Desalination 341 (2014) 120–125

Contents lists available at ScienceDirect

Desalination

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

Humidification compression desalination

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HIGHLIGHTS

- A new process with higher efficiency is synthesized and developed.
- By combination of well-known processes the efficiency of HDH systems was increased.
- The water recovery from humid air is carried out by use of a polytropic compressor.

ARTICLE INFO

Article history:
Received 7 December 2013
Received in revised form 21 February 2014
Accepted 27 February 2014
Available online 22 March 2014

Keywords:
Humidification–dehumidification
HDH
Desalination
Humidification–compression

ABSTRACT

In this communication, a new Humidification De-Humidification process desalination technology is identified which has some advantages (such as: high energy performance, high recovery flow rate, energy recovery and so on) in comparison with other similar methods; this technology is named “Humidification Compression”. This method is simulated by a commercial process simulation software and the results are compared with two conventional methods. It is seen that, gain output ratio (GOR) for proposed method is higher than conventional methods; also capital cost per product for proposed method is lower than two others.

1. Introduction

World population growth, together with increase of industrial and agricultural activities has led to excessive exploitation of available water resources and it causes to pollution of fresh water resources recently. So it is necessary to use various methods for converting polluted water or salty water into potable water.

One of the most popular methods to produce potable water is “Desalination”; by which the salty water is converted into potable water by removal of the salt content. There are many methods for desalination. These methods can be classified into four categories:

- Thermal Desalination
- Crystallization Desalination
- Membrane Desalination
- Other Methods.

One of the applicable and flexible thermal desalination methods is humidification of carrier gas [1].

There are two main techniques for desalination by carrier gas, Humidification De-Humidification (HDH) and Dew-vaporation. The HDH process is based on the fact that air can carry large quantities of water vapor. The capability of air for vapor carrying increases with temperature: 1 kg of dry air can carry 0.5 kg of vapor and consumes about 670 kcal when its temperature increases from 30 °C to 80 °C. When hot air is brought into contact with salt water, a certain quantity of vapor is extracted by air, which provokes cooling. Distilled water, on the other hand, may be recovered by bringing the humid air in contact with a cold surface, which causes the condensation of part of the vapor from the humid air [2]. Generally, the condensation occurs in an exchanger in which salt water is preheated by the latent heat of condensation. An external heat source is therefore necessary to compensate for the sensitive heat loss.

The HDH technique is especially suited for seawater desalination in arid region when the demand for water is decentralized [3,4]. Solar desalination based on the HDH cycle presents the best method of solar desalination due to overall high-energy efficiency [5].

HDH systems are classified under three main broad categories [6–11]; type of circulation, type of heating and type of circulation loop.

Dew-vaporation technique is similar to HDH process; but in this process, evaporator and condenser is the same. There is a flat plate which

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http://dx.doi.org/10.1016/j.desal.2014.02.039
0011-9164/

gains energy from produced vapor and gives it to sea water to vaporize part of the water. The mechanism in this process is the same as in HDH process [12].

Some recent works in humidification of carrier gas are as follows.

A theoretical study was carried out by Marmoucha et al. (2009) on the effect of a cooling tower on a solar desalination system. A prototype unit was designed using the humidification–dehumidification principle. It was consisted of the following independent units: a humidifier, a condenser, two solar collectors of air and of water, and a cooling tower. This process was designed to work at low temperatures (60–100 °C) of brackish water or using geothermal energy. A mathematical model based on the conservation equations of mass and energy was developed to present the temperature in every component. It was reported that, the best ratio for water/air flow rate is about 2. In a similar work, a theoretical study of a solar desalination system with humidification–dehumidification was investigated which is a promising technique of production of fresh water at small scale. A general model based on heat and mass balances in each component of the system was developed and used to optimize the system's non-dimensional characteristics. The daily production of fresh water depends on the ratio between the salt water and the air mass flow rates. It was shown that, if this ratio is continuously adjusted for optimum performance, it is possible to produce more than 40 L of fresh water daily per square meter of solar collector surface on a typical July day in Tunisia [13].

A vertical parallel-plate channel was investigated by CFD method. One of the plates is wetted by a liquid water film and maintained at a constant temperature, while the other is dry and thermally insulated. The airflow enters the channel with constant temperature, humidity and velocity. The results showed that the increase of air humidity at the channel entrance affects seriously the performances of the humidifier. On the other hand, it was stated that the humidifier works well for low inlet humidity [14].

In other work, a new method for exergy analysis of humidification–dehumidification (HD) desalination systems was presented. A methodology was developed for investigating various parametric effects on exergy losses. The method involved developing a sink and source model as well as basic relations in the system. Results showed that the mass transfer phenomenon does not have any effect on the total exergy losses of the HD systems and 80–90% of total loss is related for heater section [15].

A HDH system and a reverse osmosis were combined to increase energy efficiency. In this system, high pressure steam was used as energy driven. It was found that the performance of the new system is comparable to existing thermal desalination systems and is much higher than conventional HDH systems; a GOR = 20 was reported for this system [16]. In another work, authors proposed thermodynamic balancing of the humidifier or the dehumidifier through mass extraction and injection as a potential means of reducing the energy consumption of these systems. Balancing minimized the entropy generation caused by imbalance in driving temperature and concentration differences. Authors outlined a procedure to model the system, using on-design component variables, such that continuous or discrete extraction and/or injection of air from the humidifier to the dehumidifier or vice versa can be analyzed. Also they presented an extraction profile (mass flow rate ratio versus non-dimensional position) in the dehumidifier and the humidifier for attaining close to complete thermodynamic reversibility in an HDH system with a 100% effective humidifier and dehumidifier [17].

The work presented in a previous paper focused on desalinating sea water system using a HDH process as it is supplied with water heated by geothermal energy as clean and renewable natural resources of energy. Some variables include the ratio of sea water mass flow rate related to air mass flow rate, cooling water temperature difference across the condenser, geothermal source inlet temperatures to the heat exchanger and the amount of produced distilled water were studied. To validate the computer program, a comparison was conducted between the experimental and theoretical results, and a good agreement was obtained. The result showed that, the optimum value of the ratio of sea water mass flow rate to air mass flow rate was found to be in the range of 1.5 to 2.5. Improvement in the fresh water productivity at the optimum ratio of sea water mass flow rate to the air flow rate was observed by increasing both the geothermal source inlet temperature and the cooling water temperature difference across the condenser [18].

The limits upon the energy recovery and the water recovery (product water per unit of feed) of closed air water heated cycles were investigated. This was done by considering heat and mass exchangers to be sufficiently large to provide zero pinch point temperature and concentration differences within the humidifier and dehumidifier. For cycles operating with a feed temperature of 25 °C and a top air temperature of 70 °C, GOR is limited to approximately 3.5 without extractions (i.e. single stage system) and 14 with a single extraction (i.e. dual stage system) while Recovery Ratio is limited to approximately 7% without extractions and 11% with a single extraction. GOR increases and recovery ratio decreases as the temperature range of the cycle decreases. A single extraction was shown to be useful only when heat and mass exchangers are large in size [19].

In this paper, a new HDH technology is presented which has some advantages in comparison with other similar methods; this technology has been named “Humidification Compression (HC)”.

2. Description of the proposed technology

The proposed technology is compared with two conventional HDH systems for 1000 kg/h capacity. In the proposed technology, there are three main units; humidification, compression and energy recovery. Operating conditions and parameters are obtained by using a commercial process simulation software.

Sea water (or brackish water) with 1000 kg/h flow rate is entered into a double pipe heat exchanger and heated by a hot air discharged from the compressor. After heating, water is entered into the top of the humidifier (with 100 °C) and contacted with air (that flows from the bottom to the top of column) in order to humidify the air [two equilibrium stages are considered for humidifier column]. Water is partially evaporated and discharged from the bottom of the column at 53 °C.

Humid air is discharged from top of the humidifier column (with 77 °C) and entered into a polytropic compressor [assumed that compressor efficiency is equal to 75%]. During compression, air temperature is increased. Outlet air from the compressor has 2 barg pressure and 302 °C temperature. Heated air is entered into the double pipe heat exchanger and cooled to 65 °C. Finally, humid air is cooled by an auxiliary cooler and entered the flash drum to separate the desalinated water. Saturated air is discharged from the flash drum and returned to the humidifier after reducing its pressure.

Fig. 1 illustrates process flow diagram for this technology.

In this process, produced desalinated water is 151 kg/h. Now, the proposed technology is compared with two conventional methods: 1 — water heated process, 2 — air heated process.

For better comparison, all operating condition and energy consumptions are the same which are used for the proposed technology.

2.1. Water heated process (CAOW)

In this arrangement, sea water with 1000 kg/h flow rate is heated by a heater (using fuel, electrical heater or steam with 47.2 kW power) until reaching a water temperature of 66 °C. The heated sea water is entered into the top of the humidifier and contacted with the air and discharged from bottom of the column at 48 °C.

Humid air is discharged from top of the humidifier column (at 56 °C) and entered into a heat exchanger and cooled with cold air and then by an auxiliary cooler to 35 °C (like the proposed technology). Cooled air is