IMPROVING THE CONTACT PATTERN OF THE HUMIDIFICATION STEP IN THE WATER DESALINATION PROCESS BY HUMIDIFICATION DEHUMIDIFICATION TECHNIQUE

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ABSTRACT

The present paper shows the results for a water desalination system based on a modified HDH by developing an innovative route of the contact pattern between the input air and the saline water to enhance the humidification step. This system composed of the saline water heater (by natural gas), Humidification unit, and condenser (dehumidification) unit. In this system, the air was introduced by external air blower to the HD unit and the exhaust air was allowed to get out of the system (open air loop), in turn, this supposed to enhance the rate of humidification by maintaining an appreciable driving force between dry air and hot water. We used two techniques for air-water contact, first by introducing water in the air stream, then by contacting the air with water in the backed column. This modified process improved the humidification step without extra energy supply. The dehumidification process was done by water-cooled condenser. The results showed that the production rate of this unit reached 19.8 L/h, with an average rate equation of V= 0.3162×t. However, the most important parameter that affects the stability of the production was the saline water temperature. To enhance the production process, the saline water temperature should be maintained at 85^{o}C or above, also, energy recovery from the miscarried water should be incorporated to further enhance the energy consumption.

Keywords: Desalination, Water, Humidification, Dehumidification, Contact pattern

1 INTRODUCTION

The Middle East and North Africa (MENA) countries will face water crises soon unless they develop a reliable and cost effective water desalination process. Out of these countries, four of them haveaccess to a renewable freshwater resources that provides their nations with sufficient water supply above the limit of the physical water scarcity of 1000 cubic meters per capita and per year. With a population expected to be doubled to 2050, the MENA region will face a serious water shortage, if they remain relying on the available natural water resources. It is also known that the commercially available, large-scale desalination plants are both energy consuming and located near electricity power plants. They are totally dependant on the fossil fuels like oil, natural gas and coal. It is also commonly acceptable that renewable energy sources should partially displace the fossil ones. Each country sets a plan for this replacement where it is expected that the annual growth rate can reach over 25 % per year. Solar energy is receiving much attention due to the relative easiness of thermal energy harvesting from it. The term solar water desalination in used increasingly to define the processes with small scale that used solar energy to power the selected water desalination process. This process has particularimportance for the development of rural areas, but does not address the increasing water deficits of the quickly growing urban centers of demand.

Solar water desalination distillation has been investigated initially and it is successfully used for the production of fresh water from brackish or saline water in many parts of the world. However, the productivity of such devices was relatively low. Also, many researchers have been focusing on developing efficient means of utilizing solar energy for water desalination. Small plants, based on multi-effect humidification process (MEH) were constructed and tested in many countries. In these plants, heat is recovered by air circulation between the humidifier and the condenser using natural draft or forced draft circulation [1, 2].

To date, both the RO and MSF processes are the most cost efficient processes to produce water among the different processes. Other processes are receiving appreciable attention, such a the mechanical vapor compression (MVC) and multiple effect evaporation (MED)[3].

In the last years, the RO process was employed rapidly for water desalination due to the continuous decrease in the water cost of this process compared to the MSF process. This is achieved through rapid progress and developments of membrane technology. These membranes have highly selective separation properties and have high recovery ratios [3].However, the use of HDH technique continues to produce drinking water for remote areas in some countries. Hashemi Fard and Azin [4] stated the advantages of this process but more energy loss in the systems with two separate columns, larger unit size and presence of a large amount of air together with water, which reduces the process efficiency may be the reasons of limited uses of HDH in the industry [5, 6]. Many researches are devoted to utilizing renewable resources, such as solar energy, and reducing the energy demand of the HDH process [5, 7, 8, 9]. One of the problems that faces the HDH technique is the contact between air and water. Commonly this is done through a packed column where the area available for mass transfer is increased.

The aim of this study is to present the results for water desalination unit by humidification dehumidification techniques using a novel contact pattern between air and saline water. We studied the effect of the new pattern using open air system. The effect of inlet saline water temperature has also been investigated.

2 UNIT DISCRIPTION AND THEORITICAL CALCULATIONS

A bench scale unit has been built to verify the effect of the new contact pattern on the humidification step. Figure 1 shows a simplified diagram of the unit as well as actual photos after fabrication. The unit consists of humidification cylinder made from plastic, dehumidification unit made of stainless steel, an air blower for air circulation, a gas heater for heating the saline water a circulation pump of water and storage tanks for saline water, fresh water and miscarried water. The humidification chamber has a diameter of 40 cm and height of 160 cm. The container is divided into two parts, the lower part is filled with a stainless steel scrap from steel workshop, the upper part is left without packing to be used for spraying of hot saline water in the air stream. The condensation units consist of a stainless steel parallelepiped. A bundle of stainless steel tubes was installed inside the condenser. The humid air coming from the humidification step passes through the shell side and a cooling water passes through the tube side. The saline water was stored in a plastic tank supplied with a 3kW electrical heater to adjust the temperature together with the water gas heater.In an actual operation, the saline water passes with a flow rate of 10 L/min once through the gas heater where it is heated by the convection and radiation energy transfer from theignited gas to the water. Then, it returns to the storage tank, then, the feeding pump feed the water to the humidification unit from the upper surface. The saline water is firstly sprayed by the agitator fixed in the upper part of the humidifier, then passes through the packing material.The air was circulated through the HDH system by a blower. At the condensation step, the humidified air loses the fresh water and it is collected through a header channel mounted below the condenser. The unit has discharge weir fixed at the bottom of the humidifier to recyclethe miscarried water to the storage tank. In this HDH design, the exhaust air coming out of the condenser is allowed to exit the unit (open loop of air). Previously, we investigated the operation parameters of the HDH unit such as the sprayer rotation speed, the air speed and the feed water temperature [10]. The concentration of salt was measured bythe TDS salinity meter, and the initial salt concentration is fixed at 50,000 ppm [11]. Measurements of the temperature of hot feed water and air and the humidity at the inlet and the outlet of each part of the unit and the water and air mass flow rates have been done.

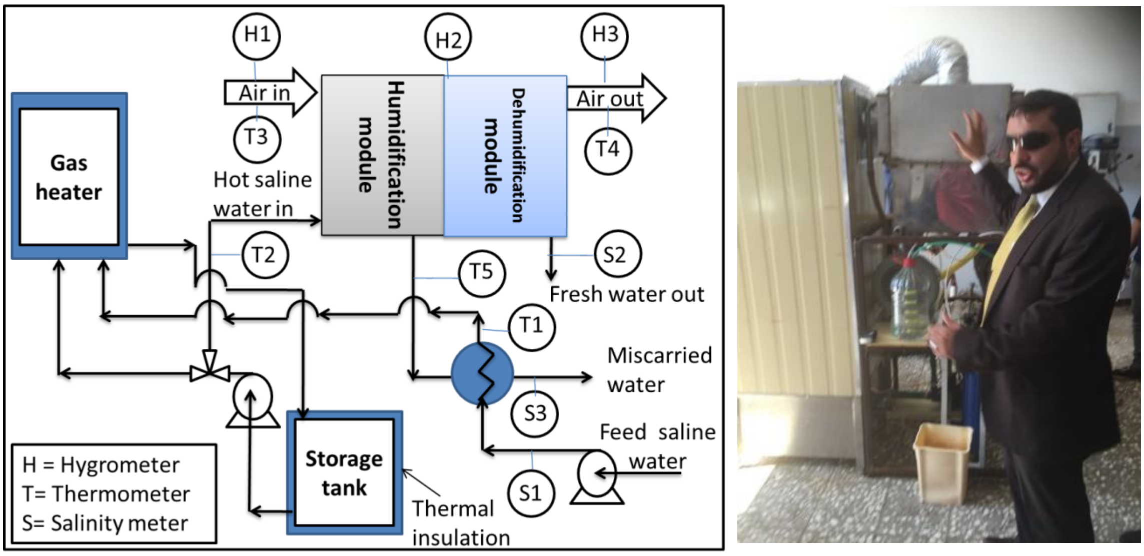

Figure 1. The process diagram and a photo of the HDH unit

The evaporation of water from solution is a surface process that depends on the contact pattern between water and air. The theoretical design of the humidification column is done through two different parts. In the first part of the humidification process, hot saline water is sprayed as spherical drops in the air stream.The rate of evaporation depends on the particle diameter as follows[12].

$$k_c^{`} = \frac{2D_{AB}}{D_p} \qquad (1)$$

It is clear from Eq. (1) that by decreasing particle diameter, the mass transfer coefficient will increase and consequently, the rate of water evaporation will increase. Therefore, production of very fine droplets moving in high speed through the air stream is vital to enhance the evaporation step. We can estimate the condition by boundary layer theory. The rate of mass transfer (N_A) for the transfer of water from the drops to the air is calculated from [12]:

$$N_A = k_c(c_{A1} - c_{A2}) = k_G(p_{A1} - p_{A2}) \qquad (2)$$

The mass transfer coefficient (kc) can be calculatedfrom the following formula for Reynolds number (Re) range (1-480000) and Schmidt number (Sc) of (0.6-2.7) [12]:

$$Sh = 2 + 0.552\, Re^{0.53} Sc^{1/3} \qquad (3)$$

We can compute the evaporation rate per unit time (C) starting form N_A

$$C = N_A \times M_{wt} \times \frac{A_w}{V_w \times \rho_w} = N_A \times M_{wt} \times \frac{4\pi R^2}{4/3\, \pi R^3 \times \rho_w} \qquad (4)$$

Equation (4) shows that asmall water droplet with a diameter of 0.002 m travels in the air stream at a speed of 10 m/s will evaporates within 1 second.

For the packed part of the column the calculation has been done according to the procedure described in ref. [12] and using EXCEL^{TM} software. We will consider in the packed humidification part of the column that the air is flowing upward and water is flowing downward. The first assumption is that the total interfacial area between air and water pass is not known.This is because the surface area of the packing is not equal to the interfacial area between the water droplet and the air. The height of the packed bed can be calculated from[12]:

$$z = \frac{G}{M_B k_G a\ P} \int_{H_{y1}}^{H_{y2}} \frac{dH_y}{H_{yi} - H_y} \quad (5)$$

Where G, is the dry air flow in kg/s, M_B is the molecular weight of the air, $K_G a$ is the volumetric coefficient in kgmol/s m^3 volume Pa, P is the total pressure, Pa, H_y is the enthalpy of the air-water vapor mixture, J/kg dry air. The calculated values are shown in Table 1. It can be noticed that the required height of the packed bed part is 1.33 m according to the given data.

Table 1. The calculated parameters of the packing part of the humidifier

Parameter	Value
Saline water flow rate, L/min	10
Hot water temperature , ^{o}C	50-90
Air speed, m/s	25-30
Air av temp. before condenser ^{o}C	40
k_c, m/s	0.138
K_G, kgmol/s m^2 Pa	5.352×10^{-08}
Particles area, m^2	0.126
Specific surface area, m^2/m^3	60
$K_G a$,kgmol/s m^3 Pa	3.211×10^{-06}
Area under curve m^2	0.586
z(height of column), m	1.335
Theoretical condensed water @ T= 315 K	26.39

3 RESULTS AND DISCUSSION

3.1 Performance of the HDH unit

The results are shown in Fig 3. It is noticeable that the production rate of this unit reached 19.8 L/h, with an average rate equation of V= 0.3162×t. However, the most important parameter that affects the stability of the production was the saline water temperature. To enhance the production process, the saline water temperature should be maintained at 85^{o}C or above, also, energy recovery from the miscarried water should be done to improve the energy utilization.

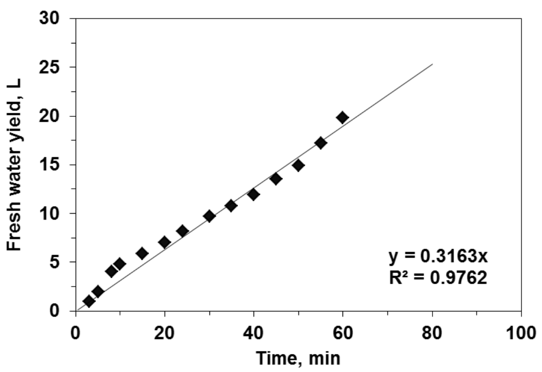

Figure 2.The fresh water yield for the experiment at starting temperature of 90^{o}C

The units were designed with new ideas that could enhance the performance of the HDH these are including:

1- Saline water (50000 ppm) at a set temperature is circulated in the humidification chamber for air humidification.
2- Air enters to the humidification chamber tangentially so more time of contact is proposed.

3- Material of construction is plastic for the humidifier to avoid any corrosion when utilizing salt water for a long time. The packing material is a stainless steel scrap from the workshop.
4- The condenser was made from stainless steel pipes for ease of cleaning when scales developed inside it.
5- The blower was mounted above the condenser so no saline water could be carried by the air from humidification to condensation chamber.

The energy consumption was measured using a clamp meter as shown in Table 2, it is clear that the calculated power used by the HDH unit is lower than the theoretical designed power which indicates that further reduction of the necessary power from renewable source could be done to reduce the overall cost of the unit.

Table 2. The deigned power vs the actual utilized power for the main constituents of the HDH unit

Energy device consumer	Designed power, W	Start current during use, A	Working current during use, A	Calculated power during use, W
Air blower	746	8.1	1.1	242
water circulation pump main	372.85	1.5	0.8	176
mixer motor	559.2	6.3	0.9	198
∑	1678.05	15.9	2.8	616

3.2 Effect of saline water temperature

The effect of temperature of the inlet saline water has also been investigated. Based on the present design and operation, we could obtain fresh water with 192 ppm. The effect of temperature of the inlet saline water is shown in Table 3. Each experiment was repeated three times and the average value out of these values was presented. It is evident that the productivity of freshwater strongly depends on the stability of the feed temperature to the humidifier. Also it is noticeable that if the miscarried saline water is introduced to another stage, the production rate will be increased, for example, the miscarried water that gets out form run No. 1 in Table 3 can be fed to a second stage (run No. 3) and it will give additional 8 L/h of fresh water. Similarly, the miscarried water from run No. 3 can be admitted to the third stage (run No. 5) and yield additional 6.5 L/h of fresh water. This arrangement will be verified in the subsequent work.

Table 3. the effect of inlet water temperature on the yield of the HDH unit

Run no.	Inlet temperature range (T_2 in Fig. 1)	Fresh water yield L/h (L/m^2 solar water heater/ d)
1	90^{o}C at the start to 75 ^{o}C at the end	19.8 (41.6)
2	80^{o}C at the start to 65^{o}C at the end	10 (21)
3	70^{o}C at the start to 58^{o}C at the end	8 (17.8)
4	60^{o}C at the start to 49^{o}C at the end	7.6(16)
5	50^{o}C at the start to 40^{o}C at the end	6.5(13.6)

CONCLUSIONS

To conclude, this work was dedicated to enhancing the contact pattern of the humidification process by using both saline water spraying in the air stream and using a packed bed for contacting the saline water and the air stream. The results indicated the maximum attainable fresh water of 19.8 L/h at starting temperature of 90^{o}C. Also, the productivity is highly affected by the stability of the saline water temperature. Furthermore, if the miscarried saline water is introduced insubsequent stages, the production rate could be increased. The actual power consumption of the unit is lower than the theoreticalrequirement.

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