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Thermodynamics and economics of liquid desiccants for heating, ventilation and air-conditioning – An overview

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HIGHLIGHTS

- Thermodynamic properties of different desiccant solutions are reviewed.
- The economic factors on the system performance are described.
- Effects of different application and climatic conditions are summarized.
- The method to evaluation of alternative desiccant fluids is presented.

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ABSTRACT

In an effort to minimise electricity consumption and greenhouse gases emissions, the heating, ventilation and air-conditioning sector has focused its attention on developing alternative solutions to electrically-driven vapour-compression cooling. Liquid desiccant air-conditioning systems represent an energy-efficient and more environmentally friendly alternative technology for dehumidification and cooling, particularly in those cases with high latent loads to maintain indoor air quality and comfort conditions. This technology is considered particularly efficient in hot and humid climates. As a matter of fact, the choice of the desiccant solution influences the overall performance of the system. The current paper reviews the working principle of liquid desiccant systems, focusing on the thermodynamic properties of the desiccant solutions and describes an evaluation of the reference thermodynamic properties of different desiccant solutions to identify which thermodynamic, physical, transport property influences the liquid desiccant process and to what extent. The comparison of these thermodynamic properties for the commonly used desiccants is conducted to estimate which fluid could perform most favourably in the system. The economic factors and the effect of different applications and climatic conditions on the system performance are also described. The paper is intended to be the first step in the evaluation of alternative desiccant fluids able to overcome the problems related to the use of the common desiccant solutions, such as crystallization and corrosion to metals. Ionic liquids seem a promising alternative working fluid in liquid desiccant air-conditioning systems and their characteristics and cost are discussed.

1. Introduction

Due to rapid population growth and the higher standards of human living, the electric consumption for the heating, ventilation and air-conditioning (HVAC) sector and the resulting HVAC equipment demand has reached record levels, as displayed in Fig. 1 [1]. This increase of the energy consumed for the HVAC results in higher fossil fuel consumption, increase in peak electric demand, straining the electricity grid at peak times [2]. As shown in the figure, the trend of the equipment demand for the HVAC sector is significantly increased in last years, reaching a 6.2% growth in the period 2009–2014, while the energy consumption for air-conditioning in the non-residential building sector accounts between 20% and 60% [3].

In the design of HVAC systems, it should be carefully evaluated the quantity of moisture present in the ventilation air, which could be responsible for structural problems to the building and comfort and health problems for the occupants. The sources of the moisture in a building are permeation through floors, walls and ceiling, evaporation from occupants' clothing, breath and perspiration, air infiltration through leaks, holes and door openings, and outside air ventilation [4]. Ventilation air is the most responsible for the moisture load in different applicative sectors [4]. This moisture in the air contributes to the latent

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Nomenclature

a_P	wetted surface area of packing [m^2/m^3]
a_w	water activity [–]
c_p	specific heat capacity [kJ/(kg °C)]
D	diffusion coefficient [m^2/s]
d_{eq}	equivalent diameter of packing [m]
d_p	normal diameter of packing [m]
F	superficial flow rate [kg/(m^2 s)]
Δh_{abs}	heat of absorption [kJ/kg]
h_h	heat transfer coefficient [W/(m^2 °C)]
h_m	mass transfer coefficient [kg/(m^2 s)]
k	thermal conductivity [W/(m °C)]
Le	Lewis number [–]
m	mass flow rate [kg/s]
Nu	Nusselt number [–]
NTU	number of mass transfer units [–]
P	pressure [kPa]
Pr	Prandtl number [–]
R	universal gas constant [kJ/(mol °C)]
RH	relative humidity [–]
Re	Reynolds number [–]
T	temperature [°C]
Sc	Schmidt number [–]
Sh	Sherwood number [–]
x	mass fraction of desiccant solution [$kg_{solute}/kg_{solution}$]
y	molar fraction of desiccant solution [$kmol_{solute}/kmol_{solution}$]

Greeks symbols

γ	activity coefficient [–]
μ	chemical potential [J/kg]
ρ	density [kg/m^3]
ν	dynamic viscosity [mPa s]
λ	latent heat of vaporization [kJ/kg]
ω	moisture content [$kg_{H2O}/kg_{dry\ air}$]
ω_{equ}	equilibrium moisture content [$kg_{H20}/kg_{dry\ air}$]
Φ	osmotic pressure [Pa]
σ	surface tension [N/m]

Subscripts

a	air
conc	concentrated solution
dil	diluted solution
g	gas phase
in	inlet
l	liquid phase
out	outlet
sol	desiccant solution
w, s	saturated water vapour
w	water

Abbreviations

$CaCl_2$	calcium chloride
$Ca(NO_3)_2$	calcium nitrate
CHP	combined heat and power
e-NRTL	electrolyte non-random two liquid model
ERH	equilibrium relative humidity
HCO_2K	potassium formate
$MgCl_2$	magnesium chloride
IL	ionic liquid
LiBr	lithium bromide
LiCl	lithium chloride
LDAC	liquid desiccant air-conditioning
NH_4NO_3	ammonium nitrate
TEG	tri-ethylene glycol
[BMIM][BF_4]	1-butyl-3-methylimidazolium tetrafluoroborate
[DMIM][OAc]	1,3-dimethylimidazolium acetate
[DMIM][BF_4]	1,3-dimethylimidazolium tetrafluoroborate
[EMIM][OAc]	1-ethyl-3-methylimidazolium acetate

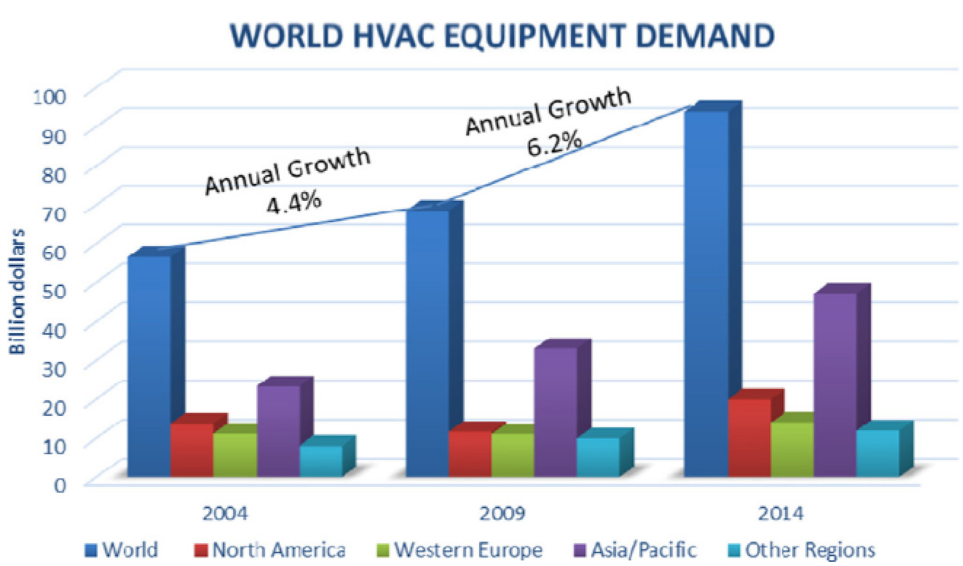

Fig. 1. Overall HVAC equipment demand and trend [1].

load in the HVAC system. As reported by [2,5], latent loads are always higher than sensible loads, except for desert climates. The high latent load could result in an inefficient dehumidification process with conventional vapour-compression systems [6]. Due to the development of ASHRAE standards 62 [7] and 90 [8], the conventional vapour-compression systems have progressively become less efficient in dealing with latent loads present in buildings, causing an oversize of the system when it must deal with high moisture content [2]. An oversized system