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Experimental study of internally cooled liquid desiccant dehumidification: Application in Hong Kong and intensive analysis of influencing factors

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ABSTRACT

Due to the complicated structure, experimental studies of internally cooled dehumidifiers are much less than those of adiabatic ones. The complicated structure also results in error in deciding the real contact area for calculating the mass transfer coefficient. Moreover, it was found experimental studies of liquid desiccant dehumidifiers in Hong Kong were still limited and the analysis of influencing factors was not comprehensive. Therefore, in present work, a single channel internally cooled dehumidifier was designed for comprehensive investigation of its performance under various conditions. It was easy to observe the contact area with the test rig, making the calculation of mass transfer coefficient more accurate. The air state points were set on the basis of Hong Kong climate. The results indicated that the liquid desiccant dehumidification was very suited to this region. The experimental results also showed good agreement with our previous simulation results in terms of the influence of the air flow rate. In particular, the advantage of present study was that more intensive analysis of the influences of various factors was reported.

1. Introduction

At present, a large amount of energy is needed to create a livable building environment, contributing significantly to the total negative environmental impact of buildings [1–4]. It was reported that the global contribution from buildings towards energy consumption had steadily increased reaching figures between 20% and 40% in developed countries [5]. Especially in Hong Kong, about 90% of energy is consumed by buildings as there are very few industrial sectors.

Among all of the power-driven equipments in buildings, the air conditioning system is well-known for its high power consumption [6]. As shown in Fig. 1(a) and (b) [7], the energy consumption for air conditioning take up about 54% and 23% of the total building's energy consumption in Hong Kong's typical office buildings and residential buildings, respectively. The contribution is considerable. In addition, the traditional air conditioning system depends greatly on the electrical energy, most of which is generated by burning fossil fuels and therefore resulting in serious air pollution problems [8]. Therefore, how to reduce the building energy use, especially air conditioning energy use, becomes the key issue for achieving a sustainable city.

Liquid desiccant air conditioning (AC) system is regarded as an energy-saving and environmental-friendly alternative to the conventional AC system [9–12]. The main advantage is that its separate handling of latent load with desiccant absorption can avoid re-heat energy waste. Meanwhile, the system can be driven by low grade thermal energy, such as solar energy, waste heat and so on. Until now, lots of studies have been conducted to improve the design scheme and operation management of the dehumidifier, one of the most critical components of the system [13–16].

In general, the dehumidifiers are divided into two types, which are adiabatic and internally cooled dehumidifiers. It was proven that the internally cooling could not only increase the dehumidification rate, but also improve energy utilization efficiency [17]. Early in 1999, Deng and Ma [18] reported the experimental studies of a film dehumidifier with internally

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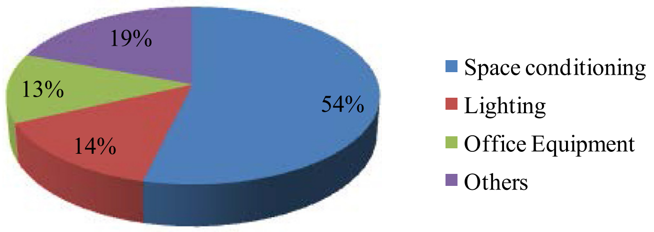
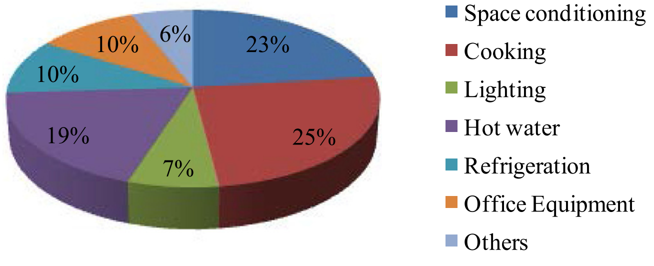


(a) Office building



(b) Residential building

Fig. 1. Hong Kong's breakdown of energy usage in a office and residential building (Year 2011) [7].

cooling, modifying the Nusselt number with considering the effect of inlet solution concentration. Chung and Wu [19] added some fin coils with lower temperature refrigerant to the spray tower, which performed better mass transfer than the case without coil. Jain et al. [20] studied a liquid desiccant system with internally cooled dehumidifier, and introduced two wetness factors to calculate the actual wetting area. Saman and Alizadeh [21] designed a cross-flow type plate dehumidifier with evaporative cooling. Three different sets of experiments were carried out. It was found that the performance of the heat exchanger was improved with liquid desiccant dehumidification. Yin et al. [22] studied the behavior of a new internally cooled dehumidifier on the basis of plate-fin heat exchanger. The effects of cooling water temperature, air flow rate and desiccant temperature on the dehumidification performance and the cooling efficiency were illustrated. Zhang et al. [23] designed a stainless steel internally-cooled dehumidifier to study the effects of inlet parameters on the moisture removal rate, dehumidifying efficiency, and volume mass transfer coefficient. Luo et al. [24] studied a cross-flow fin-tube type internally-cooled dehumidifier experimentally. The heat transfer coefficient had been correlated on the basis of experimental data and applied in theoretical model to predicate the dehumidifier performance.

To sum up, the effect of some operating parameters and conditions on the internally-cooled dehumidifier performance had been analyzed experimentally in previous studies. But compared with adiabatic one, less literature were reported due to its more complicated structure. Moreover, the analysis of influencing factors was not comprehensive enough. It was also found that most of previous dehumidifiers were complicated in terms of structure, making it difficult to observe the real contact area for heat and mass transfer. This might result in error in calculating the mass transfer coefficient. Finally, the liquid desiccant dehumidifier might be suitable for hot and humid area, such as Hong Kong. However, its application for this kind of climate is still limited.

Therefore, in present work, a single channel internally cooled dehumidifier was designed for better investigation of its performance under various conditions. It was easy to observe the heat and mass transfer area, which made the calculation of mass transfer coefficient more accurate. The operating conditions of the air were set on the basis of Hong Kong climate. The dehumidifier performance was evaluated by the air absolute humidity change and mass transfer coefficient. Compared with previous studies, the influences of various factors were analyzed more intensively in present work.

2. Description of test rig

To investigate the mass absorption of falling film on vertical surface in the dehumidifier, a single channel experimental setup was fabricated, as shown in Fig. 2. The size of the test channel was 400×100×500 mm ($L \times W \times H$). In the channel, the air and solution flowed in opposite directions. The test rig was mainly composed of three paths for three different kinds of media, which were desiccant solution, air and water. The real picture of the test rig is provided in Fig. 3. The solution flow loop was designed to enable the transportation of liquid desiccant solution in the test section. It was mainly consisted of a solution provider tank, a solution distributor, a solution collector, a solution collection tank, a pump and some PVC pipes for connection. The air duct system made the moist air flow in countercurrent way with desiccant solution, exchanging moisture and heat with the desiccant. An electrode humidifier and several fin electric heaters were installed to handle the air to the set temperature and humidity. The water loop offered cold/hot water which flowed behind the working surface. It consisted of a cold/hot water producer and some pipes.

During the experiment, the inlet parameters of air, solution and water were controlled within certain ranges. The air and solution temperature could be adjusted to the pre-set values with Proportion Integration Differentiation (PID) controllers. The air flow rate was adjusted by air valve with manual operation. The air humidity was controlled indirectly by direct current (DC) regulator, which could provide different DC voltages to decide the water vapor generation amount of the humidifier. The flow rates of solution and water were regulated by ball valves installed on the pipelines. The water was supplied by cold/hot water producer, which was composed of a compressor, evaporator, condenser, throttle and heater. By setting a value on the control panel, the chiller/heater could offer water entering the cavity behind the test surface with a certain temperature. All of the above control devices are presented in Fig. 4. To make the operation more convenient and safer, all of the switches were located in the control board.

The whole channel was insulated with neoprene foam to reduce environmental infection, and the main test surface was no exception.

To evaluate the dehumidifier performance, the parameters of air, solution and water needed to be measured and recorded, including the inlet and outlet temperatures of all fluids, flow rates of all fluids, air humidity, and solution concentration. The measurement instruments and specifications are shown in Table 1 and Fig. 5.

Some platinum resistance temperature detectors (RTDs) were used to measure the inlet and outlet temperatures of air, solution and water, with the accuracy of 0.1 K. The flow rates of solution and water were measured by turbine flow rate sensors, with the accuracy of ±3% of reading. The air flow rate or air velocity was obtained by the standard nozzles plus manometer. The principle of the device is to measure static pressure and total pressure in the air duct to obtain velocity pressure, which can be used to calculate the air velocity. For non-standard air condition, the formula is,