Study of an adsorption desalination with improved performance

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Abstract

Adsorption cycle is a practical and inexpensive method of desalinating the saline and brackish water to produce potable water for both industrial and residential applications. In this article, thermodynamic modeling of adsorption desalination systems (ADS) is studied. The advanced operation cycle with mass and heat recovery between the beds, the condenser, and the evaporator have been carried out. The particular ADS thermodynamic mathematical model is developed and it is validated against experimental data reported in the literature. Also, the performance of the advanced adsorption desalination system with mass and heat recovery between the beds, the condenser, and the evaporator is investigated. The specific daily water production (SDWP) of the advanced ADS cycle is 150% more than the conventional ADS cycle.

Keywords: Adsorption; Desalination; Thermodynamic modeling; Mass recovery; Heat recovery.

Introduction

Many people lack access to clean drinking water. Therefore, there is a need to improve water use efficiency, deploy clean technologies, policies to encourage conservation and reuse of water, and ultimately the use of freshwater resources such as seawater to minimize the impact of water scarcity [1]. Approximately, the percentage of salt water on earth is 97% of the total volume of water that cannot be used for drinking or other applications. Desalination processes Separate dissolved salt and other minerals from water. Feedwater sources may include brackish water, seawater, groundwater, sewage, industrial and processed water [2, 3].

conventional methods of desalination include distillation, reverse osmosis and electrodialysis [4-6]. Conventional desalination technologies use a lot of energy, they also have relatively high costs and have not been able to utilize low-temperature waste heat sources or solar energy, and so on [7-14]. In recent years, adsorption desalination technology has been invented for the production of drinking water and cooling that can use low-tempreture waste heat, solar or geothermal energy as input. Adsorption desalination system (ADS) can provide high quality drinking water and cooling power by using low temperature heat sources [15]. The concept of the adsorption desalination cycle differs from conventional desalination because it involves hydrophilic adsorbents. Recently, a lot of research has been done in the field of absorption desalination. Ng et al. [16-18] studied the performance of the adsorption desalination system with silica gel adsorbent to produce desalinated water and cooling power. Also, they investigated the effect of cooling water and hot water temperature, condenser and evaporator temperature and cycle time with respect to cycle performance parameters.

Thu et al. [19, 20] have examined the performance of the ADS with different heat recovery modes. they studied the condenser to the evaporator heat recovery and the integrated evaporator condenser unit. In this design, the evaporator temperature is increased because of the heat recovery from the condenser. In addition, increasing of evaporator temperature leads to higher water production.

In order to expand the research on adsorption desalination, this article has tried to increase the efficiency of this technology by using heat and mass recovery. There are also two new mass and heat recovery designs that are quite different from previous research on advanced ADS. As motivated by such advantage, this paper is dedicated to mathematically study the thermodynamic cycle modeling and performance evaluation of the ADS with new mass and heat recovery strategies and without it. The cycle performance is evaluated in terms of specific daily water production (SDWP), specific cooling capacity (SCC) and coefficient of performance (COP). The recovery mode is the novelty of this design. This configuration can significantly improve the ADS performance.

As mentioned, this paper deals with the mathematical investigation of thermodynamic cycle modeling and performance evaluation of ADS with and without new mass and heat recovery strategies. The cycle performance is evaluated in terms of specific daily water production (SDWP), specific cooling capacity (SCC) and coefficient of performance (COP). The recovery mode is new to this design. This configuration can greatly improve ADS performance.

The ADS cycle configuration

Figure 1 shows the two-bed ADS design with mass and heat recovery schemes. The system consists of an evaporator, two adsorption beds and a condenser. It works on three main processes: adsorption/desorption, mass recovery and heat recovery. When repeating these processes, it produces desalinated water.

Mathematical modeling of ADS

Adsorption isotherm is a plot that describes the amount of adsorbate adsorbed by the adsorbent at constant temperature versus pressure. The linear driving force (LDF) model states the transient uptake as below [21]:

$$\frac{dw}{dt} = \frac{f_0 D_{so} \exp\left(\frac{-E_a}{RT}\right)}{\left(R_p^2\right)(w^* - w)} \tag{1}$$

Where f_0 is constant, D_{so} is diffusion factor of the adsorbate in the adsorbent, E_a is the energy of activation, R_p is the radius of particle, w is the instant uptake. The equation of mass balance for each cycle is obtained. The energy balance during adsorption/desorption mode was also written.

Mass and Energy balance equations

The equation of mass balance for each cycle is obtained by:

$$\frac{dM_{s,evp}}{dt} = \dot{m}_{s,in} - \dot{m}_{d,cond} - \dot{m}_b \tag{2}$$

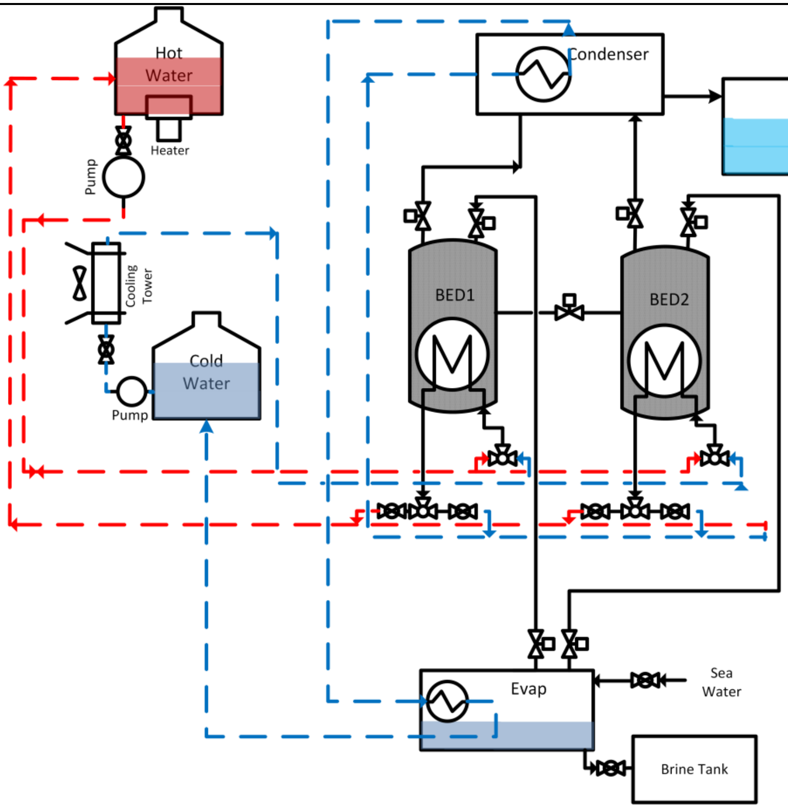

Fig. 1. Schematic design of the two-bed ADS.

The energy balance during adsorption/desorption mode can be written, as follows:

$$\begin{aligned}\left(M_{sg}cp_{sg}+M_{cu}cp_{cu}+\ M_{al}cp_{al}\ +\ M_{sg}\,w\ cp_g(T_{bed})\right)_{bed}\frac{dT_{bed}}{dt}\\ =\ M_{sg}\frac{dw_{bed}}{dt}\ Q_{ST}\left(T_{bed},P_{evap/cond}\right)\\ -\ \dot{m}_{cw/hw}\ cp_w\left(T_{bed}\right)\left(T_{cw/hw,out}-T_{cw/hw,in}\right)_{bed}\end{aligned} \tag{3}$$

The energy balance during mass and heat recovery mode is given as below respectively :

$$\left(M_{sg}cp_{sg}+M_{cu}cp_{cu}+\ M_{al}cp_{al}+\ M_{sg}\,w\ cp_g+M_{w,ads}\ cp_w(T_{bed})\right)_{bed}\frac{dT_{bed}}{dt}=\ 0 \tag{4}$$

$$\begin{aligned}\left(M_{sg}cp_{sg}+M_{cu}cp_{cu}+\ M_{al}cp_{al}\ +\ M_{sg}\,w\ cp_g(T_{bed})\right)_{bed}\frac{dT_{bed}}{dt}\\ =-\dot{m}_{cw}\ cp_{cw}\left(T_{bed}\right)\left(T_{cw,out}-T_{cw,in}\right)_{bed}\end{aligned} \tag{5}$$

Results and discussion

In this study, for the validation of the present ADS mathematical modeling, temperatures of main equipment are compared with Alsaman et al. [21] experimental results (figure 2). Next, the new ADS strategy with heat and mass recovery is introduced. Figure 3 shows the reduction of seawater mass inside the evaporator versus time. As shown, the evaporation rate decreases with increasing seawater concentration. In the first two cycles, the mass of seawater decreases from 3 to 1.8 kg, while in the next three cycles its mass only decreases from 1.8 to 1.45 kg.

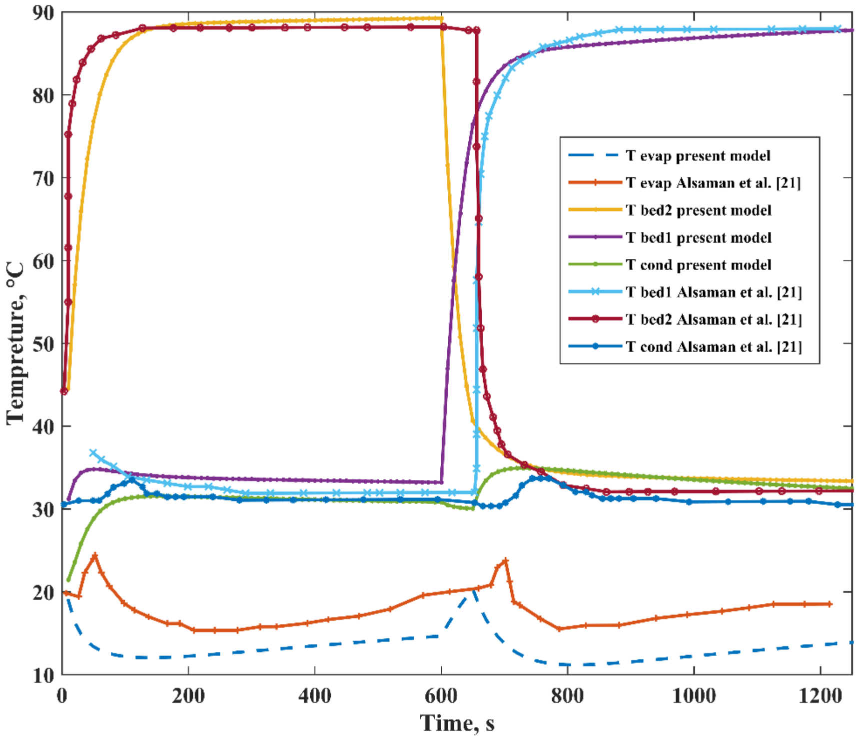

Fig.2. time history of temperatures of the ADS without mass and heat recovery that predicts by the present model against Alsaman's data [21].

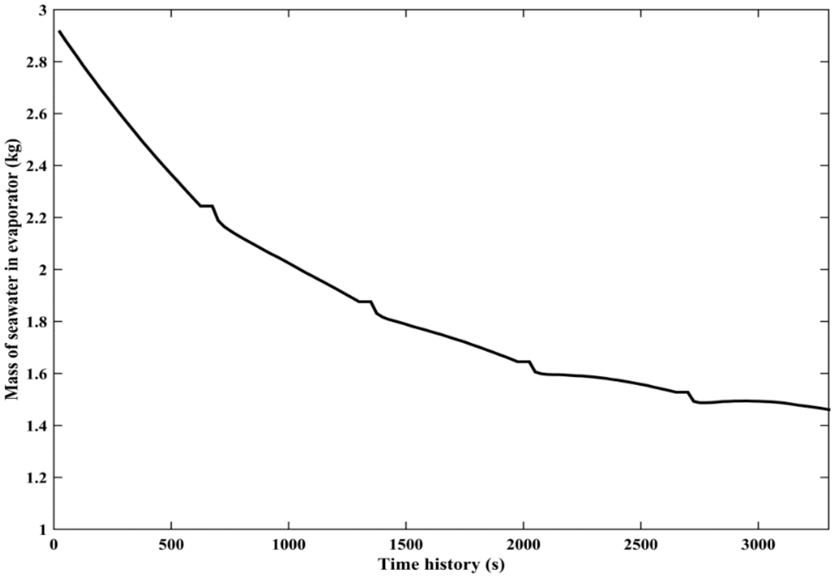

Fig.3: Time history of seawater mass in evaporator.

Figure 4 shows the amount of desalinated water in different cycles. In the first cycle, the adsorption beds are free of water vapor at first, therefore the rate of desalinated water production is lower. Over time and with the added mass and heat recovery effect, the amount of water produced is 14.37 m^3 per ton of silica gel. On the other hand, the amount of water produced in the Alsaman et al.'s paper [21] is 5.32 m^3 per ton of silica gel at the hot water temperature

92.5 ° c. This increased rate of desalinated water production is due to the mass and heat recovery of the ADS process. It is worth noting that the fin pitch in the bed heat exchanger was assumed to be 4 mm.

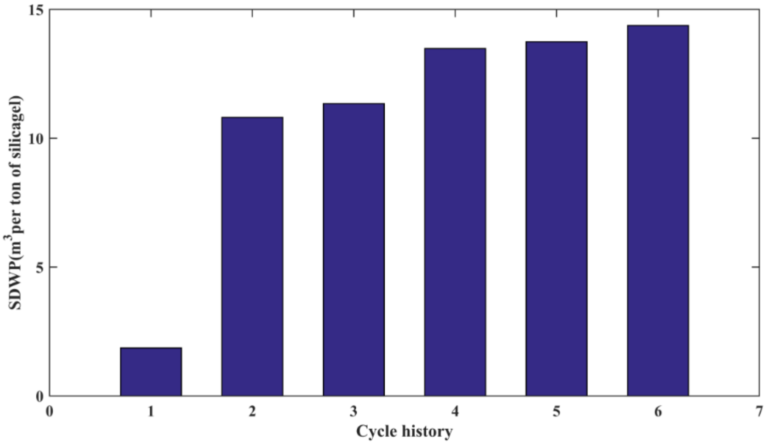

Fig. 4. SDWP at different cycle with mass and heat recovery.

Conclusions

According to the results, the performance of the new ADS is significantly enhanced by heat and mass recovery between the beds, condenser and evaporator. The results show that the heat and mass recovery designs are keys for the performance improvement of the ADS.

The maximum water production for this ADS is 14.37 (m^3 /ton of silica gel/ day) at the hot water temperature of 92.5 (°C) and the fin pitch of 4 mm. As a Consequence, the SDWP of the new ADS is 150% more than the conventional ADS.

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