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Performance comparison of three typical types of internally-cooled liquid desiccant dehumidifiers

Jun Liu, Xiaohua Liu*, Tao Zhang

Department of Building Science, Tsinghua University, Beijing 100084, China

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ABSTRACT

Numerous types of internally-cooled liquid desiccant dehumidifiers have been proposed in recent studies. In the present study, detailed quantitative comparisons of three typical types of internally-cooled dehumidifiers with different structures (parallel plate, fin coil, and packed tower with cooling tubes) were performed. The heat and mass transfer coefficients and the specific surface areas of the different types of devices were compared and a heat and mass transfer model of an internally-cooled dehumidifier was adopted to analyze the performance of different devices. The results showed that internally-cooled dehumidifier with the fin-coil structure demonstrated superior performance compared to the other two systems; the packed tower with cooling tubes displayed the poorest performance among the three devices. In addition, the effects of the heat transfer ability between the desiccant and cooling water and the mass transfer ability between the desiccant and air on dehumidification performance were investigated. Results showed that the main reason for the difference in performance is that mass transfer ability influenced current device performance to the greatest degree. Thus, to further improve the devices, greater attention should be paid to the mass transfer process between the air and desiccant.

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1. Introduction

In recent years, liquid desiccant dehumidification has become an efficient method for indoor air humidity control. Based on the absence or presence of an internal cooling/heating source in the dehumidifier/regenerator, liquid desiccant air-conditioning systems can be classified as either an adiabatic type or an internally-cooled/heated type, respectively. The adiabatic type is the most commonly adopted type in current studies of liquid desiccant systems. However, scholars [1,2] have pointed out that the mass transfer driving force will drop significantly as the liquid desiccant temperature rises (or drops) quickly in an adiabatic dehumidifier (or regenerator). Thus, previous efforts to improve the performance of adiabatic devices have included increasing the solution flow rate and adopting an extra heat exchanger to cool the solution [2]. However, these improvement methods also require greater pump power and device volume. As a consequence, researchers developed a substitute process by introducing internal cooling/heating water into a dehumidifier/regenerator. This is the internally-cooled/heated process of liquid desiccant, and due to its superior performance in reducing the solution flow rate and device volume compared to the adiabatic process, research on internally-cooled/heated devices has continued to increase [3–9].

To meet the requirements of the internal process, various types of devices have been proposed by researchers. Such devices [3–18] can be categorized into 3 main types, as shown in Fig. 1: parallel plate, fin coil, and packed tower with tubes.

In a classic parallel-plate dehumidifier, the desiccant solution is sprayed from top to bottom and flows down with gravity while humid air is blown from the bottom of the device in counter-flow to the solution. At the same time, internal cooling water is pumped into water passages located inside the plate. Kessling et al. [3] developed and tested a plastic-plate internally-cooled dehumidifier, in which the distance between plates was 5.5 mm and the heat transfer coefficient through the plate wall was about 170 W/(m^2·K). In this device, the area of the parallel plate functioned as the area of both the heat transfer process between the desiccant and cooling water (F_h) and the mass transfer process between the air and desiccant (F_m). As the thickness of the plate was rather small, the device showed satisfactory heat transfer performance between the desiccant and cooling water. Experimental results showed that the parallel-plate device continued to demonstrate satisfactory

* Corresponding author. Department of Building Science, Tsinghua University, Beijing 100084, China.
E-mail address: lxh@mail.tsinghua.edu.cn (X. Liu).

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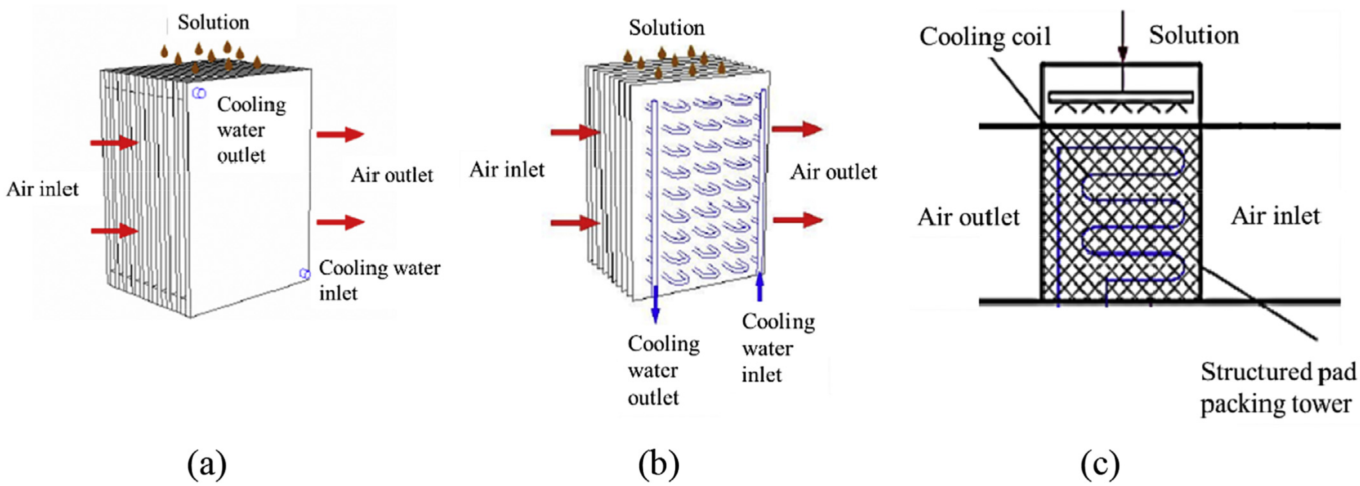

Fig. 1. Schematics of three typical internally-cooled dehumidifiers: (a) parallel plate [3,4]; (b) fin coil [5,6]; and (c) packed tower with cooling tubes [7].

dehumidification performance even under a low desiccant flow rate. However, in consideration of the relatively small mass and heat transfer area of parallel-plate devices, Yin et al. [4] designed a new type of internally-cooled/heated dehumidifier/regenerator based on a plate-fin heat exchanger (PFHE). Starting with Kessling et al.'s device, Yin et al. added fins to the plates to provide a larger contact area for the desiccant solution and air, and dehumidification and regeneration performance was measured under different air flow rates, water inlet temperatures, and solution inlet temperatures.

In a fin-coil dehumidifier, cooling water flows inside the coil to cool the liquid desiccant coming down from the top of the device, and humid air can be blown from either the front or the bottom side of the fin coil. Zhang et al. [5] designed and tested an internally-cooled dehumidifier made of stainless steel. The device consisted of eight rows with 22 cooling water channels in each row; fins made of stainless steel were installed outside the heat exchanger to increase the heat transfer area and to enhance the heat and mass transfer processes between the air and liquid desiccant. The total specific surface area of the device was 790 m^2/m^3 (i.e., much higher than that of a parallel-plate device). To consider the problem of corrosion, Liu et al. [6] proposed an internally-cooled fin-coil dehumidifier made of thermally conductive plastic. Due to the unique processing of the conductive plastic, the total specific surface area of the device was 342 m^2/m^3, making it considerably smaller than the device designed by Zhang et al.

Beyond parallel-plate and fin-coil dehumidifiers, Bansal et al. [7] introduced an internally-cooled dehumidifier with a packed-bed structure. This device utilized a non-adiabatic structured packed bed absorber consisting of rigid media pads with cooling water flowing through tubes embedded in the packing. On one hand, this device showed good mass transfer performance between the air and solution, especially considering the large specific surface area of the structured packed bed. On the other hand, the heat transfer area between the solution and cooling water was relatively small, which resulted in slightly disappointing dehumidification performance. The parameters of the different types of devices are summarized in Table 1. Current researches on the comparison of different types of internally-cooled dehumidifier are limited. Chung et al. [8] once compared various studies of triethylene glycol (TEG) solution used in different dehumidification systems and analyzed the advantages and disadvantages of different systems.

In conclusion, previous studies have been chiefly concerned with either the qualitative comparison among different types of internally-cooled/heated devices or the quantitative analysis of a certain type of device. However, quantitative comparisons of different types of internally-cooled dehumidifiers are largely absent from the literature.

Thus, the present study focuses mainly on quantitative comparisons of different internally-cooled dehumidifiers in terms of their dehumidification performance. Performance indices of different types of devices are compared and the common ranges of indices for different devices are given. Then available heat and mass transfer model for the internally cooled dehumidifier with various structure types is adopted in present paper and the model is validated by the experimental results from literature. The validated model is then used to analyze dehumidifier performance of different types of devices. The essential reasons for performance discrepancies among the various types of devices are discussed, and suggestions for future improvements are given.

2. Heat and mass transfer model

2.1. Model

In previous studies, there are several typical flow types for internally-cooled dehumidifiers, as shown in Fig. 2. Since the heat and mass transfer theoretical model is about the same for different flow patterns [13], only the heat and mass transfer model for Flow type 1 is adopted here. As shown in Fig. 2(a), the *x* axis represents the desiccant flow direction, and the direction of the air and cooling water is opposite to it.

Inside the internally-cooled dehumidifier, as shown in Fig. 3, the desiccant directly contacts the humid air and the heat and mass transfer processes occur between the desiccant and the air. On the other side, the desiccant is cooled simultaneously through indirectly contacting with the cooling fluid. In current model, it is assumed that the desiccant solution is welled spread on the plate or tubes, thus there exists no direct heat transfer between the humid air and the cooling fluid.

As a result, there exist three transfer processes in the internally-cooled dehumidifier: the mass transfer process between desiccant and air, the heat transfer process between desiccant and air, and the heat transfer process between desiccant and the cooling water. Fig. 4 shows the influencing mechanism of above three transfer processes. For the heat and mass transfer between desiccant and the air, the energy and mass conservation equations can be written as follows [10–12]:

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