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A solar desalination system using humidification–dehumidification process: experimental study and comparison with the theoretical results

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Abstract

In this study, influence of the different system operating conditions on the performance of a solar desalination system using humidification-dehumidification process have been investigated experimentally under the climatological conditions of Ankara (40°N, 33°E), Turkey. An experimental set-up that consists of a double-pass flat plate solar air heater with two glass covers, pad humidifier, dehumidifying exchanger and water storage tank was designed and manufactured. Working principle of the set-up is based on the idea of closed water and open-air cycles. A series of tests were performed on it in outdoor environment, in order to assess the effect of mass flow rate of the feed water, process air and cooling water, double-pass flat plate solar air heater, initial water temperature and amount of the water inside the storage tank on the productivity of the system. Additionally, an evacuated tubular solar water heater unit was integrated to the existing system and the effect of this integration on the performance of the system was examined. Solar radiation, wind speed, relative humidity, mass flow rate of the feed water, process air and cooling water, mass of condensate water and temperatures at various locations were obtained during the experiments.

The results of the experimental study showed that under certain operating conditions, the system productivity decreases about 15% if double-pass solar air heater is not used and significant improvement on the productivity of the system is achieved by increasing the initial water temperature inside the storage tank. In addition, productivity of the system increases with increasing the feed water mass flow rate and quantity of water inside the storage tank. However, productivity of the system remains approximately the same when the air mass flow rate is increased. Moreover, increasing the cooling water mass flow rate results in the improvement on the productivity of the system investigated. Finally, results obtained from the present investigation were compared with the theoretical study and a good agreement between them is observed.

Keywords: Solar desalination; Humidification–dehumidification; Double-pass flat plate solar air heater

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1. Introduction

Fresh water is an indispensable requirement for humanity and other living beings to continue their daily life. In many parts of the world, especially in the Middle East, fresh water demand of the people is largely increasing and this demand can not be met by the existing natural water sources, since existing water sources are becoming scarce and insufficient, and also, they are being polluted gradually with the large amount of sewage and industrial wastes. On the other hand, in these regions, abundant of solar energy is available with the large amount of sea or underground saline water. Therefore, it is possible to produce fresh water from sea or underground saline water using solar energy (i.e., solar desalination) economically. Consequently, increasing of fresh water demand of the people can be solved partially by using solar desalination technologies.

Up to now, different solar desalination processes, such as active and passive basin type solar stills and systems working on humidification-dehumidification principle, have been used to produce fresh water from sea or underground saline water. Among these processes, however, the daily productivity of the basin type solar stills does not exceed the 5 L/m^2 even in areas having relatively high levels of solar radiation. On the contrary, the productivity of the solar desalination systems based on the humidification–dehumidification technique is higher than that of the basin type solar stills under the same climatic conditions [1], that is, it can produce as much as five times the water produced by a basin type solar still of the same solar energy collecting area [2]. For that reason, the solar powered humidification–dehumidification desalination process is one of the simple and the most efficient methods for small capacity of fresh water production. The following is a review of some of the literature related to the solar desalination systems working on humidification–dehumidification principle and double-pass flat plate solar air heaters.

J. Orfi et al. [1] studied theoretically and experimentally a solar desalination system using humidification–dehumidification process. The system studied consists of two solar collectors (air and water), an evaporator and a condenser. In the experimental set-up, however, an electrical water heater was used instead of solar water collector. The evaporator used in this study is horizontal and has a rectangular cross-section area. In order to improve the productivity of the system, the authors utilized the latent heat of condensate water vapor in the condenser to preheat the feed water and they concluded that the global efficiency of the system depends on the efficiency of each component (solar water and air heaters, evaporator and condenser). G. Al-Enezi et al. [3] presented a mathematical model and experimental evaluation of the low-temperature humidification–dehumidification desalination system. Main features of this system are that it operates at low temperature, i.e., feed water temperature is between 35°C and 45°C and utilizes sustainable energy sources, i.e., solar and geothermal. In their study, authors suggested several new correlations for determination of the water physical properties and the air humidity. In addition, the performance characteristics of a small capacity experimental system including a packed humidification column, a double-pipe glass condenser, a constant temperature water tank and a chiller for cooling water were evaluated at different operating conditions of the system. It was found that the highest production rates were obtained at high hot water temperature, low cooling water temperature, high air flow rate and low hot water flow rate. Moreover, they reported that the main advantage for low temperature operation is the cost savings related to the capital of the feed water-heating device. Finally, experimental results were compared with the previous literature results. Nafey et al. [4,5] conducted theoretical and experimental investigations to study the influence of the different system configurations, weather and operating conditions on the productivity of a solar desalination system