Energy 118 (2017) 729–741

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Energy saving potential in humidification-dehumidification desalination system

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ARTICLE INFO

Article history:
Received 24 April 2016
Received in revised form
3 September 2016
Accepted 24 October 2016
Available online 9 November 2016

Keywords:
Humidification-dehumidification desalination
Twisted tape
Conical insert
Circular insert
Energy analysis
Exergy analysis

ABSTRACT

Humidification dehumidification desalination (HDH) system is viewed as an auspicious technique for medium level investment and productivity. The objective of this work is to enhance the productivity with the saving of input power in a modified HDH system by various changes in its components. Inserts like short length taper twisted tape; internally finned cut out conical turbulator and half perforated circular inserts with various orientations and three different pitch ratios (PR) are used in the air heater. Two types of packing materials (Gunny bag and saw dust) are employed in humidifier section and two different dehumidifier are tested to choose the good one and it is further integrated with spring inserts of different PR to enhance its performance. The best combination is identified when the air heater equipped with divergent twisted tape of PR 3, humidifier furnished with gunny bag and dehumidifier fixed with spring insert of PR 3. Higher productivity of 0.8 kg/h with the reduction in salinity (3.2 mg/l of chloride content) attained with 40% saving of input power in the modified HDH desalination system. A noticeable saving in energy with significant development in energy and exergy efficiency is observed. The economic analysis is also carried out.

1. Introduction

There are several methods for purifying the saline water like Multi-stage flash distillation, Multi-effect distillation, Vapor compression distillation, Electro dialysis, Solar desalination, Humidification-dehumidification desalination and Reverse osmosis.

Humidification-dehumidification (HDH) found to be suitable for medium level productivity with affordable initial and running cost. The major components of HDH desalination system are air heater, water heater, humidifier and dehumidifier. A detailed review has been carried out on the above said components.

Most of the researches generally used inserts or additional devices to enhance the turbulence effect to the air flows in an air heater for different applications. Eiamsa-ard et al. [1] made a comparative study on oblique delta winglet twisted tape and straight delta winglet twisted tape in an air flow inside a circular tube. Result confirmed that due to more effective turbulence in the above said insert, heat transfer rate was inflated. Eiamsa-ard et al. [2] also presented an experimental study on air flow characteristics in a tube fitted with full length twisted tape insert and short-length twisted tape. The short-length tape generated a strong swirl flow at the tube entry and enhanced the heat transfer rate.

Tandiroglu and Ayhan [3] developed an energy dissipation analysis for the hot air flows through the tube assembled with a series of half circled baffle inserts. These inserts were examined with different pitch ratios. Baffles in the tube accelerated the dissipation energy compared to the plain tube without insert. .

Akansu [4] presented a numerical analysis on heat-transfer and pressure drop in an air flow through a pipe fitted with porous rings with various pitch ratios. In the result, decrease in the pitch ratio caused an increase in friction factor and augmented the heat transfer rate.

The effect of using nozzle turbulators on heat transfer rate with convergent (C) and divergent (D) mode turbulators in an air flow had been carried out by Promvonge and Eiamsa-ard [5]. It was understood that this work could effectively be utilized with divergent-type turbulators having pitch ratio of 2. Kongkaitpaiboon et al. [6] experimented the performance of perforated conical rings in an air heater. Results revealed that the heat transfer was enhanced by modifying the thermal boundary layer in the air flow.

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http://dx.doi.org/10.1016/j.energy.2016.10.098
0360-5442/

Some of the research works dealt with the performance of double pipe and shell and tube heat exchanger are presented below.

Yildiz et al. [7] investigated the performance of double-pipe heat exchanger fitted with propellers in the flow passage and predicted that the overall heat transfer coefficient increased with increase in mass flow rate and number of propellers. Durmas et al. [8] showed that by using snail type swirl generators, the heat transfer rate in concentric tube heat exchanger was augmented at the low Reynolds number ranges.

Amer et al. [9] carried out the experiment in a HDH desalination system by changing various operating conditions and different packing materials (gunny bag and wooden slates) in the humidifier and showed that the system productivity increases with increase in mass flow rate of water and wooden slates contributed the maximum productivity compared to other packing material.

Chang et al. [10] investigated the operational and performance characteristics of a multi-effect solar desalination system based on HDH process. The use of porous plastic balls packed in the humidifier enhanced the evaporation rate. Narayan and Lienhard [11] conducted an energy consumption analysis in two different types of HDH system such as open air closed water and closed air open water systems.

Chehayeb et al. [12] presented the mathematical model for HDH system consisting of a packed bed humidifier and a multi-tray bubble column dehumidifier. The study evaluated the effect of mass flow rate ratio on the performance of fixed size system.

Garaway and Grossman [13] tested the wetting performance of different sheets such as cotton cloths, synthetic cloths, wool, paper and plastic as the packing material in the humidifier of HDH desalination system. Results revealed that the tight weave cotton cloth proved better performance and higher productivity compared to other packing materials.

Al-Enezi et al. [14] presented the effect of operating parameters such as temperature and flow rate of feed water, air and cooling water on the productivity in a HDH desalination system. Maximum productivity attained for high feed water temperature of the humidifier and air mass flow rate and low cooling water temperature of the dehumidifier.

Ashrafizhadeh and Amidpour [15] conducted an exergy analysis in the HDH system and found that the mass transfer does not have any effect on the total exergy loss of HDH system. Shaobo Hou et al. [16] conducted the exergy analysis in the components of solar HDH desalination process and identified that the solar collector has the lowest exergy efficiency.

Xiong et al. [17] proposed a baffled shell and tube desalination system to perform humidification and dehumidification simultaneously at tube and shell side of the single column. The baffled plate significantly enhanced the productivity of the column.

Numerous research works have been carried out to enhance the heat transfer rate in the air heater and condenser by using insert for various applications. There is a research gap available to introduce such insert in the various components of HDH system. Previous researchers used half circled baffle inserts, plain cut out conical inserts and uniform width twisted tape for heat transfer enhancement for other application and leaves a gap of introducing half perforation in full circled baffle, fins in cut out conical turbulator and tapered width twisted tape for enhancing the heat transfer in the air heater of the HDH system. Two different packing materials, such as random type (saw dust) and cloth type (gunny bag) are used to augment the humidifying effect in the humidifier. Some of the works utilized the double pipe or shell and tube dehumidifier for HDH desalination system. It leaves the gap to perform the comparative study of those two types of condenser in HDH desalination system. Also the performance of dehumidifier is enhanced by using spring inserts.

2. Experimentation

A laboratory scaled HDH desalination system is constucted for this study, which mainly consists of an air heater, water heater, humidifier and dehumidifier. Fig. 1 shows the schematic sketch of the HDH desalination system. The air heater made with iron pipe, 1000 mm in length and 38 mm in diameter. It is centrally covered

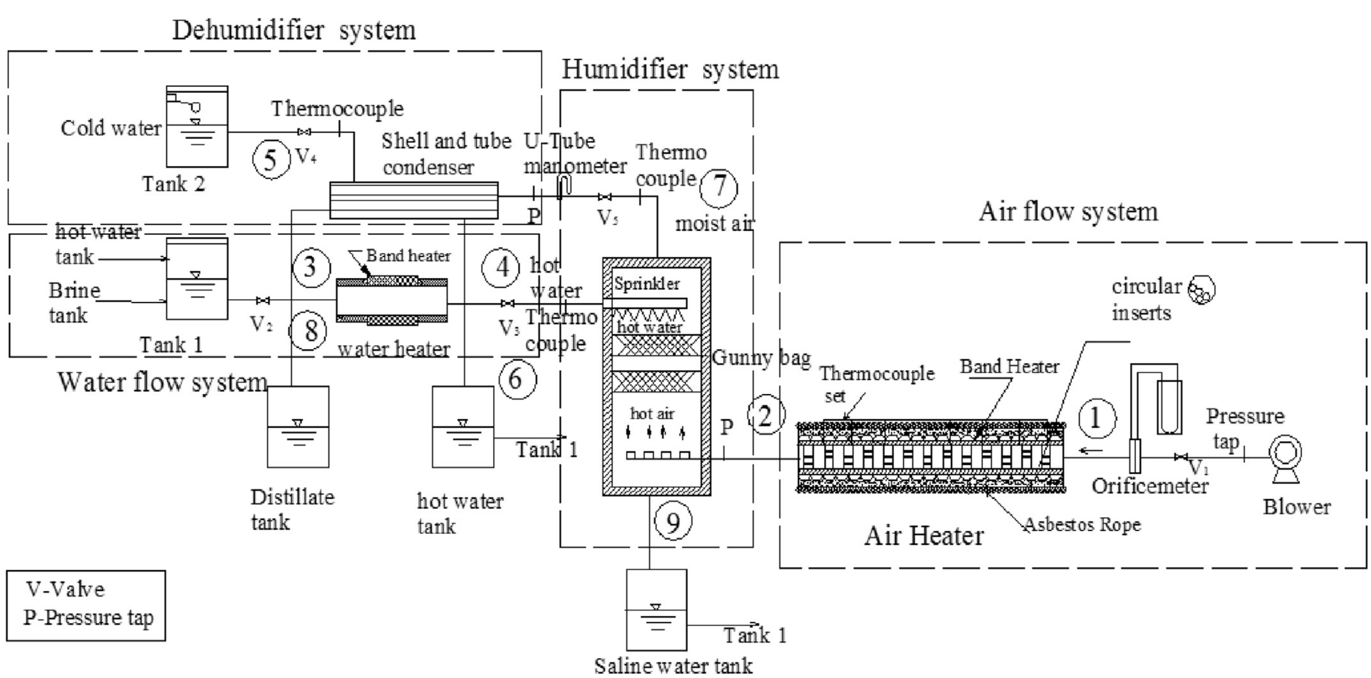

Fig. 1. Experimental setup of HDH desalination system.