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A review of the mathematical models for predicting the heat and mass transfer process in the liquid desiccant dehumidifier

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ABSTRACT

The paper aims to overview various mathematical models for modeling the simultaneous heat and mass transfer process in the liquid desiccant dehumidifier. Firstly, the dehumidification principle is introduced briefly. Then the models are interpreted in terms of two classes of dehumidifiers. For the adiabatic dehumidifier, the models are mainly classified into three types: finite difference model, effectiveness *NTU* (ε–*NTU*) model, and simplified models. For the internally cooled dehumidifier, there are also three kinds of models: models without considering liquid film thickness, models considering uniform liquid film thickness, and models considering variable liquid film thickness. This review is meaningful for comprehending the development process and research status of the models and choosing suitable models for prediction. In addition, some suggestions are proposed for the model improvement.

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1. Introduction

With the acceleration of urbanization and improvement of people′ living standard, a larger proportion of building energy consumption will be needed to keep a comfortable indoor environment [1]. But it is well-known that the traditional air conditioning system is notorious as a result of heavy dependence on electric power, limited ability of humidity control, and occurrence of wet

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Nomenclature

A	specific surface area per unit volume [m^{-1}]
C_P	specific heat [$J\ kg^{-1}\ K^{-1}$]
C_{sat}	saturation specific heat [$J\ kg^{-1}\ K^{-1}$]
d_h	hydraulic diameter [m]
D_m	mass diffusion coefficient [$m^2\ s^{-1}$]
D_t	thermal diffusivity [$m^2\ s^{-1}$]
g	gravity [$m\ s^{-2}$]
G	specific mass flow rate [$kg\ m^{-2}\ s^{-1}$]
G'	mass flow rate [$kg\ s^{-1}$]
h	specific enthalpy [kJ/kg]
h_e	enthalpy of humid air in equilibrium with liquid desiccant [kJ kg]
$h_{e,eff}$	effective saturation enthalpy [kJ kg], Eq. (18)
H	height of the dehumidifier [m]
k	heat conduction coefficient [$W\ m^{-1}\ K^{-1}$]
L	length of the dehumidifier [m]
Le	Lewis number
m	water condensation rate [$g\ s^{-1}$] or per unit cross-sectional area [$g\ m^{-2}\ s^{-1}$], Eq. (23)
m^*	capacity ratio similar to the one used in sensible heat exchangers
M	molecular weight [$g\ mole^{-1}$]
NTU	number of transfer units
Nu	Nusselt number (dimensionless)
P	pressure [Pa]
P_a	partial vapor pressure in air [Pa]
P_s	partial vapor pressure over the solution [Pa]
P_t	total pressure [Pa]
$\overline{P}$	dimensionless vapor pressure difference ratio
Q	heat transferred from solution to water [$kW\ m^{-1}$]
T	temperature [K]
$\overline{T}$	dimensionless temperature difference ratio
u	velocity [$m\ s^{-1}$]
V	volume [m^3]
w	humidity ratio [$kg\ H_2O\ kg^{-1}$ dry air] or the width the dehumidifier [m]
W_e	humidity ratio of humid air in equilibrium with liquid desiccant [kmol H_2O (kmol air)$^{-1}$]
$W_{e,eff}$	effective humidity ratio [kmol H_2O (kmol air)$^{-1}$], Eq. (19)
X	desiccant concentration [kg desiccant kg^{-1}solution]
X_w	concentration of water in solution [kg water kg^{-1}solution]
X_v	concentration of water vapor in air [$kgH_2O\ kg^{-1}$]

Greek letters

α_C	heat transfer coefficient [$W\ m^{-2}\ K^{-1}$]
α'_C	heat transfer coefficient corrected for simultaneous mass and heat transfer [$W\ m^{-2}\ K^{-1}$]
α_D	mass transfer coefficient [$kg\ m^{-2}\ S^{-1}$]
α'_D	molar mass transfer coefficient [$kmol\ m^{-2}\ S^{-1}$]
ϑ	dimensionless temperatures $(T-T_r)/\overline{h}$, Eq. (33)
ρ	density [$kg\ m^{-3}$]
μ	dynamic viscosity [$kg\ m^{-1}s^{-1}$]
ν	kinetic viscosity [$m^2\ s^{-1}$]
ε	air side effectiveness
ε_{HE}	heat exchanger effectiveness
λ	latent heat of vaporization [$kJ\ kg^{-1}$]
δ	film thickness [m]
Δ	change of or difference between parameters

Subscripts

a	air
c	critical
f	cooling fluid, like water, air, refrigerant
i	inlet
int	interface
o	outlet
p	primary air
r	secondary (return air)
s	desiccant solution
v	water vapor

surface for breeding mildew and bacteria and so on [2]. Thus, to reduce the energy consumption in buildings and improve the indoor air quality, the liquid desiccant assisted air conditioning system has drawn more and more attention [3–7].

The major component of interest regarding heat and mass transfer of such a system is the dehumidifier. Compared with the experimental research, the simulation method is more time and cost saving. Also, some parameters in the dehumidifier interior can be observed by simulation while it is impossible to be achieved by experiment. Most importantly, the verified simulation models are effective tools to assess and optimize similar dehumidifiers. Therefore, a large amount of studies have been done to establish reasonable mathematical models for evaluating the liquid desiccant dehumidifiers. However, there is short of detailed and specific summary of the models until now. Thus, it is meaningful to classify and assess the models, which will provide useful suggestion for future research.

In the paper, the function principle of the liquid desiccant dehumidifier is introduced firstly. Based on whether there is heat removal, the dehumidifier is divided into two types: adiabatic and internally cooled dehumidifier. Correspondingly, the models are summarized in two respects in terms of the different structures. For each model, the assumptions, governing equations, boundary conditions and other relevant information are provided. The applied conditions, development process, and research status of the simulation models are also presented. In addition, some suggestions are put forward for the model improvement.

2. Problem description

2.1. The mechanism of heat and mass transfer in liquid desiccant dehumidifier

It is well know that in the dehumidifier, complicated heat and mass transfer occurs. The driving force for heat transfer is the temperature difference between the air and desiccant solution, and for mass transfer is the water vapor pressure difference between the air and the surface of the desiccant solution. The most classic and typical mass transfer theories include film theory, penetration theory and surface renewal theory. The theory used most for the dehumidifier is the film theory. It is Nernset [8] who proposed the film theory first in 1904. He assumed that the whole resistance of mass transfer in a given phase lied in a thin and stagnant region of that phase at the interface. This region is called film. Based on it, Whiteman [9] developed the two-film theory.