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Experimental Investigation of a Small Scale Humidification Dehumidification Desalination Unit

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Abstract

A psychrometric energy process desalination unit has been experimentally tested. The system is based on humidification and dehumidification process where seawater is heated and then sprayed to humidify the incoming air in the humidification chamber. The humidified air enters the dehumidification chamber and is cooled by the incoming cold seawater. The moisture is condensed out and the pure water is accumulated at the base of the chamber, and the dehumidified air is discharged to the outside. The seawater was heated to temperature between 60 - 90°C using a 2.4kW electric heater. Performance data on temperature, seawater mass flow rate, air flow rate and the amount of fresh water produced were obtained, and the maximum coefficient of performance (COP) of the system was calculated based on the data obtained. The result achieved indicates the system had a maximum fresh water production of 13kg/h with a maximum COP of 3.6. The initial test shows that the system has great potential with room for improvements and further optimisation.

Keywords: Solar; Humidification; Dehumidification; Desalination.

I. Introduction

The global water problems are attracting interesting attention. About 80 countries which consist of mainly rural communities have no access to clean water which threatens their health and economic activities. About 70% of earth surface is covered with water and about 95.5% of it is salt water. Hence desalination technique is the most promising solution for supply of fresh water. As energy plays a crucial role in the supply of fresh water, solar energy makes water desalination using thermal processes more practical than any other form of desalination technique.

The thermal Multistage flashing (MSF) and membrane reverse osmosis (RO) processes are two dominant desalination methods. The multistage flashing desalination operates at vacuum condition and is characterized by the large size of its production plants typically more than 25,000 m^3/day while the reverse osmosis desalination is modular by design with the capacity varying from a few m^3/day up to 100,000 m^3/day [1]. However, the conventional Humidification Dehumidification Desalination Unit (HDD) process may be more suitable for small scale application because the process requires less maintenance and technical support [2, 3].

Reference [4] carried out a study on cost optimization and concluded that solar HDD is a suitable choice for decentralized production of fresh water in remote arid areas. The specific capital cost of a HDD system is one tenth of a MSF system [5]. It is more important that the process is thermally driven and is suitable for low temperature heat such as solar heat and waste heat from power generation systems. Other studies on low temperature HDD systems include that of [6] which employed a double-pass flat plate solar air heater in the system, and [7], which studied the parametric effects on the performance of a HDD system and optimised the operating parameters. These studies both showed that a HDD system may operate at a temperature as low as 50°C.

II. Experimental setup

In the proposed system, a specifically designed concentrating solar collector will be used to heat up seawater to temperature above 50~55°C. The hot seawater is then sprayed to humidify the incoming air in the humidification chamber. The humidified air enters the dehumidification chamber and is cooled by the incoming seawater, in the meantime the seawater is pre-heated to recover heat. The moisture is condensed out using a specially designed membrane and the pure water is accumulated at the base of the chamber. The dehumidified air is discharged to the outside or re-circulated.

The experimental set up as shown in Fig. 1 consists of the desalination unit with dimension of 1.5m x 0.5m x 0.8 m. The unit incorporates the humidification and dehumidification chambers and also a fan to blow air into the system. An electric heater of 2.4 kW heat capacity was used to supply the energy required. Two pumps were used to circulate the feed water in the system; one pump circulates the feed water through the dehumidification chamber and the other pump circulates the feed water through the electric heater to the humidification chamber.

(a)

(b)

Fig 1(a): Side view of the desalination unit Fig. 1(b): view of the inner core (membrane) of the desalination system showing fresh water condensation

The measuring instruments include dry and wet bulb thermometers Fig. 2(a) which are used as probes at different points of the system. An air flow meter Fig. 2(b) for measuring the velocity of air flow in the system, and a scale Fig. (2(c) for measuring the amount of fresh water produced.

(a) (b) (c)

Fig. 2. (L-R) Dry/Wet bulb thermometer (a) Air flow meter (b) Scale (c)

III. Experimental Results

A. *Feed Water Mass Flow Rate*

The system uses two different feed water flow rates at inlet of the humidification chamber and at inlet of the dehumidification chamber. As illustrated in Fig. 3, while keeping the flow rate at the inlet of the dehumidification chamber low (30 kg/h), the amount of fresh water production increases with increase in feed water flow rate at the inlet of the humidification chamber. However, there is need for smaller water flow rate through the heater in order to increase the temperature of feed water.

When the water flow rate at the inlet of the dehumidification chamber was increased (60 kg/h), the amount of fresh water produced was reduced. There is need to investigate further the effect of the difference of feed water flow rates between the two inlets.

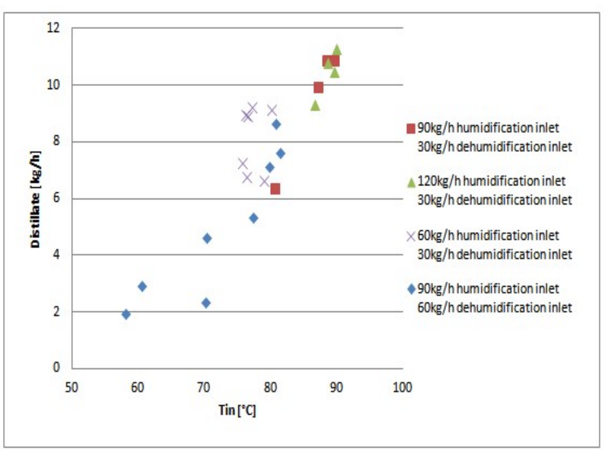

Fig. 3. Amount of water produced as function of feed water temperature at inlet of the humidification for different water flow rates at both the dehumidification and humidification chamber inlets

B. *Outside Air Flow Rate*

The system was tested using two different air mass flow rates. When the air mass flow rate was increased, it can be seen as illustrated in Fig. 4 that there was no any significant change in the amount of fresh water produced.

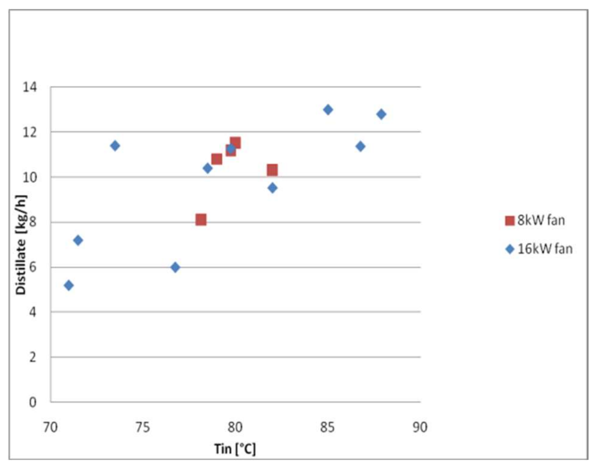

Fig. 4. Amount of fresh water produced as function of temperature at the inlet of the humidification chamber for two different air mass flow rates

C. *Feed Water Temperature*

The system depends on temperature of feed water into the humidification chamber and that of the dehumidification chamber. As earlier seen, higher temperature difference results in higher fresh water output. In order to get higher temperature difference, the temperature of water at inlet of the humidification chamber should be kept as high as possible and that of the dehumidification chamber should be kept as low as possible.

However, according to the experimental result as illustrated in Fig. 5, when the temperature at inlet of the dehumidification chamber is low and less than 40°C, the output of fresh water is lower when compared to when the temperature is more than 40°C. Also, when the temperature is above 50°C, the output then tends to reduce. This means that there is a limit on how low and how high the temperature can be in order to obtain an optimum output of fresh water.

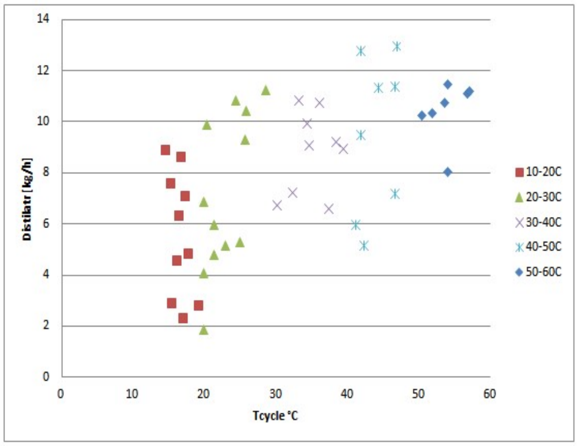

Fig. 5: Amount of fresh water produced as function of temperature at the inlet of the dehumidification chamber.

D. Outside Air Temperature

The amount of fresh water produced for two different weather conditions of 21°C and 16°C atmospheric weather condition at the same energy inputs and flow rates is shown in Fig. 6. It was found out that there is no significant effect on the amount of fresh water produced.

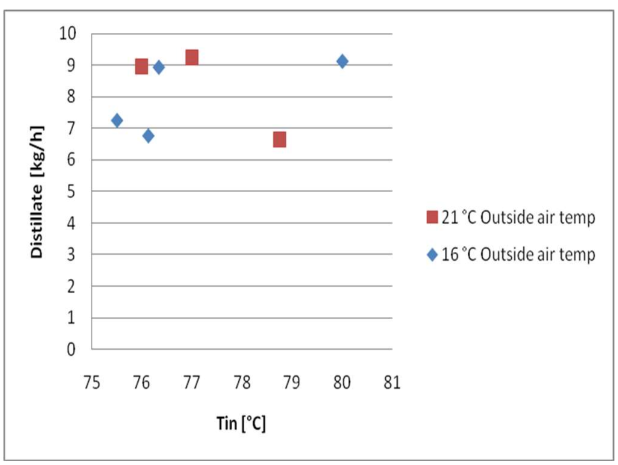

Fig. 6: Amount of water produced as function of temperature at inlet of the humidification chamber for two different weather conditions

IV. System Performance

As shown in Fig. 7, the highest amount of fresh water was obtained at higher temperatures at the inlet of the humidification chamber. A high temperature difference between the inlet of the humidification chamber and that of the dehumidification chamber results in higher fresh water output. When the temperance difference is small, the amount of fresh water production is very low. Fig. 7 is a representation of about 20 experiments which were carried out at 15 minutes intervals. The maximum amount of fresh water produced is about 13 kg/h with 2.4 kW energy input

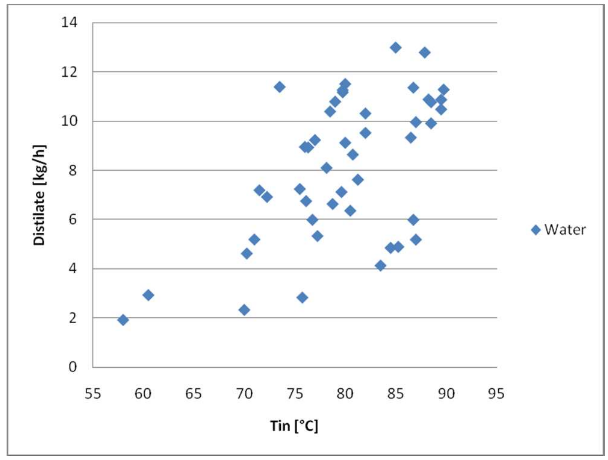

Fig. 7: Amount of fresh water produced as function of temperature at inlet of the humidification chamber.

The coefficient of performance (COP) of the system indicates how efficient the system operates. A very high COP means the system is highly efficient. An energy balance analysis is performed for each test based on the electric energy input to the heater in order to determine the COP of the system. Taking input energy Qin =2.4 kW as an example and the maximum fresh water produced from Fig. 7, the COP of the system is calculated as follows:

$$Energy\ input\ per\ hour\ (kJ) = Q_{in}(kW) \times hour(sec) \quad (1)$$

$$Energy\ input\ per\ hour\ (kJ = 2.4 \times 3600 = 8640kJ$$

$$Energy\ required\ for\ water\ evaporation = max\ water\ that\ condenses \times latent\ heat\ of\ condensation \quad (2)$$

= 13 (kg/h) x (2400 kJ/kg) = 31200 kJ

$$Max\ COP\ = \frac{Energy\ for\ water\ evaporation}{Energy\ input} \quad (3)$$

$$Max\ COP\ = \frac{31200}{8640} = 3.6$$

The COP of the system was calculated base on the data obtained. It was found that the system had a maximum fresh water production of 13kg/h and a COP of 3.6 was calculated.

The initial test shows that the system has great potential with room for improvements and further optimisation.

V. Conclusion

Several experiments were carried out on the water desalination unit under different conditions. The effect of heat input, temperature and flow rates on the amount of fresh water produced were examined. The data obtained was validated using energy balance analysis and then compared with other published data. The experimental result showed that:

- The amount of energy supplied to the system is a direct function of amount of fresh water produced.
- The temperature of feed water at the inlet of the humidification chamber is a direct function of the amount of fresh water produced.
- While the temperature of feed water from source varies with amount of fresh water production, the experimental result suggests a temperature of around 40-50°C for the optimum operation of the system.
- A ±5°C temperature of the environment does not affect the performance of the system. This suggests the need to test the system in a temperature controlled lab or as a field trial for commercial exploitation in other geographic locations.
- The mass flow rate of air into the system does not affect the amount of fresh water produced and hence it is suggested to use a fan with lowest power consumption without compromising performance of the system.

Also, a larger mass flow rate of feed water into the humidification chamber leads to higher amount of fresh water. However, higher flow means lower temperature. Hence there need to automatically adjust the amount of energy supply or the flow rate of the system in order to obtain an optimum performance.

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