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Capacity matching in heat-pump membrane liquid desiccant air conditioning systems

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ABSTRACT

Two improvements for liquid desiccant air conditioning (LDAC) systems are recently gaining much attention. First, one heat pump is used to simultaneously cover the solution heating and cooling loads, instead of using separate cooling and heating equipment. Second, liquid-to-air membrane energy exchangers (LAMEEs) are being investigated for use as the dehumidifier and regenerator to eliminate the carryover of desiccant droplets by the air streams. These two improvements are combined in the current work in a heat-pump membrane LDAC (H-M-LDAC) system. The focus of this paper is on matching the capacities of the heat pump evaporator and condenser to meet the solution cooling and heating needs. A comprehensive review is presented and a novel capacity matching index (CMI) is proposed. A parametric study and sensitivity analysis are performed to quantify the influences of six key design and operating parameters on the CMI and coefficient of performance (COP) of the H-M-LDAC system.

Adaptation de la puissance dans des systèmes de conditionnement d'air à déshydratant liquide et à membrane de pompe à chaleur

Mots clés : Déshumidification par déshydratant liquide ; Échangeur d'énergie à membrane liquide-air ; Pompe à chaleur ; Adaptation de la puissance ; Etude paramétrique

1. Introduction

Liquid desiccant air conditioning (LDAC) technologies are promising for air dehumidification compared to the widely used vapor compression technologies (Bergero and Chiari, 2013; Kim et al., 2013; Zhang and Zhang, 2014; Abdel-Salam and Simonson, 2014). This is due to the capability of a LDAC system to achieve dehumidification without overcooling the air below its dew point temperature. The core components of a LDAC system are the air dehumidifier, solution regenerator, and solution heating/cooling equipment, as shown in Fig. 1.

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Nomenclature

Symbols

A	surface area of the semi-permeable membranes (m^2)
c_p	specific heat capacity ($kJ\ kg^{-1}\ K^{-1}$)
Cr^*	solution-to-air heat capacity ratio
h	enthalpy ($kJ\ kg^{-1}$)
$\dot{m}$	mass flow rate ($kg\ s^{-1}$)
NTU	number of heat transfer units
P	energy consumption rate (kW)
q	rate of heat transfer (kW)
T	temperature (°C)
U	overall heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
W	humidity ratio ($g\ kg^{-1}$)

Subscripts

amb	ambient
aux	auxiliary
comp	compressor
cond	condenser
cool	cooling
deh	dehumidifier
evap	evaporator
heat	heating
in	inlet
out	outlet
reg	regenerator
sol	desiccant solution

Acronyms

CMI	capacity matching index
COP	coefficient of performance
H-M-LDAC	heat-pump membrane liquid desiccant air conditioning
LDAC	liquid desiccant air conditioning
M-LDAC	membrane liquid desiccant air conditioning

The principles of operation of LDAC systems are as follows. Ambient air passes through the dehumidifier to be cooled and dehumidified using a cool and concentrated desiccant solution stream. The solution stream leaves the dehumidifier both warm and dilute, and it needs to be concentrated before it can be re-used in the dehumidifier. Thus, the dilute solution stream is heated to a specific temperature, and it then passes through the regenerator where it is dried (reconcentrated) by moisture transfer to the regeneration air. The warm and concentrated solution stream leaving the regenerator is then cooled in order to reduce its equilibrium humidity ratio below that of the ambient air, prior to re-entering the dehumidifier.

Many research projects have been performed on LDAC technologies during the last few decades, and the focuses of these projects can be briefly divided as follows (Lowenstein, 2008). (1) Several studies focus on heat and mass transfer in the dehumidifiers and regenerators (e.g. packed beds (Bassuoni, 2011), solar regenerators (Peng and Zhang, 2011), membrane exchangers (Ge et al., 2014; Abdel-Salam et al., 2014a), and falling-film exchangers (Mesquita, 2007)). (2) Other studies focus on the properties of pure and mixed liquid desiccant solutions (e.g. LiCl and $CaCl_2$ (Conde, 2004; Ahmed et al., 1997), and the crystallization limits of desiccant solutions (Afshin et al., 2010)). (3) The third focus area is on the LDAC system as a whole considering different equipment and systems configurations to heat and cool the liquid desiccant (e.g. solar thermal and/or electric heat pump (Crofoot and Harrison, 2012; Abdel-Salam et al., 2014b), solar thermal and direct/indirect evaporative cooling (Kim et al., 2013), combined heat and power (Nayak et al., 2009), concentrated solution storage tanks (Kessling et al., 1998)). In order to foster the wide spread of LDAC systems in residential and commercial applications, some concerns still need to be addressed. There are two specific topics which have received much attention in recent years, and will be addressed in the current study:

- Desiccant droplets carryover in air streams;
- Capacity matching in heat-pump LDAC systems.

The problem of desiccant droplets carryover in air streams may occur in direct-contact liquid desiccant devices (e.g. packed beds, spray towers), especially at high air and solution

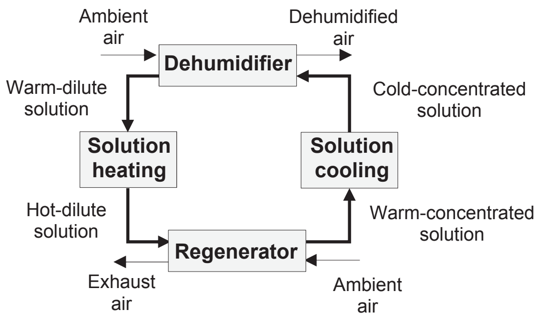

Fig. 1 – A conceptual schematic diagram of a liquid desiccant air conditioning (LDAC) cycle.

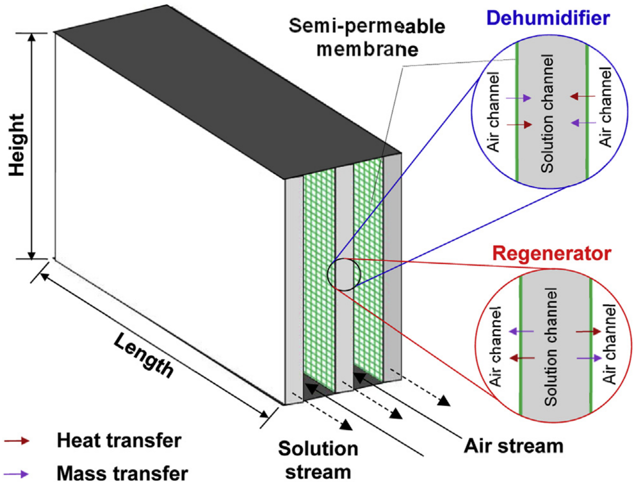

Fig. 2 – Schematic diagram of a liquid-to-air membrane energy exchanger (LAMEE).