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Modeling of heat and mass transfer in parallel plate liquid-desiccant dehumidifiers

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Abstract

In the last few years there has been renewed interest in solar driven air-conditioning. One concept that has been investigated is the use of liquid-desiccant cooling systems. Such systems have the advantage of improved humidity control, particularly in applications with high ventilation rates. Moreover, lower regeneration temperatures can be employed, allowing for a more efficient use of heat from low temperature sources, e.g., flat plate solar collectors. In the present work, mathematical and numerical models were developed for internally cooled liquid-desiccant dehumidifiers, using three different approaches. The first approach is based on heat and mass transfer correlations. The second one numerically solves, by the finite-difference method, the differential equations for energy and species assuming a constant film thickness. The third approach introduces a variable film thickness. All approaches assume fully developed laminar flow for the liquid and air streams. The variable thickness model results closely matched the experimental data available in the literature.

Keywords: Liquid-desiccant cooling; Flat-plate dehumidifiers; Solar air-conditioning; Solar cooling

1. Introduction

In the last few years there has been renewed interest in solar driven air-conditioning (International Energy Agency, 2002). Some of the previous work has focused on desiccant cooling systems. Such systems have the advantage of improved humidity control, particularly in applications with high ventilation rates (Mesquita et al., 2003). Most of the systems already developed employ solid desiccants, with relatively high regeneration temperatures. One alternative is the use of liquid-desiccant systems. In these systems, lower regeneration temperatures can be employed, allowing for a more efficient use of heat from low temperature sources, e.g., flat plate solar collectors (Öberg and Goswami, 1998). Another advantage of liquid-desiccant systems is the potential for using the desiccant solution for energy storage.

The main components in a liquid-desiccant air-conditioning system are the dehumidifier and the regenerator. Many different technologies have been

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Nomenclature

C	water mass fraction in solution (kg kg^{-1})
C_p	specific heat (J kg^{-1} K^{-1})
D	diffusivity (m^2 s^{-1})
d_h	hydraulic diameter (m)
g	gravity acceleration (m s^{-2})
h_h	heat transfer coefficient (W m^{-2} K^{-1})
h_m	mass transfer coefficient (m s^{-1})
h_{fg}	latent heat of vaporization (J kg^{-1})
k	heat conduction coefficient (W m^{-1} K^{-1})
$\dot{m}$	mass flow rate (kg s^{-1})
Nu	Nusselt number
p	pressure (Pa)
p_w	water vapour pressure (Pa)
Sh	Sherwood number
T	temperature (°C)
u	velocity (m s^{-1})
x	coordinate in the direction along the channel (m)
y	coordinate in the direction across the channel (m)

Greek characters

α	thermal diffusivity (m^2 s^{-1})
γ	kinematic viscosity (m^2 s^{-1})
γ_d	film thickness (m)
δ_c	channel half depth (m)
μ	dynamic viscosity (kg m^{-1} s^{-1})
ρ	density (kg m^{-3})

Subscripts

a	air–water
d	water–salt
i	inlet
o	outlet
w	wall

developed for these two components. For the dehumidifier, the most common technology employed today is the packed bed. However, packed beds must work with high desiccant flow rates in order to achieve good dehumidification levels without internal cooling. Higher desiccant flow rates typically result in only small changes in the concentration of the desiccant solution during the process. This, and the higher level of heat dumping from the regenerated solution that follows higher flow rates, reduces the coefficient of performance of the liquid-desiccant cycle. One option that allows lower flow rates is the use of internally cooled dehumidifiers (Lowenstein et al., 1998; Lowenstein, 1994). Fig. 1 presents a schematic for one channel of an internally cooled dehumidifier, which is composed of several of these channels stacked together.

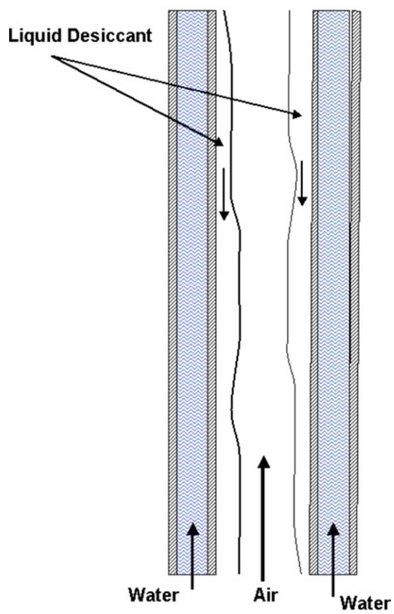

Fig. 1. Internally cooled dehumidifier channel.

Most of the previous studies related to the modeling of internally cooled dehumidifiers have used mass transfer coefficients derived from heat and mass transfer analogies (see Jain et al., 2000; Krause et al., 2005; Mesquita et al., 2003; Pietruschka et al., 2006; Saman and Alizadeh, 2001). One disadvantage of models using heat and mass transfer analogies is the fact that the boundary conditions have to be similar for both phenomena, e.g., an isothermal boundary condition has to be accompanied by an uniform concentration condition. Park et al. (1994) analyzed, experimentally and numerically, a three dimensional cross flow configuration, assuming constant film thickness, fully developed air and desiccant flow streams, and no drag between the air and the film at the interface. The same approach was used by Ali et al. (2004). They also evaluated the influence of the addition of Cu-ultrafine particles in the desiccant solution on heat and mass transfer. Keßling