Desalination 373 (2015) 1–9

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

Improving the double slope solar still performance by using flat-plate solar collector and cooling glass cover

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ARTICLE INFO

Article history:
Received 9 March 2015
Received in revised form 8 June 2015
Accepted 22 June 2015
Available online 9 July 2015

Keywords:
Solar still
Thermal analysis
Thermal efficiencies
Flat-plate solar collector
Desalination
Still cover cooling

ABSTRACT

Thermal analysis, for double slope solar still, was carried out based on internal and external heat transfer and energy balance equations to predict its performance. Depending on the thermal analysis, passive and active solar stills were installed (solar still and solar still integrated with flat-plate solar collector) to use solar desalination technology for producing fresh water. Water temperature as well as both internal and external temperatures of glass cover, added to ambient temperature was measured with hour intervals, under all experimental conditions, for both solar stills. Performance of both solar stills was studied as a function of change in basin brine depth and glass cover thickness under conditions of applying glass cover cooling (flash tactic) or without cover cooling. Performance of solar stills was evaluated in terms of recorded temperatures, instantaneous and internal thermal efficiencies and system productivity. The experimental results revealed that active solar still maximizes both fresh water productivity (10.06 $l/m^2 \cdot day$) as well as internal thermal efficiency (80.6%) compared with passive solar still (7.8 $l/m^2 \cdot day$ productivity and 57.1% internal efficiency) under conditions of 1 cm basin brine depth and 3 mm glass cover thickness and by applying flash tactic cover cooling with 5 min on and 5 min off.

1. Introduction

Desalination of brackish water by solar powered systems is a practical and promising technology for producing potable water in the regions which suffer from water scarcity especially in arid areas.

Non-availability of drinking water is one of the major problems faced by both the underdeveloped and developing countries all over the world. Vinothkuumar and Kasturibai [1] stated that around 97% of the water in the world is in the ocean, approximately 2% is stored as ice in polar region and 1% is fresh water available for the need of the plants, animals and human life. Alarms have recently been sounded about Egypt's limited water resources. Surface water resources originating from the Nile are fixed at 55.5 billion m^3 a year and are being completely used, whereas non-renewable ground water sources in the western desert are being brought into full production. The situation is worsening by growing water requirements, demanded by a population boom, which needs more agricultural areas to produce more food. As natural fresh water resources are limited, seawater plays an important part as a source for drinking water as well. In order to use this water, it has to be desalinated. It is therefore beneficial to exploit solar energy directly by installing solar stills. Great efforts have been carried out by some researches, to improve the production capacity of the solar stills by adapting different techniques under proper operational conditions. Nafey et al. [2] discussed the effect of cooling water flow rate on the desalination system productivity at different values of cooling water inlet temperature. They observed that by increasing the cooling water flow rate and decreasing the inlet cooling water temperature, the surface temperature of the air cooler decreased; hence the condensation rate and the unit productivity increased. Badran and Al-Tahaineh [3] studied the effect of coupling flat plate solar collector on solar still productivity. They found that coupling solar collector with solar still increased the productivity by 36%. Tarawneh [4] showed that the deciding role of cooling the glass cover was strongly observed on the increased temperature difference (glass temperature − water temperature) as well as on the increased water productivity. The effect of cooling the glass cover shows an increase on the water productivity with about 17–23%. Tiwari et al. [5] discussed the effect of water depth on the daily yield of the active solar still integrated with a flat plate solar collector. They showed that the yield decreased with the increased of water mass. Velmurugan and Srithar [6] showed that an enhancement in productivity of the still can be increased by introducing a sprinkler (Cooling film) to the outer layer of the glass cover of the still. This modification will increase the productivity by 22%. Omara et al. [7] presented a new hybrid desalination approach comprising of evacuated solar water heater, jut geotextile and solar still. An evacuated solar water heater is integrated with the desalination stills to evaluate the continuity production of distillate. Water productivity was increased by 114% over conventional still for double layer square wick (DLSW) solar still at 30° base slope angle. The daily average efficiency of DLSW was 71.5%. During experimentation, the distillate water productivity increased

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http://dx.doi.org/10.1016/j.desal.2015.06.017
0011-9164/

by 215% when hot brackish water was fed during night time. Sethi and Dwivedi [8] designed and fabricated a basin type double slope active solar still under forced circulation mode and a performance evaluation was carried out for different water depths of 0.03 m, 0.04 m and 0.05 m. The distillate output was maximum 4.82 kg for water depth 0.03 m and minimum 4.36 kg for water depth 0.05 m. The maximum instantaneous thermal efficiency was 46.96% at water depth of 0.04 m. Shanmugasundaram and Janarthanan [9] enhanced the productivity of the single basin double slope solar still by integrating with shallow solar pond. It was found that the productivity of the solar still integrated with shallow solar pond was increased compared with the still without integration. The productivity of the solar still integrated with and without shallow solar pond was found to be 5.09 l/m^2 day and 3.17 l/m^2 day and the theoretical results were in good agreement with the experimental results. Eltawil and Omara [10] enhanced the productivity of a single slope solar still by using 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 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 led to increase the DSS productivity by 56% and 82%, respectively.

It is clear from the above literature review, that numerous studies were published dealing with the use of solar desalination systems and the most important problems arising during their use. But such studies had to be carried out to develop and operate these systems with maximum efficiency and minimum cost. From this point of view, the main target of the present study is to introduce a developed double slope solar still depending on thermal analysis and enhance its performance by using flat-plate solar collector and cooling its glass cover with flash tactic.

So, the objectives of the present study are to:

- Predict the performance of passive solar still and active solar still (solar still integrated with flat-plate solar collector) by carrying out thermal analysis based on internal and external heat transfer and energy balance equations.
- Install passive and active solar stills depending on the thermal analysis to use solar desalination technology for producing fresh water.
- Apply flash tactic cover cooling to improve the performance of solar still.
- Investigate the performance of both solar stills under different operational conditions.

2. Materials and method

The present study was carried out at the Faculty of Agriculture, Zagazig University, Zagazig city (30° 2′ N latitude and 31°12′ E longitude), in Eastern Delta, Egypt during the summer season of 2014. The climatic conditions of the experimental region were shown in Table (1).

Table 1
The climatic conditions of the experimental region.

Parameter	Summer months (2014)			
	June	July	August	September
Max. Temperature (°C)	34	34	35	33
Min. temperature (°C)	22	23	24	23
Avg. wind speed (km/h)	12	10	10	9
Solar intensity (W/m^2)	603.2	618.9	632.4	583.5

2.1. Experimental setup

2.1.1. The saline water

The saline water used in the present work was ground water (TDS of 4.5 dS/m).

2.1.2. The passive solar still

The passive solar still was manufactured and constructed at a workshop in Zagazig city, Sharkia Governorate, Egypt. The manufactured solar still consisted mainly of raw water tank, solar still unit and connection piping, as shown in Figs. 1 & 2.

2.1.2.1. The raw water tank. The water tank was made of 2 mm thickness galvanized iron sheet, it has a diameter of 40 cm, a height of 45 cm and its volume is 56.6 l. The water tank is located at a suitable level from the still unit to allow saline water to flow regularly from its outlet hole (at its bottom) through control valve with flow rate of 0.8 l/h to the solar still unit due to thermosyphon effect.

2.1.2.2. The solar still unit. The solar still unit consists mainly of a black tray (rectangular box shape) as evaporator (170 × 70 cm) which created a net area of 1.19 m^2.

The still unit wall consists of three layers: counter wood of 20 mm thickness, fiberglass of 27 mm thickness and galvanized iron sheet of 3 mm thickness. The outside height of the basin is 15 cm. The space above the basin is completely enclosed with airtight glass covers as a triangular shape with slope of 25°. The glass cover (which was oriented east west) is sloped towards a condensate channels (U-troughs) which run along the lower edges of the glass pan with a small inclination in order to speed up the condensate velocity and to avoid the tendency of re-evaporation. Two sprinklers are constructed and installed on the top part of the solar still in order to ease splashing method for cooling the glass cover with tap water.

2.1.2.3. The connection piping. The connection piping is made from rubber tubes fixed between both inlet and outlet pipes with metal seal and insulated with sticking rubber tube to prevent any heat loss through saline water flow. It is associated with control valves to control water flow rate.

2.1.3. The active solar still

In the passive solar still, the solar radiation is received directly by the basin water which is considered the only source of energy for raising the water temperature and consequently, the evaporation leading to a lower productivity. So, the solar still integrated with a flat plate solar collector have been developed. Hence, an extra thermal energy is supplied to the basin through an external mode to increase the evaporation rate and in turn improve its productivity.

The active solar still (solar still integrated with flat plate solar collector), which consists mainly of raw water tank, flat plate solar collector, solar still unit and connection piping, is shown in Figs. 3 & 4. Raw water tank, solar still unit and connection piping are the same as described with the passive solar still.

Fig. 1. The double slope solar still (passive solar still) with glass cover cooling.