MICROORGANISM CONTAMINANTS REMOVAL IN A LIQUID DESICCANT DEHUMIDIFICATION SYSTEM

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ABSTRACT

The main focus of this research is to estimate the ability of a liquid desiccant (LD) system operation to remove microorganism particles. The dehumidification performance of the LD systems generated by using a lithium chloride (LiCl) solution as the liquid desiccant material. To verify the removal performance of microorganism particles, the experimental method was divided into cases where the process air passed or bypassed the LD unit. Two types of microorganism particles, bacteria and mold, were considered for the measurement of the microorganism particles, with a minimum fan flow rate (800 m^3/h). To verify the accuracy of the experiment, a duct system and an LD system were sealed with duct tape to prevent air leakage. Experimental results were obtained with a bio-contaminant sampler using a tryptic soy agar (TSA) and a potato dextrose agar (PDA). The measuring points were situated at a same distance from the liquid desiccant system inlet and outlet duct. The results show that the LD system has the ability to remove microorganism contaminants. The bacteria removal efficiencies were 77.5% and 81.3% for the sampling process air of 200 and 500 L, respectively, while the fungi removal efficiencies were 38.8% and 44.4% for 200 and 500 L, respectively, of sampling process air. In addition, experiment results show that the LD system significantly affected the removal of microorganism contaminants. When the process air passed through the LD unit, microorganism contaminants contained in the process air were inactivated by the sanitizing effect of the desiccant solution or by filtering of the LD unit.

KEYWORDS

Liquid desiccant, Indoor air quality, Microorganism contaminants, Removal efficiency

1 INTRODUCTION

For the last couple of decades, modern building designs have become technically advanced in order to ensure air tightness and energy saving. To inhibit heat losses from air leakage and infiltration, buildings are constructed with airtight materials and advanced technologies. However, if sufficient ventilation (i.e., fresh outdoor air) is not supplied, it could possibly cause health problems for the occupants (e.g., sick building syndrome (SBS)). To overcome this problem, a minimum required outdoor air (OA) flow rate has been recommended by ASHRAE (ASHRAE. 2013). In spite of the recommended minimum ventilation rate, the required ventilation rate is insufficient. Owing to the absence of an adequate ventilation rate, the indoor air quality (IAQ) does not meet the occupants' satisfaction level.

Several existing studies have indicated that the ventilation rate has a significant effect on the IAQ. In addition, based on the relationship between the ventilation rate and IAQ, researchers have proposed a new type of ventilator to meet the required ventilation and IAQ by using 100% OA as the supply air (SA) (Jeong et al. 2003, Kim et al. 2013). If the 100% OA system is operated without a filter, contamination of the IAQ can occur owing to pollutants in the room and secondary contamination in the polluted SA. In urban environments, there is an increased need for an appropriate response against contaminated SA when polluted OA is supplied (Baek et al. 1997).

Several studies addressed the potential of a liquid desiccant (LD) application to improve air quality of the process air (Rafique et al. 2016). In conventional heating, ventilation, and air conditioning (HVAC) systems, condensation occurs on the cooling coil surface to perform the dehumidification of process air. This causes the growth of microorganism compounds, such as bacteria and fungi, on the coil surface, which threatens indoor air quality. However, the LD system can dehumidify the process air without cooling coils causing such problems (Liu et al. 2006).

In addition, the desiccant solutions have a sanitizing effect on biological contaminants such as fungi, bacteria, and viruses. Wang (Wang et al. 2011) conducted an empirical analysis on the microorganism removal effect in an LD system using LiCl and triethylene glycol (TEG) solutions. They showed that the TEG solution provided higher microorganism removal performance than the LiCl solution. Kovak (Kovak et al. 1997) also indicated the sanitizing effect of liquid desiccant in the desiccant-based air conditioning system. The LD system prevents the growth of microorganisms inside the conditioned space indirectly through the humidity control of the indoor air (Harriman 1989).

The main purpose of this study is to empirically analyze the microorganism contaminant removal performance of the LD unit. To evaluate the microorganism removal impact of the LD unit, the existing pilot LD unit was operated and then the variation of microorganisms contained in OA was measured while the OA was passing through the LD unit. Tryptic soy agar (TSA) and potato dextrose agar (PDA) samplers were used to quantitatively estimate biological contaminant removal from the process air in an LD unit operation (BUCK Co. 2016).

To verify the direct removal efficiency of the LD unit, the experimental method was divided into a natural removal method and a forced removal method. The natural removal method is defined to be the removal effect caused by natural air flow, and the forced removal method is caused by the removal effect of the LD unit operation. The microorganism removal efficiency of the LD unit is evaluated by comparing the natural and forced removal methods.

2 SYSTEM OVERVIEW

The LD system can effectively remove latent heat loads by removing the moisture included in OA. Moisture removal performance is generated by a partial pressure difference between the process air and the desiccant solution. Any change in this partial pressure difference caused by the temperature and concentration of the desiccant solution affect the dehumidification performance (ASHRAE. 2009, ASHRAE. 2012). During the dehumidification process, the LD system may remove air contaminants by injecting the desiccant solution into the dehumidifier and passing it through the packed-bed packing material. An LD pilot system was used in this study to evaluate the air contaminants removal performance. The LD pilot system considered in this study used a LiCl solution for generating the dehumidification effect on the process air designed by 2000 m^3/h. The pilot system consisted of a packed-bed tower absorber and regenerator with solution cooling and heating sources. The dehumidification process of the process air was carried out in the absorber tower, which was packed with a honeycomb medium made of porous wood fiber material (Figure 1).

As shown in Figure 1, two dry-bulb temperature and humidity sensors (T/R1 and T/R2) and one airflow sensors (F1) are installed at the inlet and outlet of the LD unit. In addition, water temperature sensors (T1) is also installed at the cooling water supply paths. The solution concentration supplied to the absorber is also measured by using a specific gravity hydrometer.

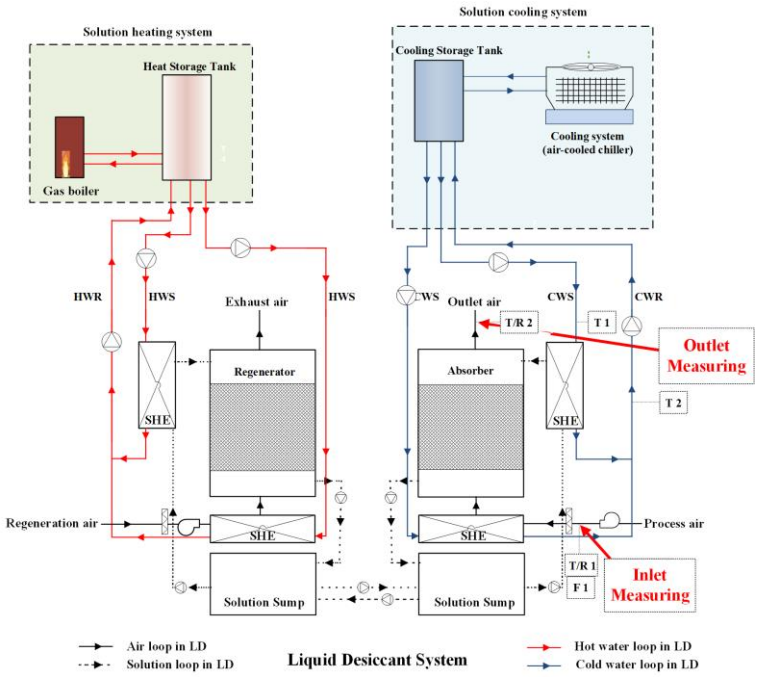

Figure 1: Schematic diagram of the LD unit

3 EXPERIMENTAL SETUP

In order to confirm microorganism removal efficiency of the LD unit with the LiCl solution, a removal efficiency of the microorganism contaminants was estimated on August 4, 2016. Bacteria and fungi were conducted as sample microorganism contaminants to measure the number of colony forming units (CFU) at the inlet and outlet of the LD system. To detect the microorganism contaminants, a bio-contaminant sampler was used to collect both bacteria and fungi by using a TSA and PDA, respectively. While detecting the microorganism contaminants, the sampler was sampled at a flow rate of 100 L/min at the inlet and outlet of the LD system. According to the characteristics of the sampler, the microorganism sampling collected was 200 L and 500 L of induced OA, four times each sampling. In addition, to verify the accuracy of the experimental data, the base condition of OA was collected by the TSA and PDA without the sampler, before the data were measured.

The experiment condition was also controlled by system bypassed/passed methods. The experimental data were measured four times for each experimental method (bypassed and passed), and were considered with the minimum system fan flow rate (800 m^3/h), in accordance with ASHRAE standard 52.2 (ASHRAE. 2012). The average dry-bulb temperature of the OA at the time of the experiments was 30–32 °C, and the average relative humidity was 52−58% (e.g., a humidity ratio between 0.0152 and 0.0174 kg/kg). In addition, the LiCl solution was maintained in a 25 °C and 36% condition and 0.63 kg/s of inlet mass flow rate while injecting into the absorber tower. Figure 2 shows the experimental conditions on the microorganism contaminants.

The microorganism contaminants were collected by a bio-contaminant sampler (BUCK BioCulture Model B30120), which can detect the microorganism contaminants by using the agar, depending on the contaminants type (BUCK Co. 2016). According to the agar type, the bacteria and fungi were collected, and then, each type of contaminant was counted in the CFU after incubating in the incubator (Vision Scientific Co. 2010). The bacteria were cultivated for 1–2 days at 32 °C and the fungi were incubated for 3–4 days at 25 °C. Table 1 shows the specification of the bio-contaminants sampler.

Table 1: Specification of the bio-contaminant sampler (BUCK Co. 2016).

Device	Type		Characteristics
Bio-contaminants sampler	Impactor type	Detection flow	30–120 L/min
		Detecting accuracy	±5% of set point
		Holes	380 (1 mm diameter)
		Compatibility	90 mm agar plate

Figure 2: Experimental conditions of the microorganism contaminants

After cultivation, the experimental data were counted with the CFU value under conducted experiment conditions. However, in order to convert to CFU per unit volume (CFU/m^3), a calibration was carried out by means of following equations.

$$l_{ave} = \frac{l_{beg} - l_{end}}{2} \quad (1)$$

$$V = \frac{l_{ave} \times T}{10^3} \quad (2)$$

$$V_{25°C,1atm} = V_{air} \times \frac{K}{T^2} \times \frac{P}{P_{1atm}} \quad (3)$$

$$F = \frac{CFU}{V_{25°C,1atm}} \quad (4)$$

$$\varepsilon_{mic} = \frac{(F_{in} - F_{out})}{F_{in}} \times 100 \quad (5)$$

A sampling flow rate of the bio-contaminants sampler can be estimated as the average flow rate during the experiment period, which can be calculated by means of Equation 1. According to the calculated average sampling flow rate, a total volume of the collected sampling air was calculated by means of Equation 2. The total volume of the collected air is estimated under experiment conditions, but in order to calibrate the total volume in standard state air (25 °C, 1 atm), Equation 3 was used. Based on the calculated standard state air volume, a concentration of the total airborne microorganism contaminants was calculated using Equation 4. In this study, the concentration of the total airborne microorganisms was considered as experimental data to evaluate the microorganism contaminants removal

efficiency of the LD system. The microorganism contaminants removal efficiency of the LD unit is presented by means of Equation 5.

4 EXPERIMENTAL RESULTS

4.1 Microorganism removal efficiency

In order to verify the microorganism removal efficiency of the LD unit, a variation of bacteria and fungi concentrations were sampled by using the bio-contaminant sampler with a TSA and PDA, respectively.

Figure 3 shows the bacteria and fungi removal efficiency of the LD unit measured in this research. One can see that bacteria removal efficiency was 77.5% and 81.3% for the sampling process air of 200 and 500 L, respectively. On the contrary, when the LD unit was bypassed, the number of bacteria colonies increased approximately 37.5% and 13.7% for 200 and 500 L of sampling air, respectively, because of resuspended bacteria from the duct surface (Figure 4).

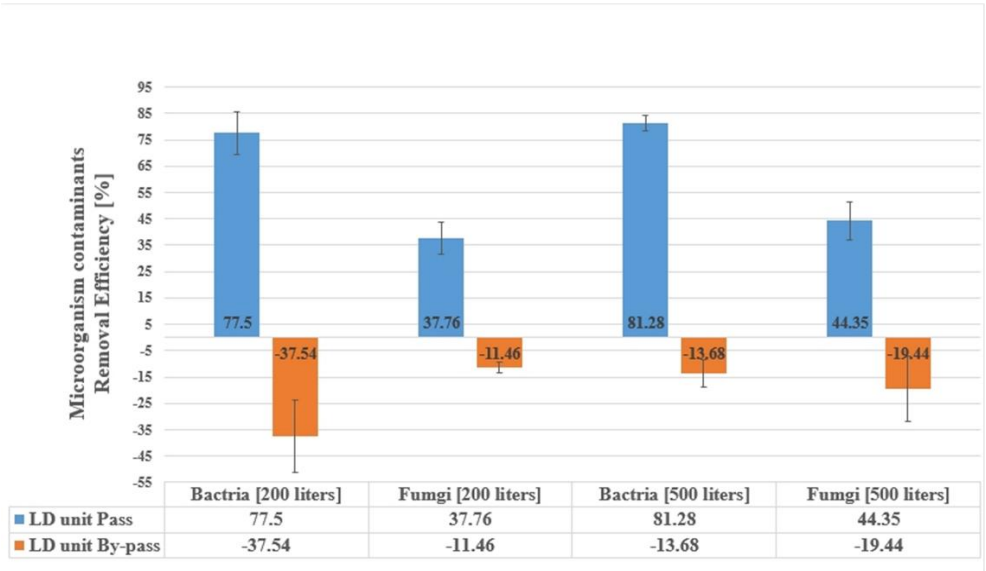

Figure 3: Microorganism removal efficiency

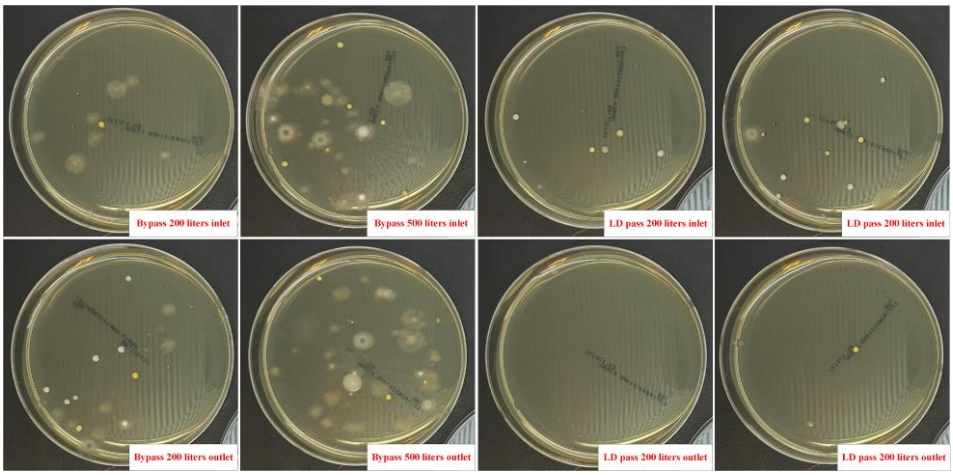

Figure 4: Representative experimental results of the bacteria

Similarly, one can also see that the fungi removal efficiency of the LD unit was 38.8% and 44.4% for 200 and 500 L of sampling process air, respectively. However, when the process air bypassed the LD unit, the results show that the number of fungi colonies was increased 11.5% and 19.4% for 200 and 500 L of sampling air, respectively, because of resuspended fungi from the duct surface (Figure 5).

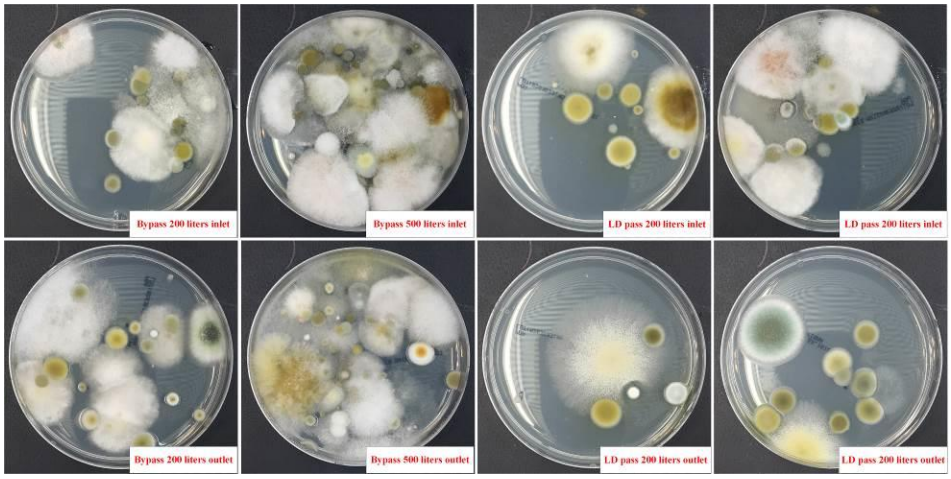

Figure 5: Representative experimental results of the fungi

4.2 Discussions

Based on the literature review of the air quality improvement potential of the LD unit, this study focused on conducting an empirical analysis on the removal ability of the LD unit. The sanitizing effect of the liquid desiccant solution observed in the study had a significant impact on microorganism removal. When the process air passed through the LD unit, the concentration of both bacteria and fungi was decreased at the outlet of the LD unit. However, these results have shown that the differences in removal efficiency between bacteria and fungi were due to the high resistance of fungi on the sanitizing materials.

5 CONCLUSIONS

In this study, the microorganism contaminant removal efficiency of an LD unit was evaluated by empirical analysis based on a pilot system operation. The literature review on the air quality improvement potential of LD units showed that the LD unit has the ability to remove microorganism contaminants. Similar to previous research, the experimental results of this study showed that the LD unit can remove microorganism contaminants.

The experimental results showed microorganism removal efficiencies of 77.5% and 81.3% for bacteria with the process air of 200 and 500 L. However, while bypassing the LD unit, the number of bacteria increased approximately 37.5% and 13.7% for the 200 and 500 L of sampled OA, respectively. Similarly, the results on fungi removal shows 38.8% and 44.4% for 200 and 500 L of collected OA. In addition, when the process air bypassed the LD unit, the removal efficiency results increased by 11.5% and 19.4% for 200 and 500 L of OA, respectively.

These results indicate that the LD unit can promptly remove microorganism pollutants that have negative effects on the human health. Considering that the outdoor air has pollutants, the

advantages of the LD unit in terms of microorganism removal performance would be helpful in improving the indoor air quality.

6 ACKNOWLEDGEMENTS

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