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Performance evaluation of gauze packing for liquid desiccant dehumidification system

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ABSTRACT

Desiccant systems have found applications in a very large variety of industrial and daily usage products including the new HVAC installations. The dehumidifier is one of the essential parts of those systems, which severely affects the whole system performance. This paper theoretically and experimentally studies the performance of the cross flow dehumidifier, which has been less studied than the counter flow dehumidifier, although it is more applicable in practice. Channel gauze structured packing was used in the dehumidifier and a LiCl aqueous solution was used as the liquid desiccant. The humidity reduction and dehumidifier effectiveness were adopted as the dehumidifier performance indices. The effects of the dehumidifier inlet parameters, including inlet air and desiccant flow rates, inlet air and desiccant temperature, inlet desiccant concentration and inlet air humidity ratio, on the two indices were investigated. The characteristics of the dehumidifier performance agreed well with the other studies reported in the open literature.

1. Introduction

Dehumidification is the process of removal of water vapor from moist air. It can be achieved by either cooling or increasing the pressure of air or by absorption/adsorption of moisture by a solid or liquid material (called a desiccant). The two methods, cooling and increasing the pressure of air, require high energy consumption.

Recently, a number of hybrid air conditioning systems have been proposed, in which liquid and solid desiccants are used to meet the latent heat load. A liquid desiccant system is preferable because of its operational flexibility, ability to absorb inorganic and organic contaminants from air [1–4] and its ability also to operate under a relatively low regeneration temperature. Besides, using of brine as absorbents is frequently environmentally friend as it does not cause ozone depletion [5].

The liquid desiccant air-conditioning system has been proposed as an alternative to the conventional vapor compression cooling systems to control air humidity, especially in hot and humid areas, due to its advantage in removing the latent load as well as the potential to remove a number of pollutants from the air stream [6–8]. The removal of moisture from the air depends on the difference in water vapor pressure held by the desiccant and that of water vapor present in the air [9].

The main components of a liquid desiccant system are two gas–liquid contactors, a dehumidifier, and a regenerator. The air is dehumidified by being in contact with concentrated solution in a dehumidifier. The solution is diluted during the dehumidification process, and needs to be regenerated before being reused. There are two types of gas–liquid contactors, namely, structured packing and random packing [10–12].

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Nomenclature

a	specific area of packing per volume (m^2/m^3)
$C_{p,\ a}$	specific heat of liquid desiccant (kJ/kg K)
D_{eq}	equivalent diameter (m)
H	height of the cross flow dehumidifier (m)
k	thermal conductivity (kW/mK)
L	length of cross flow dehumidifier (m)
Le	Lewis number, ($\alpha/\alpha_m C_{p,a}$)
$\dot{m}_a$	air flow rate (kg/s)
$\dot{m}_s$	liquid desiccant flow rate (kg/s)
Nu	Nusselt number, $\alpha D_{eq}/K$
P	total pressure (kPa)
Pr	Prandtl number, $\mu C_{p,a}/K$
P_v	vapor pressure (kPa)
Re	Reynolds number, $\rho u D_{eq}/\mu$
R_v	characteristic gas constant for water vapor (kJ/kg K)
T	temperature (°C)
u	air velocity (m/s)
W	width of cross flow dehumidifier (m)
X	concentration (mass ratio of desiccant to solution) of the liquid desiccant (%)

Greek symbols

α	heat transfer coefficient (kW/m^2 °C)
α_m	mass transfer coefficient (kg/m^2 s)
ε_m	dehumidifier effectiveness (%)
ζ	pressure drop coefficient per meter in flow direction (1/m)
ρ	density (Kg/m^3)
ω_a	humidity ratio of air ($g_{w.v}/kg_{d.a}$)
ω_e	humidity ratio of air in equilibrium with liquid desiccant ($g_{w.v}/kg_{d.a}$)

Subscripts

a	air
d.b	dry bulb
e	equilibrium
g	gas
i	inlet
m	mixture
o	outlet
s	liquid desiccant solution
v	vapor
w	water
w.b	wet bulb

The use of liquid desiccants offers an important advantage; in addition to reducing humidity, the quality of the air can be controlled through the co-absorption of pollutants into the solution. However, direct-contact liquid desiccant air-conditioning systems have the risk of carry-over of aerosol droplets to the supply airstream, which may cause health problems for occupants and corrosion of the ducting system. The desiccant carry-over problem can be eliminated by using a liquid-to-air membrane energy exchanger (LAMEE). The LAMEE is a novel energy exchanger, in which air and desiccant solution streams are separated using semi-permeable membranes [13–18]. These membranes allow simultaneous heat and moisture transfer between the air and desiccant solution streams, but do not allow the transfer of any liquid droplets, and thus eliminate the desiccant carry-over problem. A new liquid-to-air (LAMEE) was developed and progress has been made on the research and applications of LAMEEs in building HVAC systems [13–16].

The dehumidifier and regenerator can be divided into adiabatic and internally cooled types. In the adiabatic module, only air and desiccant exchange heat and mass (moisture content). The adiabatic dehumidifiers can afford large air-desiccant contacting area with relatively simple geometry configuration. Internally cooled or heated liquid desiccant–air contact units can be used for effective air dehumidification or desiccant regeneration, respectively [19–23]. Since the desiccant is cooled/heated synchronously, as it contacts humid/dry air, and thus maintains its low/high surface vapor pressure. Abdel Salam [19] presented an experimental data for a new 3-fluid liquid to air membrane energy exchanger which uses cooling/heating water to cool/heat the desiccant solution.

Packing materials is the place where mass transfer occurs between falling film of the LD and inlet air. Hence, The packing material is one of the most important factors affecting the performance of the dehumidification process . The structured packing, namely gauze-type has been selected for a lot of advantages such as low pressure drop, sensitivity to fouling, liquid holdup, ease of handling high or low desiccant flow rate, resistance to corrosion, and reasonable cost. Many studies provided rigorous models for predicting the pressure drop in both structured and random packing materials, and most of them revealed that the structured packing has the lower pressure drop and higher capacity compared with random packing. This study, therefore, investigates the performance of a cross-flow liquid desiccant dehumidification system. Structured gauze packing slides have been selected; the installation and pressure drop are more convenient, compared with other packing.

2. Experimental facility

2.1. Description of the liquid desiccant dehumidifier

The schematic and photograph of the structure packing and the components of the experimental cross-flow packed bed dehumidifier are shown in Fig. 1a and b respectively. The main apparatus consists of gauze packing slides (1), dilute solution