Performance investigation of Freezing Desalination Coupled with Carbon Dioxide Refrigeration System

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ABSTRACT

The world is currently facing the prospect of a severe global shortage of fresh water. Desalination of seawater can provide an almost inexhaustible source of freshwater if it can be made affordable. Freezing is a well-known technique for water desalination. The carbon dioxide refrigeration system is used for cooling required in the freezing desalination system and the evaporator and condenser of the refrigeration system are respectively crystallized and melted in the freezing desalination system. In this paper the basic principles of freeze concentration processes are presented and a model of a freeze desalination that coupled with CO_2 refrigeration has been developed based on the theories of heat and mass transfer. To examine the performance of the system, a parametric study is performed to investigate the effect of different parameters such as FD feed temperature, feed concentration, distillate temperature, distillate concentration and FD recovery ratio on COP and energy consumption have been explored. It can be concluded that increasing the feed concentration and feed temperature is accompanied with the reduction of COP and a raise in SEC. Increasing the ice fraction also increases the SEC system. Freezing desalination System in the present study is comparable in energy consumption to reverse osmosis desalination system.

KEYWORDS

Indirect freeze desalination, Ice crystallization, recovery rate, Ice fraction, SEC

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1. Introduction

Despite important progress in the management of water resources, the drinking water scarcity increases and represents a major technical and economic issue in many countries. To overcome this problem, the main solutions are the wastewater reuse and seawater desalination. Two major types of technologies are used for desalination and can be classified as either thermal or membrane process.

Although, freeze desalination is not widely used commercially, this process has some advantages. The most important one is the very low energy requirement compared to that of distillation processes. Reduction in energy costs results as the latent heat of ice fusion is only one seventh the latent heat of water vaporization [1].

The main flow of any separation by crystallization method involves sequentially: the crystallization, the separation, the washing and finally the melting [2].

In 2011, Rendell et al. [3] investigated a hybrid desalination system. This paper describes a case study in which FD was used to treat the liquid waste obtained from a Reverse Osmosis (RO) plant. In addition to the recovery of 99 % of the water available in wastewater, calcium sulfate and sodium sulfate were recycled. lu et al. [4] proposed a FD-MD hybrid system developed for zero liquid discharge desalination (ZLDD). In this research, by mathematical modeling, the effects of inlet water temperature, salt concentration in inlet water and recovery ratio of FD system on energy consumption were investigated. In addition, the potential of using new energy for energy supply of this hybrid system is evaluated.

Refrigerant in a freezing desalination system has requirements such as that the material must be non-toxic, chemically inert, impermeable to water, and resistant to the formation of hydrates. In recent years, the growth of environmental concerns about global warming and ozone layer degradation has attracted a great attention .Carbon dioxide as a natural refrigerant with obvious advantages such as nontoxic, nonflammable, destruction of zero ozone layer, suitable heat transfer properties, easy access and low price are used in various engineering fields. [5]

According to the studies, no significant research has been done on the combination of freezing water desalination system with cooling system. With this approach, in this study, an FD system has been investigated that provides the required cooling from a refrigeration system. In the refrigeration system, condenser is heated by sea water or ambient air, but in the case study, the condenser of the refrigeration system returns its output heat to the desalination melter to melt the ice. The combined system is modeled completely with thermodynamic relations. The effect of governing parameters on the issue such as salt water temperature, salt concentration, and ice fraction were investigated.

2. Methodology

Fig. 1 shows a schematic of the proposed system and the p-H diagram of the CO_2. In which the crystallizer and melter unit of the freeze desalination system are replaced by evaporator and condenser respectively,

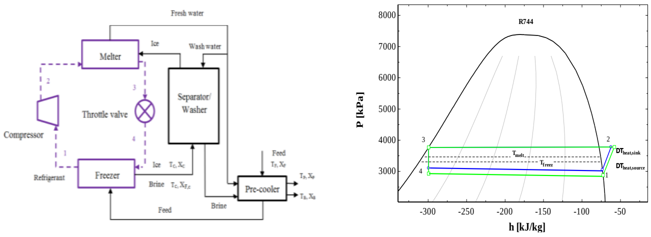

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Fig.1 a) Schematic of the combined FD system and a CO_2 refrigeration system, b) p-h diagram of CO_2 refrigeration system

In order to analyze the energy of the hybrid system of freeze desalination and CO_2 refrigeration system, each of the components of the system is considered as a control volume.

$$\sum \dot{m}_i - \sum \dot{m}_o = 0 \quad (1)$$

$$\sum \dot{m}_i x_i - \sum \dot{m}_o x_o = 0 \quad (2)$$

$$\sum \dot{m}_{in} h_{in} - \sum \dot{m}_{out} h_{out} - \dot{W}_i - \dot{Q}_i = 0 \quad (3)$$

In this research, The coefficient performance (COP) and specific energy consumption (SEC) are equal to:

$$COP = \frac{Q_{evaporator}}{W_{compressor}} \quad (4)$$

$$SEC = \frac{W}{m_{product,water}} \quad (5)$$

3. Results and Discussion

Since parameters such as inlet saline water temperature, inlet saline water concentration, freshwater production concentration and ice ratio have the greatest impact on the performance of the combined system, so in a parametric study, the rate The effect of each of these factors on system performance has been studied. Examination of the degree of freedom for the proposed hybrid system shows that in order to solve the equations of mass and energy conservation, the parameters of table 1 must be considered constant.

Table.1 Input parameters of simulation

parameters	value
Sea water temperature(°C)	25
Sea water salinity (ppm)	35000
Capacity (m^3/d)	2000
Output water salinity of FD(ppm)	220
Output water temperature of FD (°C)	20
Ice fraction (%)	35

Fig. 2a shows the effect of supply water temperature on the SEC of the system at different salt concentrations. The more the supply temperature increases the more the SEC increases. This is due to the effect of sensible heat quantity increasing. Fig. 2b illustrates the effect of TDS of sea water on the SEC. This figure shows that the energy consumption increased with the salt quantity.

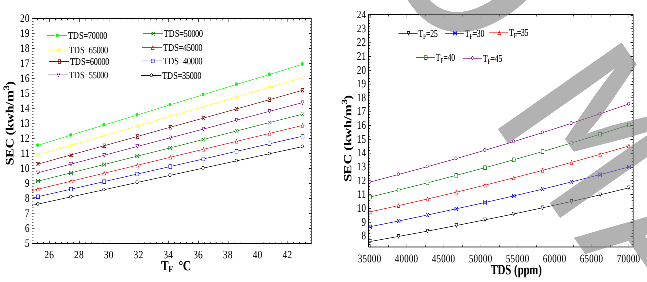

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Fig2. Variation of SEC with a)supply salty water temperature at different salt concentrations, b) TDS of salty water at different supply salty water temperatures.

The effect of ice ratio on the SEC at different salt concentrations is illustrated in Fig.3a. As shown in the figure, up to a certain salinity percentage, with increasing F_s, the SEC gradually decreases, but this decrease has an optimal value. The lower the TDS of feed water, the lower the ice fraction. As the Fs increase, the salt concentration in the remaining brine solution increases, followed by a decrease in the freezing point temperature of the brine. Fig. 1b shows the linear relationship between the ice fraction and the brine production together with the non-linear relationship between ice fraction and SEC.

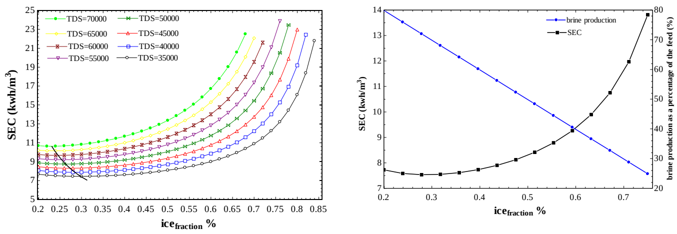

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Fig3. a) Variation of SEC with the ratio of ice fraction at different salt concentrations, b) Relationship between SEC, ice fraction and brine production rate

4. Conclusions

Seawater desalination as a source of drinking water is likely to increase in the future as available pure water resources are depleted. Although the freeze desalination method is not widely used commercially, this system has several advantages. In this research, CO2 refrigeration system has been used to produce the cooling required for freezing desalination. Thermodynamic analysis can lead to a better understanding of the system's overall performance and effective parameters on system energy consumption. As expected, desalination energy consumption increased with increasing the salt water temperature, in addition, increasing the salt concentration in the input saline water, decreased the COP and increased the SEC and increased the concentration of salt in the wastewater. The results also show an increase in the ice fraction as an effective parameter increases SEC. Energy analysis of the system shows that the combined system of freeze desalination and refrigeration as a low energy consumption system can be used.

5. References

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