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Performance characterisation of liquid desiccant columns for a hybrid air-conditioner

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Abstract

Use of liquid desiccant-vapor compression hybrid system is encouraged for low humidity applications. The liquid desiccant is primarily used to further dehumidify the supply air. In the present study, by using psychrometric equations and liquid desiccant property data, heat and mass transfer analysis for the dehumidifier and regenerator columns in counter flow configuration has been carried out. The simulation of the columns corresponds to low solution to air (S/A) flow ratio where precooled air gets dehumidified in the absorber while preheated air is used for regeneration of the solution. A detailed study of the performance characteristics for the absorber and regenerator columns confirms the requirement of the desiccant loop for additional dehumidification of the conditioned air. This need develops the main motive towards the concept of hybrid air conditioning.

Keywords: Liquid desiccant; Vapor compression; Hybrid system; Dehumidification; Regeneration

1. Introduction

Reducing sensible heat and humidity of a stream of air is a major air conditioning process especially in tropical areas. The required humidity level is achieved by reheating the cooled air. In many occasions the conditioning of air streams can also be achieved by modifying their latent heat using desiccants. Desiccants may be either solid or liquid. The solid desiccants used in air conditioning include silica gel, molecular sieves, etc., whereas liquid desiccants are lithium chloride, lithium bromide, calcium chloride, etc. More details about desiccant types, properties and the regeneration processes are given by [1]. Liquid desiccants have less drying capacity than their solid counter parts, but they are employed because of the advantages like ease in operation, less pressure drop for air in the packed columns, ability to remove dirt and floating contaminants from air and the possibility of heat exchange between desiccant streams [2]. Further, they offer several design and performance advantages especially when solar energy is used for regeneration. Studies were carried out and reliable data for air dehumidification and desiccant regeneration using liquid desiccants were obtained [3–6]. Aging of the liquid desiccant reduces the cooling performance of the system [7]. Lof [3] suggested and tested experimentally one of the earliest liquid desiccant systems where triethylene glycol was used as desiccant and solar energy was used for regeneration.

Packed beds are one of the devices used for air dehumidification and have been evaluated for different operating and design conditions [2,8–10]. Heat and mass transfer between air and laminar desiccant films in parallel flow [2] and cross flow [11,12] columns were studied and suggested that lower air flow rates give better control over humidity and cooling. Similar studies for inclined parallel and counter flow configurations [13] revealed that inclination angle plays an important role in enhancing the dehumidification, cooling and regeneration process.

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Nomenclature

A_c	cross-section area of the column, m^2
A_1–A_6	air state points
C	area per unit volume of the fill, m^2/m^3
c_p	specific heat, kJ/kg K
D	diffusion coefficient, m^2/s
D_1–D_4	desiccant solution state points
dA	wetted area in differential element, m^2
dm	moisture removed from differential element, g/s
h	enthalpy, kJ/kg
h_c	heat transfer coefficient, W/m^2 K
h_m	mass transfer coefficient, kg/m^2 s
h_s	solution enthalpy, kJ/kg
k	thermal conductivity, W/m K
Le	Lewis number (dimensionless number)
M	molecular weight
m	mass flow rate, kg/s
p	pressure, kPa
R_1–R_4	refrigerant state points
S/A	solution to air flow ratio, %
t	temperature, °C
W	specific humidity, g/kg of dry air
x	solution concentration, %
Z	height of the column, m

Greeks

α	thermal diffusivity, m^2/s
Δt	change in air temperature, °C
ΔW	change in specific humidity, g/kg of dry air
ρ	density, kg/m^3

Subscripts

a	air
aa	air in absorber
ar	air in regenerator
sa	solution in absorber
sr	solution in the regenerator
i	interface
s	solution
v	vapor
1	inlet
2	outlet

Superscript

*	instantaneous incremented value

Low humidity is essential for certain applications like archives and museums. It is also desirable for human comfort. Recent studies showed that perceived freshness of supplied air increases with decrease in its humidity. But the compression based air conditioning (AC) systems only cool the air with limited scope for dehumidification and hence cannot meet the low humidity requirements. Hence, a hybrid system capable of providing low humidity was proposed [14]. This gives a scope to reduce the ventilation air and decrease the cooling load.

Present study deals with an analysis of the packed column used as an absorber or regenerator in the proposed system (Fig. 1). It uses only small desiccant flow rate, i.e., very low S/A flow ratio. Heat and mass transfer between air and the desiccant are achieved without external heat interaction. The column is adiabatic and precooled/ preheated air is used. The analysis is carried out in counter flow configuration by varying parameters like (i) S/A ratio, (ii) temperature of air and (iii) specific humidity of air for absorber and regenerator. The above values are given in Table 2.

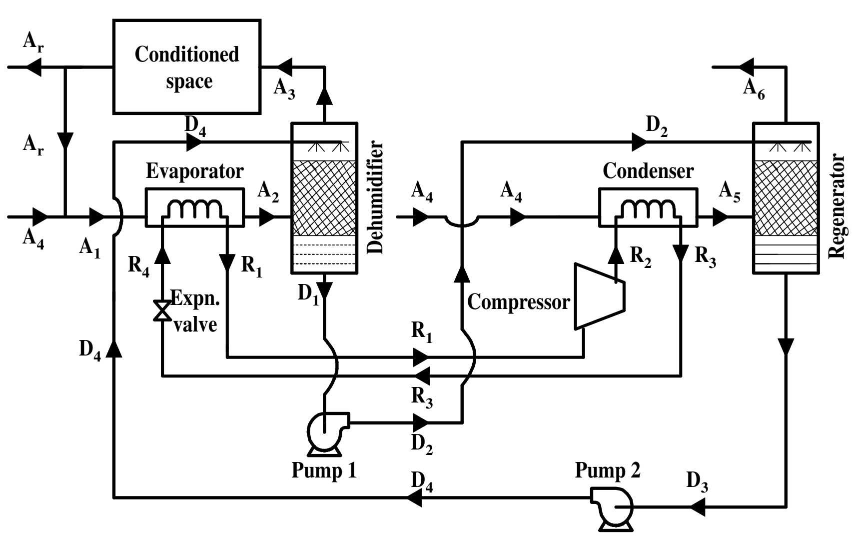

Fig. 1. Block diagram of the proposed system.