Applied Energy 177 (2016) 393–408

Contents lists available at ScienceDirect

Applied Energy

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

Investigation of a solar energy driven and hollow fiber membrane-based humidification–dehumidification desalination system

Guo-Pei Li [a], Li-Zhi Zhang [a,b,*]

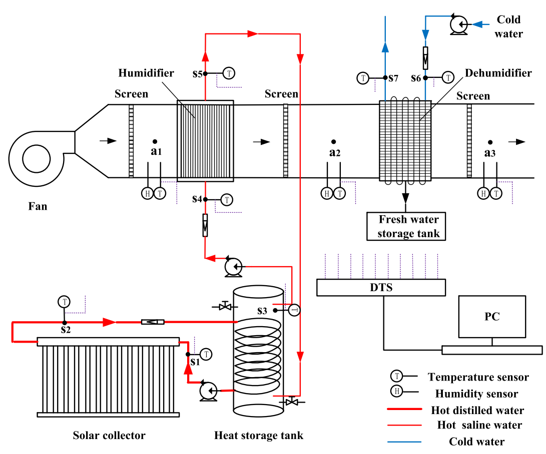
[a] Key Laboratory of Enhanced Heat Transfer and Energy Conservation of Education Ministry, School of Chemistry and Chemical Engineering, South China University of Technology, Guangzhou 510640, China
[b] State Key Laboratory of Subtropical Building Science, South China University of Technology, Guangzhou 510640, China

HIGHLIGHTS

- A solar energy driven and membrane-based desalination system is proposed.
- Testing and modeling for the whole system is performed.
- High-purity water is produced at a specific water production rate of 25.88 kg m^{-2} d^{-1}.
- The system COP is 0.75 and its electric COP is 36.13.

GRAPHICAL ABSTRACT

A solar energy driven and membrane-based humidification–dehumidification desalination system (MHDD).



ARTICLE INFO

Article history:
Received 29 December 2015
Received in revised form 17 May 2016
Accepted 20 May 2016

Keywords:
Hollow fiber membrane
Humidification
Dehumidification
Desalination
Solar energy

ABSTRACT

A solar energy driven and membrane-based air humidification–dehumidification desalination (MHDD) system is proposed. A test rig is designed and constructed to investigate the performance of the system. The test rig consists of a U-tube evacuated solar collector, a heat storage water tank, a membrane-based humidifier (hollow fiber membrane module) and a dehumidifier (a fin-and-tube heat exchanger). A theoretical model for the whole system simulation is developed and validated. Performance indices of the system, such as the specific water production rate on the basis of unit area of membrane (SWR), specific electric energy consumption on unit volume of water production (SEC), coefficient of performance (COP) and electric coefficient of performance (COP_E) are investigated. The effects of various parameters including the saline water flow rate, the air flow rate and the packing fraction of the membrane module, etc., on system performance are examined. It indicates that solar energy accounts for 92.0% of the energy consumption by the whole system. Sensible heat losses account for most of the energy losses from the system. High-purity water is produced by this system at a SWR of 25.88 kg m^{-2} d^{-1}, a SEC of 19.23 kW h/m^3,

* Corresponding author at: State Key Laboratory of Subtropical Building Science, South China University of Technology, Guangzhou 510640, China.
E-mail address: Lzzhang@scut.edu.cn (L.-Z. Zhang).

http://dx.doi.org/10.1016/j.apenergy.2016.05.113

Nomenclature

A	area (m^2)
A_a	outer surface area of absorber tubes (m^2)
A_e	effective heat absorption area of absorber tubes (m^2)
A_p	the projection area of absorber tubes (m^2)
A_v	packing density (m^2/m^3)
c_{pa}	specific heat of air (kJ kg^{-1} K^{-1})
c_{ps}	specific heat of solution (kJ kg^{-1} K^{-1})
C	correction factor
d/D	diameter (m)
D_h	hydraulic diameter (m)
D_{vm}	moisture diffusivity in membrane (m^2/s)
f	friction factor
F_R	the collector heat removal factor
H	enthalpy (kJ/kg), height (m)
H_w	latent heat of water evaporation (kJ/kg)
h	convective heat transfer coefficient (kW m^{-2} K^{-1})
I_t	the global solar radiation on horizontal plane (W/m^2)
J	Colburn j factor
k	convective mass transfer coefficient (m/s)
l/L	length (m)
Le	Lewis number
m	mass flow rate (kg/s)
m^*	dimensionless mass ratio
m^* Lat	dimensionless latent heat ratio
m^* Sen	dimensionless sensible heat capacity ratio
n_{col}	number of solar collector tubes
n_f	number of fibers
N_L	number of fibers along air flow direction
N_r	number of tube row
NTU	Number of Transfer Units
Nu	Nusselt number
P	pressure (Pa)
P_F	fin pitch (mm)
P_L	longitudinal pitch (mm)
P_T	transverse pitch (mm)
Pr	Prandtl number
q	heat transfer rate (kW)
Re	Reynolds number
RH	relative humidity (%)
R_w	thermal conduction resistance (K/W)
Sh	Sherwood number
T	temperature (K)
U	heat transfer coefficient (W m^{-2} K^{-1})
U_L	the collector overall loss coefficient (W m^{-2} K^{-1})
u	velocity (m/s)
V	specific volume (m^3/kg)
W	width (m), power (kW)
X	solution concentration (%)
x	spatial coordinate (m)
y	spatial coordinate (m)

Greek letters

α	absorptivity of the selective absorbing coating
δ	thickness (m)
ε	effectiveness
φ	packing fraction
η_H	humidification efficiency
η_o	fin efficiency
θ	incidence angle (degree)
κ	incidence angle modifier
λ	heat conductivity ($Wm^{-1}K^{-1}$)
λ_E	electric conductivity of solution
ν	kinematic viscosity (m^2/s)
ρ	density (kg/m^3)
τ	transmissivity of the outer glass
ω	humidity (kg/kg)
Π_c	wet perimeter of channel (m)

Superscripts

$*$	dimensionless

Subscripts

a	air
c	cold side, channel
coil	coil heat exchanger in the heat storage tank
Cal	calculated
D	dehumidifier
e	environment
E	electrical
f	distilled water in the collector tube
fan	fan
fin	aluminum fins in the dehumidifier
h	hot side
H	humidifier
i	inlet, inner
Lat	latent heat
m	membrane, mass
max	maximum value
min	minimum value
o	outlet, outer
p	the absorber tube
pump	pump
real	real
s	solution
Sen	sensible heat
solar	solar energy
t	heat storage tank
tot	total
Test	tested
w	water

a COP of 0.75 and a COP_E of 36.13. The feasible operating parameters investigated are: hot saline water flow rate, 236 L/h for per unit area of membrane; air flow rate, 25 m^3/h for per unit area of membrane; module packing faction, 30%.

1. Introduction

Water is the source of life. Nowadays, drinkable water has become a scarce commodity in many places of the world. An increasing amount of water is demanded by many developed Countries (USA, EU, Japan, etc.) as well as highly crowded emerging countries (China, India, Brazil, etc.) [1]. Following the energy crisis, water crisis has become a key bottleneck restricting the