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A hybrid reverse osmosis/adsorption desalination plant for irrigation and drinking water

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ABSTRACT

The hybridisation of brackish water reverse osmosis (BWRO) desalination technology and an adsorption cycle (AD) are considered in this work as a means of producing large quantities of a) water for irrigation and; b) high quality water for domestic use. The RO process and the AD cycle are represented as numerical models and have been optimised to produce fresh water and cooling. An existing RO plant can be retrofitted to become an RO-AD process to improve its specific energy consumption and simultaneously produce a cooling effect which can be exploited for local process cooling or air conditioning. A pressure exchanger (PX) and AD are combined to recover the reject from the RO, resulting in reduction in power consumption. The hybridised RO-AD desalination processes can be considered as the optimum solution for rural areas due to its capability for the production of water for irrigation and drinking as well as cooling for air-conditioning. Nevertheless, the temperature and feed salinity may negatively effect on RO production, with the AD cycle producing more than 6 m^3/tonne s.g of drinking water (< 15 ppm) at 85 °C, additionally the AD evaporator is not effected significantly by salinity. The proposed plant could produce 24,000 m^3/day for irrigation and 6.3 m^3/tonne s.g for drinking as well as 75 RTon/tonne s.g. Another interesting finding was that the minimum specific energy for the combined RO-PX-AD plant with a capacity of 24,000 m^3/day is 0.8 kWh/m^3 at RO recovery = 45%. The small-scale combined system was also examined to produce 2000 m^3/day and cost of different configurations was estimated as well. The results showed that the cost of the combined RO-AD system is the lowest, 0.44 £/m^3 compares with other RO configurations.

1. Introduction

Despite three quarters of the earth surface being covered by water, 97.5% of the water on the earth surface is seawater with TDS higher than 35,000 ppm. In the 2.5% of the total fresh water, only 30% is suitable for use because the majority of 69% fresh water is frozen in the icecaps and glaciers [1]. Around 71% of the total global fresh water withdrawal (3100 billion m^3) is used for agriculture purposes and by 2030, if there are no efficiency gains, it will increase to 4500 billion m^3 [2,3]. The gap between demand and supply can be filled by several types of desalination processes. Desalination is a significant method for producing potable water for human drinking, irrigation and industry [4,5]. There are numerous well established desalination technologies which have been developed commercially aimed to reduce power consumption, shown in Table 2. The best and most practical desalination plants offer a cost-effective solution for removing suspended salt or solid from sea or brackish water to produce potable water while being environmentally friendly. Among existing desalination plants, the Reverse Osmosis (RO) and Multi-Stage Flash (MSF) technologies represent 66% and 21% respectively of all these plants producing 77.4 million m^3 per day [1]. However, energy consumption for all types of desalination technologies remains high.

The number of Reverse Osmosis (RO) processes in major desalination plants have expanded considerably in recent times [6]. In an RO purification system, a semi-permeable membrane removes ions, proteins, and organic chemicals, often not easily accomplished with conventional methods [7]. An RO system's advantages include a small land footprint, a modular design and the availability of automatic process control and comparatively low-cost water production [8]. RO desalination plants have been frequently called into service for water and wastewater treatment, particularly in those areas where water is scarce [9]. Also, the RO process is recommended by Al-Karaghouli and Kazmerski [10] to address a brackish water, and is considered more cost effective economically when TDS is > 5000 ppm. Nevertheless, RO

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Nomenclature

J_W	Permeate flux, m/s
A_w	Permeability coefficient m/s-Pa
ΔP	Pressure difference, Pa
D_w	Water diffusivity, m^2/s
C_w	Water concentration, mol/m^3
V_w	Water molar volume, m^3
J_s	Solute transport, m/s
B_s	Solute transport parameter, m/s
Cm	Solute concentration in the membrane, mol/m^3
Cp	Solute concentration at permeate, mol/m^3
Bs	Solute transport parameter, m/s
Ds	Diffusivity of solute, m/s
Ks	Solubility of solute, m^2/s
Rs	Salt rejection, %
Pf	Feed water pressure, Pa
Qf	Feed flow rate, m^3/day
E	Specific energy consumption, kWh/m^3
$\Delta\pi$	Osmotic pressure difference, Pa
Qr	Rejected flow rate, m^3/day
Qp	Permeate flow rate, m^3/day
Pp	Permeate pressure, Pa
Cf	Concentration of feed water, mol/m^3
q	Uptake by adsorbent material, $kg\,kg^1$
Q	Total heat or energy, W
q^*	Equilibrium uptake, $kg\,kg^{-1}$
$\dot{m}$	Mass flow rate, $kg\,s^{-1}$
M_a	Mass, kg
t	Time, sec
hfg	Latent heat, $kJ\,kg^{-1}$
t-cycle	Number of cycles per day
k	Thermal conductivity, $W\,m^{-1}\,k^{-1}$
T	Temperature, K
E	Specific energy consumption, kWh/m^3
E_{pump}	Pump energy consumption, kWh
A	Area, m^2
Cr	Concentration in the concentrate, mol/m^3

Subscripts

f	Feed water
p	Permeate
r	Rejected
ads	Adsorption
des	Desorption
HX	Heat exchanger
out	Outlet
hw	Hot water
cw	Cooling water
cond	Condenser
evap	Evaporator
sg	Silica gel
b	Brine

Greek symbols

η	Efficiency, %
δm	Membrane thickness, m

Abbreviations

ERD	Energy recovery device
RO	Reverse osmosis
HPP	High pressure pump
BWRO	Brackish water
PX	Pressure exchanger
SCP	Specific cooling power

desalination technologies have shortcomings such as high energy requirement, high maintenance and high amount of rejected water [6,7,11].

The RO process performance is strongly influenced by feed water temperature due to the impact of a reduction in solution viscosity [12,13] and expansion of membrane pores which finally results in an increase of permeate production [14]. Jin et al. have studied the effects of feed water temperature on separation performance for brackish water RO membranes [15]. A range of feed water temperatures (15, 25, and 35 °C) were used to treat brackish water by RO membranes. Model

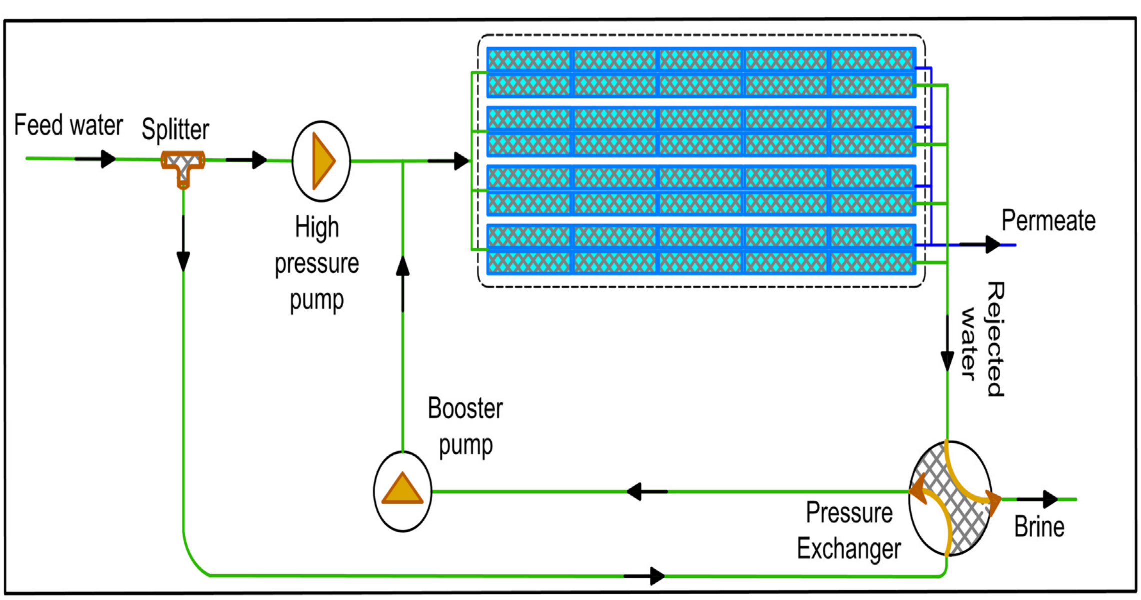

Fig. 1. Schematic diagram of the RO plant.