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Performance comparison of different mathematical models in the simulation of a solar desalination by humidification-dehumidification

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ABSTRACT

Solar desalination by humidification and dehumidification (HDH) is an interesting desalination technique, which has been the subject of many studies, including mathematical modeling. The objective of this work was to propose a mathematical model that is more efficient to predict distillate production than the ones in literature, maintaining reasonable temperature predictions. The heat and mass transfer coefficients were estimated by the minimization of sum of squared errors of both temperature and distillate predictions, joined in a parametric global multi-objective function. Different modeling strategies were proposed and seven models were compared. For the studied system, not considering air saturation for the hot air stream improved distillate predictions significantly, but the introduction of sodium chloride property equations had no considerable impact in model performance. The distillate mean error of models C and D (4.3%) is 31% lower than the model in literature that presented the best predictions. A sensibility analysis showed that an increase in the column heights may cause beneficial and adverse effects in distillate production, so that there are optimum values for each specific system. In the studied process of the present work, the recommended heights for the condenser and the humidifier are 0.50 and 0.35 m respectively.

1. Introduction

Over the years, the access to fresh water has become progressively more difficult in many regions. According to [1], it is estimated that in 2025 1.8 billion people will suffer from water shortage and two thirds of the global population will have some sort of difficulty to have access to fresh water. A detailed analysis from [2] showed that economic growth is the most important driver of future water scarcity, which overwhelms by far any realistic savings attempts by increasing technology and improving water efficiency. The other important drivers of water scarcity are population growth and climate change. According to [2], besides the investments in water efficiency, economic losses could be prevented if the overall water demand is reduced by decreasing wasted water, developing less water-intensive products and increasing trade in virtual water. It is pointed out though, that there is no general solution and each country has a specific situation to deal with. Besides the decrease in water demand, an increase in availability by desalination processes is an interesting well-developed alternative. Although traditional methods like multiple effect distillation, multistage flash distillation and reverse osmosis are efficient in large scale production, their energy source is generally non-renewable fuels. The combustion of these sort of fuels contributes to intensify the greenhouse effect, which can cause climate changes and worsen fresh water availability [3]. Besides, traditional methods are not economically viable for small capacities [4]. In order to solve these problems, solar energy desalination processes have been developed, such as solar stills (SS) and solar desalination by humidification-dehumidification (HDH).

The HDH process is an interesting desalination technique, which uses clean and renewable energy, and contains an energy recovery cycle. Fig. 1 shows a scheme of a process with closed-air and open-water cycles, and forced convection. Seawater is fed into the condenser bottom (Stream 1), is heated by hot air and leaves the condenser top (Stream 2). The seawater heating process is completed in the solar collector. Hot seawater (Stream 3) is sprayed onto the top of a packed humidification column, where it gets in contact with cold air, its temperature is decreased and some water evaporates. The brine (Stream 4) leaves the humidifier at the bottom of the column. The air cycle begins with hot and humid air (Stream 6) entering the condenser top, where heat is transferred from the gas phase to the seawater in the inner tubes. Because of the temperature decrease, the vapor is partially condensed and the distillate is collected at the bottom of the column. Cold air (Stream 5) leaves the condenser at the bottom, passes through a vent,

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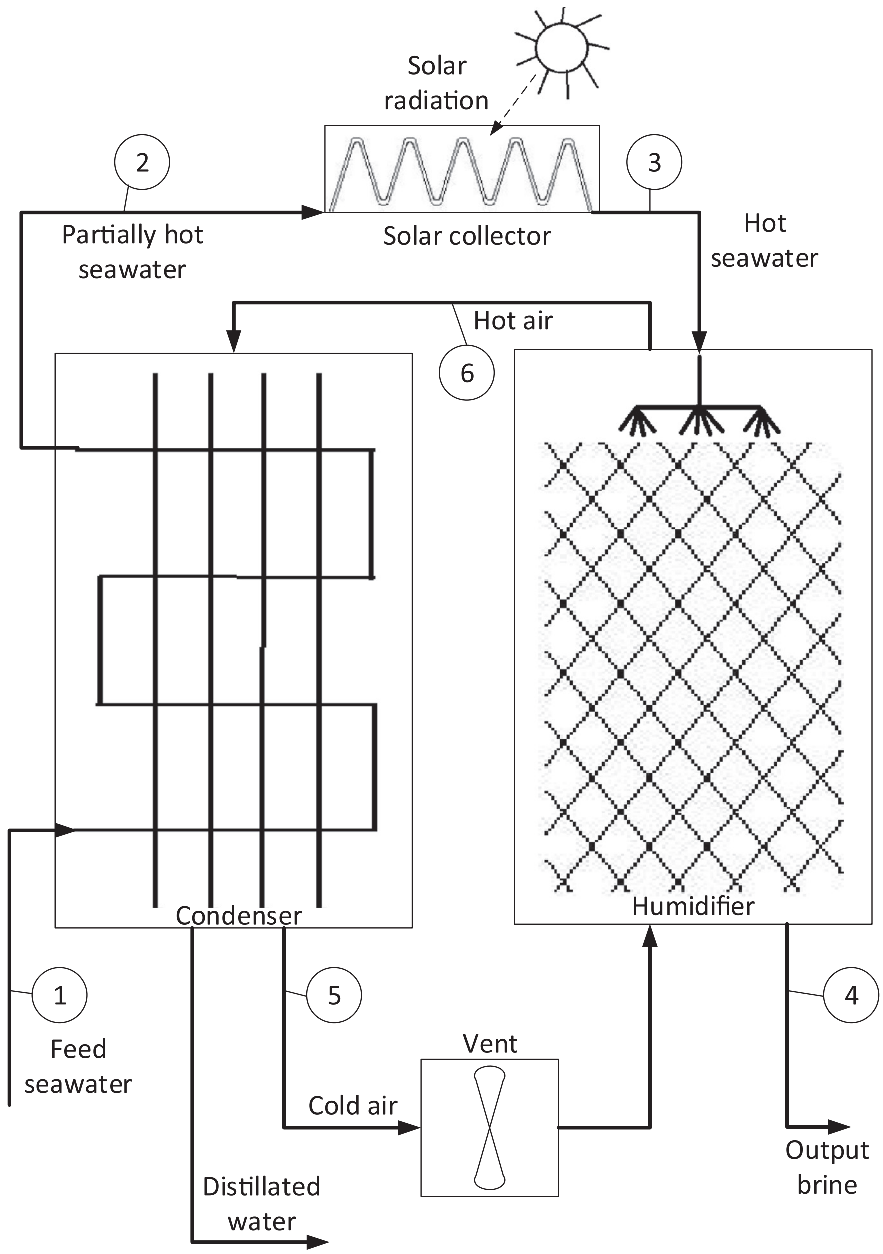

Fig. 1. Solar desalination by humidification-dehumidification – scheme of a closed-air open-war process with forced convection.

and enters the humidifier at the bottom, where it gets in contact with hot seawater, gaining heat and humidity. Hot and humid air leaves the humidifier top, completing its cycle [5–7].

Over the years, several authors have developed mathematical models to simulate the HDH process. The present work is focused on the steady-state models, which consider a constant solar irradiation. In order to have steady-state experimental data, it is common to substitute the solar collector for an electrical heater, which can indeed maintain a constant heat input [5,8]. Although these models are in steady-state, they can be very useful in simulating the HDH process at different conditions, as well as finding an optimum operation point.

Nawayseh et al. [5] developed a lumped parameter model for a steady-state operation consisting of five variables (temperatures T_2, T_3, T_4, T_5 and T_6) and five equations, which come from energy balances in the equipment. One mass balance is also used to calculate the distillate production after the system is solved. The authors considered that saturated air leaves both columns (Streams 5 and 6). The methods used to obtain the heat and mass transfer coefficients were reported by [9], in which theoretical and empirical models as well as experimental measures were applied. The authors also considered that the heat transfer coefficient from the condenser to the environment was the same as the heat transfer coefficient from the humidifier to the environment, resulting in a total of three parameters to be estimated (gas-liquid heat transfer coefficient in the condenser, mass transfer coefficient in the humidifier and heat transfer coefficient from the system to the environment). For a distillate experimental mean value of 1.084 kg·h^{-1}, the average error of the model predictions was approximately 12% (from Fig. 3 of [5]).

Soufari et al. [10] proposed a distributed parameter mathematical model to simulate a steady-state HDH process. The authors considered that the system is adiabatic, and no consideration of air saturation was made. Differential mass balances and energy balances, as well as energy balances on the interface were made to describe the system. The heater was simulated by a lumped parameter energy balance equation instead of a differential balance [10]. used the technique of finite differences to transform the ordinary differential equations into a larger set of