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Numerical and experimental study of a passive solar still integrated with an external condenser

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ABSTRACT

This paper presents a numerical and experimental investigation to study the effect of the condenser area on the Natural Circulation Loop (NCL) solar still features under typical summer and winter conditions. A computer code has been developed to predict the transient thermal behaviour of the still. This computer code is used to predict the effect of condenser area and wind velocity, on the still daily yield in summer and winter conditions. The results revealed that the still daily productivity increases with the increase of the condenser area until a critical value beyond which its effect becomes insignificant. In addition, it was found that the wind effect is more effective for small condenser area. The simulation shows that the maximum daily output of NCL solar still, under summer and winter conditions, can reach 4.73 kg/m^2 and 2.71 kg/m^2, respectively.

Introduction

Solar desalination is an alternate solution to provide potable water in remote and isolated areas [1]. Farther, it represents an ecofriendly technology which can contributes efficiently in the social and economic development of countries [2,3]. Conventional Solar Still (CSS) is the oldest, economical and simple technology used for purifying of brackish and salt water for drinking purposes. It is a valuable device that can be used especially in remote and arid areas where sunshine is abundant and fresh water is scarce [4,5]. The CSS is selected due to its simplicity and passive features. There is no need for hard maintenance or skilled persons, which leads to little operation and maintenance costs. However, the CSS suffers from some drawbacks, which sometimes limit the use of this system for large-scale production [6]. Some of these drawbacks are, large solar collection area requirement, system vulnerability to weather-related damage, less market demand of technology and low interest of the manufacturers [7,8]. The main limitation is the low productivity compared with modern desalination processes, where the daily yield from a single slope basin type solar still may vary from 0.5 to 2.5 kg/m^2 and its efficiency is usually about 5–40% [9]. Therefore, they are more recommended for a single house or a small community (less than 200 m^3/day) for supplying good quality drinking water [10,11].

Increasing solar still productivity has been the subject of intensive research efforts and remains a challenge for scientists. However, this improvement can be achieved by a proper modifications in the still design and its operating parameters [12,13]. In fact, this improvement concern generally enhancing evaporation, condensation, heat storage and reducing thermal losses [14,15]. The water evaporation

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rate in the solar still is directly proportional to the difference in temperature between the evaporating area (basin water) and the condensing area (glass cover). In summer condition (high solar radiation and ambient temperature), the difference in temperature between the glass cover and the water is thus reduced, causing a decrease in the solar still productivity. To overcome this problem of high temperature of the glass cover, numerous improvement methods are suggested [16–18].

As solution to this problem, external cooling of the glass cover was used to increase the still productivity. Flowing thin film water on the external glass cover has been proposed by several authors [19]. Cooling the glass cover was also achieved by forcing the air flow over the glass cover using an external fan [20]. The experiments show that the still daily yield can be improved by about 25–40% with air flow.

Adding an external passive condenser seems to be the most appropriate solution to improve the CSS performances [21,22]. This is achieved by increasing the temperature difference between the water and the condenser wall and maintains the still at low pressure [23]. As a result, an increase of about 50–75% can be obtained in comparison to the CSS [24,25]. Transferring the generated vapor from the still to the condenser can be either through purging-diffusion (due to pressure and vapor concentration difference) or by natural circulation (due to the air density differences between evaporator and condenser) [26,27] or by forced circulation using an electric fan [28].

In a previous work [29] we have experimentally performed an attempt to enhance the basin type solar distiller productivity by generating air-convection inside the still using the thermo-siphon effect. The proposed solar still is designed to operate as a Natural Circulation Loop (NCL) with the humid-air as the working fluid. In which the still serves as a heater, a separate tubular condenser serves as a cooler and the vertical PVC tubes acting as hot and cold legs. The experimental tests of the proposed solar still show that significant improvements in terms of distillate water productivity and thermal efficiency are achieved. In comparison to the CSS and the integrated NCL is found to have a good effect on the still performances using air-convection.

Thermal modeling of the proposed NCL solar still has also been published [30]. A transient thermal-hydraulic model has been developed based upon energy balance equations of each component in the NCL solar still and the appropriate correlations describing heat/mass transfer phenomena taking place in the still. The proposed still was treated as a rectangular double diffusive NCL with the humid air as the working fluid. Fluid flow along the loop is created by the buoyancy forces that evolve from the density gradients induced by the simultaneous effect of temperature and humidity.

The objective of the present study is to investigate the effect of the condenser area and wind velocity, on the still daily yield of the NCL solar still in summer and winter conditions. Numerical and experimental investigations were performed to optimize the condenser area under summer typical days. The developed computer code is used to simulate the transient behaviour of the still during the test days as well as to predict further improvements of the solar still performances. The effect of condenser area on the still performances is studied by varying of the condenser tubes number. The experimental data presented in the scope of this work are relative to outdoor tests conducted during May and June 2015 at the Faculty of Science and Applied Sciences, Oum-El-Bouaghi University, Algeria (Latitude: 35°79′N, Longitude 7°40′E).

Overview of the NCL solar still

A schematic illustration of the proposed solar still is shown in Fig. 1. The system is a combination of a modified CSS with a passive natural circulation loop where the still serves as a heat source (heater), an integrated passive separate condenser serves as a heat sink (cooler). The link between the heater and the cooler is performed by a vertical insulated PVC tubes acting as hot and cold legs. The condenser is a horizontal heat exchanger made of three (03) identical and parallel aluminium tubes in which the water steam is separated from the air and forms a condensate film. It is slightly inclined to facilitate the drainage of the condensate water. The condenser is shaded from sun rays by a plastic cover. The air-convection in this case is created by the buoyancy forces that evolve from the density gradients induced by the simultaneous effect of temperature and humidity between evaporator and condenser. More details about the still design and the experimental tests can be found in Ref. [29].

Experimental test

The experimental test presented concern a typical summer day of 10/07/2015. The system was filled with 3.5 kg seawater and oriented in north-south direction to receive maximum solar radiation during the test day. The water mass/depth is kept constant during the tests by feeding an amount of sea water equal to that of output distillate water at ambient temperature every half-hour. The main temperatures of the still, namely: basin absorber, inner/outer glass covers and condenser external wall are measured by a calibrated K-type thermocouples. A CMP3-type pyranometer is used to measure the global horizontal solar radiation. Both thermocouples and pyranometer are connected to an automatic data acquisition system (VDAS) which displays the temperatures and the global solar radiation. WT-2 type digital thermometers are used to sense the ambient temperature, basin water temperature and the humid air temperature at the hot and cold legs. Wind velocity is measured using a Davis anemometer. A graduated transparent glass bottle of 1.5 litters is used to collect and measure the distillate output. All measured parameters were recorded every 30 min starting from 7:30 a.m. to 6:00 p.m.

Mathematical model

The proposed solar still is treated as a rectangular single-phase natural circulation loop with humid air as the

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