Desalination 425 (2018) 22–29

Contents lists available at ScienceDirect

Desalination

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

Experimental evaluation of a two-stage indirect solar dryer with reheating coupled with HDH desalination system for remote areas

A.E. Kabeel*, Mohamed Abdelgaied

Mechanical Power Engineering Department, Faculty of Engineering, Tanta University, Egypt

ARTICLE INFO

Keywords:
Indirect solar dryer
HDH water desalination
Solar air collector
Solar water collector
Gain output ratio

ABSTRACT

In the present study, the performance evaluations of a two-stage indirect solar dryer with reheating coupled with humidification-dehumidification (HDH) water desalination systems are experimentally investigated. The distillate water production, drying the products and energy-saving represents the main objective of the present experimental work. Due to problems in the availability of distillate water and energy sources in remote areas, the proposed system represents a good option for remote areas. The proposed system consists of two sub-systems: (i) two-stage indirect solar dryer with reheating, which can use to remove the moisture contents from the plants and fruit; (ii) the HDH water desalination, which can use to production of distillate water. The experimental results show that, as the air flow increases from 50 to 75 m^3/h, the distillate water productivity increases from 29.55 to 42.3 l/day and the moisture removal from the product increases from 8.33 to 12.37 kg/day during the period 8:00 am to 7:00 pm. Use a two-stage dryer with reheating improved the moisture removal from the product by 71.78% in average as compared only to the first stage of drying unit. Also, the gain output ratio varies over ranges of 1.24–1.79 and 0.97–1.38 for the proposed system and the HDH desalination system only, when the airflow rate increases from 50 to 75 m^3/h. The gain output ratio of the proposed system improved by 29% in average as compared only to the HDH desalination system.

1. Introduction

Solar energy represents an important alternative source of energy. Solar energy is available at very high rates in Egypt. So it would be wise to use them in water desalination and in drying agricultural plants before conservation and storage. Energy saving is an important focus in the different engineering applications so in this study was a combination of solar dryers and humidification-dehumidification water desalination, in order to dry the products and production of distillate water.

Solar drying systems are among the most promising applications of solar energy systems. This type of system saves energy and protects the environment. This method is economical and important in most developing countries. Drying is the process by which water content of food or other biologically sensitive substances is removed before storage. The quality of the dried product depends on many factors, including drying temperature and duration of drying. Some products such as medicinal herbs through the drying process require a low drying temperature [17,25]. Many types of solar dryers have been designed, tested and developed throughout the globe. These systems have been tested showing varying degrees of technical performance. Various designs of solar dryers for agricultural products [9,10,26], such as the type of dryer room and the type of dried chimney, have been addressed. These designs for solar dryers have been recommended for commercial use.

Zhao et al. [21] studied the effects of the drying methods on the physicochemical properties of *Lycium barbarum*. Three different methods of drying system, including vacuum drying (40–60 °C), hot air drying (40–80 °C), and spray drying are tested to obtain the physicochemical properties of *Lycium barbarum*. Kabeel and Abdelgaied [13] numerically studied the behavior of the solar dryer coupled with the rotary desiccant wheel. Atalay et al. [11] conducted the behavior of the solar dryer coupled with a packed bed thermal storage system. El-Sebaii and Shalaby [8] experimentally studied the behavior of indirect solar dryer under the natural and forced mode.

Humidification-dehumidification (HDH) desalination is one technique used to production of distillate water. This technology is characterized by being able to operate at low temperatures and the possibility of integrating this technology with sustainable energy sources. In addition, it uses separate components for each of its thermal processes, which allows great flexibility in the design of each part separately and depends on a great deal of flexibility in The thermal cycle of evaporation of water in the air and vapor condensate [20]. Wang et al. [27]

* Corresponding author.
E-mail address: kabeel6@f-eng.tanta.edu.eg (A.E. Kabeel).

http://dx.doi.org/10.1016/j.desal.2017.10.016
Received 7 August 2017; Received in revised form 25 September 2017; Accepted 8 October 2017

conducted the productivity of HDH desalination system driven by a photovoltaic under the free and forced convection mode. They found that the productivity of forced convection mode is higher than that of free convection mode. Zamen et al. [28] experimentally studied the performance of two-stage solar HDH desalination system. They found that the performance of the system improved when the multi-stage process was used as compared to single-stage process. But, the percentage improvement is very low when the number of stages is greater than two-stage. Muthusamy and Srithar [19] studied the effect of design parameters of the humidifier and dehumidifier on the productivity and energy saving of HDH desalination system. Sharqawy et al. [24] studied the effects of the design conditions on the performance of HDH desalination system. Two HDH cycles (air-heated cycle and water-heated cycle) are used to obtain the better thermal design conditions is required to maximize the productivity for a given heat input.

Hossam et al. [1] experimentally conducted the performance of HDH desalination system with a new zigzag packing made from aluminum sheets in the humidifier. Kabeel et al. [15] experimentally investigated the effects of wet surface area of packing materials on the performance of HDH desalination system. Hamed et al. [18] numerically and experimentally studied the effect of operating times during the test days on the productivity of solar HDH desalination system. Al-Sulaiman et al. [2] conducted the effect of parabolic trough solar collector on the performance of HDH system. Elminshawy et al. [7] studied the effect of geothermal water flow rate and temperature on the productivity of HDH desalination system. He et al. [12] conducted the behavior of air-heated HDH desalination system powered by low-grade waste heat integrated with a heat exchanger. Elattar et al. [6] investigated the behavior of air conditioning coupled with HDH desalination system.

Arunkumar et al. [4] experimentally studied the effect of compound conical concentrator on the performance of single slope solar still coupled crescent absorber with top cover cooling. Arunkumar et al. [5] conducted the performance of a compound parabolic concentrator-concentric tubular still integrated with a conventional solar still. Arunkumar et al. [3] experimentally investigated the impact of air and water flow rate on the behavior of a compound parabolic concentrator integrated with a tubular still with a rectangular basin.

The main objective of the present experimental work is the production of distillate water, drying the products and energy saving. To achieve this, two-stage indirect solar dryer with reheating coupled with humidification-dehumidification water desalination systems were designed, fabricated and constructed in Tanta city, Egypt. The performance of the proposed system is experimentally investigated under the Egyptian conditions. The results of the present experimental work have been evaluated to quantify the performance of the proposed system in terms of moisture removal from the products, distillate water productivity, and the gain output ratio.

2. Experimental work

Two-stage indirect solar dryer with reheating coupled with humidification-dehumidification water desalination systems was designed, fabricated and tested in Tanta city, Egypt (Longitude 31° E and latitude 30.47° N). This work is investigated in the period from May to July 2017. Fig. 1(a, b) shows the schematic diagram and a photo of a two-stage indirect solar dryer with reheating coupled with humidification-dehumidification water desalination systems. Two-stage indirect solar dryer with reheating coupled with humidification dehumidification water desalination systems consists of two sub-systems: (i) two-stage indirect solar dryer with reheating, which can use to remove the moisture contents from the plants and fruit; (ii) humidification-dehumidification (HDH) water desalination, which can use to production of distillate water. The main components of the two-stage indirect solar dryer with reheating coupled with humidification dehumidification water desalination systems are air blower, two-stage dryer unit, two double passes corrugated absorber solar air collector, humidifier (evaporator), two-stage dehumidifier (two condensers), and evacuated tube solar water collector. The descriptions of the unit main components are as follows:

The drying unit made from a galvanized steel of 1.5 mm thickness and has a dimension of 40 cm × 90 cm × 160 cm height. The drying unit contains two stages of drying separately from each other by a galvanized steel 1.5 mm thickness (first stage of drying unit and second stage of drying unit). Each stage contains three trays, the vertical distance separating the trays each other is 20 cm. All trays are constructed from a steel wire mesh to facilitate the air flow. The dimensions of each two large sides 90 cm × 160 cm and the dimensions of each two small sides is 40 cm × 160 cm. One of the large sides contains the door of dimensions 80 cm × 155 cm. The other large sides contain two rectangular opening connected to rectangular channels has a dimension of 4 cm × 80 cm × 12 cm height, one at the exit of the first stage of dryer unit and the other at the entrance of the second stage of dryer unit. The first rectangular channel used to connect the exit of the first stage of dryer unit with the entrance of solar air collector (II) and the second rectangular channel used to connect the exit of solar air collector (II) to the inlet of the second stage of dryer unit. The circular pipe 10 cm diameters in the center of the bottom base of drying unit used to connect the exit of solar air collector (I) with the entrance of the first stage of dryer unit. The ceiling of the drying unit is designed in the shape of a pyramid connected to the 10 cm diameter chimney (exit of the second stage of dryer unit). All sides of dryer unit are insulated with a fiberglass of 5 cm thick to reduce the loss in heat between drying unit and its surroundings.

Two solar air collector used in the present study is a double passes corrugated absorber solar air collector. Two solar air collectors have a same outside dimension of 116 cm × 121 cm × 18.6 cm height. Each collector contains two glass covers with 3 mm thick and v-groove absorber plate made from copper 0.4 mm thick with v-corrugated (60°). The each collector insulated with a low thermal conductivity fiberglass of 5 cm thick and located inside the wooden box with 3 cm thick. The v-groove absorber is coated with black paint to increase the absorptivity of the solar radiation. Steel frame used to support the collector at an angle equal to the latitude angle of Tanta city.

The evacuated tube solar water collector consists of 15 tubes (58 mm diameter and 1800 mm length), cylindrical water tank 150 l capacity made from stainless steel and insulated with 5.5 cm polyurethane foam and the frame. The evacuated tube solar water collector used to heat the brackish water before supplied to the humidifier.

The humidifier shell made from the galvanized steel of 1.5 mm thickness and has a square cross-section area 45 cm × 45 cm and 140 cm height. The brackish water distribution system is located over the packing surface. The packing materials made from the cellulose papers have approximately honeycomb shape. The dimensions of a packing material are 45 cm × 45 cm × 60 cm height. At the top of packing materials, the hot brackish water is injected by using the water distribution system, the height of the gap between water distribution system and the packing materials is 25 cm. The height of the gap between the water distribution system and the top base of humidifier is 15 cm; in this gap, the demister with thickness 3 cm is supported above the water distribution system to separate the water droplets from the humid air. The height of the gap at the bottom of backing materials between the backing material and bottom base is 40 cm. The water is collected in the bottom and pumping to solar water collectors, while the air inlet to humidifier passes down the packing materials. The water flows downward but the airflow upward. All sides of humidifier are insulated with a fiberglass of 5 cm thick to reduce the loss in heat between the humidifier and its surrounding.

Two-stage dehumidifiers used to condense the water vapor from the air. Each dehumidifier constructed from a radiator type cross-flow heat exchanger consists of a finned flat copper tube matrix. The dimensions of the radiator are 40 cm × 38 cm × 10 cm height. The radiator is