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A regulation strategy of working concentration in the dehumidifier of liquid desiccant air conditioner

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HIGHLIGHTS

- Proposed a new strategy to regulate the working concentration of the LDAC.
- Developed a mathematical model to describe the dynamics with unstable concentrations.
- Simulations and experiments are conducted to validate efficiency of this strategy.

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ABSTRACT

This study presents a new desiccant concentration regulation strategy for the dehumidifier of a liquid desiccant air conditioner (LDAC). Starting from the mass balance principle, the proposed strategy supplies the strong solution in an intermittent manner to maintain the required working concentration, and the dehumidification rate is monitored as the feedback to improve the regulation performance. Compared with the conventional method, this new solution transfer strategy avoids the continuously solution exchanging, while allows multiple dehumidifiers to work simultaneously with only one regenerator. A mathematical model emphasizing on the concentration profiles is developed to determine the parameters of the proposed strategy. Simulations and experiments are conducted to evaluate the effectiveness of this strategy in different working conditions. The results prove that the proposed strategy can keep the working concentration at the pre-specified range with less energy consumption during the solution transfer. With this strategy, conventional LDAC can be extended to a mode with multiple dehumidifiers and one regenerator for large-scale applications in buildings.

1. Introduction

Liquid desiccant air conditioner (LDAC) has been intensively investigated as an alternative to conventional cooling-based dehumidification schemes in handling the latent load of process air. LDAC has the potential to apply low grade heat and renewable energy [1–3], prevent the breeding of bacteria [4], avoid unnecessary water condensation and realize the independent control of outlet air humidity [5–7]. Recently, numerous efforts have been devoted to implement LDAC in the industrial or commercial buildings to handle the latent loads [8–10], and distributed operating LDAC [11,12] is one of these new attempts. In industrial and commercial buildings, dehumidifiers are usually located on different floors in a distributed manner, while the heat source such as the waste heat from chiller plant or solar energy are in the basement or on the rooftop in a centralized form. A distributed operating LDAC allows one regenerator to handle multiple dehumidifiers, which is an energy-efficient arrangement for building applications.

Though LDAC has been widely discussed in structure improvement [13–15], system analysis [16,17] and operation optimization [18–20], very little attention has been paid to the importance of liquid-desiccant concentration. Chen et al. [21] and She et al. [22] addressed the impacts of solution concentration on the dehumidification efficiency and energy conservation, but did not mention their strategy in maintaining the working concentration at a system level. Currently, most of the LDAC relies on swapping the desiccant solution continuously between dehumidifier and regenerator to maintain the working concentration of the dehumidifier [23,24]. Regeneration temperature is adjusted to match

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Nomenclature

c	concentration of desiccant solution
c_p	specific heat (kJ/kg °C)
$\tilde{c}_p$	dynamic specific heat as a function of temperature and concentration (kJ/kg °C)
d	humidity ratio of the air (g/kg dry air)
D	tube diameter (m)
h'	heat transfer coefficient (W/(m^2 °C))
h_1	height of liquid in the strong solution buffer (m)
h_2	vertical height of the connecting tube between the two tanks (m)
ΔH	vaporization/condensation heat (kJ/kg)
K'_G	mass transfer coefficient (kg/(m^3 s Pa))
L	tube length (m)
M	mass (kg)
$\dot{m}$	mass flow rate (kg/s)
N_{H_2O}	mass transfer rate of H_2O (kg/m^3 s)
p_a	water vapor pressure of air (kPa)
p_s^*	water surface vapor pressure of desiccant solution (kPa)
$\dot{H}_{as}$	heat transfer rate (kw)
S	cross area of dehumidification column (m^2)
T	temperature (°C)
V	volume (m^3)
$\dot{V}$	volume flow rate (m^3/s)
v	velocity of strong solution (m/s)

Greek letters

α	effective mass transfer area (m^2/m^3)
β	energy distribution ratio
ε	void fraction of packing
ζ	coefficient of local resistance
λ	friction coefficient
$\lambda_1 - \lambda_9$	parameters of heat and mass transfer model
μ	dynamic viscosity of the fluid (Pa s)
ρ	density of desiccant solution (kg/m^3)
$\tilde{\rho}$	dynamic density as a function of temperature and concentration (kg/m^3)

Subscripts

a	process air
dilu	diluted desiccant solution
in	the inlet of components or pipes
lower	lower range
mix	fully mixed desiccant solution
mid	median value
s	desiccant solution
str	strong desiccant solution
trf	solution transfer
out	the outlet of components or pipes
upper	upper range

the rate of regeneration with dehumidification to keep the working concentration stable [25]. Therefore, the conventional concentration regulation method involves with two complicated processes: dehumidification and regeneration. Moreover, the energy consumed by solution transfer accumulates over the system operating time, especially in buildings, where the functional components have a certain distance between each other. Apart from the drawbacks explained above, the conventional method suggests the dehumidifier and the corresponding regenerator working at a small concentration gradient during the whole operating procedure, which makes it inapplicable in a distributed operating manner. In distributed LDAC, multiple dehumidifiers need particular working concentration to handle the corresponding loads [11,12], whereas one regenerator cannot provide different concentrations at the same time.

To regulate the working concentration, a clear knowledge of the concentration profile in the dehumidifier is indispensable. In the dehumidifier, the desiccant solution absorbs the moisture in the air and becomes diluted, eventually loses the affinity for moisture [26]. Inversely, the regenerator removes the moisture absorbed in the dehumidifier to regain the concentration [27]. Many researches have been carried out to analyze the system mathematically, but few have discussed its performances under unsteady working concentrations. Ren [28] proposed a model with approximations on the coefficients to derive an analytical solution. Wang et al. [29] developed a steady state heat and mass transfer model with only 7 parameters in all and was appropriated for monitoring and control. Recently, considerable efforts have been made to investigate the dynamics of LDAC [30–34]. Diaz [35] discussed the transient properties of the heat and mass transfer processes through a two-dimensional model of the dehumidifier. Coca-Ortegón et al. [36] built up a dynamic model of an LDAC in TRNSYS and proposed some control strategies based on their solar-assisted system. Li et al. [37] developed a dynamic model from the control view based on the heat and mass transfer principles, and mentioned that the desiccant solution would be swapped when its concentration was too low. But the specifications related to this swap process were not provided in details. Wang et al. [38] developed a dynamic model for a counter flow liquid desiccant dehumidifier. Experimental validations and sensitivity analysis were carried out to prove the efficiency of this model. They mentioned that a fixed initial concentration was provided, but no further clarifications on how they kept this value in a long-term operation. Moreover, none of these dynamic studies concerned about the system response to unstable concentration fluctuations, which potentially impedes the usage of concentration as a control variable.

In the design and optimization of LDAC, a steady dehumidification performance is always an important question deserves considerations. For a practical systems applied in buildings, the humidity ratio of supply air is expected to be regulated to sustain the indoor air quality, and raises the necessity of control issues of LDAC [39,40]. Zhao et al. [41] realized the independent control of the temperature and humidity, and their method was proved to have an improved energy efficiency. Ge et al. [42] presented two control strategies, and indicated the solution inlet temperature had a significant influence on the dehumidification rate. In dehumidifiers, stable working concentration is a pre-request criterion to guarantee a stable dehumidification rate, especially when the dehumidifier is in a distributed operation mode. Thus, to apply LDAC in a more intelligent way, a concentration regulation strategy is pressingly needed.

By considering the necessaries of distributed operation and drawbacks of the conventional LDAC, this study proposes a new strategy to maintain the working concentration in a flexible way, and the concentration is successfully employed as a controllable variable by a wise utilization of tanks and valves. A new mathematical model has been developed to describe the dynamic concentration profiles during the operation, including the moisture absorption, strong solution charging, solution mixing, circulating and excavating. This new solution transfer strategy avoids the continuously solution exchanging, and realizes a continuously operation of the whole system. Model-based simulations are