Desalination 408 (2017) 13–24

Contents lists available at ScienceDirect

Desalination

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

Recycling brine water of reverse osmosis desalination employing adsorption desalination: A theoretical simulation

Ehab S. Ali [a], Ahmed S. Alsaman [b], K. Harby [c], Ahmed A. Askalany [b,*], Mohamed Refaat Diab [c], Sobhy M. Ebrahim Yakoot [d,e]

[a] Holding Company for Water and Waste Water in Sohag, 82524, Egypt
[b] Mechanical Engineering Dept., Faculty of Industrial Education, Sohag University, Sohag 82524, Egypt
[c] Mechanical Power Engineering and Energy Dept., Faculty of Engineering, Minia University, Minia 61511, Egypt
[d] Biochemistry Dep., Prince Mutaib Chair for Biomarkers of Osteoporosis, College of Science, King Saud University, PO Box 2455, Riyadh 11451, Saudi Arabia
[e] Atomic Energy Authority, Hot Laboratories Centre, 13759, Egypt

HIGHLIGHTS

- An innovative combination between RO and AD desalination systems has been proposed.
- RO brine is recycled by employing adsorption desalination.
- The proposed system has been studied theoretically by using a MATALB code.

ARTICLE INFO

Article history:
Received 19 July 2016
Received in revised form 4 December 2016
Accepted 4 December 2016
Available online xxxx

Keywords:
Reverse osmosis
Adsorption
Desalination
Cooling

ABSTRACT

Intake, pretreatment and brine disposal cost of reverse osmosis sea water desalination systems represent about 25% of total cost of the desalinated water. The present study investigates effect of reverse osmosis brine recycling employing adsorption desalination on overall system desalinated water recovery. The adsorption desalination produces dual useful effects which are high quality potable water and cooling effect. Reverse osmosis desalination is simulated by engineering equation solver (EES). The brine leaving reverse osmosis system is fed to adsorption desalination system. The adsorption desalination is driven by a low temperature heat source such as solar energy. The adsorption desalination system has been simulated by MATLAB. Results show that the proposed combination system recovery increases and permeate salinity decreases. In addition to system performance improvements, a cooling effect is generated and can be utilized for cooling applications.

Nomenclature

A	area (m^2)
A_m	membrane area (m^2)
Cp	specific heat (kJ/kg·k)
D_s	coefficient of surface diffusion (m^2/s)
D_{so}	pre-exponential coefficient (m^2/s)
E	characteristic energy (kJ/kg)
E_a	activation energy (kJ/kg)
h_{fg}	water latent heat (kJ/kg)
H_{st}	isosteric heat of adsorption (kJ/kg)
k_s	salt permeability (kg/m^2 s ppm)
k_w	water permeability (kg/m^2 s kPa)
M	mass (kg)
m	mass flow rate (kg/s)
$\overline{m}$	average mass flow rate (kg/s)
P	pressure (kPa)
Q	heat energy (kJ/s)
R	permeate recovery, dimensionless
$\bar{R}$	universal gas constant (kJ/kg·k)
R_p	average radius of the particle (m)
SR	salt rejection, dimensionless
T	temperature (°C)
t	time (s)
U	overall heat transfer coefficient (w/m^2·k)
X	concentration (ppm)
$X_{average}$	average salinity in the feed compartment (ppm)
τ	number of cycle per day (–)
ΔP	pressure drop through RO membrane (kPa)
$\Delta\pi$	osmotic pressure drop through RO membrane (kPa)
π	osmotic pressure (kPa)

* Corresponding author.
E-mail address: ahmed_askalany3@yahoo.com (A.A. Askalany).

http://dx.doi.org/10.1016/j.desal.2016.12.002

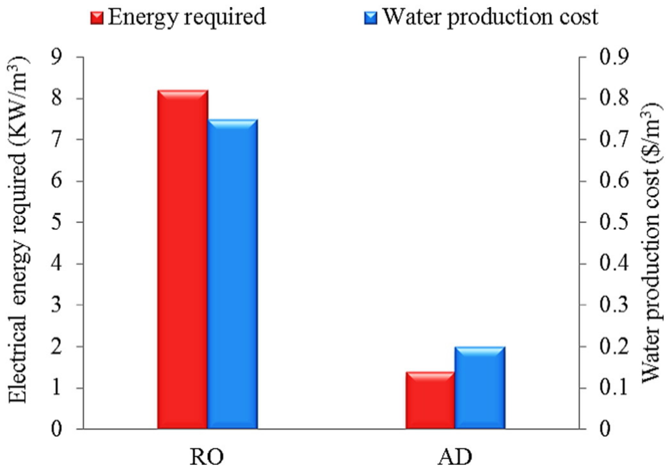

Fig. 1. The electrical energy and cost required for desalinated water for RO and AD systems [22,23].

ω	adsorption capacity (kg/kg)
ω_o	maximum adsorption capacity (kg/kg)

Subscripts

ads	adsorption
b	brine
ch	chilled water
cond	condenser
des	desorption
evap	evaporator
f	feed
hex	heat exchanger
hw	heating water
i	reverse osmosis module no in pressure vessel
in	inlet
out	outlet
p	permeate
s	salt
sat	saturation
sg	silica gel
sur	surrounding
sw	sea water
v	vapor
w	water

1. Introduction

Rapid growth of reverse osmosis (RO) desalination system is because it has the ability of producing desalinated water with a relatively low cost [1]. RO desalination system consists of four major components: pretreatment, high pressure pump, RO membrane modules assembly and post-treatments (permeate post-treatment and brine disposal) [2]. Intake, pretreatment and brine disposal cost of RO sea water desalination system represent about 25% of total cost [3,4].

The adsorption desalination system (ADS) is being developed steadily over the past decades and is considered one of the possible alternatives to traditional desalination systems to overcome their problems [5,6]. This technology depends on employing adsorbent materials such as silica gel. The ADS mimics the evaporation in the ambient by low temperature solar collectors and condensing water vapor at high altitude producing pure water with no need for fossil fuel. Evaporation of the seawater occurs at low-temperatures between 5 °C and 20 °C [7].

Unlike the conventional methods, adsorption technology is driven by low-grade heat such as waste heat or solar energy [6,8]. Also, ADS has few moving parts. The ADS has the ability to treat or desalinate seawater and brackish water which contain organic compounds [9]. In addition to these advantages, the ADSs produce cooling water which could reduce the dependency on the conventional electric driven cooling systems contributing to global warming with high-energy consumption.

A hybrid of Multi Effect desalination (MED) with ADS has been studied by Thu et al. [5]. AD-MED water production rate was increased to about two folds with comparing to a traditional MED while the gain output ratio (GOR) and the performance ratio (PR) had been increased by 40% [5].

Thu et al. [10] reported a hybrid AD-MED system with different numbers of effects compared to conventional MED systems. The simulation showed that the increase of AD-MED system performance is more effective at lower top brine temperature.

Shahzad et al. [11] reported that hybrid of AD-MED system could increase the desalinated water to about three folds with same top brine temperature comparing to conventional MED systems.

Thu et al. [12] proposed a hybrid AD-MED system utilizing low heat source temperature. The evaporation ensued at low temperatures ranging from 35 °C to 7 °C. This proposed cycle provided a significant high performance ratio. The specific water production, PR and GOR were about 1.0 m^3/h ton of silica gel, 6.3 and 5.1,

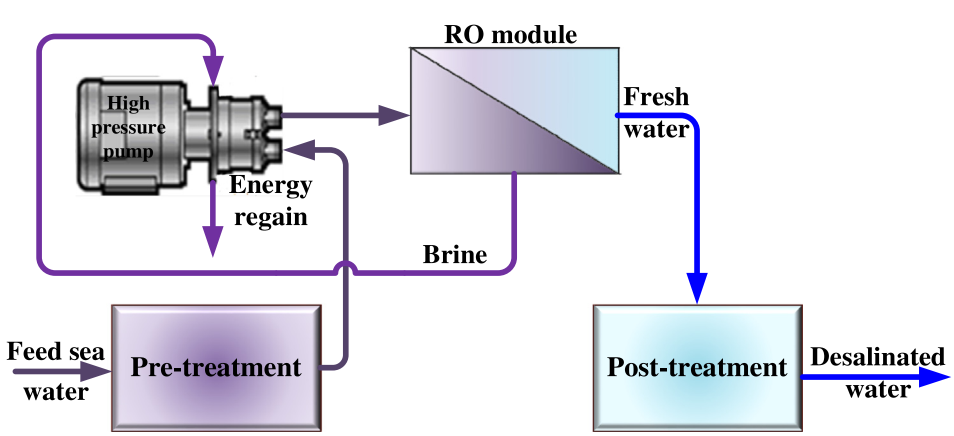

Fig. 2. RO system components.