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Experimental investigation of stepped solar still with continuous water circulation

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ABSTRACT

This paper presents a modification of stepped solar still with continuous water circulation using a storage tank for sea and salt water. Total dissolved solids (TDS) of seawater and salt water before desalination is 57,100 and 2370 mg/l. A comparison study between modified stepped and conventional solar still was carried out to evaluate the developed desalination system performance under the same climate conditions. The effect of installing a storage tank and cotton black absorber for modified stepped solar still on the distillate productivity was investigated. The results indicate that, the productivity of the modified stepped still is higher than that for conventional still approximately by 43% and 48% for sea and salt water with black absorber respectively, while 53% and 47% of sea and salt water, respectively with cotton absorber. Also, the daily efficiency for modified stepped still is higher than that for conventional still approximately by 20%. The maximum efficiency of modified stepped still is occurring at a feed water flow rate of 1 LPM for sea water and 3 LPM for salt water. Total dissolved solids (TDS) of seawater and salt water after desalination is 41, and 27 mg/l.

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1. Introduction

The solar energy can be used to produce the heat using solar collectors, solar cooking, desalination, and cooling systems. The main practical problem of the conventional solar sill that is observed in the first phase is low productivity and efficiency. The efficiency and productivity could be increased by increasing the surface area of the solar distillation unit.

Al-Hinai et al. [1] studied the effect of design, climatic, and operational parameters on the productivity of a simple solar still. The results show that the daily productivity increased by 8.2% with a rise in ambient temperature from 23 to 33 °C. The water depth is batter in the range of 0.02–0.06 m.

Kumar and Tiwari [2] presented the newly design of the hybrid (PV/T) active solar still. The effect of water depth for passive and hybrid active solar still was studied. The maximum daily productivity from passive and hybrid active solar still was 2.26 kg and 7.22 kg at 0.05 m water depth. The productivity of a hybrid active solar still was about 3.2 and 5.5 times higher than the passive solar still in summer and winter month.

The effect of tilt angle on productivity and the value of the optimum tilt angle were reviewed by Khalifa [3]. The review conclusions show that the cover tilt angle should be large in winter and small in summer. Also, the various seasons and latitudes effected in choosing the proper cover tilt angle.

The effect of wind speed on the daily productivity of some designs of basin type, vertical, active and passive solar stills was investigated by El-Sebaii [4,5]. The results showed the value of wind speed is independent of the still shape and heat capacity of the brine. The wind is more effective in summer and at higher water masses.

Gude et al. [6] developed and evaluated the performance of the two-stage operation of the low temperature desalination process using a low-grade heat source. The results show that in a double stage configuration, the specific energy consumption of the process was less than 3.6 kJ/kg of mechanical energy and 1500 kJ/kg of thermal energy.

Xiong et al. [7] designed a new multi-effect solar still with enhanced condensation surface, which applied the corrugated shape, structure to decrease the condensation resistance and increase the freshwater yield. The results showed that, the seawater temperature change of the model reveals the existence of a reverse temperature difference in the second stacked tray, which can make the seawater temperature increase quickly and was advantageous for enhancing the freshwater yield in the subsequent process.

Abdallah et al. [8] studied three design modifications to improve the performance of a traditional single slope solar still. First, addition of internal reflecting mirrors on all interior sides of

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still, secondly, using stepwise water basin instead of flat basin and thirdly coupling the solar still with a sun tracking system. The results showed that, coupling of the stepwise basin with sun tracking system gives the highest efficiency thermal performance with an average of its 38% efficiency.

Khalifa et al. [9] studied some modifications of single and double slope stills on productivity and efficiency. The results showed improvements in the output and efficiency of the solar stills due to the employment of the above modifications.

Velmurugan et al. [10] compared the performance of ordinary single basin solar still and wick type still. The enhance evaporation of the still basin water, fins and sponges were integrated at the basin of the still. It was found that productivity increased about 29.6%, when wick type solar still was used, productivity increased about 15.3%, when sponges were used and it increased about 45.5%, when fins were used.

Velmurugan et al. [11] studied integrating two different depths of trays of the fin at the basin solar air heater with the stepped solar still. They reported that, the production increases by 53.3% when using fins type stepped solar still. The productivity increases by 68% for sponge, and 65% for pebble. When using both sponge and pebble in fin type stepped solar still, the productivity increases by 98% than the conventional stepped solar still.

Velmurugan et al. [12] enhanced the productivity of the stepped solar still. Experimental, theoretical, and economical analyses of stepped solar still with fin, sponge, and the combination of fin and sponge types was presented. The results show that, the average daily productivity of stepped solar still was found to be 80% higher than that the single basin solar still when used the fin and sponge type.

El-Zahaby et al. [13] presented a new design of a solar desalination system to improve the freshwater productivity by using two air heaters. The results showed that both inlet seawater temperature and the power consumed have a strong effect on the stepped still performance. In addition, El-Zahaby et al. [14] investigated experimentally performance of the solar stepped still using the spray system for seawater at different velocities of the water spray's holder and flow rates.

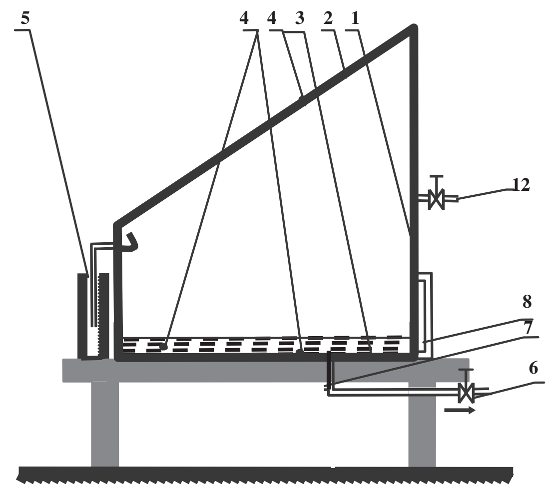
Other studies have considered the use of phase change material (PCM) as storage media in stepped solar stills. Radhawan [15] studied the effect thermal energy storage for transient performance of a stepped solar still. The results show that the modification still was efficient for water produced during the lack of sunlight especially at night. In addition, El-Sebaii et al. [16] developed a new mathematical model under the simplifying assumptions to study the thermal performance of a single basin solar still with phase change material (PCM).

Dashtban and Tabrizi [17] studied a weir-type cascade stepped solar still with phase change material as a thermal energy storage system to improve the productivity. The results show that still with PCM was superior in productivity (31% improvement) compared with still without PCM by considering a limited set of data in a typical day. The daily productivity of still with PCM increased by about 32%.

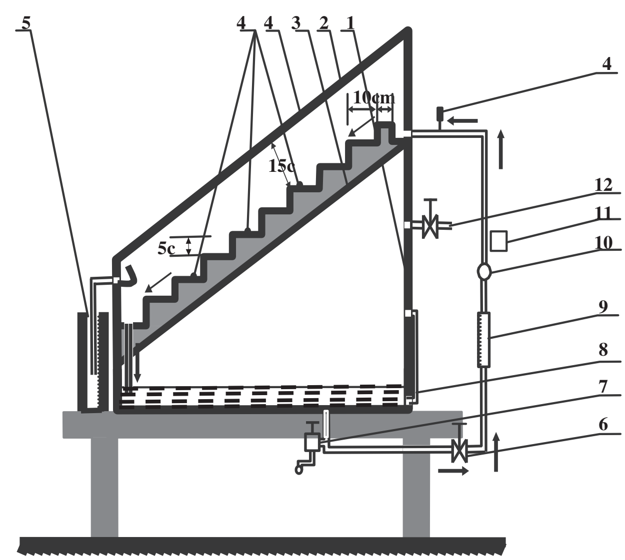
Kabeel et al. [18] studied the effect of varying both depth and width of the trays on the performance of the stepped still theoretically and experimentally. The results show that, maximum productivity of stepped still was about 57.3% higher than that of the conventional still at a tray depth H = 5 mm and width W = 120 mm. Also, the daily production of the stepped still by using wick on the vertical sides was increased from 3% to 5%.

Omara et al. [19] presented a modification of stepped still through internal and external reflectors and they influenced in the performance of the stepped solar still. The results show that the productivity of the modified stepped solar still with internal and external reflectors was higher than that conventional still approximately by 125% during experimentation.

The enhancement of the productivity of the solar desalination system, in a certain location, could be attained by a proper modification in the system design. However, the increase in the system productivity with high system cost may also increase the average annual cost of the distillate.



(a) Conventional solar still



(b) Stepped solar still

Fig. 1. Schematic diagram of the experimental setup. (1) Solar still frame, (2) glass cover, (3) absorber plate, (4) digital thermometer, (5) water vessel, (6, 12) control valve, (7) water drain, (8) graduate level, (9) flow meter, (10) water pump and (11) control timer.

Table 1
Accuracies and ranges of measuring instruments.

Instrument	Accuracy	Range	Error (%)
Flow meters	±0.2 l/min	0.5–7 l/min	5
Kipp–Zonen Pyranometer	±1 W/m^2	0–5000 W/m^2	0.2
Anemometer	±0.1 m/s	0–15 m/s	4
Digital thermometer	±1 °C	−50–300 °C	0.25
Graduate lab vessel	±10 ml	0–1000 ml	4

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