Dimensions (m × m)
1	3.52	3.24	(1.910 × 0.850) + (1.910 × 0.850)
2	2.64	2.43	(1.910 × 0.850) + (0.955 × 0.850)
3	1.76	1.62	1.910 × 0.850
4	0.88	0.81	0.955 × 0.850