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Development and experimental study of a novel plate dehumidifier made of anodized aluminum

Tao Wen [a], Lin Lu [a, *], Chuanshuai Dong [a], Yimo Luo [b]

[a] Renewable Energy Research Group, Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China
[b] Faculty of Science and Technology, Technological and Higher Education Institute of Hong Kong, Hong Kong, China

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ABSTRACT

The falling film dehumidifier is a key component in the liquid desiccant cooling system (LDCS). However, the most commonly used metals, such as steel and aluminum, can hardly resist the erosion of liquid desiccant. It greatly limits the fabrication of compact dehumidifiers and hinders the promotion of LDCS. The present study introduced a novel falling film dehumidifier which was made by the metal of anodized aluminum. Experiments were carried out to compare the dehumidification performance between ordinary aluminum dehumidifier and anodized one. The influences of air temperature, mass flow rate, inlet humidity and solution temperature, mass flow rate, temperature on dehumidification performance were identified. The results showed that the anodized aluminum could alleviate the erosion significantly. In addition, with the surface treatment by anodizing, the contact angle of lithium chloride solution decreased from 85.2° on an ordinary aluminum plate to 43.1° on an anodized one. Accordingly, the wetting area on the plate dehumidifier increased from 0.143 m^2 to 0.178 m^2 with a 24.5% increment at certain operating conditions. Both the absolute moisture removal and dehumidification effectiveness increased in various degrees for anodized dehumidifier compared with the ordinary type. The relative increments could reach up to 50.6% and 36.7% under certain conditions respectively. The newly introduced anodized aluminum dehumidifiers can not only alleviate the plate corrosion but also improve the dehumidification capability due to smaller surface contact angles, which can be promisingly applied in LDCS.

1. Introduction

The traditional vapor compression cooling system (VCS) has been criticized for its reliance on electricity consumption and limited control ability of dehumidification. Compared with the VCS, the liquid desiccant cooling system (LDCS) is more efficient by handling the sensible and latent load separately. With the quest of high quality life among people in nowadays, the LDCS has shown its unique attraction with the ability to create a more comfortable indoor environment. What is more, the regenerator as another key component in LDCS can make use of low grade energy, such as solar energy, waste heat, during the regeneration of liquid desiccant. Therefore, LDCS is considered as a promising candidate in the cooling field, especially in humid regions, such as Hong Kong.

The existing study focuses on the dehumidification performance of dehumidifier which is one of the main components in LDCS [1–5]. Generally, most dehumidifiers can be classified into three types, i.e. packed bed, falling film dehumidifiers and indirect contact type [1,2,4,6–8]. In a packed bed dehumidifier, the concentrated liquid desiccant is sprayed in the bed and flows along the packed material. The processed air also flows through the space in the bed and contacts with the solution. Due to the partial pressure difference of water vapor between liquid desiccant and air, water vapor in the air is absorbed by the concentrated solution. During this process, latent heat due to water vapor absorption would release. So the solution temperature will increase continually along the flow direction, and this inevitably deteriorates the absorption performance to some degree. In addition, other problems, such as low wetting ability of packed materials, possibility of liquid entrainment, high pressure drop of air, further limit its wide application [2,4,5].

In order to solve the problems mentioned above, researchers introduced another kind of absorber, namely falling film absorber.

* Corresponding author.
E-mail address: vivien.lu@polyu.edu.hk (L. Lu).

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Nomenclature

d	Absolute humidity(g/kg)
G	Flow rate(kg/s)
h	Enthalpy(kJ/kg)
$LDCS$	Liquid desiccant cooling system
T	Temperature(C)
X	Concentration(%)
Greek symbols	
ϕ	Relative humidity(%)
ρ	Density(kg/m^3)
ξ	Dehumidification effectiveness (Dimensionless)
Δ	Change value
Subscripts	
a	Air
dry	Dry bulb
e	Equilibrium
in	Inlet
out	Outlet
s	Solution
w	Cooling water

Compared with the packed bed one, the solution can be internally cooled by other media, and it also overcomes liquid entrainment and high pressure loss to a great extent [2,4,5]. Researchers have carried out studies to investigate the simultaneous heat and mass transfer characteristics in an internally cooled dehumidifier both numerically and experimentally [1–5]. To summarize, the mathematic models for dehumidifier can be divided into two categories, i.e. effectiveness-NTU model and finite difference model [9]. Their applications can be found for parallel flow, counter flow and cross flow [10–13]. However, in the mathematics model, the properties of materials, such as resistance and corrosion, were not considered and validated.

For tube absorber, Jeong et al. [14] developed a model to predict the heat and mass transfer in falling film and droplet mode flow of a tube absorber. In their model, incomplete wetting was considered by introducing a wetting ratio. After model validation, they studied the effects of different parameters on the dehumidification performance. Three copper tubes with different outer diameters were employed by Yoon et al. [15] to explore the heat and mass transfer characteristics during absorption process. The absorber with smaller diameters showed better heat and mass transfer performance. Luo et al. [16] experimentally studied the performance of a fin-tube internally-cooled dehumidifier and reported a good absorption performance of the fin-tube absorber. In their study, in order to enhance the corrosion resistance performance of the dehumidifier, the surface treatment technology of electroplating was employed. Some antiseptic materials were adhered to the surface of the fin through electroplating. Comparative corrosion resistance tests demonstrated good anti-corrosion performance of the adopted fin-tube dehumidifier and the poor anti-corrosion performance of stainless steel 304 and copper.

However, the dehumidifier based on tubes has lower efficiency and bigger volume compared with the absorbers made by plates [17,18]. So, the plate type dehumidifier has drawn more attention naturally [14–21]. The dehumidification performance of a stainless steel dehumidifier was studied by Luo et al. [19,20]. The influence of various parameters which included the film thickness on absorption behavior was identified. Yin et al. [21] studied both the dehumidification and regeneration performance of an internally cooling/heating absorber made by stainless steel. Their results revealed that the heat and mass transfer efficiency of internally-cooled/heated dehumidifier/regenerator was higher than those adiabatic ones. Gao et al. [22] also conducted experiments to compare the dehumidification effectiveness and moisture removal rate between an internally cooled and an adiabatic dehumidifier. Internally cooled dehumidifier was verified to have higher dehumidification effectiveness and bigger moisture removal rate. However, they did not give detailed information about the dehumidifier. In the work done by Zhang et al. [23], the dehumidifier made of stainless steel was designed and investigated both by experiments and simulation analysis. After the experimental and numerical study of absorption performance under various operating conditions, an internally cooled/heated LDCS system driven by exhaust heat of heat pump was proposed with relatively high COP. In consideration of the strong corrosion of liquid desiccant, Liu et al. [24] introduced an internally-cooling dehumidifier made of thermally conductive plastic. Unlike the normal plastic, the thermal conductivity of the mentioned thermally conductive plastic reaches as high as 16.5 $W/(m \cdot K)$. On one hand, the new dehumidifier could achieve superior corrosion resistance capacity. On the other hand, it had considerable heat and mass transfer performance compared with dehumidifiers made of metals as well. Lee et al. [25] also introduced a kind of plastic dehumidifer made of heat-resistant acrylonitrile butadiene styrene plastic. In order to overcome the low wettability of plastic, hydrophilic coating and groove shape were treated on the surface of the plate. The *Sh* and *Nu* correlations for the process of heat and mass transfer were developed with an error within ±25% according to their experimental results. Mortazavi et al. [18] designed an internally cooled dehumidifier with offset fins made of copper. The new surface structure could not only increase the wetting area but also enhance the absorption rate significantly, which made it to be a very promising framework for the development of highly compact absorber.

It is well known that commonly used materials for falling film dehumifier are metals, such as stainless steel [19–21] and copper [18]. But if no special treatment is provided, the plate corrosion would probably occur [16]. Therefore, some surface treatment process, such as electroplating [16], was introduced. Besides, some researchers gave up metal directly and chose special plastic for utilization [24,25]. However, compared with metals, plastic has the inherent disadvantage of relative low wettability and thermal conductivity. It is quite necessary to find other material alternatives with the excellent anti-corrosion performance, good wettability, high heat conductivity and good workability.

Based on the above observations, the present study newly introduced an anodized aluminum plate for dehumidifiers which has been widely used in heat exchanger. Two single channel aluminum plate dehumidifiers with and without anodizing with the size of 500 mm × 500 mm (Length*Width) were fabricated. The corrosion resistance performance was examined within a period of 30 days. The wettability were identified and compared by the means of contact angles and wetting areas between these two aluminum plates. Finally, the dehumidification performance under various operating conditions was investigated.

2. Research method

2.1. Description of test rig

A test rig was designed and fabricated for the purpose of experimental investigation on the absorption performance of the