Study on the influencing factors of Heat and Humidity and Vocal Coupling Adsorption Characteristics of Runner

Hong Hao¹, Siyu Li*¹

¹ School of Municipal and Environmental Engineering, Shenyang Jianzhu University, Shenyang, Liaoning, China
*Corresponding author’s e-mail: hj_hh@sjzu.edu.cn

Abstract: In order to realize the purpose of indoor air purification and dehumidification at the same time, the mathematical model of heat and humidity and VOC coupling adsorption was established. The coupled adsorption characteristics of heat and humidity and VOC and the influence law of each factor were simulated by using VB program. The results show that the higher the inlet humidity is, the better the water desorption is, but not the adsorption and desorption of toluene. And the higher the inlet temperature of the treated air is, the more unfavorable the adsorption and regeneration of moisture and VOC is. Different toluene concentration in the inlet of air affected mainly its own adsorption and desorption, but had little effect on the adsorption and desorption of toluene. The increase of humidity in the inlet of regenerated air is not conducive to the desorption of water, but can promote the adsorption and desorption of toluene. The increase of inlet temperature of regenerated air can promote the adsorption and desorption of water and VOC. The coupling of heat and moisture and VOC on the runner can be adsorbed and purified at the same time.

1. Introduction

Dehumidification and air purification technology have always been important aspects of indoor air quality research. Dehumidification wheel can reduce indoor air humidity, and also has a good purification ability for volatile organic compounds VOC[1,2]. In China, Feng Qing et al.[3] established a two-dimensional mathematical model of heat and mass transfer for thermal-wet coupling adsorption of runner[4]. By solving the governing equation and programming RDEH program, the simulation results were compared with experimental data of Barby[5] to verify the correctness of the model. Banks and Close[6] from the United States analyzed the coupled heat and mass exchange process in porous media by nonlinear analogy method and predicted the performance of silica gel air drier. Previous studies[7,8] show that porous adsorption materials can meet the needs of dehumidification and adsorption of VOC and other pollutants at the same time. Therefore, the performance of heat - moisture and VOC coupling adsorption and purification of the runner was studied in this paper.

2. Numerical simulation and result analysis

The design conditions of air parameters in the study are as follows: inlet air temperature in the treatment area is 30°C. Inlet air toluene concentration is 10μg/m³. The values of toluene concentration and other influencing factors selected in this paper are shown in Table 1.
Table 1. Value table of influencing factors

| Affecting factors                                      | Evaluation |
|--------------------------------------------------------|------------|
| Handle air inlet humidity (kg/kg)                      | 0.01 0.013 0.016 |
| Handle air inlet temperature (°C)                      | 25 30 35    |
| Treatment of toluene concentration in air inlet (μg/m³) | 300 500 700 900 |
| Inlet humidity of regenerated air (kg/kg)              | 0.01 0.013 0.016 |
| Regenerated air inlet temperature (°C)                 | 60 70 80    |

2.1. Addressing the influence of air inlet humidity

Figure 1: Temperature and mean temperature at outlet of air inlet and regeneration zone corresponding to different treatments.

Figure 2: Humidity and average humidity of air inlet and outlet of regeneration zone corresponding to air inlet humidity of different treatments.

Figure 3: Concentration and average concentration of toluene in circumferential direction at outlet of different treatment air inlet humidity corresponding to treatment and regeneration area.

Figure 1: for the treatment area, the humidity of the treated air inlet is higher, the temperature of the treated air outlet is higher, and the corresponding average temperature of the outlet is also higher. For the regeneration area, the result is opposite. Figure 2: For the treatment area, the average humidity at the exit corresponding to the humidity at the inlet of different air treatments is $7.3038 \times 10^{-3}$ kg/kg, $9.5195 \times 10^{-3}$ kg/kg and $1.1839 \times 10^{-2}$ kg/kg. For the regeneration area, the average humidity at the exit corresponding to the humidity at the air inlet of different treatments is $1.9415 \times 10^{-2}$ kg/kg, $2.1233 \times 10^{-2}$ kg/kg and $2.2747 \times 10^{-2}$ kg/kg. It shows that the increase of humidity in air inlet is beneficial to the desorption of water.
Figure 3: for the treatment area, the greater the humidity of the inlet of the treated air, the higher the concentration of toluene at the outlet, that is, the less sufficient the purification; For the regeneration area, the greater the humidity of the inlet of the treated air, the smaller the concentration of toluene at the outlet, that is, the less sufficient the regeneration.

In summary, the increase of air inlet humidity is beneficial to water desorption, but the increase of air inlet humidity is not conducive to toluene adsorption purification and desorption.

2.2. Deal with the effects of air inlet temperature

Figure 4: the average outlet temperatures corresponding to the air inlet temperatures of different treatments are 39.7198℃, 42.9725℃ and 46.2514℃. For the regeneration zone, the average outlet temperature corresponding to different air inlet temperatures were 33.6596℃, 37.9981℃ and 42.1964℃. Figure 5: the higher the inlet temperature of the treatment air, the greater the humidity of the corresponding outlet air, that is, the more insufficient the dehumidification. For the regeneration zone, the higher the inlet temperature of the treated air, the smaller the outlet air humidity, so the higher the inlet temperature of the treated air is, the more unfavorable the adsorption and regeneration of water.

Figure 6: the higher the inlet temperature of the treated air is, the higher the toluene concentration in the outlet air, that is, the increase in the inlet temperature of the treated air is not conducive to the purification of VOC. For the regeneration zone, the higher the inlet temperature of the treated air, the lower the toluene concentration of the outlet air, that is, the increase of the inlet temperature of the treated air is not conducive to the regeneration of VOC.
In summary, the higher the inlet temperature of the treated air is, the more unfavorable it is for the adsorption and regeneration of water and VOC.

2.3. Effect of treatment on toluene concentration in air inlet

![Graph of circumferential temperature and mean](image1)

Figure 7: The circumferential temperature and mean. Figure 7: when the concentration of toluene at the inlet of the treated air is different, the outlet temperature of the treated air changes little. The difference in temperature is about ±0.03°C, that is, the concentration of toluene at different inlets has little effect on the temperature.

![Graph of relative humidity and average humidity](image2)

Figure 8: Relative humidity and average humidity of treatment and regeneration zone outlet at different treatment air inlet toluene concentrations along the circumferential direction.

![Graph of concentration and average concentration of toluene](image3)

Figure 9: The concentration and average concentration of toluene in the circumferential direction at the outlet of the regenerated area corresponding to the concentration of toluene at the inlet of the air treated with different treatments.

Figure 8: different treatment air inlet toluene concentration corresponding to the treatment and regeneration zone outlet along the circumferential humidity and average humidity difference is not big, the difference is about $2 \times 10^{-3}$ kg/kg, is due to the VOC content in the air is far lower than the content of moisture, so in the process of adsorbent adsorption of moisture and VOC, moisture is easier to adsorb, VOC concentration change has little effect on dehumidification. Figure 9: although the change of toluene concentration at the inlet of the treatment air has little effect on dehumidification, it has a great influence on the adsorption of toluene itself.

In summary, it is concluded that the toluene concentration of different air inlets is mainly affected by their own adsorption and desorption, and has little effect on the adsorption and desorption of water.
2.4. Influence of humidity on inlet of regenerated air

Figure 10. Temperature and average temperature of the outlet in the circumferential direction of the treatment and regeneration zone corresponding to different regeneration air inlet humidity.

Figure 11. Humidity and average humidity at outlet of regenerated air along circumferential direction corresponding to different inlet humidity of regenerated air.

Figure 10: The greater the inlet humidity of reclaimed air, the smaller the air outlet temperature. For regeneration zone, the greater the inlet humidity of regeneration air, the greater the outlet temperature of air.

Figure 11: The average air outlet humidity were $9.2029 \times 10^{-3} \text{ kg/kg}$, $9.5195 \times 10^{-3} \text{ kg/kg}$, $9.8209 \times 10^{-3} \text{ kg/kg}$. For the regeneration area, the average air outlet humidity is $1.9130 \times 10^{-2} \text{ kg/kg}$, $2.1233 \times 10^{-2} \text{ kg/kg}$, and $2.3371 \times 10^{-2} \text{ kg/kg}$. It indicates that the increase of inlet humidity of regenerated air is not conducive to the adsorption of water.

Figure 12. Concentration and average concentration of toluene in circumferential direction at outlet of different regenerated air inlet and outlet of regenerated air.

Figure 12: The average concentrations of toluene in the outlet air were $1.0384 \times 10^{-7} \text{ kg/kg}$, $0.8639 \times 10^{-7} \text{ kg/kg}$ and $0.7044 \times 10^{-7} \text{ kg/kg}$, respectively, that is, the higher the inlet humidity of the regenerated air was, the lower the concentration of toluene in the outlet air was. For the regeneration zone, the average concentrations of toluene in the outlet air were $6.3532 \times 10^{-7} \text{ kg/kg}$, $7.2435 \times 10^{-7} \text{ kg/kg}$ and $8.1526 \times 10^{-7} \text{ kg/kg}$, respectively. The higher the inlet humidity of the regeneration air, the higher the concentration of toluene in the outlet air, indicating that the increase of the inlet humidity of the regeneration air promotes the adsorption and desorption of toluene.

In summary, the increase of inlet humidity of regenerated air is not conducive to the adsorption of water, but it can promote the adsorption and desorption of toluene.
2.5. Influence of inlet temperature of regenerated air

Figure 13: Treatment of different inlet temperatures of regenerated air and the circumferential and mean temperatures of outlet of regenerated air.

Figure 13: the inlet temperature of regenerated air increases, and the corresponding outlet air temperature also increases. For the regeneration zone, the higher the inlet temperature of the regenerated air is, the higher the temperature of the corresponding outlet air is.

Figure 14: Humidity and average humidity in circumferential direction of outlet of different regenerated air inlet and outlet of regenerated air.

Figure 14: the higher the inlet temperature of regenerated air is, the lower the outlet air humidity is. For the regeneration area, the higher the inlet temperature of regenerated air is, the higher the humidity of outlet air is, that is, the higher the inlet temperature of regenerated air promotes the adsorption and desorption of water. Figure 15: the higher the inlet temperature of reclaimed air, the lower the outlet air toluene concentration. For the regeneration zone, the higher the inlet temperature of regeneration air, the higher the outlet air toluene concentration.

In summary, the increase of inlet temperature of reclaimed air can promote the adsorption and desorption of water and VOC at the same time.

3. Conclusions
   - The increase of air inlet humidity is beneficial to the desorption of water, the increase of air inlet humidity is not conducive to the adsorption purification and desorption of toluene.
The higher the inlet temperature of treatment air is, the more unfavorable it is for the adsorption and regeneration of water and VOC, that is, the lower the inlet temperature of treatment air is, the more favorable it is for the adsorption and regeneration of water and VOC.

The effects of different treatments on the concentration of toluene in air inlet were mainly their own adsorption and desorption, and had little effect on the adsorption and desorption of water.

The increase of inlet humidity of regenerated air is not conducive to water desorption, but it can promote the adsorption and desorption of toluene. The increase of inlet temperature of recycled air can promote the adsorption and desorption of water and VOC simultaneously.

Acknowledgments
This work is supported by the National Natural Science Foundation of China (52078308): Study on coupled migration discontinuous model of ham and dynamic performance of porous crack retaining structure.

References
[1] Xu, Q.J. (2011) Study on adsorption and reaction Mechanism, characteristics and Evaluation of Indoor VOC purifying Materials. D. Tsinghua University.
[2] Long, W.L. (2013) Adsorption and Desorption of low concentration volatile Organic compounds on spherical activated carbon. D. East China University of Science and Technology.
[3] Feng, Q., Yu, J.D., Zhang H.F. (1994) Mathematical model and RDEH program of rotary desiccant dehumidifier. J. Journal of Solar Energy., 15(3): 209-217.
[4] Zhang, L.Z., Niu, J.L. (2002) Performance comparisons of desiccant wheels for air dehumidification and enthalpy recovery. J. Applied Thermal Engineering., 22:1347-1367.
[5] Pla-Barby, F.E., Vliet, G.C., (1979) Rotary bed solid desiccant drying: An analytical and experimental investigation. In: joint ASME/AICHE 18th National Heat Transfer Conference. San Diego. pp. 7-8.
[6] Close, D.J., Banks, P.J. (1972) Coupled Equilibrium heat and single adsorbate transfer in fluid flow through a porous medium:II. J. Sci. Predictions for a silica-gel air-drier using characteristic charts., 27:1157-1169.
[7] Fang, L., Zhang, G., Fanger, P.O. (2005) Experimental Investigation of the Air Cleaning Effect of a Desiccant Rotor on Perceived Air Quality. Proceedings of Indoor Air 2005. pp. 2976-2980.
[8] Hao, H. (2006) Study on the performance of coupled Air-conditioning system with desiccant Runner and Heat pump. D. Tianjin University.