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A modified model of solar collector/regenerator considering effect of the glazing temperature

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ABSTRACT

Solar liquid collector/regenerator (C/R), combining the functions of solar collector and regenerator of absorbent solution together, can be effectively utilized in solar energy-driven liquid desiccant cooling systems. Based on thermal balance of the glazing of solar C/R, a group of modified heat and mass transfer models, validated by experimental results to reflect solution regeneration process more truly, were put forward in this paper. Numerical simulation showed only preheating air stream, keeping an equal humidity ratio, did raise the performance of solar C/R, but preheating solution increased the regeneration efficiencies to reach twice that of preheating air stream. There occurred optimum mass flow rates for both air stream and solution film reaching 36–48 kg m^{-1} h^{-1} and 4~6 kg m^{-1} h^{-1} respectively for solar C/Rs of 3~6 m long. As for effect of the length of solar C/Rs, the regeneration efficiency η_r reached a maximum value at about 4 m and shorter or longer solar C/Rs failed to increase solution regeneration efficiencies.

Un modèle modifié pour capteur/régénérateur solaire prenant en compte l'effet de la température du vitrage

Mots clés : Régénération de solution ; Le Vitrage ; Taux d'humidité égale ; Taux de débit massique optimal

1. Introduction

Liquid desiccant cooling systems (Lychnos and Davies, 2012; Audah et al., 2011; Zeidan et al., 2011; Qi et al., 2012) can utilize low grade thermal energy such as solar energy to bring remarkable potential to replace conventional vapor compression systems. The solution regenerator and solar collector possess important roles in the solar liquid desiccant air conditioning systems. In the solution regenerator, water vapor in the weak solution evaporates away to increase its concentration as a result solution recovers the dehumidification ability. In solar collector, the solar radiation energy, after being transformed into thermal energy, can be absorbed by liquid film directly or indirectly. In solar liquid desiccant cooling systems, the regenerator and solar collector might be designed respectively (Gommed and Grossman, 2004, 2007). Moreover, solar collector and solution regenerator might be combined together to design solar collector/regenerators (C/

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Nomenclature

ASMR	air-to-salt mass flow rate ratio
C_p	specific heat capacity, kJ (kg·K)$^{-1}$
C^*	air-to-solution heat capacity rate ratio
G	air mass flow rate, kg s^{-1}
h	heat transfer coefficient between air stream and solution film, kW (m^2·K)$^{-1}$
h_c	convective heat loss coefficient of glazing, kW (m^2·K)$^{-1}$
h_m	mass transfer coefficient between air stream and solution film kg (m^2·s)$^{-1}$
h_r	radiation heat transfer coefficient of solution, kW (m^2·K)$^{-1}$
h_{rg}	radiation heat loss coefficient of glazing, kW (m^2·K)$^{-1}$
h_s	heat of vaporization for water from the absorbent solution, kJ kg^{-1}
$\bar{h}_s$	(=$h_s C_{pa}^{-1}$) normalized heat of absorption
I_c	solar radiation intensity, kW m^{-2}
I_a	effective solar radiation intensity, kW m^{-2}
l	total length of the absorber, m
L	solution mass flow rate, kg s^{-1}
NTU	number of heat transfer units
q_r	part absorption of the glazing to solar energy, kW m^{-2}
q'_r	radiation absorption of the glazing to liquid film, kW m^{-2}
q_s	heat loss from air stream to surrounding for unit area, kW m^{-2}
Q	sensible heat transferred, kW
R_{cv}	water vapor to dry air specific heat capacity ratio
T	temperature, °C
T_0	environment temperature, °C
W	water evaporation rate, kg s^{-1}, kg h^{-1}
X	mass fraction of water in solution, kg water/kg solution
Y	humidity ratio of the air, kg water vapor/kg dry air
Greek letter	
ρ	reflectance of the glazing cover
$(\tau\alpha)$	effective absorption-transmittance product
σ	Stefan–Boltzmann constant
ε	emissivity of the salt solution
ε_g	emissivity of the glazing
ξ	salt concentration of desiccant solution, kg salt/kg solution
Δ	increment of parameters from inlet to outlet
θ	dimensionless temperature
η	efficiency
ΔT_0	total temperature difference, °C
$\Delta\theta_0$	dimensionless total temperature difference
δ_a	flow direction indicator, "+1" for parallel flow and "−1" for counterflow
Subscripts	
a	air
s	solution
eL	equilibrium situation
in	inlet of the labeled flow
out	outlet of the labeled flow
v	water vapor
t	thermal
s	solution
Sky	effective black body of sky
x	local position of solar C/R (Collector/Regenerator)

Rs) having higher regeneration efficiencies of hygroscopic solution (Peng and Zhang, 2011; Kabeel, 2005). The different performances between both were compared by Haim et al. (1992) that constructed two kinds of open absorption systems: one kind using solar collector/regenerator to take place solution regeneration, the other using a packed tower injected by hot air to regenerate solution.

According to the different impetus of air flow, solar collector/regenerators were divided into natural and forced flow collector/regenerators (C/R).

As for the natural flow C/R, a completely open solar collector/regenerator was adopted firstly by Kakabaev et al. (1976) in a solar liquid desiccant cooling system and regeneration of lithium chloride solution took place on its open surface. Collier developed an analytical procedure to calculate evaporation rate of water vapor in the open natural C/R (Collier, 1979). Except for the open C/R, the natural flow C/Rs can also be covered by a glazing to prevent liquid film from being polluted and losing its thermal energy. A numerical method has been applied by Nelson and Wood (1990) to model the water evaporation rate in a glazed collector/regenerator. A modified open system suitable for humid climates was proposed by Gandhidasan and Al-Farayedhi (1994, 1995) in which the upper part of solar C/R was covered with a single glazing where the desiccant can be heated without water evaporation and evaporation started at beginning of the open surface. That solar C/R was called as partly open solar C/R.

Another more efficient method of solar regeneration of hygroscopic solution is the forced flow collector/regenerator, which employs an inclined flat blackened surface over which the absorbent solution trickles down and is concentrated. In the forced solar C/R, the rear is well insulated and heat loss can be neglected, but the top heat loss must be under consideration though it is covered by a single or double glazing. Due to the absorption of solar energy by the plate, water vapor evaporates from the liquid surface and enters the air stream as a result the weak solution is concentrated. The air stream can flow parallel or counter to the liquid film.

A numerical model on the forced flow collector/regenerator was developed by Alizadeh and Saman (2002a,b) to evaluate the thermal performance of the solar collector/regenerator and a parametric analysis has been performed to calculate the evaporation rate of water from the solution as a function of the system variables and the climatic conditions. Yang and Wang (1994a,b, 1995, 2001) performed simulation studies of single-glazed and double-glazed collector/regenerators to find that double glazed forced convection C/R gave a better system performance and the heat recovery unit