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Enhancing the dehumidification efficiency of solar-assisted liquid desiccant air dehumidifiers using nanoscale TiO_2 super-hydrophilic coating

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Abstract

Humidity control of indoor air is very important to both indoor occupants and indoor building materials. The liquid desiccant air dehumidifier is attracting much attention due to its lower energy consumption. However, the incomplete wetting conditions present negative effect on the development of liquid desiccant air dehumidifiers. Therefore, this paper aims to develop a novel nanoscale TiO_2 super-hydrophilic coating to increase the surface wettability and improve the dehumidification performance as well. XRD test and FESEM test are conducted to investigate the characteristics of the TiO_2 super-hydrophilic coating. The dehumidification performance is significantly improved by the coating. The absolute humidity change increases from 3.2 g/kg to 4.9 g/kg and the mass transfer coefficient from 70.05 $g/(m^2 \cdot s)$ to 90.05 $g/(m^2 \cdot s)$. The performance enhancement is attributed to the increase of wetting area and the decrease of falling film thickness. This research provides an effective approach to improve the dehumidification performance and to reduce the building energy consumption.

Keywords: Liquid desiccant air dehumidifier; Nanoscale TiO_2 super-hydrophilic coating; Surface wettability; Energy consumption

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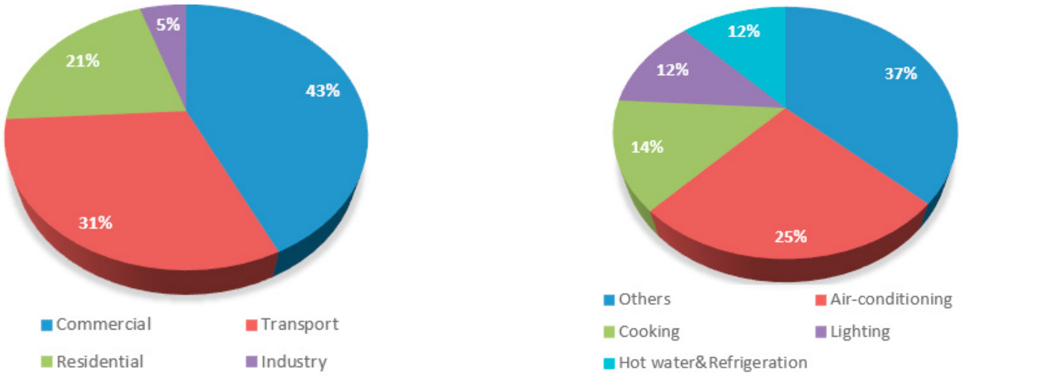
1. Introduction

Air humidity partly affects the indoor thermal comfort of building occupants. The excess moisture of the air can lead to mold and mildew, thereby affecting the building materials and reducing air quality [1]. Therefore, humidity control is drawing increasing attention in recent years. Besides, the energy consumption of air-conditioning system is huge, especially in hot and humid regions. In Hong Kong, the commercial building sector occupy 43% of the whole energy consumption, among which air-conditioning systems occupy around 25% [2], as shown in Fig. 1.



(a) Breakdown of total energy consumption (b) Breakdown of energy consumption in commercial sector

Fig. 1 Hong Kong energy consumption analysis (2016)

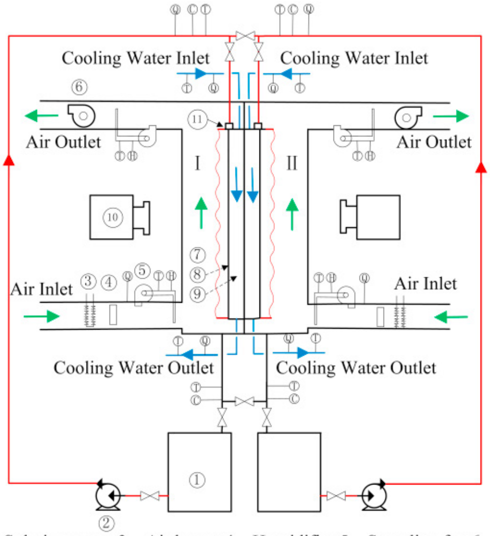
The liquid desiccant air-conditioning system (LDACS) is regarded as an energy-saving and environment-friendly alternative to traditional air-conditioning system [3]. By removing the extra moisture through liquid desiccant absorption, the LDACS can handle the sensible and latent load separately. In addition, the regeneration of the weak liquid desiccant can be driven by low-grade energy such as solar energy and industrial waste heat, which can also reduce the energy consumption and increase the coefficient of performance (COP) of the whole system [4].

The incomplete wetting conditions have been investigated for several years. Jain et al. [5] developed two wetness factors in theoretical model to illustrate the effect of incomplete wetting conditions on dehumidification performance. Zhang et al. [6] investigated the shrinkage characteristics of the falling film on stainless steel plates and found that the falling film shrank sharply along the flow direction due to the Marangoni effect. Dong et al. [7] and Qi et al. [8] found that the wetting area of falling film was heavily determined by the contact angles of the liquid desiccant on working plates and reducing the contact angles could significantly increase the wetting area.

Several approaches have been investigated to improve the surface. Glebov et al. [9], Cheng et al. [10] and Kang et al. [11] found that certain surfactant additions could significantly improve the wettability of liquid desiccant on solid surfaces through experimental study. Kim et al. [12] adopted micro-scale surface treatment to improve the wettability of the falling film $LiBr/H_2O$ absorber and the results showed that 10% improvement of the wetting area was achieved. Besides, plasma method [13] and chemical etching method [14] are also adopted to improve the surface wettability.

In this paper, a novel super-hydrophilic coating is developed using nanoscale anatase TiO_2 particles. The characteristics of the TiO_2 super-hydrophilic coating are investigated using XRD and FESEM test. Then, an experimental setup with two single-channel liquid desiccant air dehumidifier is fabricated to investigate the effect of TiO_2 super-hydrophilic coating on dehumidification performance. A big increment in dehumidification performance is achieved by using the novel TiO_2 super-hydrophilic coating.

2. Experimental test rig



1、Solution tank 2、Solution pump 3、Air heater 4、Humidifier 5、Sampling fan 6、Fan 7、Air channel 8、Working surface 9、Internally cooling unit 10、Thermal Image Camera 11、Solution distributor

T Temperature Sensor C Density Sensor Q Flowmeter H Wet-bulb temperature sensor

Fig. 2 Schematic diagram of experimental setup

An experimental setup with two single-channel internally-cooled liquid desiccant dehumidifiers was fabricated to investigate the enhanced dehumidification performance caused by TiO_2 superhydrophilic coating, as shown in Fig. 2. The size of the working channel was $550 \times 100 \times 600$ mm$(L \times W \times H)$. The experimental setup mainly consists of three subloops, i.e., the liquid desiccant loop (in red), the air loop (in green) and the cooling water loop (in blue).

In liquid desiccant loop, the desiccant solution was firstly stored in the solution tank and then pumped to the inlet of the plate dehumidifier. To achieve the even distribution of the falling film, a new solution distributor with a baffle inside was developed and applied in the experiment. The liquid desiccant solution contacted with the process air in the working channel and the extra moisture was removed from process air to desiccant solution due to the surface vapor pressure difference. Lastly, the weak desiccant solution after absorbing the moisture was collected and returned to the solution tank.

In air loop, the process air was supplied by air fans. Before flowing in the working channel, the air was heated and humidified to the required conditions. Then, the humid air interacted with the desiccant solution and dehumidified. In addition, the sampling devices were equipped at both the inlet and outlet of the plate dehumidifier to measure the air temperature and humidity.

In cooling water loop, the cooling water was provided by a chiller. In internally-cooled liquid desiccant dehumidifier, the cooling water was used to remove the heat released during the absorption process and prevent the temperature increase of the desiccant solution. Therefore, the dehumidification performance of internally-cooled dehumidifier was usually higher than that of the adiabatic one.

3. Results and discussion

3.1. Characterization of TiO_2 super-hydrophilic coating

To improve the surface wettability of plate dehumidifiers, a novel super-hydrophilic coating is developed using anatase TiO_2 particles. Firstly, the Titanium ethoxide (30 ml, Ti 7.3 wt.%) is diluted with the ethyl alcohol under vigorous stirring. Then, the colloidal solution is concentrated using a rotary evaporator. After the rotary evaporation process, the hydrochloric acid (36 wt.%) and nitric acid (60 wt.%), acting as the corporative acid catalyst, are put into the solution. Then, the the synthesized solution is heated to 70℃ for 3 hours and autoclaved in a autoclave at 160℃ for 8 hours. Finally, the nanoscale TiO_2 super-hydrophilic coating is successfully developed.

To investigate the characteristics of the newly-developed TiO_2 super-hydrophilic coating, X-ray diffraction (XRD) test and FESEM test were conducted, as shown in Fig. 3 and 4. The XRD test shows that there is not any other crystal characteristics, indicating that the TiO_2 particles are well synthesized.

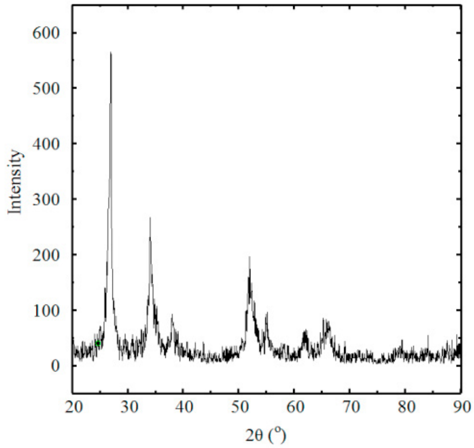


Fig. 3 XRD test of TiO2 super-hydrophilic coating

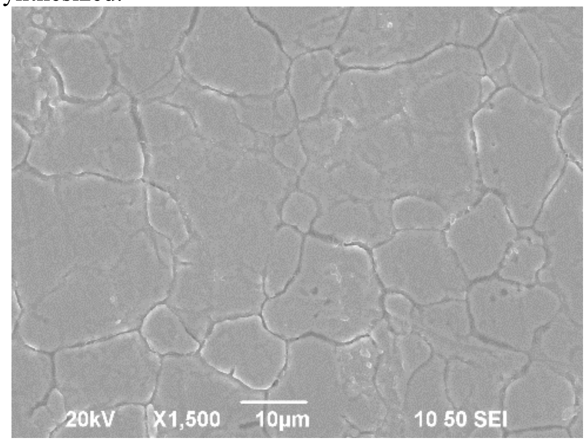
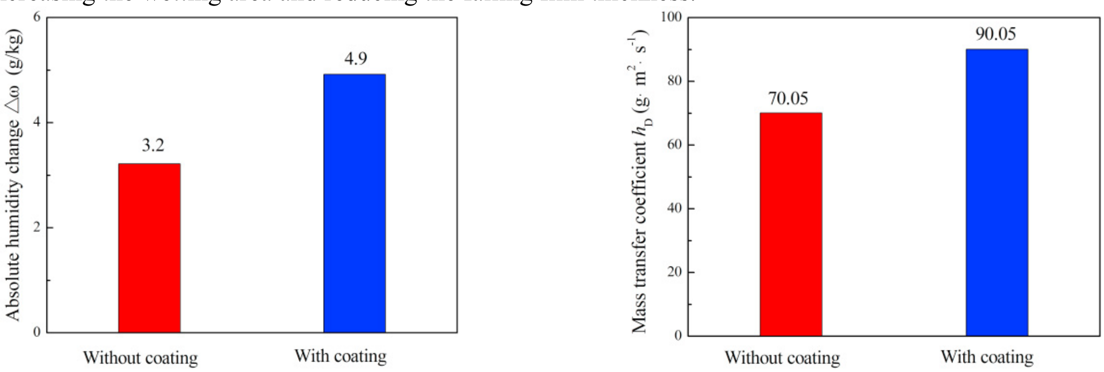


Fig. 4 FESEM test of TiO2 super-hydrophilic coating

3.2. Dehumidification performance analysis

Fig. 5 presents the dehumidification performance, including the absolute humidity change and mass transfer coefficient, of plate dehumidifiers with and without TiO_2 super-hydrophilic coating. As shown in Fig. 5(a), the absolute humidity change increased from 3.2 g/kg to 4.9 g/kg, i.e., by a factor of 1.53, with the substrate plates coated by TiO_2 super-hydrophilic coating. The mass transfer coefficient also increased from 70.05 $g/(m^2 \cdot s)$ to 90.05 $g/(m^2 \cdot s)$, i.e., by a factor of 1.29. The performance enhancement was mainly attributed to the increase of wetting area on the coated plate. Another interesting observation in Fig. 5 was that the increasing ratio of absolute humidity change 1.53 was greater than that of the wetting area 1.3. This interesting phenomenon resulted from the decreasing falling film thickness. On one hand, the decrease of the falling film thickness could reduce the heat transfer resistance between the liquid desiccant and the cooling water. On the other hand, it could also help to accelerate the replenishment of the superficial liquid desiccant and reduce the heat and mass transfer resistance inside the falling film. Therefore, the adoption of TiO_2 super-hydrophilic coating could effectively improve the dehumidification performance by increasing the wetting area and reducing the falling film thickness.



(a) Absolute humidity change (b) Mass transfer coefficient

Fig. 5 Dehumidification performance of plate dehumidifiers

4. Conclusions

In this paper, a novel super-hydrophilic coating is developed using nanoscale anatase TiO_2 particles. The characterization of the coating is conducted using XRD and FESEM test. The dehumidification performance is significantly improved by the nanoscale TiO_2 super-hydrophilic coating. The absolute humidity change increased from 3.2 g/kg to 4.9 g/kg and the mass transfer coefficient increased from 70.05 $g/(m^2 \cdot s)$ to 90.05 $g/(m^2 \cdot s)$. The dehumidification performance enhancement is attributed to the increase of wetting area and decrease of falling film thickness. This research provides a new solution to improving the dehumidification performance and reducing the energy consumption.

Acknowledgements

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