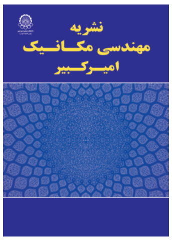

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Thermodynamic Analysis of Humidification-Dehumidification Desalination System with Semi-open Air Circulation

E. Mahdizade, M. Ameri*

Department of Mechanical Engineering, Shahid Bahonar University of Kerman, Kerman, Iran

ABSTRACT: Humidification-Dehumidification (HDH) desalination is a thermal desalination method with the potential to be driven using solar heating. The HDH cycles are classified based on the arrangement of components, the nature of the flow pattern of each of the streams and the type of heating by either water or air stream. In this paper, the semi-open method for air circulation is proposed and thermodynamically analyzed. It is shown that when the water stream is heated and top temperature of system is fixed, this method is efficient for water heating cycle but not for air heating cycle. Also, it is shown that for a designed HDH at a specific mass rate ratio, regardless of the method of air circulation, the performance of HDH is fixed. Analyzing other parameters reveals that the impact of environment temperature is more vital than the relative humidity of the environment on cycle performance, therefore HDH is efficient for both dry and humid climates. It was observed that there is a specific mass flow ratio for any specified system at which the performance of cycle is constant regardless of the percentage of the air leaving the dehumidifier and returning to the humidifier.

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1- Introduction

Fresh water demands escalate on a daily basis due to industrialization, motorization and increased life standards of mankind. Naturally available fresh water reserves are not capable of meeting the fresh water demands because of less than sufficient availability [1]. It has been estimated by United Nations Organization that by 2025, nearly 1800 million people around the globe will be under severe water scarcity [2]. A fundamental problem with most desalination technologies is that they are very energy consuming. However, many areas that suffer from water scarcity have high solar insolation, which suggests that solar powered desalination could be very beneficial.

One such technology, which mimics nature's water cycle (rain), is the humidification dehumidification (HDH) desalination. The simplest form of the HDH process is illustrated in Fig. 1. Simple schematic of a HDH desalination with open water and semi-closed semi-open air circulation. with both a water and an air heater. While a heater can be placed in both fluid streams, in this paper, only one heater is used forming either a water or an air heated cycle. This technology has received ongoing attention in recent years, and researchers have studied different types of HDH cycles with closed (F=1) or open (F=0) pattern of air circulation [3]. F defined as the ratio of mass flow of dry air that returned from the output of dehumidifier to the system, to the total mass flow of dry air circulating inside the system (shown in Fig. 1)

$$F = \frac{\dot{m}_{da,retuned}}{\dot{m}_{da}} = 1 - \frac{\dot{m}_{da,fresh\ air,in}}{\dot{m}_{da}} \quad (1)$$

Corresponding author, E-mail: ameri_mm@uk.ac.ir

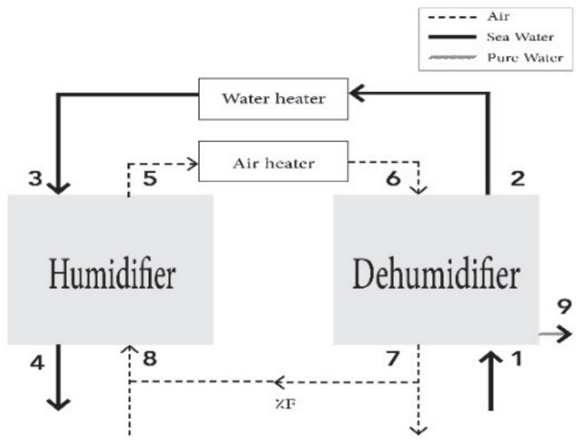

Figure 1. Simple schematic of a semi-open air open water (SOAOW) HDH desalination system.

Despite all the publications on the subject, there has not been clear conceptual thermodynamic understanding of a cycle characterized by a semi-open air and open water circulation. Hence, the objective of this paper is to analyze the performance of the specified HDH cycle thermodynamically and use this analysis to improve the performance of HDH desalination technology.

2- Methodology

In order to evaluate the state of each of the sections (Fig. 1), the governing equations of humidifier and dehumidifier is written. For understanding the HDH cycles, the following performance parameters are defined. Gained Output Ratio (GOR): defines energy performance for HDH and other thermal desalination systems. This parameter is a dimensionless number that measures the effectiveness of water production and directly relates to the amount of heat recovered within the system. Thus, a higher *GOR* corresponds to a more efficient system.

$$GOR = \frac{\dot{m}_p h_{fg}}{\dot{Q}_{in}} \tag{2}$$

Modified Heat Capacity Ratio (*HCR*): For heat and mass exchange devices like the humidifier and the dehumidifier, the modified heat capacity ratio is the ratio of maximum possible enthalpy change of the cold stream to the maximum possible enthalpy change of the hot stream.

$$HCR = \frac{\Delta \dot{H}_{max,c}}{\Delta \dot{H}_{max,h}} \tag{3}$$

In order to further validate the model presented here, the results were compared to the results observed in the paper by Mistry et al. [4].

3- Results and Discussion

A previous study [5] has shown that *GOR* is a strong function of mass flow rate ratio, component effectiveness, and system top temperatures (or heat flow rates). Therefore, this study looks at the same parameters but closely considers the effect of the percentage of retuned air from dehumidifier to humidifier (%*F*).

Figs. 2 and 3 illustrate the effect of top temperature on the cycle performance (*GOR*) of water heating and air heating, respectively. Depending on the effective parameters, per each value of *F* there is an optimum top temperature of cycle at which the peak *GOR* occurs. In other words, for a constant top temperature of cycle, there is a value of *F* for optimal *GOR* which is *F*=0 or *F*=1 for air heating cycle, but can take other values for the water heating.

Figs. 4 and 5 illustrate the effect of mass flow rate ratio on the cycle performance (*GOR*) of water heating and air heating respectively. The visible result is that with a specific amount of mass flow rate ratio and regardless of *F*, *GOR* is constant and corresponds to constant amount of heat capacity ratio of dehumidifier for both cycles.

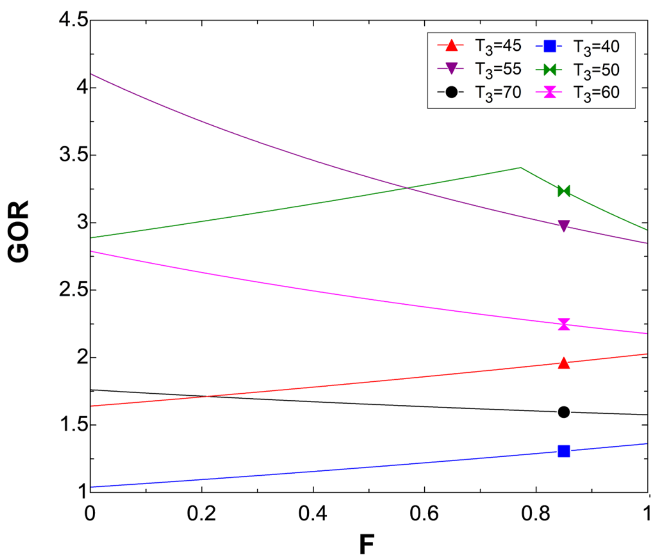

Figure 2. ***GOR*** **as a function of 'F' for a water heating cycle with** $m_r = 2$ **,** $\varepsilon_H = \varepsilon_D = 0.9$

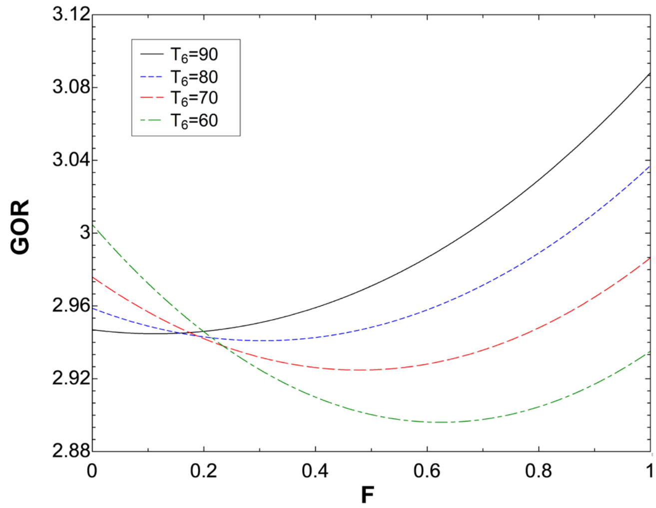

Figure 3. ***GOR*** **as a function of 'F' for an air heating cycle with** $m_r = 1.5$ **,** $\varepsilon_H = \varepsilon_D = 0.9$

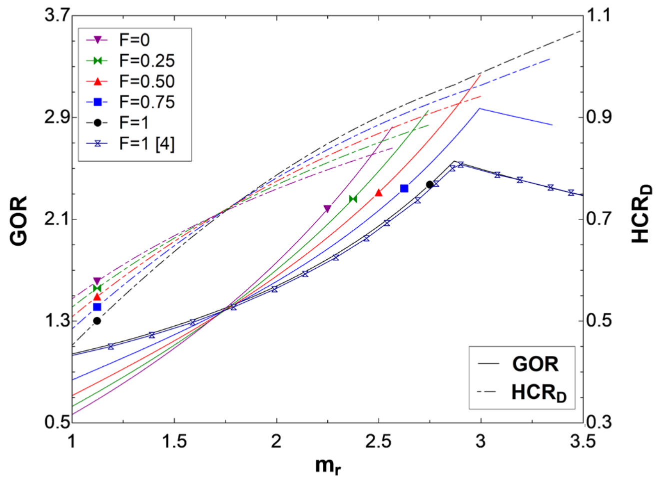

Figure 4. ***GOR*** **as a function of mass flow rate ratio for a water heating cycle with** $T_{inlet,H} = 70°C$ **,** $\varepsilon_H = \varepsilon_D = 0.9$

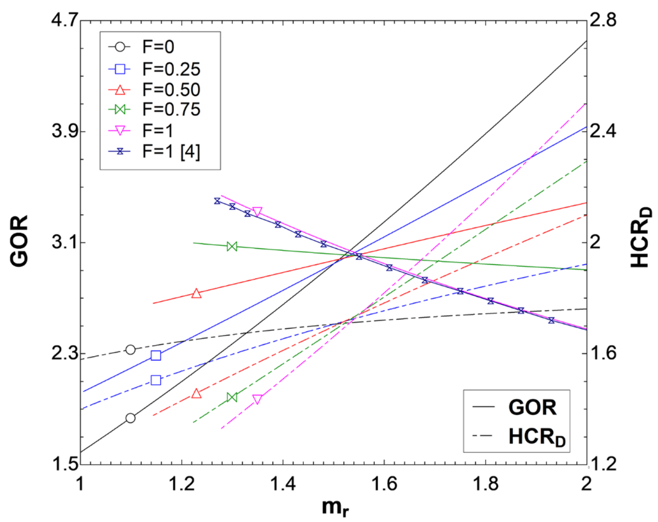

Figure 5. ***GOR*** **as a function of mass flow rate ratio for an air heating cycle with** $T_{inlet,D} = 90°C$ **,** $\varepsilon_H = \varepsilon_D = 0.9$

4- Conclusions

Thermodynamic analysis of Humidification-dehumidification desalination system with semi-open air circulation has helped create a better understanding of the key components and operating conditions, the following conclusions have been achieved:

- For a given water heated cycle, there is a specific F that maximizes *GOR*. Due to solar radiation variation during the day, by changing F, HDH will operate at maximum efficiency.
- For a given Air heated cycle, maximum *GOR* occur at F=0 or F=1.
- For any given F value, the dehumidifier effectiveness (ε_D) is more vital than the humidifier effectiveness (ε_H) to the performance of a water heated cycle.
- For the air-heated cycle, both the humidifier and dehumidifier effectiveness have a similar impact on the cycle performance. But as F value increases, the impact of dehumidifier effectiveness becomes more vital.
- For a given cycle of water heating or air heating, the impact of environment temperature is more vital than the relative humidity of the environment on cycle performance; and according to the results, HDH is efficient for both dry and humid climates.
- For a given cycle, there is a specific mass flow ratio at which the performance of cycle is constant regardless of the percentage of the air leaving the dehumidifier and returning to the humidifier (%F).

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