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ORIGINAL ARTICLE

Modeling for the influence of variable inlet airflow states on liquid desiccant wheel performance at low flow conditions

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Abstract Desiccants can be a part of a sustainable approach to maintaining healthy and comfortable indoor environments. The use of desiccants is a unique technique in that it can dry the air without precooling below its dew point. The removed latent load may be double the removed sensible load. This paper presents an analysis of a low-flow liquid desiccant air conditioning system. This analysis was designed to identify and study the various parameters that affect the performance of the desiccant air conditioning system. LiCl was used as a desiccant in this study. A liquid desiccant air handling-machine was thermally modeled. The system performance was evaluated for a regenerative hot water temperature of 88 °C, and the recorded parameters included the required heating water flow rate, cooling water flow rate, and thermal C.O.P. The results show that the system C.O.P is more affected by changing dry bulb temperature than by changing air flow rate. It is also shown that in our case study, 36 °C dry bulb temperature is a reversed point as before that temperature the heating rate is more than the total cooling rate but after it the opposite is true.

1. Introduction

Ventilation of buildings has a substantial influence on building energy consumption, the health of occupants, and the productivity and satisfaction of occupants. The minimum acceptable ventilation rate is defined by the standards set forth by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). In building used for industrial production, such as medical supplies, the humidity ratio must be decreased to lower levels. One of the methods used to dehumidify the indoor air is desiccant method [1–14] in which the moisture will transfer from one air stream to another by using two processes. During the first process, called sorption, moisture is absorbed by the desiccant. This requires that the desiccant material is dry and cold so the surface vapor pressure is lower than that of the moist air so the moisture in the air will be absorbed by the desiccant. In the second process, called desorption, captured moisture is released, and the desiccant is regenerated. This is achieved by increasing the temperature of the desiccant. Many contributions have been made in the research for environmental-friendly and CFC-free alternative dehumidification techniques and systems. Oberg and Goswami [15] reviewed common system configura-

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Nomenclature

C	solution concentration (kg_w/kg_{sol})
c_p	specific heat at constant pressure (J/kg K)
D	diffusion coefficient (m^2/s)
g	gravitational acceleration (m/s^2)
H	model height (m)
k	thermal conductivity (W/m^2 °C)
L	model length (m)
p	pressure (N/m^2)
T	temperature (°C)
u	velocity in the axial direction (m/s)
w	velocity in the z-direction (m/s)
x	x-coordinate
y	y-coordinate
z	z-coordinate

Greek symbols

ρ	density (kg/m^3)
μ	dynamic viscosity (N s/m^2)
δ	desiccant film thickness (m)
υ	velocity in the transverse direction (m/s)
ω	humidity ratio of the air (kg_w/kg_a)

Subscripts

a	air
d	desiccant components of the solution
i	inlet conditions
w	water

Abbreviations

COP	coefficient of performance
LHR	latent heat ratio

tions in the field of desiccant dehumidification using calcium chloride, lithium chloride, lithium bromide, and tri-ethylene glycol as solutes. It was concluded that COP could be defined in a variety of ways and that basing a comparison on a single figure of merit could lead to errors in evaluating different schemes of air conditioning. Daou et al. [16] reviewed the benefit of desiccant air conditioning for humid climates. It was concluded that energy savings, humidity control, and indoor air quality brought about by contaminant removal were all improved. Ameel et al. [17] compared the performance of various absorbent candidates, including LiCl, CaCl, and LiBr. They concluded that LiBr outperformed the other absorbents. Al-Farayedhi et al. [18] listed several important considerations in choosing or designing the optimal liquid desiccant solution for a dehumidification application. Wimby and Berntsson [19] investigated aqueous solutions of various desiccants, including LiCl and $CaCl_2$, producing experimental data of density as a function of temperature and mass fraction. These data were of critical importance when experimenting with liquid desiccant materials, providing concentration as a function of density, which was relatively easy to measure in the laboratory. A mixture of LiCl and $CaCl_2$ was the subject of study by Ertas et al. [20]. LiCl had excellent regeneration performance and stability but a high cost, while $CaCl_2$ had lower performance but also a lower cost. A mixture of the two at various ratios was analyzed to produce functions of vapor pressure for various temperatures. In an important study of aqueous LiCl and $CaCl_2$, Conde [21] gathered data from 1850 and onward, and fit empirical curves to selected data. Functions of density, heat capacity, enthalpy of dilution, vapor pressure, solubility, and others were presented. These correlations were used extensively in the present study. A 2-dimensional numerical analysis of an internally cooled or heated flat plate liquid desiccant system was conducted by Mesquita and Harrison [22]. A further experimental analysis of a single channel low flow flat-plate liquid desiccant system was conducted by Mesquita [23]. The system was operated under both isothermal and non-isothermal conditions. It was concluded that water temperature and mass flow rate of the desiccant have a strong effect on the performance of the flat plate dehumidifier and regenerator. Ronghui et al. [24] performed the simulation of solar-assisted LDAC (SLDAC) in commercial buildings in five cities of four main climate regions, including Singapore in Tropical, Houston and Beijing in Temperate, Boulder in Arid and Los Angeles in Mediterranean. Results showed that the system's performance was seriously affected by the ratios of building's sensible and latent cooling load. For buildings located in humid areas, the electricity energy reduction of SLDAC was high. For buildings in a dry climate, the total cooling load was low, but up to 45% electricity of AC system could be saved in Boulder. However, for the buildings in Temperate, the application of SLDAC was not that suitable. The match properties of the heat and mass transfer processes in the Heat pump-driven liquid desiccant (HPLD) systems varying with the inlet air states were investigated by Zhang et al. [25]. Also, the unmatched coefficient based on entry dissipation was adopted to evaluate the performance of HPLD systems. It was demonstrated that the unmatched coefficient of the process along the iso-concentration line was much lower than that along the isenthalpic line. Liu et al. [26] used Celdek packing's structured in the dehumidifier and a LiBr aqueous solution as the liquid desiccant in their experimental studies of the performance of the cross flow dehumidifier. The moisture removal rate and dehumidifier effectiveness were adopted as the dehumidifier performance indices. The objective of the present investigation is to evaluate the performance of a liquid desiccant air handling unit using a numerical model. The scope of this study is aimed at studying the effect of changing air flow rate and dry bulb temperature of the inlet processing on the system performance.

2. Problem mathematical modeling

To assess the performance of a liquid desiccant air handling unit, system equations for the conservation of mass and energy must be solved. Air is considered as an incompressible multi-component fluid, composed of dry air and water vapor in thermal equilibrium. This type of analysis involves modeling the transfer of heat and mass between the three working fluids, which are moist air, desiccant solution, and cooling or heating