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Influence of plate surface temperature on the wetted area and system performance for falling film liquid desiccant regeneration system

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ABSTRACT

The falling film liquid desiccant air conditioning system is a promising technology. The wetted area, as a key factor affecting the system performance, is significantly influenced by the plate surface temperature. With a single channel internally heated regenerator, this paper experimentally investigated the impact of plate temperature on the wetted area and system performance, by obtaining the film area and temperature with a thermal camera. LiCl was chosen as the desiccant. By reducing the film contraction in the transverse direction, the increase of plate surface temperature could enhance the wetted area significantly, especially for the low solution mass flow rate. The growth rate of area increased from 0.0017 to 0.0022 m^2/°C when the flow rate reduced from 0.062 to 0.034 kg/s. The regeneration performance also increased with the temperature. A theoretical model with an analytical solution was developed to obtain the wetted area by describing the film contraction caused by the Marangoni effect. A good match was observed for the prediction and experimental results, with an average error of 10.8%. Furthermore, the wetted width was numerically found to also increase with the decrease of film thickness and contact angle, and its change with the solution concentration was slight. This research helps researchers and engineers to accurately predict the wetted area of falling film and to improve the heat and mass transfer performance of liquid desiccant regeneration system.

1. Introduction

As most people spend about 70–90% of their time in the built environment, there are increasing concerns regarding the indoor thermal comfort and air quality, which are usually related to the air-conditioning (AC) systems [1]. The application of the conventional vapor compressor AC system has several disadvantages, such as limited humidity control, energy wastage, and the creation of a wet surface which may become a breeding ground for mildew and bacteria [2]. Such problems become more serious in humid climates [3]. Regarded as an energy-saving and environmental-friendly alternative, the liquid desiccant AC system is an effective solution for handling the sensible and latent loads separately and dealing with the moisture with desiccant absorption. In this system, the carryover of desiccant droplets with the process air is an important concern [4]. Due to its low possibility of droplets carried by the air and low pressure drop, the falling film dehumidifier/regenerator has become a promising type for liquid/gas contacting [5]. It is also widely used in industrial applications [6].

In adiabatic liquid desiccant applications, the heat and mass transfer happens only between the air and the desiccant, so the performance decays quickly because of the change of temperature and concentration gradients. Different from adiabatic applications, the internally cooled/heated dehumidifier/regenerator could maintain the thermal and mass transfer performance as it is cooled or heated synchronously by introducing the extra cooling/heating fluid, [4]. The energy consumption, which is usually supplied by low-grade thermal energy provided by the waste heat or renewable energy, could also be reduced. In addition, the system dimensions could also be minimized [7].

To investigate the efficiency and operation performance of internally cooled/heated systems, the wetted area is a key parameter [8]. It was found to be significantly influenced by the plate temperature of the working surface, especially under intermittent operation or part-load conditions. As the working surface is usually not completely wetted by the desiccant [9,10], the plate surface temperature could be observed as the surface temperature of the dry area, which could impact the heat and mass transfer during the whole dehumidification/regeneration process. As shown in Fig. 1, the plate surface temperature is determined by the temperature of air and extra hot fluid, the heat transfer coefficient of the working surface, the thermal resistance of the insulation and the

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Nomenclature

A	area, m^2
a	thermal diffusivity, m^2/s
c	specific heat capacity, kJ/(kg °C)
D	width of rim part, m
h	convection heat transfer coefficient between solution and air, kW/(m^2 °C)
$\dot{m}$	mass flow rate, kg/s
RH	relative humidity, %
$\overline{R}_w$	dimensionless hydraulic radius, –
t	temperature, °C
u	flow velocity, m/s
W	width, m
Δx	contraction distance of solution film in the transverse direction, m
δ	thickness of solution film, m
μ	dynamic viscosity, Pa s
ρ	density, kg/m^3
θ	contact angle, °
χ	proportional coefficient between solution surface tension and temperature
ε	deformation indicator of solution film, –
σ	surface tension, N/m
ζ	concentration of desiccant solution, –
ω	moisture content, kg/kg
λ	thermal conductivity, kW/(m °C)
A_0, A_1, S_y, S_0	expressions (defined in the paper), –

Subscripts

a	air
s	solution
p	plate
e	environment
in	inlet
out	outlet
i	initial
m	maximum
w	wetting
cen	central part
rim	rim part

surrounding temperature of the regenerator. By certain assumptions, the temperature of working surface could be calculated with the equations of heat transfer by conduction and convection.

When the working surface is cooled/heated by the extra fluid, the heat transfer changes the properties of the falling film [11,12]. These variations lead to an uneven distribution of surface tension upon the liquid–vapor interface, which could induce a fluid flow in the transverse direction [13]. This effect, namely the Marangoni effect, could significantly influence the wetted area and flow dynamics, and the heat and mass transfer of the falling film dehumidifier/regenerator as well.

Most previous studies of the Marangoni effect have focused on the applications of the vertical condenser or absorption tower [14]. The formation of waves on the film surface led by the inherently instability has been investigated by many researchers [15–17]. In 2002, Chang and Demekhin summarized and discussed the properties of waves experimentally and theoretically [18]. However, most of these works only considered the Marangoni effect in the streamwise direction, and the fluid instability in the transverse direction was ignored. In 2001, Geng et al. experimentally found that, the wetted width of falling film changed with the surface temperature, by using water as the working fluid [19]. In 2006, Zhang et al. developed a model to predict the contraction distance of water film, and found that the uneven distribution of surface tension in the transverse direction was much higher than that in the streamwise one [20].

In terms of the liquid desiccant system, insufficient wetting has been observed in many previous studies. Jain et al. [21] and Yin et al. [5] experimentally investigated the actual wetting factors in falling film dehumidifiers and regenerators, but their values differed greatly. The influence of surface temperature on the liquid desiccant system has also been the focus of research in recent

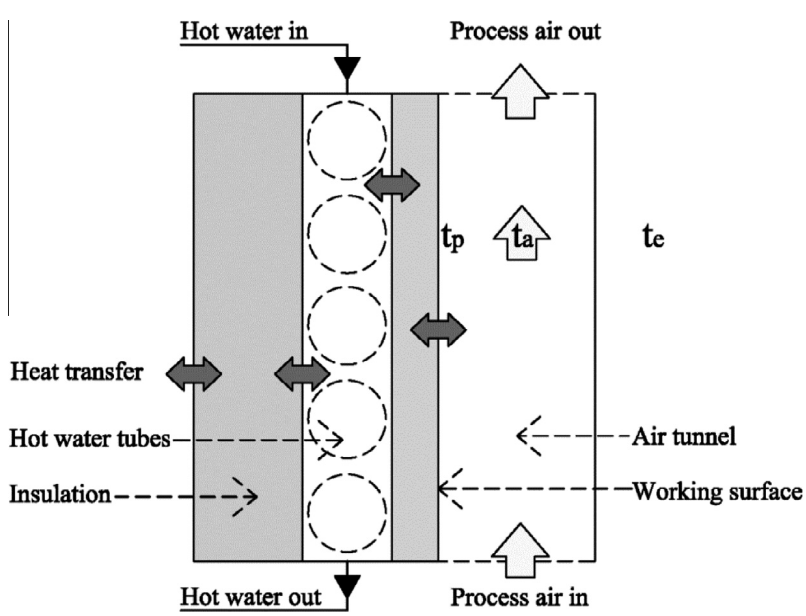

Fig. 1. Schematic of plate surface temperature during internally heated regeneration process.