

# SOLAR BUBBLING HUMIDIFICATION–DEHUMIDIFICATION DESALINATION UNIT

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## ABSTRACT

The paper presented solar bubbling humidification–dehumidification desalination unit. Water is heated by a tuber solar heater and ambient air is pumped to the water through a sieve. The generate bubbles is changed by using three sieve plates, each one has a different hole size. The paper studied the effects of water temperature, air flow rate, water level, the hole (nozzle) diameter, and holes (nozzles) number on desalination productivity. The result showed that, relative humidity reached to 100% and remained constant with constant water temperature, although the water level changed from 5 cm to 20 cm. The productivity of the system is moderately affected by the saline water temperature, airflow rate and slightly affected by the saline water level. The maximum achieved daily productivity is  $21 \text{ kg}_w/\text{day}$ .

Keywords: humidification-dehumidification, desalination, air bubbling, solar.

## **1 INTRODUCTION**

It is expected by the year 2040 the world demand for fresh water will be greater than the available amount. Therefor, it is important to search for other sources to obtain water. Desalination can be achieved this problem by many methods. Gahin et al. (1980) presented a preliminary design study of a solar humidification-dehumidification desalination unit. They studied the performance of the two most important components of the loop: the humidifying and dehumidifying columns or stacks. Farid and Al-Hajaj (1996) designed and studied experimentally the performance of solar air humidification desalination. The results showed achievement in daily productivity to  $12 \text{ l/m}^2/\text{d}$ , which was over three times that for single-basin still. Ben-Bachaa et al. (1999) studied experimentally a solar multiple condensation-evaporation cycle desalination technique. The results showed that the pilot units during good weather conditions produced as much as 60% of daily water needed for irrigation. Dai et al. (2000) conducted experimentally a solar humidification and dehumidification desalination unit. The performance of the system was strongly dependent on the temperature of inlet salt water to the humidifier, the mass flow rate of salt water, and the mass flow rate of the process air. Garg et al. (2002) studied experimentally and theoretically a multi-effect humidification/dehumidification solar desalination system when air was circulated by natural convection. The results showed difference between experimental and theoretical values due to energy losses in the humidifier, which increases as temperature increases. Nafey et al. (2004 a,b) investigated theoretically and experimentally a solar humidification debumidification desalination unit under different environmental and operating conditions. The productivity of the unit was strongly influenced by the air flow rate, cooling water flow rate and total solar energy incident through the day. Amer et al. (2009) investigated theoretically and experimentally the effect of operating parameters on the characteristics of a humidificationdehumidification desalination system. The results showed that the maximum productivity was 5.8 l/h at of 2.8 kg/min water flow rate and 85 °C inlet water temperature. Yanniotis and Xerodemas (2003) studied experimentally a tubular spray humidifier and a pad humidifier. They found that the evaporation rate of the spray humidifier is approximately the same as 100 mm thickness pad humidifier. However the 300 mm thickness pad humidifier gave substantially higher evaporation rates than that for spray humidifier at high air to water flow rate ratios. Zhani (2013) studied experimentally and theoretically solar HD desalination unit for drinking and irrigation. The thermal performance was evaluated by the gained output ratio (GOR). The results showed that Max GOR was at 0.4 kg/s of inlet water. Vlachogiannis et al. (1999) studied experimentally and theoretically a novel desalination concept, combining between the principles of air humidification-dehumidification and mechanical vapor compression. The emerging saturated stream was compressed by a blower to a slightly higher pressure (P=0.05-0.25 bar) and was directed to the adjacent condensation chamber. EL-Agouz and Abugderah (2008) studied experimentally the humidification process by air passing through seawater. The result showed that the exit air relative humidity reached to 95%. The maximum water extraction of air reached to 222 g/kgs at 75 °C. Kabeel (2010) studied experimentally the performance of the liquid desiccant system during a dehumidification-humidification process injecting air through a series of pipes with homogenous distribution. El-Agouz et al. (2010) studied experimentally a single air bubbling humidification desalination unit. The results showed that the productivity increases with the increase of water temperature and the decrease of the airflow rate. Maximum productivity of the system reached to 8.22 kg w /hr at 86 °C water temperature and 14 kg/h air flow rate. Zhang et al. (2011a) studied experimentally the operating factors affecting on bubbling humidification by using a single sieve plate. The result showed that relative humidity reached to 100%. Humidification capacity would be increased by about 80% when water temperature increased by 10 °C. Zhang et al. (2011b) studied experimentally the influence of design of solar bubbling humidification desalination unit on its gain output ratio, electric power consumption, and fresh water production cost. The result showed that relative humidity reached to 100%. Gain output ratio increases with the humidification temperature increases, while electrical power consumption decreases. The current works investigated experimentally a small-scale solar air bubbling humidification -dehumidification unit. The study includes the effect of operating condition parameters on the unit performance. These parameters include water temperature, water level, air flow rate, and orifice diameter of the sieve plate.

### 2 EXPERIMENTAL SETUP AND INSTRUMENT

#### 2.1 Experimental setup description

Figure (1) illustrates a schematic diagram of the experiment setup. Figure (2) shows a photograph of the humidifier. The system main components are humidifier (HUM), dehumidifier (DEH), and solar water collector (SWC). HUM is made of Acrylic plastic sheet of 10 mm thickness with 580 mm×580 mm cross section, and 900 mm height. DEH is shell and tube heat exchanger. SWC has a thermal storage tank (TST) that fitted with evacuated glass tubes that collect solar energy to heat water. The present system consists of two loops, a closed water loop and open air loop. In the water closed loop, TST is supplied with feed water. Then it is heated and circulated between evacuated tubes and TST by natural convection. At TST exit (1) hot water is pumped to HUM inlet (2) through the control valve (CV) and flow meter (FM). In HUM there is the interface between hot water and air .HUM has two exit points. At HUM exit (3) the water is pumped back to TST inlet (5) through CV and FM. Then hot water moves in a closed cycle between (TST) and (HUM). High concentration water is rejected from CV at (6). In the open air loop, a compressed air is supplied from service unit at (7). It passes through an air pressure control valve (PCV), air control valve (CV), and air flow meter (FM) to reach the humidifier inlet at (9). In HUM the air pass through the orifices of a sieve plate (S.P) to generate bubbles in the hot water pool. Saturated hot air at HUM exit (10) moves through 3 inch pipe to reach DEH inlet at (11), where it is dehumidified and cooled by domestic water. Then air exits to the atmosphere at (12) with low humidity and low temperature. Distillates water is collected in a fresh water tank (FWT).

#### **2.2 Instrumentation**

Water temperature was measured by a K-Type thermocouple. Digital sensor with data logger was used to measure air temperature and relative humidity. Its accuracy is  $\pm 0.1$ °C and  $\pm 1\%$  for relative humidity. A pressure gauge with 0.1 bar resolution was used for air pressure measurement. MS-802 Pyranometer sensor with 7  $\mu$ v/w/m<sup>2</sup> sensitivity was used to measure solar radiation and digital anemometer with an accuracy of  $\pm 2\%$  for wind speed measurement. The air and water flow rate were measured by a Rotameter with an accuracy of  $\pm 2\%$  at full scale and an orifice meter respectively.



Figure1. experimental set-up schematic diagram.

Figure 2. photo for humidifier

#### **3 RESULTS AND DISCUSSIONS**

In the present study ambient average relative humidity was between 15-40% and wind speed was between 1.5-3 m/s.

#### 3.1. Effect of the water height.

Fig. 3 shows the relation between inlet water temperature and the amount of water extraction at different water height and air mass flow rate. It can be seen that as the inlet water temperature increases the amount of extracting water height, as inlet water temperature increases from 60 to 70 °C, the amount of extracting water increases by 51.4, 76, 73, and 60.7 % at 11, 13.2, 15.4, and 17.7 kg/hr for air mass flow rate, respectively. In addition, as air mass flow rate increases, the amount of extracting water slightly increases due to increase of the air bubble rise velocity and size. In addition, the increase of the number of air bubbles increases the rate of interface area, which increase the heat and mass transfer. Also, as the water height increases, the amount of extracting water slightly increases due to increases.

Fig. 4 shows the effect of average hot water temperature on daily productivity, daily efficiency and GOR at different inlet hot water flow rate. It can be seen from the figure that both of average daily water temperature and water flow rate promote the daily productivity, daily efficiency and GOR increases. Therefore, water flow rate and temperature play an important role in the system performance.

To know the performance achieved in real systems it is important to calculate the hourly efficiency, daily efficiency, and gained output ratio (GOR) of the desalination unit. The hourly and daily efficiencies are calculated as:

$$\eta_{h} = 100 \times \frac{(M_{w} \times L_{wav})/3600}{(A_{S} K + P_{p} + W_{c})} \qquad \eta_{l} = \frac{1}{n} \sum_{1}^{n} \eta_{h} \qquad (1)$$

$$LH_{wav} = 10^{3} \times (2501.92.4070 \text{G}_{w} + 1.19221 \times 10^{3} T_{w}^{2} - 1.586 \times 10^{5} T_{w}^{3}) \qquad (2)$$

Where  $L_{w,av}$  is the average water latent heat of vaporization, El-Dessouky(2002),  $P_p = I \times V$  is the power of pumps that are measured at a different water flow rate, and n is the number of effective running hours (duration of producing desalinated water). GOR is a measure of the latent heat of water produced per unit of heat input; the following expression for GOR, McGovern et al. (2013):

$$GOR = \frac{M_w \times LH_w}{[(m \times h)_{w,i} - (m \times h)_{w,o}]}$$
(3)

The hot water flow rate, leaving the system is calculated as:  $(m \times h)_{WO} = (m \times h)_{Wi} - (M)_{Wi}$ 

#### 3.3 Effect of sieve plate holes diameter.

Fig. 5 illustrates the effect of sieve's hole diameter on the amount of water extracted and efficiency. It is found that as sieve holes diameter increases, the amount of extracting water decreases and a 5 mm orifice diameter gave the lowest productivity. This is because as the sieve holes diameter decreases, the diameter of the generated bubbles decreases and the number of active holes increases. Consequently, the number of generating bubbles increases and hence the heat and mass transfer surface contact area and time between bubbles and hot water increases and vice versa. It is observed that at 5mm sieve's hole diameter the flow started to transform to be jet flow. The extracting water for 1 mm hole diameter is higher than that 3 and 5 mm hole diameter by 9.1%, and 14.6%, respectively. The best performance is observed from sieve with 1 mm hole diameter, in construct, sieve with a 5 mm orifice diameter gave the worst performance



Figure 3. Effect of inlet water temperature on the amount of water extraction at different water height and air mass flow rate







Figure 5. Effect of diameter holes of sieve plate on productivity and efficiency.

#### **5** CONCLUSION

The following points could be concluded. The outlet air from the presented humidifier is saturated. The daily productivity, daily efficiency and GOR are affected strongly by inlet water temperature to the humidifier. The value of the amount of the extracting water is increased slightly with the increasing water height. The present system achieved daily productivity, daily efficiency and GOR are 21 kg, 63%, and 0.53 respectively, at inlet water temperature 62 °C. The best performance is observed from sieve with 1 mm hole diameter

#### NOMENCLATURE

| А             | Area, m2                     | h   | Enthalpy, (kJ/kg)     | Н   | Water height, (cm)                 |
|---------------|------------------------------|-----|-----------------------|-----|------------------------------------|
| LH            | Latent heat of water, (J/kg) | m   | Flow rate, (l/h)      | Μ   | Productivity, (kg <sub>w</sub> /h) |
| Рр            | Pump power, (W)              | Т   | Temperature, °C       |     |                                    |
| Greek letters |                              |     |                       |     |                                    |
| η             | Efficiency                   |     |                       |     |                                    |
| Subscripts    |                              |     |                       |     |                                    |
| Av            | Average                      | d   | Daily                 | h   | Hourly                             |
| i             | Inlet                        | 0   | Outlet                | S   | solar                              |
| W             | Water                        | а   | Air                   |     |                                    |
| Abbreviations |                              |     |                       |     |                                    |
| CC            | Cooling coil                 | CV  | Control value         | DEH | Dehumidifier                       |
| FM            | Flow meter                   | FWR | Fresh water reservoir | GOR | Gain output ratio                  |
| HUM           | Humidifier                   | SWC | Solar water collector | TC  | Thermocouples                      |
| TES           | Thermal Energy Storage       |     |                       |     |                                    |

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