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ScienceDirect

Solar Energy 119 (2015) 319–331

SOLAR ENERGY

www.elsevier.com/locate/solener

An experimental review on coupling of solar pond with membrane distillation

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Received 8 December 2014; received in revised form 7 May 2015; accepted 6 June 2015

Communicated by: Associate Editor Yanjun Dai

Abstract

The interest of using solar powered membrane distillation systems for desalination is growing worldwide due to the membrane distillation (MD) attractive features. This study experimentally investigates the utilization of direct contact membrane distillation (DCMD) coupled to a salinity-gradient solar pond (SGSP) for sustainable freshwater production and reduction of brine footprint on the environment. A mathematical model for heat and mass flux in the DCMD module and thermal model for SGSP are developed and coupled to evaluate the feasibility of freshwater production. The experiment results on RMIT University SGSP coupled with DCMD are presented. The feed stream of 1.3% salinity is heated up by the SGSP and circulated through DCMD module then injected to an evaporation pond. Also, a thermal energy system is used to recover heat from the outlet brine stream of DCMD and use it as preheating for inlet feed water stream. Results are compared and showed that if the flow is laminar, the connecting DCMD module to the SGSP could induce a marked concentration and temperature polarisation phenomenon that reduces fluxes. Therefor turbulence has to be created in the feed stream to reduce polarisation. Also, to reduce the environmental footprint, the brine is recirculated after passing through the heat exchanger.

Keywords: Solar membrane distillation; Solar desalination; DCMD & SGSP desalination; Membrane mass flux

1. Introduction

Since 1950, the growth of global demand for freshwater has increased dramatically and approximately doubled every 15 years. This growth has reached a point where today existing freshwater resources are under great stress, and it has become both more difficult and more expensive to develop new freshwater resources. One particular issue is that a large proportion of the world's population (approximately 70%) settles in coastal zones (Ranjan et al., 2009). The current mean population density at coastlines is almost 100 habitants/km^2, and it is over 2.5 times the global average and embraces 45% of the global population (Mee, 2012). Also, about 450 million people in 29 countries face severe water shortage; about 20% more water than what is now available will be needed to feed the additional three billion people by 2025 (Hanjra and Qureshi, 2010). Furthermore, the world health organization (WHO) reported that 20% of the world population already has inadequate drinkable water. Even though the two third

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http://dx.doi.org/10.1016/j.solener.2015.06.010
0038-092X/

Nomenclature

A_{DCMD}	the required membrane area (m^2)
A_o	the external surface area of the heat exchanger pipes (m^2)
A_{sp}	the area of solar pond (m^2)
C_{ap}	specific heat coefficient J/kg K
c_p	specific heat of the circulating saline water (J/kg K)
C_m	membrane mass flux coefficient kg/m^2 Pa h
D	diffusion coefficient
d	membrane pore diameter (m)
d_e	collision diameter of the water vapour and air ($2.64 * 10^{-10}$ m and $3.66 * 10^{-10}$ m)
d_h	hydraulic diameter (m)
$\dot{E}_E$	electrical energy rate
e_{sp}	solar pond efficiency
E_t	thermal efficiency
$\dot{E}_T$	thermal energy rate
G	solar radiation at the surface of the pond (W/m^2)
GOR	gained output ratio
h_f	heat transfer coefficient at feed side (W/m^2 K)
h_p	heat transfer coefficient at permeate side (W/m^2 K)
h_m	heat transfer coefficient of the membrane (W/m^2 K)
H_v	vaporisation enthalpy of water at the mean temperature (kJ/kg)
J	total mass flux of the membrane (kg/m^2/h)
k_B	Boltzmann constant ($1.380622 * 10^{-23}$ J/K)
k_m	membrane heat transfer coefficient (W/m K)
k_n	Knudsen number
L	channel length (m)
LMTD	log mean temperature difference (K)
M	molecular weight (kg/mol)
$\dot{m}_f$	hot feed flow rate (kg/s)
N_u	Nusselt number
P	average pressure inside the membrane pores (Pa)
P_a	entrapped air pressure (Pa)
P_e	channel perimeter (m)
P_r	Prandtl number
P^v	vapour pressure at given salinity (Pa)
P_1	vapour pressure at feed membrane surface (Pa)
P_2	vapour pressure at permeate membrane surface (Pa)
Q	total energy consumption (W)
q_f	feed heat flux (W/m^2)
Q_t	the rate of total heat transfer (W/m^2)
R	gas constant (J/kg K)
R_e	Reynolds number
S	path length through membrane pore (m)
T	absolute temperature inside the membrane pores (K)
$\overline{T}$	average membrane temperature (K)
T_f	Bulk feed side temperature (K)
T_i	Temperature of the inlet of the wall heat exchanger (K)
T_L	LCZ temperature (K)
T_{mf}	temperature at the hot membrane surface (K)
T_{mp}	temperature at cold membrane surface (K)
T_p	bulk permeate side temperature (K)
T_{po}	temperature of the solar pond (K)
TPC	temperature polarisation coefficient
U	the overall heat transfer through the membrane (W/m^2 K)
x_c	weight fraction of salt in water
τ	membrane tortuosity
δ	membrane thickness (m)
ε	membrane porosity

of the planet is covered with water, 99.3% of this water either has high salinity or is not accessible (Ice caps) Qtaishat and Banat, 2013. Therefore, the combined effects of increasing freshwater demand, population growth and seawater intrusion into coastal aquifers are stimulating the need for desalination. The desalination is a process of removing salts and other minerals from a saline water solution producing fresh water, which is suitable for human consumption, agriculture and industrial use. The desalination system usually consists of three main parts; water source which may be brackish or sea water, desalination unit and energy source which is playing the key role in evaluating the desalination plant performance.

The aim of producing water at less energy consumption has led to promising solution, which is solar desalination as most of countries have unlimited seawater resources and also a good level of solar energy. However, the strong potential of solar energy to seawater desalination process is not yet developed at the commercial level (Li et al., 2013). Furthermore, Solar desalination is an environmental friendly and cost saving process competitive with other conventional desalination techniques (Farahbod et al., 2013). Also, the utilization of low-temperature membrane distillation (MD) coupled with a renewable energy source can be sustainable solution for the water and energy scarcity. For instant, membrane distillation is a process working on the principle of phase change or vapour–liquid interface that has the capability to grow into a viable tool for solar water desalination. Moreover, direct contact membrane distillation (DCMD) is a configuration of MD