Desalination xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Desalination

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

Experimental study of a bubble basin intended for water desalination system

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HIGHLIGHTS

- The influence of bubbling air on water evaporation rate in a simple basin has been investigated experimentally.
- The heat and mass transfer coefficients between air and water are calculated and fitted in forms of empirical correlations.
- The results show a good agreement between the proposed model and the experimental measurements.

ARTICLE INFO

Article history:
Received 14 March 2016
Received in revised form 20 July 2016
Accepted 1 August 2016
Available online xxxx

Keywords:
Solar still
Air bubbling
Operating conditions
Heat and mass transfer
Desalination

ABSTRACT

One new technique that can increase the water evaporation rate in the solar still is to generate air bubble through its base. The aim of this research work is to perform a design basis for a modified solar still using air bubbling through water layer and to determine the heat and mass transfer coefficients between air bubbles and water in the basin. An experimental test set-up was fabricated and assembled. The process consists of air bubbles passing through the base of the basin to the seawater under some experimental conditions of airflow rate, inlet air temperature and humidity, and water temperature and depth. Detailed experiments were carried out at various operating conditions. Within the studies ranges, the results indicate that the water vapor content difference is moderately affected by the water temperature and airflow rate but slightly affected by the water level. The heat and mass transfer coefficients were obtained experimentally and fitted in forms of empirical correlations. The statistical study has shown a good agreement between the model and the experimental measurements, with an average relative error not exceeding 20%.

1. Introduction

The scarcity of fresh water is a highly important issue as most of the world population suffers from clean water shortage. Although water is available throughout the earth, only 1% of it is potable water [1]. One potential solution to tackle this issue is to develop a reliable, efficient and cost effective decentralized water desalination system to make clean water accessible for most of the world population. Countries having inadequate available water supplies have obtained fresh water from the sea using fossil fuels for a long time. Over the years, people realized that the use of fossil fuels is not a sustainable way as it damages environment. Nowadays, solar desalination has become a very affordable solution to cope with fresh water shortage, especially in remote areas, where solar radiation is available abundantly but with a bad water quality. The conventional solar still is one of the simplest and most promising techniques used to distill water. However, the major disadvantage of solar still is the low productivity. Actually, even in areas of relatively high solar radiation levels, its annual performance is limited to an average of about 3 $L/m^2 \cdot day$ [2]. This problem has motivated researchers to investigate various methods that would improve the conventional still productivity. Among the methods used are those concerned with cooling the glass cover. As the water vapor condenses on the glass cover, its latent heat is released to the glass cover, which increases the cover temperature and lowers the temperature difference between the water in the basin and the glass cover, thus reducing the driving force for water evaporation.

Other approaches have been used to increase basin water temperature, evaporation and condensation surface areas. Y. H. Zurigat et al. [2] have proposed a regenerative solar still that consists of two basins (effects). In their proposed still, the condensation latent heat released to the first glass cover is utilized to produce additional fresh water from a second effect. The second effect may be arranged in such a way that it would have either a flowing water film or a stationary one of larger thickness. The results have confirmed that the regenerative still gives >20% higher productivity in comparison to the conventional still.

A. Ghazy et al. [3] have undertaken an analytical study of a direct solar distillation system that combined solar still with an air heating humidification-dehumidification sub-system. Various procedures have been employed to improve the thermal performance of the integrated system by recovering heat losses from one component in another component of the system. Simulations have been carried out for the

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http://dx.doi.org/10.1016/j.desal.2016.08.003
0011-9164/

performance of the Still-HDH system under different weather conditions. A comparison has been held between the Still-HDH system and a conventional solar still of the same size and under the same operating conditions. They found that the total water production from the Still-HDH system is about 6.5 L/m^2/day as compared to 4.2 L/m^2/day from the conventional still, under the same conditions. In a previous work, H. Ben Halima et al. [4] developed an analytical model of a simple solar still coupled to a compression heat pump. The compression heat pump is made up of a condenser immersed in the water basin, an evaporator located below the upper region of the glass cover, a compressor and an expander. The condenser contributes to heat the basin water, and thus allows its evaporation thanks to the refrigerant flow through the heat pump. On the other hand, the evaporator condenses a large part of the water vapor. The results have proven that the productivity of this type of solar still is 75% higher than that of the conventional one. The daily production of the still reached 13.5 kg/m^2 in June 21.

A. E. Kabeel et al. [5] investigated an experimental study of a double passes solar air collector–coupled modified solar still, with Phase Change Material (PCM). A comparison between modified still and PCM, forced hot air injection and conventional still was conducted to evaluate the development in the freshwater productivity under the same atmospheric conditions. The experimental results have revealed that the daily freshwater productivity for modified still is higher than that of conventional still. The freshwater productivity reached approximately 9.36 L/m^2·day for modified still while its value was 4.5 L/m^2·day for the conventional one, with percentage of increase of 108%.

R. Sathyamurthy et al. [6] presented an experimental analysis of a portable solar still with evaporation and condensation chambers. The phase change material (PCM) is used in order to divide a single slope portable solar still into evaporating and condensing chambers. The result shows that the accumulated yield obtained with PCM is 52% more important than accumulated yield obtained for still without PCM. The still continues to produce fresh water after the sunset.

In conventional solar still, the covering glass serves two purposes: a solar radiation transmitter and a condenser. However, since it is exposed to radiation and because it relies on passive cooling by natural air convection, its condensation capacity is more limited. Moreover, solar radiation might re-evaporate some of the formed condensate. One of the possible ways to increase the capacity and thus the productivity of a solar still is to add a separate condenser.

Ayman G.M. Ibrahim et al. [7] conducted an experimental study of a modified basin type solar still equipped with an air-cooled condenser. The experimental results showed an enhancement of 16.2% and 29.7% in productivity and thermal efficiency, respectively, compared with the conventional solar still.

P. Refalo et al. [8] used a solar chimney and condensers to enhance the productivity of a solar still. Condensers in solar stills typically consist of seawater flowing through a bank of tubes. However, in their proposed configuration, water vapor was passed through a number of ducts immersed in seawater. They found that the externally water-cooled condensers coupled to the solar chimney improved condensation by separating and shifting the condensation process from the evaporation chamber to the condensers. Moreover, when comparing the efficiency based on the actual basin area, it was noted that the solar still with the solar chimney and condensers performed 8.8% better.

One new technique that can increase the water evaporation rate in the solar still is to generate air bubble through its base. The aim of this work is to perform a basis design for a modified solar still using air bubbling through water layer and to determine the heat and mass transfer coefficients between air bubbles and water in the basin. To this end, a laboratory scale basin with air diffuser was built. The experiments were carried out by bubbling air in the hot water in order to investigate the influence of the operating conditions such as the airflow rate and the hot water temperature and depth on the water evaporation rate. To simulate the solar energy, electric water heater was used.

2. Experimental setup and procedure

2.1. Experimental setup

A schematic diagram of the experimental apparatus is presented in Fig. 1, showing that the system consists mainly of an air compressor, a simple basin equipped with an air diffuser, an air flow meter and an electric water heater.

The air is delivered from the ambient milieu by the air compressor to the basin water through a perforated plate installed at the bottom of the basin which distribute the air and generate bubble. So, air bubbles will be charged by water vapor when passing through the hot water in the basin then leaves from 10 cm outlet vent. The basin was made of steel with 47 cm in length, 30 cm in width and 25 cm in height. It was insulated through the side and bottom by a 3-cm glass wool layer.

The system temperatures were checked before the implementation of any heating loads to guarantee a uniform temperature environment. Every run is accomplished when a steady state condition is achieved. At this steady state condition, all measuring variables fluctuate within their uncertainty tolerances, and continuously carried out for new experimental set conditions. The air temperature and humidity at the basin inlet and on the water surface were controlled by 2 thermo-hygrometers. The water level in the basin was controlled by a graduate level and an electric heater used to heat the water. The temperature of the water was adjusted to the desired degree through a digital reading and a thermo-regulator controller. The supply of airflow was adjusted to the desired flow through the control valve. The heat side and bottom losses were found to be negligible.

The experimental data were obtained under the steady state conditions of heat and mass transfer. Once equilibrium was reached, the measurements of airflow rate, water temperature and air temperature and humidity at the basin inlet and on the water surface were taken. The experimental conditions are as follows:

Water temperature: $T_w = 40–70$ °C,
Water level: $Z = 3–13$ cm,
Dry air mass flow rate: $G = 3.8*10^{-3} - 15.4*10^{-3}$ kg/m^2·s,
Inlet air temperature: 27–30 °C.

2.2. Experimentation error analysis

The measurements of the parametric variables, air flow rate, water temperature, water level and relative air humidity and temperature at the basin inlet and water surface, were taken during the experiments. The air flow rate was measured using the rotameter (3) with a range of 5–2000 L/h and an uncertainty of 4.6%. The water temperature in the basin was measured using the thermometer-Pt100 (class B) (7) which works in the range from −20 to +260C with an uncertainty of 2.6%. The relative humidity and temperature of air streams was measured using 2 thermo-hygrometers (4, 10) which work in the range from 0 to 100% RH and from −40 to +120C and its uncertainty is 1.4%.

3. Theoretical analysis

3.1. Air diffuser design

The air diffuser consists of steel rectangular box with 47 cm in length, 30 cm in width and 2 cm in height. A rubber plate covers this box and consists of 1168 orifices with 1 mm in diameter each (Fig.2). The air diffuser is an important accessory in such a system, since it provides the bubbles distribution. In order to obtain a homogenous distribution of bubble in the basin, analytical correlations were used for designing the perforated plate. The number of holes in the perforated plate was calculated by using the following relation:

$$n = \frac{G * A_t}{U_b * A_0} \quad (1)$$