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Ammonia Removal Performance of Desiccant Wheel in a Clean Air Heat Pump (CAHP)

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ABSTRACT

Clean air heat pump (CAHP) is a new technology that combines air cleaning with hygro-thermal control of ventilation air. In CAHP, a regenerative desiccant wheel is used for moisture control and air cleaning. This study investigated experimentally the air cleaning performance of CAHP system for ammonia removal. The results showed that, as opposed to the operating parameters of CAHP system for Volatile Organic Compounds (VOCs) removal, ammonia could not be continuously removed when the wheel was regenerated by low-temperature thermal energy. A higher regeneration temperature, possibly more than 90℃, was required. In this case, the single-pass air cleaning efficiency for ammonia reached 86.5% when the concentration was 2.5 ppm. When the concentration of ammonia was increased to 7.1 ppm, the air cleaning efficiency was still maintained above 67%.

1. INTRODUCTION

Ammonia (NH_3) is ubiquitous in indoor environment, which is emitted from urea-based antifreeze admixtures used in the building construction and decoration materials, as well as from human metabolism, mainly including the waste from respiration and excrement (Bivolarova et. al. 2016). NH_3 is a colorless and strongly irritating odor gas, which poses a threat to the health of residents. Ammonia is usually inhaled into the alveoli in the form of gas. After being inhaled into the lungs, ammonia is easy to enter the blood through the alveoli and combine with hemoglobin to destroy the oxygen transport function. Ammonia can stimulate and corrode the upper respiratory tract of human body, weaken the resistance of human body to diseases, and cause headache, sore throat, olfactory failure, chest pain, etc (Qajar et al. 2015, Seitz et al.2012, Travlou et al. 2017). Since indoor NH_3 concentration is relatively low, long-term contact will lead to olfactory fatigue, which is difficult to arouse people's vigilance. Compared with formaldehyde, benzene and other high carcinogenic pollutants, people pay less attention to NH_3 pollution in indoor environment. However, NH_3 pollution is very common. It is reported that more than 56.2% of air samples contain excessive NH_3 through the detection and analysis of air samples of decoration rooms in Nanning (Lu et al. 2013). Therefore, it is necessary to take effective measures to remove indoor NH_3.

Clean air heat pump (CAHP) is based on the adsorption theory, and the air is purified with the regenerated silica gel rotor. The chemical formula of silica gel is $mSiO_2 \cdot nH_2O$, and the water is attached to the silicon atom in the form of hydroxyl. Because of the hydrogen bond between hydroxyl and NH_3, silica gel has a strong adsorption on NH_3 (Kittaka et al, 2009). In this study, the purification ability of silica gel rotor to NH_3 in CAHP system was focused. The influence of regeneration air temperature and NH_3 concentration on NH_3 removal was described. Finally, some suggestions were put forward for the practical operation of CAHP system in improving indoor environment, and for the further development of CAHP system.

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2. METHODS

2.1 Experimental design and procedure

The experimental system as shown in Figure 1 was established to test the deamination performance of the wheel dehumidifier in the CAHP system. As shown, the experimental system consisted of CAHP and its ventilation system, outdoor air conditioning unit and additional electric heater. The CAHP system adopted 450 mm diameter and 200 mm thick honeycomb ceramic silica gel rotor. The section of silica gel rotor was divided into two parts: one was connected with process air duct, the other was connected with regeneration air duct. Meanwhile, the pretreated outdoor air was divided into two streams, one stream was mixed with a large number of return air to form a process stream, which was dehumidified, purified, cooled by the silica gel rotor and evaporated by the heat pump, and then sent to the test room. The other stream was used to regenerate the silica gel rotor, which was heated by the heat pump condenser, and then discharged with a small amount of return air.

In the implementation, firstly, the air flow speed of process / regeneration air was adjusted to two 260 L/s and 120 L/s, respectively. The outdoor air volume of process air was 62.4 L/s. Secondly, adjust the outdoor air state to the given temperature and relative humidity, and then start the CAHP rotor and heat pump motor to achieve the given regeneration air temperature. The outdoor environment was continuously set at 25 ℃, 60% RH, and the indoor air conditioning was set at 23 ℃, 55% RH. Air temperature, humidity, and air flow were measured continuously at approximately one second intervals during the equilibrium of humid and hot conditions. Innova 1312 was used to measure the NH_3 concentration of four sampling points in real time. The concentration of NH_3 was controlled in the range of 2.0-7.0 ppm. The concentration of ammonia was recorded on a computer at intervals of about 40 seconds. When the chemical concentration balance was established after adding ammonia, the average concentration measured in S1-S4 was used to calculate the ammonia removal rate and desorption rate.

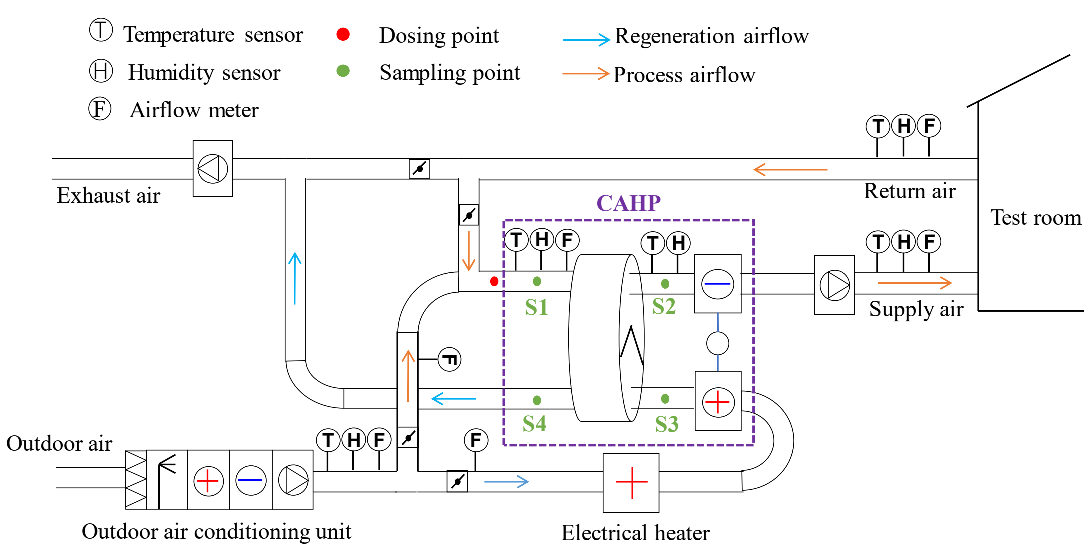


Figure 1 Schematic diagram of experimental system

2.2 Data treatment

In order to evaluate the NH_3 removal performance of the CAHP system, the removal efficiency (η) was calculated by the following equation was adopted as one performance index:

$$\eta = \frac{(c_{S1} - c_{S3}) - (c_{S2} - c_{S3})}{(c_{S1} - c_{S3})} = \frac{c_{S1} - c_{S2}}{c_{S1} - c_{S3}} \times 100\% \qquad (1)$$

Where c_{S1}, c_{S2}, c_{S3} and c_{S4} are the average concentrations of NH_3 in the sample locations S1~S4, respectively. c_{S3} represents the background pollutant concentration level that is equal to the NH_3 concentration in outdoor air.

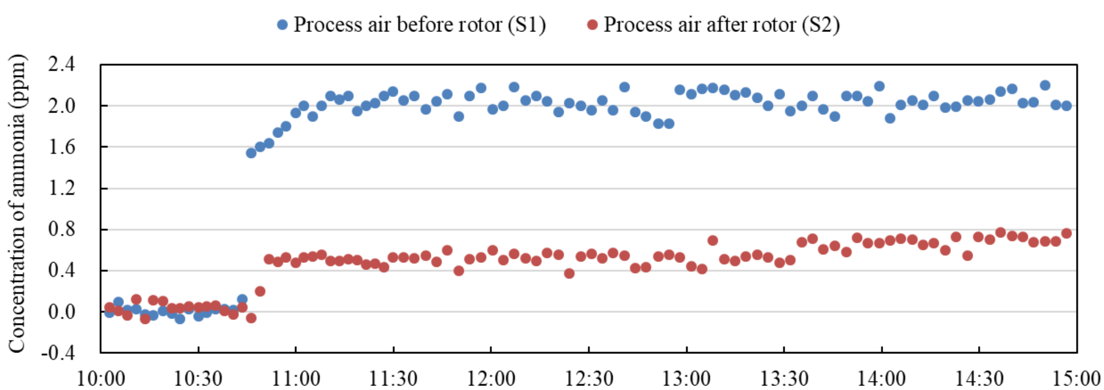
To investigate the mass balance between the process part and regeneration part, the desorption rate of NH_3 (ε) was also calculated as equation (2). It represents the ratio between the mass of NH_3 desorbed on the regeneration part and the mass of ammonia adsorbed on the process part.

$$\varepsilon = \frac{Q_{reg}(c_{S4} - c_{S3})}{Q_{pro}(c_{S1} - c_{S2})} \times 100\% \qquad (2)$$

Where Q_{pro} and Q_{reg} are the process airflow rate and regeneration airflow rate (L/s).

3. RESULTS

In the operation, the regeneration temperature was set to 60℃ to test the NH_3 removal of CAHP. Figure 2 shows the time course of the NH_3 concentration measured at four sampling locations, representing the NH_3 concentration upstream and downstream of the process/regeneration air. At 10:45, ammonia was added to the circulation pipeline, and from 10:45-13:00, the concentration of NH_3 at S1, S2 and S4 gradually increased and stabilized. However, after 13:00, the ammonia concentration in the downstream of S2 continued to increase, while the ammonia concentration in the downstream of S4 decreased, which meant that the NH_3 removal ability of CAHP was gradually lost, and the NH_3 removal of silica gel rotor appeared obvious degradation.



(a)

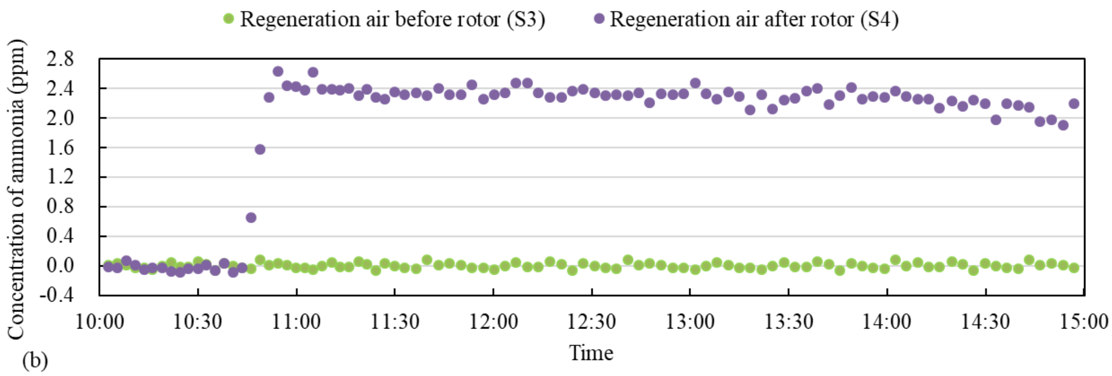


Figure 2 Time course ammonia concentration measured by Innova 1312 with regeneration air temperature of 60°C.

After the test, a large amount of NH_3 accumulated on the silica gel rotor. Then increase the temperature of regeneration air, and observe the desorption of NH_3 on silica gel rotor. At the process side of the rotor, the ammonia was not added anymore. Therefore, when the regeneration air temperature was set at 70 ℃, 80 ℃ and 90 ℃, the time course NH_3 concentration measured in the regeneration air (S3 and S4) is shown in Figure 3. From these observations, although the ammonia on the rotor could be released when the system operated under the condition of regeneration temperature at 80°C, the desorption effect was more thorough at 90°C.

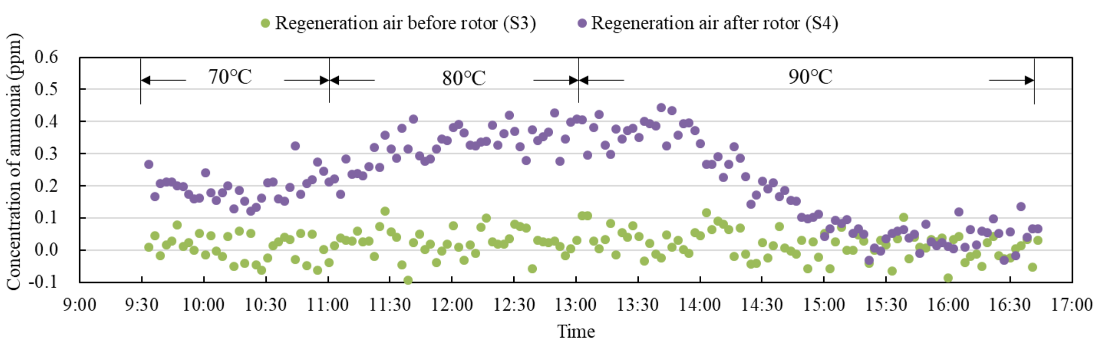


Figure 3 Time course ammonia concentration measured upstream (S3) and downstream (S4) of regeneration air with regeneration air temperature of 70°C, 80°C and 90°C

Then the NH_3 purification performance of CAHP at the regeneration temperature of 90 ℃ was studied. Figure 4 shows the air purification performance of CAHP for NH_3 at the regeneration temperature of 90 ℃ with NH_3 concentration of 2.5, 4.7 and 7.1 ppm in the process air. The experimental data showed that with the increase of NH_3 concentration, the experimental data showed a downward trend. However, NH_3 was still above 67.0%, indicating that CAHP has good air purification capacity.

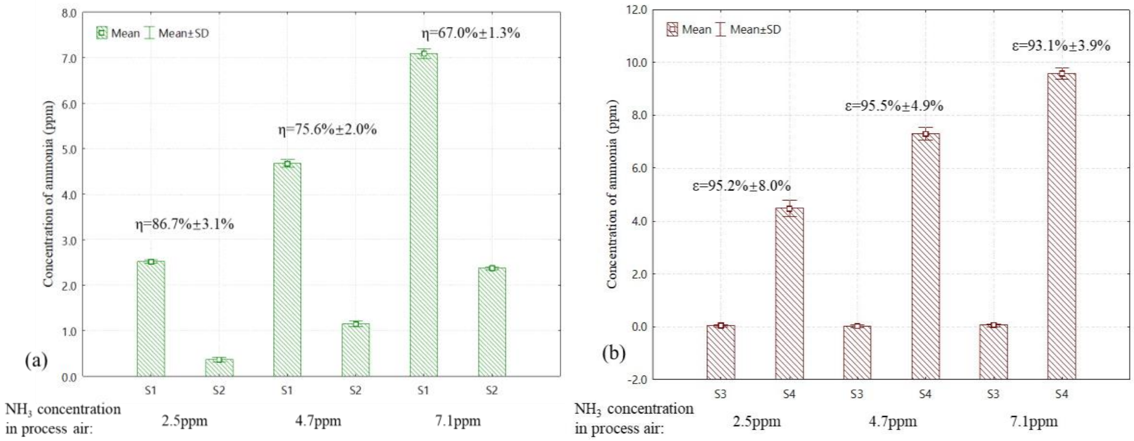


Figure 4 Average concentration of ammonia with three different ammonia dosing rates.

4. DISCUSSIONS

From the experimental observation of this study, when the temperature is lower than 60 ° C or CAHP is applied to the place with high NH_3 concentration, the adsorption of silica gel rotor will gradually lose. To solve this problem, on the one hand, we can start from the operation strategy of CAHP and adopt the single objective control based on automation system to solve it. If the concentration of indoor air pollutants is emphasized where CAHP is used, dehumidification will be an additional function to assist in improving indoor air quality. The setting of CAHP operation parameters should meet the requirements of indoor air cleanliness. However, it is inevitable that CAHP's energy-saving advantages may be lost due to higher air cleanliness and higher regeneration air temperature. On the other hand, looking for another absorbent that cannot only effectively absorb water and various air pollutants in the air, but also can easily regenerate at low temperature to replace silica gel. In recent years, Metal-organic frameworks (MOFs), a new type of porous materials, is evolved in the field of indoor air quality control, which is attracting high scientific and commercial interests. Among hundreds of MOFs materials, MIL (Materials of Institute Lavoisier) series materials not only have higher adsorption capacity and faster adsorption rate for indoor VOCs, but also have been proved to have reusable NH_3 absorption and excellent NH_3 stability (Ren et al. 2012). From these scientific findings, MIL series materials can be used as an attractive alternative to silica gel as a CAHP absorbent to achieve dehumidification and air purification with low energy input. For this respect, the air cleaning capacity of the CAHP with MIL series materials and the perceived indoor air quality are worth further study.

CAHP is an air filter. The NH_3 concentration in the air after treatment should meet the national standard. In this study, the concentration of ammonia in the air to be treated is between 2.0-7.0 ppm, which is significantly higher than the concentration of NH_3 in the real living environment. The experimental results show that when the indoor ammonia concentration is less than 2.0 ppm, the purification efficiency of CAHP will exceed 86%. CAHP has the ability to make the treated air meet the national standard. However, it should be verified in future research. CAHP is also an energy system. It is necessary to measure the energy consumption of heat pump and heater when CAHP is used for pollutant removal and air dehumidification.

5. CONCLUSION

In this study, the NH_3 removal performance of the CAHP has been obtained by means of an experimental investigation. The regeneration temperature strongly influenced the NH3 removal performance of the CAHP. The regeneration temperature of 60℃ for the silica gel rotor in CAHP was not valid for continuous removal of NH3 but the regeneration temperature more than 90℃ it was. The NH_3 removal efficiency and desorption efficiency were 86.5% and 93.8% under the condition of the regeneration temperature of 90℃, NH_3 concentration in process air of 2.5 ppm. With an increase of NH_3 concentration in process air (2.5~7.1 ppm), the removal efficiency decreased but still above 67.0%.

ACKNOWLEDGMENTS

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REFERENCES

Bivolarova, M.P., Melikov, A.K., Mizutani, C., Kajiwara, K., Bolashikov, Z.D. 2016. Bed-integrated local exhaust ventilation system combined with local air cleaning for improved IAQ in hospital patient rooms. *Building and Environment* 100: 10-18.

Kittaka, S., Morimura, M., Ishimaru, S. 2009. Effect of confinement on the fluid properties of ammonia in mesoporous of MCM-41 and SBA-15. Langmuir 25 (3):1718–1724.

Lu, R.G., Chen, Q.D., Huang, L. 2013. Investigation on indoor air pollution in decorated rooms and its prevention measures in Nanning City. *Occup and Health* 29(15): 1929-1930.

Qajar, A., Peer, M., Andalibi, M.R., Rajagopalan, R., Foley, H.C. 2015. Enhanced ammonia adsorption on functionalized nanoporous carbons. *Microporous and Mesoporous Materials* 218: 15-23.

Ren, L.F., Chen, S.G., Yang, K. 2012. Synthesis of metal-organic frameworks and the application as adsorbents in adsorptive removal of volatile organic compounds: A review. *Chemical Industry and Engineering* 32(3): 11-23.

Seitz, H., Germán, E., Juan, A., Irigoyen, B. 2012. Adsorption of ammonia on vanadium-antimony mixed oxides. *Applied Surface Science* 258(8): 3617.

Travlou, N.A., Bandosz, T.J. 2017. N-doped polymeric resin-derived porous carbons as efficient ammonia removal and detection media. *Carbon* 117: 228-239.