EXPERIMENTAL INVESTIGATION ON WATER DESALINATION SYSTEM BASED ON HUMIDIFICATION-DEHUMIDIFICATION METHOD

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Abstract:- *In this paper an experimental investigation on a lab scale open air open water HDH water desalination unit using a Heat pump was presented. The proposed system utilizes the heat rejected and the cooling effect of the mechanically driven vapor compression heat pump for fresh water production. A test rig consisting of a fan, condenser duct, water spray humidifier and evaporator duct was constructed to study the performance under different operating conditions. Air is heated through the condenser so its ability to absorb water is increased via water nozzles; water at normal temperature is sprayed in the hot air. Through the water cooled heat exchanger and evaporator, the desalinated water is condensed from the misted air. Experiments were carried out under variable inlet air conditions. Air flow rate was varied from 24 to 13.2 m³/min. Results showed that the unit's maximum production rate was found to be 8.64 Liters/hour.*

***Key Words*: Humidification, Desalination, Heat pump, Dehumidification, HDH desalination.**

1. INTRODUCTION

Water on earth represents around 70% of earth's surface area where 1.4× 109 km^3 of water covers this area; salt water represents the great divide on globe with a percentage of 97. 5 %, while the fresh water by 2. 5% with 80% of this amount is iced in the icecaps or underground water, so 0.5% of fresh water is supported for all those human life [1] this sum isn't consistently disseminated all through the planet or when or where required. What makes matters even worse that the percentage of available water is not allocated fairly on this planet. Water can be classified based on the purpose where it will be used. The first category is that water specified for safe drinking, domestic utilizes and some commercial applications, the salinity of this water ranged from 5 to 1000 ppm That can be found in river and lakes; this type of water found in cities in several levels of water salinity utilizations where water of salinity below 150 ppm can be used for drinking on the other-hand the higher salinity water of up to 1000 ppm is employed for different household applications. Also some applications that need fresh water of maximum salinity of 5 ppm like boilers of steam power plants and that related to electronic and pharmaceuticals industries [1]. The second category of water has a salinity range between 1000 to 3000 ppm, which is appropriate for irrigation and commercial uses. Brackish water salinity varies from 3000 to 10000 ppm where sea water salinity approximately 34000 ppm.

Rapid increase in the population, economic activities and the change in life style in addition to limited access to sources of water are the reasons behind that shortage. Water desalination is considered the answer for that problem. The world population is about 7 billion people and it's predicted to be doubled in the next 50 to 90 years and the amount of fresh water resources still constant. In 2003 above 400 million people around the world suffers water shortage, this statistics was estimated to increase to 2.8 billion people by 2050 [2].

The desalination process can be divided into two main techniques thermal based and membrane based. The suitable technique depends on the freshwater production rate needed and the physical nature of the seawater or brakish water being desalinated. The thermal based technique is the widely used where the common desalination processes in that category are multistage flash distillation process (MSF) and Multi-effect distillation (MED). As for the membrane technique it's the Reverse Osmosis (RO) which is most common.

Farrag et al. [3] performed experiments for two stage water desalination by HDH process closed air using saline water heated by evacuated tube solar water heater. The maximum flow rate was 18.5 L/h at inlet water temperature of 80°C with condensation efficiency of 24.6 %, the energy consumption was 12.8 kWh/m³, and also it was found that the enhancement in the rate of evaporation in the humidification process was by decreasing the water drop diameter with GOR of 4.2. Gao et al. [4] carried out an experimental and numerical investigation on a HDH desalination unit was carried by utilizing a condenser and an evaporator of a heat pump to produce fresh water. This unit utilizes the heat from the condenser and solar air collector and the cold from the evaporator of the heat pump. The effects of air flow rate, water Mass flow rate and water temperature were studied. The numerical and experimental data were accepted. The unit produced 60 kg/day of fresh water by using electrical power of 500 Watt. Reali et al. [5] proposed a desalination method called the refrigerator-heat pump desalination scheme (RHPDS). In this study, sea water was evaporated and condensed using a vapor compression heat pump. The system consists of two tanks, to contain salt and fresh water, connected at the top part. The tanks were evacuated, and seawater entered the salt water tank at atmospheric pressure. The heat pump will provide heating to evaporate seawater, and cooling to condense the vapors into the fresh water tank. The system was designed to operate with small temperature difference, around 5 °C, for the water tanks. Thus high energy efficiency was expected. A. Böhner et al. [6] presents an idea of a 100% solar powered desalination plant. The plant has a water production capacity of 2 to 20 m³ / day. The product water can be used as potable water or for agricultural applications. The plant is operating in a low temperature range of 65 to 75 °C. A small amount of electrical demand is used for circulation pumps, which can be produced from a photovoltaic system or from a wind turbine. Yanniotis et al. [7] studied two types of air humidifiers, namely pad and tubular spray humidifiers. The experimental results showed that the evaporation rate for both seawater and tap water were comparatively the same.

A. Fouda et al. [8] presented an integrated A/C and HDH water desalination system assisted by solar energy. Transient analysis and parametrical study for system performance under different operating conditions were carried out theoretically. The system was also compared with a basic system under the same conditions. The maximum fresh water production is about 27 kg/h when the total power consumption is about 7.5 kW, which is also converted to 3.6 kg / (kWh). Ghalavand et al. [9] introduced a desalination process via combining HDH with mechanical vapor compression named humidification compression (HC). By using a compressor, the dehumidification took place at a higher pressure. In this method, the heating requirement was supplied via the compressor and due to higher pressure in the dehumidifier; more distilled water produced. They also compared HC system with typical air and water-heated HDH processes. The results confirmed that the GOR in HC system reaches to 2.07 while in two other processes are 0.4 and 0.33. Mehrgoo and Amidpour [10] studied the performance optimization of direct contact HDH unit with three main sections, humidifier, dehumidifier and heating source. The results showed that, the highest production rates were obtained at high air flow rate and low hot water flow rate. Hegazi et al. [11] have performed an experimental study to a desalination unit based on humidification-dehumidification process utilizing heat pump open air open water (OAOW) air heated system the results showed that the highest evaporation rate was in the cross flow spraying. The maximum production of fresh water was 2.8 L/h at a power of 1.41 kW.

A. E. Tourab et al [12] performed an experimental study to a desalination unit based on humidification-dehumidification process utilizing heat pump open air open water (OAOW) air heated system. The results showed that the highest condensate rate was in the parallel flow spraying. The maximum production of fresh water was 2.34 L/h, while using water cooled heat exchanger a condensate rate of 3.34 L/h achieved.

1.1 SCOPE AND OBJECTIVE

Experimental investigation was carried on a HDH desalination unit to find its maximum productivity operating condition. Knowing that air when heated can carry a larger amount of vapour; a heat pump condenser was utilized as the heat source for the air stream and the evaporator with the help of a water cooled heat exchanger as dehumidifying surface.

Air flow rate was changed to find its optimal value. Humidification effectiveness was calculated at measured air flow rate. Temperature measurements were taken before and after each air process using calibrated Digital Temperature & Humidity Sensor Module (DHT22). Experimental analysis was compared to analytical calculations.

2. Experimental test rig and procedures

2.1. Experimental test rig description

The OAOW air heated HDH unit was integrated with a vapor compression unit. The cycle based on the operating principal of a vapor compression cycle. Figure (1) shows a schematic diagram of the test rig. The unit consists of four main sectors; in sector 1, the air was drawn by a blower through two adjustable gates passing through air filters to remove any dust or impurities. The blower was utilized in 753×750×700 mm duct in couple with 2 m flexible duct of 10 inches diameter to sector 2.

In sector 2, air passes through the condenser that was utilized in 530×500×400 mm. As a result, the air dry-bulb temperature increased sensibly with progress decreasing in the relative humidity made the air to be gluttonous to water. In sector 3, the air is passed through a duct of 1500×500×400 mm. Through this section, the air was adiabatically humidified via air sprayers. The humidifier was employed with 0.5 HP water pump and very fine swirl atomizers consists of 4 holes of 0.5 mm diameter each. The humidification has been achieved in parallel flow according to the direction of both air and water. At the exit of the humidifier, the humidified air was passed through a duct of 530×500×400 mm in sector 4 that was included the evaporator and the water cooled heat exchanger. In this sector, fresh distilled water was accumulated as productivity.

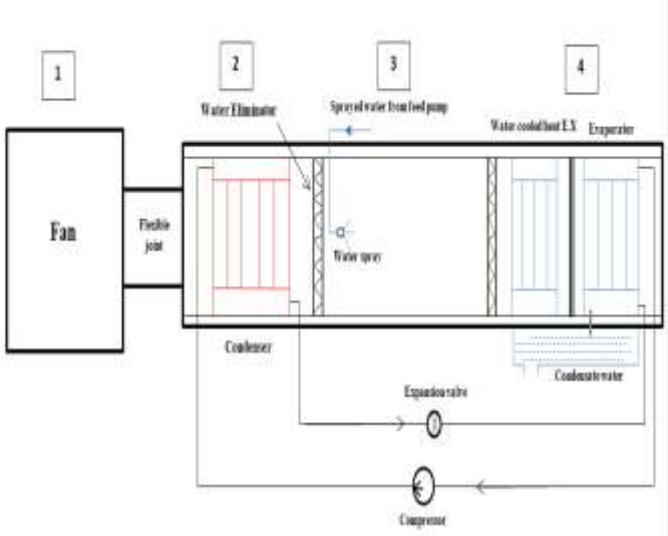

Fig -1: Schematic diagram of the test rig

2.2. Experiment procedure

The following procedures have been carried out for executing the experiments:

- Humidity and temperature monitor program was switched on and starts to record data from sensors and the data logger turned on.

- Fan gates were adjusted to the specified position that results in a specified air velocity measured by telescopic van-anemometer and hot wire anemometer and the fan was turned on.
- The heat pump of a 3 HP compressor was turned on.
- The water pump switched on.
- Monitoring the readings of temperature and relative humidity until reaches the steady state in 30 to 40 minute.
- When steady state condition achieved:
    - Start countdown timer in 30 minute.
    - Accumulate the fresh water at the starting of the counter time in a graduated cylinder.
    - Measure and record the amperage consumed by fan, pump and compressor.
    - Measure and record the flow rate of sprayed water.
- When the 30 minutes ends up, the heat pump, air blower and water pump switched off.
- Wait until the bleeding of fresh water stopped.
- Record the amount of fresh water accumulated in the graduated cylinder.

2.3. Mathematical analysis and data calculation

The dry bulb temperature and relative humidity were measured before and after each element to get the properties of air. These measured data were needed in calculating, the amount of humidity in air after the humidifier, the amount of condensate fresh water, the effectiveness of the humidifier, and the dehumidifier.

The amount of humidity in air could be estimated from:

$$\omega_{spraying} = \omega_3 - \omega_{out}$$

And for that the amount of condensate can be calculated from:

$$\dot{m}_{condansate} = \dot{m}_{air}(\omega_{spraying})$$

The humidification effectiveness of the humidifier sector can be calculated using:

$$\varepsilon_h = \frac{\omega_3 - \omega_2}{\omega_{saturation} - \omega_2}$$

The dehumidification effectiveness of the dehumidifier sector can be obtained from:

$$\varepsilon_{deh} = \frac{\omega_3 - \omega_4}{\omega_3 - \omega_1}$$

The total electrical power used in the experiment to get fresh water was calculated from:

$$Electrical\ Power = V \times I \times PF$$

Assuming that PF =0.7

The gain out ratio used to measure all the all cycle performance. It is the ratio of the latent heat of evaporation of the water produced to the heat input to the cycle can be calculated using:

$$GOR = \frac{\dot{m}_{condensate} * h_{fg}}{\dot{Q}_{in}}$$

3. Experimental Results and Discussion

For an OAOW air heated HDH desalination system, many parameters have been studied in this experimental works. The experimental measured data have been collected after reaching steady state condition which was ranged between 30 to 40 minutes. For a constant maximum sprayed water flow rate of 4.2 L/min, the quantity of the air flow was changed and the effect of the water to air mass ratio effect has been investigated on the cycle performance and the amount of output condensate. Also, the effect of sprayed water flow direction on the system performance has been studied.

As figure 2 shows, the condensate rate against water to air mass ratio at different inlet cooling water temperatures to the heat exchanger. The condensate rate increases as the inlet cooling water temperature decreases. It was noticed that the maximum productivity of the system was 8.64 L/h at a ratio of 0.13 at inlet cooling temperature of 15°C, meanwhile, the curve overturn decreases as the ratio increase.

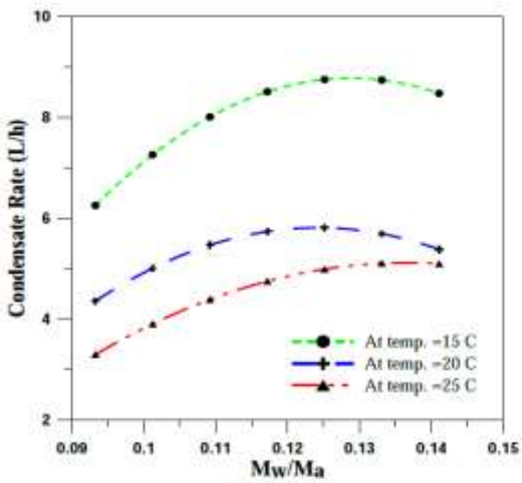

Fig -2: Condensate rate against water to air mass ratios at different cooling water temperatures.

In figure 3 dehumidifier effectiveness has been increased by using water cooled heat exchanger. The effectiveness increases as the temperature of the inlet cooling water to the heat exchanger decreases, it was found that the effectiveness have improved greatly. The dehumidifier effectiveness was at its maximum values at a ratio of 0.13 and at inlet cooling water temperature of 15 °C, which illustrates the reason that makes the maximum productivity becomes at this ratio.

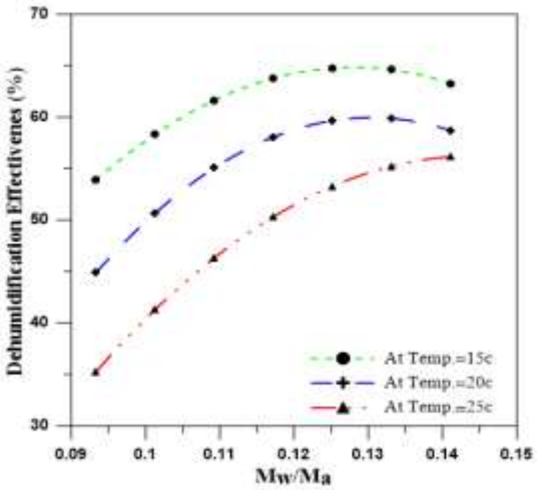

Fig -3: Dehumidifier effectiveness vs water to air mass Ratios at different cooling water temperatures

The energy consumption was measured and calculated using the pervious equations for the compressor of heat pump, water pump and fan. In figure 4, the relation between the amount of condensate that can be produced per kWh and water to air mass ratio was clarified. It was observed that as water to air mass ratio increases the productivity increases per kWh. The specific productivity was at its maximum value of 3.5 Liters per kilowatt hour at a ratio of 0.13 and at inlet cooling water temperature of 15°C, which illustrates the reason that makes the economic productivity happens at this ratio.

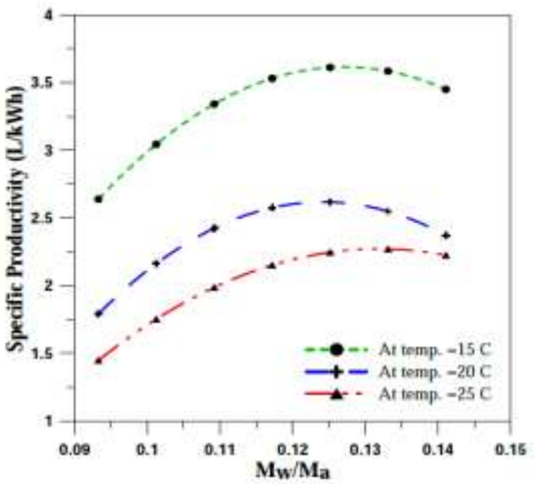

Fig -4: specific productivity at different cooling water temp.

The performance of the desalination unit was represented by GOR. Figure 5 shows the GOR at inlet cooling water temperature of 15°C, GOR was increasing until a ratio of 0.13, after this ratio GOR was decreasing as the ratio was increasing. Also as inlet cooling water temperature increases, GOR decreases. This in fact demonstrates that GOR depends on the amount of condensate rate with respect to the heat energy added to the system.

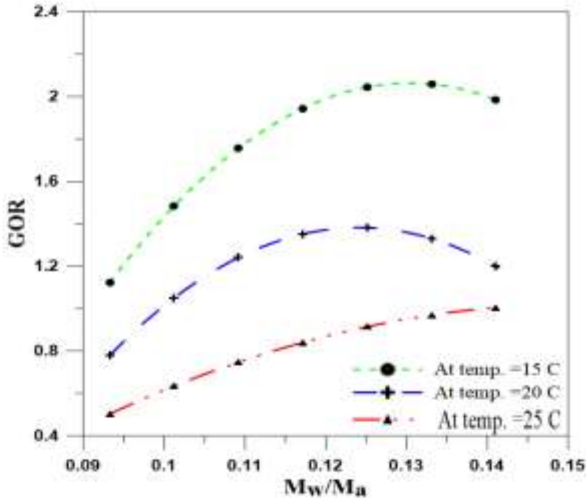

Fig -5: GOR at different cooling water temp.

4. CONCLUSIONS

In this experimental work a water desalination unit based on HDH process using heat pump was investigated to study the effect of water humidification at different air mass flow rates which ranged from 13.2 to 24m^3/min. The experiments have been done at different inlet cooling water temperatures used, Results showed that:

- As water to air mass ratio increases the amount of the condensate rate increases.
- The maximum productivity of the unit in the first stage was at a ratio of 0.13
- The temperature of the inlet cooling water to the heat exchanger have affected the dehumidifier effectiveness where as it decreases, the dehumidifier effectiveness increases.
- The optimum operating condition was at inlet cooling water temperature of 15°C to the heat exchanger.

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