Desalination 372 (2015) 7–16

Contents lists available at ScienceDirect

Desalination

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

Solar water desalination using an air bubble column humidifier

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HIGHLIGHTS

- Desalination using an air bubble column humidifier is investigated.
- Effect of water temperature and height, air flow rate and hole diameter is studied.
- At inlet water is 62 °C, productivity, efficiency and GOR are 21 kg, 63%, and 0.53.
- Air bubble column achieves higher performance than that conventional humidifier.
- Temperature difference along air column is less than 2.5 °C for all measurements.

ARTICLE INFO

Article history:
Received 18 April 2015
Received in revised form 6 June 2015
Accepted 13 June 2015
Available online xxxx

Keywords:
Humidification–dehumidification
Air bubbles
Solar desalination, sieve plate

ABSTRACT

An experimental study of a solar water desalination using an air bubble column humidifier is investigated. The characteristics of the generated bubbles are modified by using a different sieve plate with different hole size. The effect of water temperature, air flow rate, water height, and sieve's hole diameter on desalination performance is studied. The results showed that the daily productivity, efficiency and gain output ratio are 21 kg, 63%, and 0.53 respectively; at inlet water temperature is 62 °C. The change in the temperature difference along the column is less than 2.5 °C for all measurements. The best performance is observed from sieve with 1 mm hole diameter at which the outlet air from the bubble columns is always saturated. The air bubble column achieves higher performance than that for the conventional humidifier.

1. Introduction

Desalination can be achieved by many methods. Thermal method is considered to be the simplest one. In this method, saline water is heated in an evaporator and generates water vapor free of salts. The generated vapor is condensed in a condenser then fresh water is collected. Water, air, or both can be heated by conventional energy source or by renewable energy source such as solar energy.

The latter desalination process can be called solar air humidification–dehumidification desalination process. The humidification–dehumidification (HD) desalination process is one of the secondary desalination processes. This system is very useful for places which have low freshwater demand. The main advantages of this system are; consume a small amount of energy and simplicity in both plant layout and management.

Bourouni et al. [1] presented the technique of air humidification–dehumidification (HD) process. The principle, technique and state of the art of the HD process were presented. Gahin et al. [2] presented a preliminary design study of a solar collector humidification–dehumidification desalination unit. They studied different parameters affecting the global performance of the unit. Also, they studied the performance of the two most important components of the loop which are humidifying and dehumidifying columns or stacks. Farid and Al-Hajaj [3] designed and studied experimentally the performance of multi-effect solar air humidification desalination unit. The unit had two different loops; air closed loop and water open loop. The results showed that the multi-effect humidification–dehumidification process, with forced air circulation, was found suitable for water solar desalination. The unit achieved a daily productivity of 12 $l/m^2/d$, which was over three times that for single-basin conventional solar still. Al-Hallaj et al. [4] studied experimentally the indoor and outdoor performance of two desalination units based on air humidification desalination. The results showed that water productivity was increased as the feeding water flow rate was increased to an optimum value. Moreover, they concluded that forced air circulation was effective in the unit performance at low operating water temperatures. Ben-Bachaa et al. [5] studied experimentally a solar multiple condensation evaporation cycle (SMCEC) desalination technique. The results showed that the pilot units produced as much as 60% of daily water needed for irrigation. Dai et al. [6] conducted experimentally a solar humidification and dehumidification desalination unit. The performance of the unit was strongly dependent on the

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http://dx.doi.org/10.1016/j.desal.2015.06.010

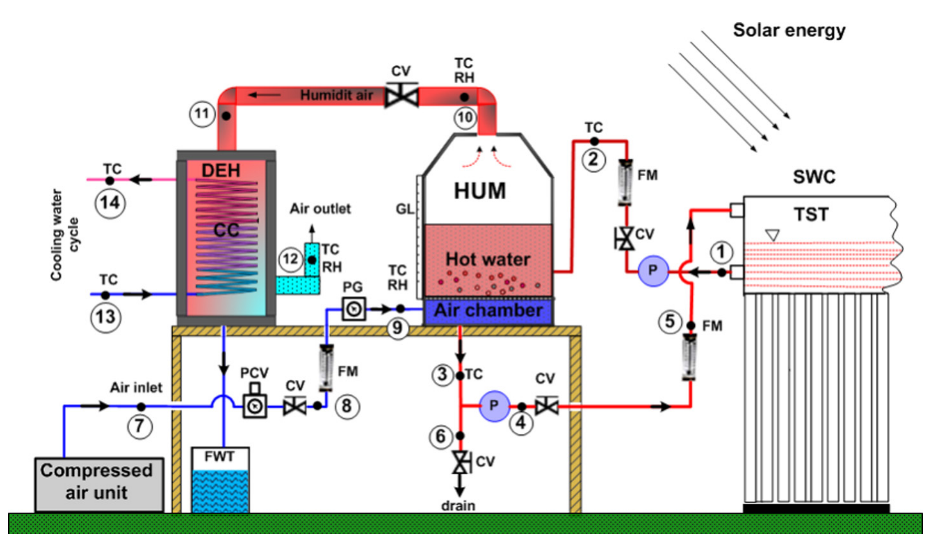
temperature and mass flow rate of the inlet salt water to the humidifier and the process air mass flow rate, which was forced by a fan. The unit thermal efficiency was above 80%. Garg et al. [7] studied experimentally and theoretically multi-effect humidification/dehumidification solar desalination system when air was circulated by natural convection. The differences between the values of the experimental and theoretical results were increased as the water temperature was increased due to the energy losses in the humidifier. Nafey et al. [8,9] investigated theoretically and experimentally a solar humidification dehumidification desalination unit under different environmental and operating conditions. The productivity of the unit was strongly affected by the cooling water flow rate, airflow rate, and total solar energy incident through the daytime. Amer et al. [10] investigated experimentally and theoretically the effect of operating parameters on the characteristics of a humidification–dehumidification desalination system. The system was based on a closed cycle for the airstream and an open cycle for water. The results showed that the maximum daily productivity was 5.8 l/h at 2.8 kg/min water flow rate and 85 °C inlet water temperature. Yanniotis and Xerodemas [11] studied experimentally the performance of tubular spray humidifier and a pad humidifier in seawater desalination plants. The evaporation rate of the spray humidifier was approximately the same as 100 mm thickness pad humidifier. Also, the pad humidifier with 300 mm thickness gave the highest evaporation rate at high air to water flow rate ratios. Zhani [12] studied theoretically and experimentally solar humidification–dehumidification desalination unit. The results showed that the maximum GOR was obtained at 0.4 kg/s inlet hot water flow rate. Vlachogiannis et al. [13] studied experimentally and theoretically a novel desalination concept, combining between the principles of air humidification–dehumidification and mechanical vapor compression. Air was injected into the evaporation chamber through a porous bottom wall and dispersed as small diameter bubbles.

Inaba et al. [14] studied experimentally heat and mass transfer of air bubbles in a hot water layer. The results showed that the mean diameter of generating air bubbles increased with an increase in the superficial air flow velocity.

EL-Agouz and Abugderah [15] studied experimentally the humidification process by air passing through seawater. The air was fed to the evaporator chamber from 32 holes of 10 mm diameter located on the surface area of a PVC pipe, which was submersed in the water of the evaporator chamber. They found that the maximum vapor content difference of the air was about 222 gm_w/kg_a at 75 °C and exit relative humidity of air was reached to 95%. Kabeel [16] studied experimentally the performance of the liquid desiccant system during a dehumidification–humidification process using an injected air through the liquid desiccant solution (calcium chloride). The air was injected through a series of homogeneous distribution. Holes in a vertical pipe El-Agouz et al. [17] studied experimentally a single air bubbling humidification desalination unit. They studied the influence of the electrically heated water temperature, water level, and airflow rate on the desalination performance. The productivity was slightly affected by water level and the maximum productivity of the system reached to 8.22 kg_w/h at 86 °C for water temperature and 14 kg/h for air flow rate.

Zhang et al. [18] studied experimentally operating factors that affects bubbling humidification by using a single sieve plate. The result showed that air relative humidity reached to 100%. Moreover, humidification capacity was increased by about 80% when water temperature was increased by 10 °C. Zhang et al. [19] studied experimentally the influence of working design parameters of solar bubbling humidification desalination unit on its gain output ratio, electric power consumption, and fresh water production cost. They found that gain output ratio was increased as the humidification temperature was increased, while electrical power consumption decreased.

Emily and John [20] experimentally studied the heat flux and effectiveness of a bubble column dehumidifier. It was found that the effectiveness was decreased while the heat flux was increased with decreasing coil area and increasing the temperature and air flow rate. Ghazal et al. [21] examined air bubble regeneration on the performance of a solar still using humidification–dehumidification desalination (HDD) process. The results showed that the exit air from the humidification process was fully saturated. The effectiveness of the solar



HUM	Humidifier	**C.C**	Cooling coils	**PCV**	Pressure control valve
SWC	Solar water collector	**SP**	Sieve plate	**P**	Pump
CV	Control valve	**DEH**	Dehumidifier	**PG**	Pressure gauge
FM	Flow meter	**TST**	Thermal storage tank	**GL**	Graduate level
RH	Relative humidity sensor	**TC**	Thermocouple	**FWT**	Fresh water tank

Fig. 1. Experimental set-up schematic diagram.