Research on the influence of relative humidity on the purification efficiency of sponge activated carbon system purification system

Chunzhen Qiao*, Ruijie Zhao, Jinxin Hao, Yuyi Pan, Yuzhe Tian, Nanyu Zhao

North China University of Technology, Beijing, 100144, China

Abstract: An indoor air purification system coupled with adsorption and heat storage was designed based on a prefabricated building, which has the advantages of high purification efficiency, does not take up indoor space and does not require additional power consumption. It has been shown that the relative humidity has a significant impact on the purification effect of particulate matter. Using sponge activated carbon as adsorption material, the effect of different relative humidity on the purification efficiency of PM2.5 and PM10 was experimentally studied, and the purification effect of the purification system on PM2.5 and PM10 under various relative humidity conditions was analyzed. The results show that in the relative humidity interval of 20%-70%, with the increase of relative humidity, the sponge activated carbon purification system shows an increasing trend in the purification efficiency of PM2.5, and the effect on the purification efficiency of PM10 is not obvious.

1 Introduction

Long term exposure of the human body to high concentrations of PM2.5 and PM10 can trigger various diseases[1-2], and it is imperative to seek an efficient and energy-saving method for particle removal.

At present, the main way of indoor air purification is still to add filtering device in the air conditioning system or directly place air purifiers indoors[3-4], which cannot simultaneously meet the needs of low energy consumption, good purification effect, convenient maintenance and other aspects in the later stage. In recent years, domestic and foreign scholars have experimented and studied the adsorption and purification effects of various composite materials on inhalable particulate matter and TVOC under different conditions[5-6]. This article designs an indoor air purification system that combines adsorption and heat storage based on prefabricated buildings. By placing the purification system into a hollow wall that can be opened and closed, the system is equipped with sponge activated carbon that can adsorb particles and phase change materials that play a role in heat storage. The purification device induces indoor air to continuously enter the wall through active or passive ventilation, achieving the effect of purifying pollutants in the air. Early experiments have shown that activated carbon particles as adsorption purification materials can effectively remove formaldehyde and inhalable particulate matter (PM2.5 and PM10) in indoor air[7]. Under simulated heat storage conditions, the system has a better purification effect on inhalable particles[8-9].

Activated carbon particles are considered to be the best material for purifying indoor PM and gaseous pollutants due to their well-developed pore structure and low price. However, activated carbon particles are not easy to modularize and the regeneration method is complicated after adsorption of particles. Therefore, in this paper, a homemade sponge activated carbon was used instead of activated carbon particles for the experiments.

Previous studies have shown that relative humidity can has an impact on the sedimentation and adsorption efficiency of fine particulate matter[10-12]. This article is based on the adsorption heat storage coupling air purification system established in the previous research of the project[13].The experimental study investigates the effect of sponge activated carbon purification system on the purification efficiency of PM2.5 and PM10 under different temperature and humidity conditions.

2 Experiment

2.1 Basic properties of sponge activated carbon adsorption and purification module

The raw materials for sponge activated carbon adsorption and purification module are water, polyvinyl alcohol, activated carbon powder, starch, sulfuric acid solution, formaldehyde solution, sodium lauryl sulfate, sodium bicarbonate, and the activated carbon powder is fixed on the three-dimensional grid structure formed by the reaction by using the acetalization reaction characteristics of polyvinyl alcohol and formaldehyde under acidic conditions, and a sponge-like activated carbon material

*Corresponding author's e-mail: qcz@ncut.edu.cn

with rich pore structure, good water absorption and easy cleaning is made. The density of the sponge activated carbon is 0.15 g/cm3, and the water absorption quality is 5.66 times that of its own mass. The appearance of sponge activated carbon and the internal structure under electron microscopy are shown in Figure 1 and Figure 2. Due to the use of formaldehyde in the process of module fabrication, the formaldehyde concentration verification experiment was carried out on the sponge activated carbon module in the range of 0~70°C, and the results showed that the sponge activated carbon would not release formaldehyde when used in the temperature range of 0~70°C.

In this paper, based on the air purification system with adsorption and heat storage coupling established in the previous research of the subject, we seek a method to rapidly remove respirable particles and gaseous pollutants indoors while storing heat, and experimentally study the effect of relative humidity on the purification efficiency of the sponge-filled activated carbon system by using sponge activated carbon as the adsorption and purification material.

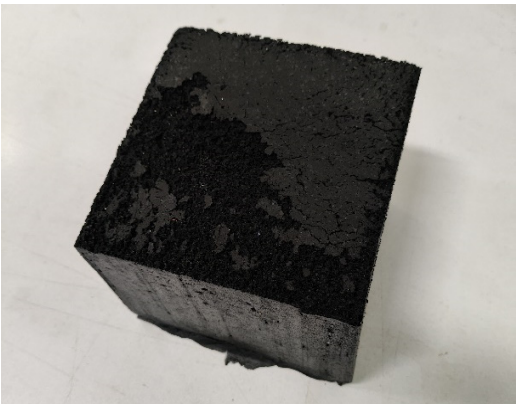

Fig.1. The appearance of sponge activated carbon.

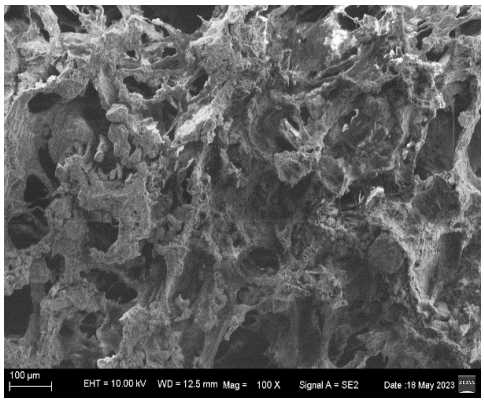

Fig.2. Internal structure of spong activated carbon under electron microscope.

2.2 The construction of the experimental platform

Earlier studies have experimentally investigated the purification effect of PM2.5 and PM10 when the system is filled with activated carbon particles and sponge activated carbon under thermal storage[8-9], non-thermal storage[13-14], active ventilation, and passive ventilation conditions. This experiment focuses on the adsorption and purification effect of PM2.5 and PM10 when the system is filled with sponge activated carbon.

The air purification system test bench shown in Figure 3, which is composed of an outer glass test chamber and an internal purification device. The test chamber is 1 m long, 1 m wide and 1.5 m high, the internal purification device is bonded by acrylic plates, which is 0.6 m long, 0.2 m wide and 1.1 m high, the air inlet is in the lower part of the device, and it is 0.6 m long and 0.1 m high, the air outlet is at the top of the device, and a fan with a diameter of 0.12 m is placed. The purification device is equipped with steel frames. The prepared sponge activated carbon is placed on the steel frames as shown in Figure 4, with a total of three layers. There is a 10 cm air channel left between each layer. In order to realize the need for zero energy consumption for subsequent systems, solar cells are designed on the outside of the purification unit.

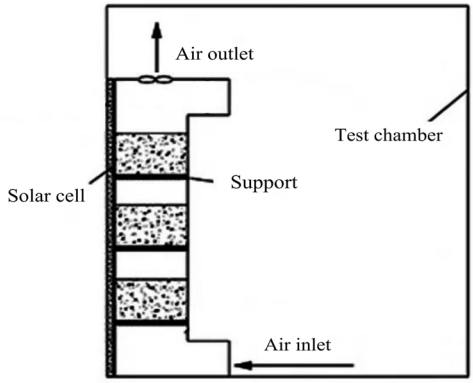

Fig. 3. Test chamber diagram.

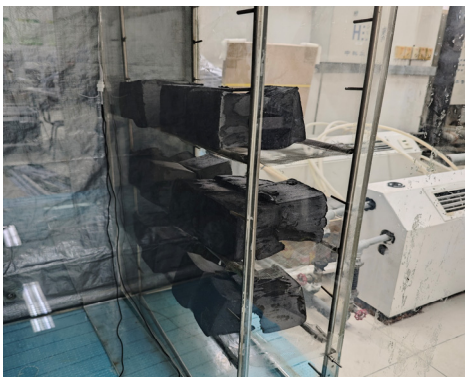

Fig.4. Sponge activated carbon module in purification unit.

2.3 Experimental methods

In the experimental group that discussed the correlation between purification efficiency and humidity, humidifier was placed in the experimental device to improve and control the humidity in the laboratory module, and B-HT-RS30 produced by Lankon Electronic Technology Company was used to measure the humidity in the laboratory module.

The target pollutants PM2.5 and PM10 were generated by burning mosquito-repellent incense. The initial concentration of PM2.5 was (350±50)μg/m^3, and the concentration of PM10 was more than 450μg/m^3, and the fan air volume was 78 cfm. The duration of each experiment was 30min. Before the experiment began, the

sponge activated carbon was tightly placed on the steel frame of the adsorption device, which placed three layers with spacing of 10 cm and then seal the laboratory module. Put the lit mosquito repellent incense into the laboratory module through the reserved hole, and use the DT-9851M air quality detector to monitor the concentration of PM2.5 and PM10. Put the lit mosquito repellent incense into the experimental chamber through the reserved hole, and use the DT-9851M air quality detector to monitor the concentration of PM2.5 and PM10. When the concentration of PM2.5 in the laboratory module is greater than 350μg/m^3 and the concentration of PM10 is greater than 450μg/m3, the mosquito repellent incense is taken out and start the experiment. The sampling time is 30s. The sampling interval is 1.5 min.

The purification efficiency of the purification system is calculated by equation (1):

$$\eta = \frac{C_0 - C_i}{C_0} \times 100\% \quad (1)$$

Where C_0 is the corresponding particle concentration in the cabin at the initial time[μg/m^3], C_i [μg/m^3] is the corresponding particle concentration in the chamber at the current moment.

3 Results and analysis

Figure 5 shows the comparison of the purification efficiency of PM2.5 after 30 min of sponge activated carbon purification system at different humidities. It can be seen that under the condition that the relative humidity is lower than 50%, the purification efficiency of the system for PM2.5 is about 80%, and the humidity has little effect on the purification efficiency. After the humidity is higher than 50%, the purification efficiency is improved to a certain extent. The maximum purification efficiency is 95.8% at 70% relative humidity.

Figure 6 shows the relationship between PM2.5 concentration and time in the experimental cabin, and it can be seen that under all experimental conditions, the decline relationship between particulate matter concentration over time showed a trend of first fast and then slow, and the fastest decline trend was concentrated within 20 min after the start of the experiment. Under the experimental condition of 20%-60% relative humidity, the downward trend of PM2.5 was similar, and the trend was first fast and then slow before and after 20 min. Under the condition of 70% relative humidity, the PM2.5 concentration decreased sharply after 3 min and finally flattened after 20 min.

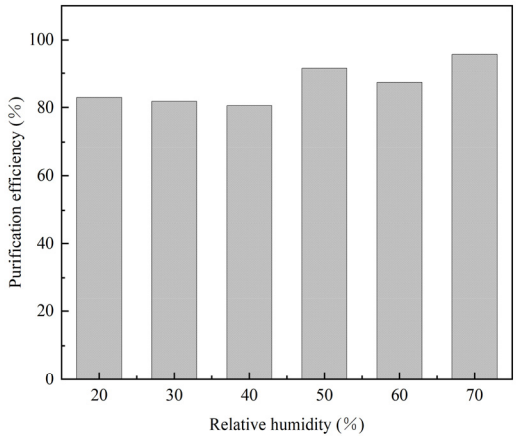

Fig. 5. Purification efficiency of PM2.5 under different relative humidity.

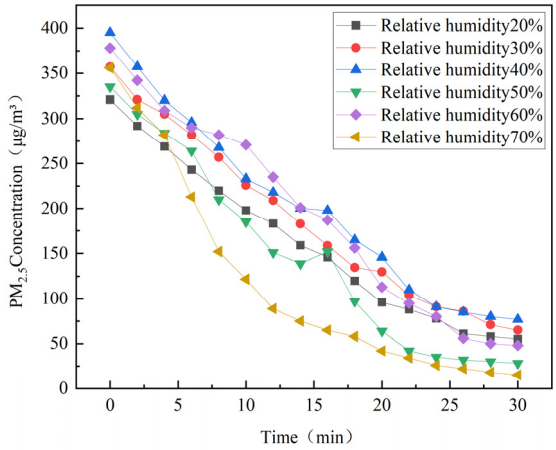

Fig. 6. PM2.5 concentration in cabin with different relative humidity.

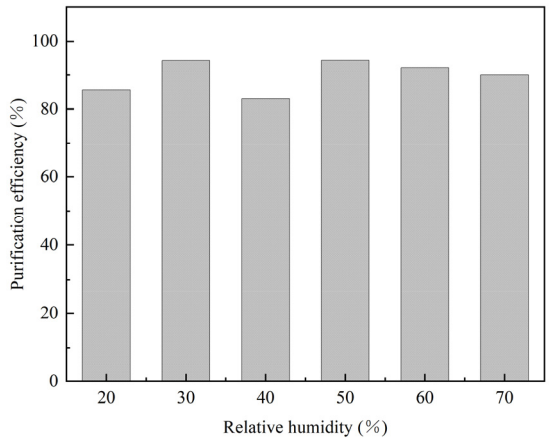

Fig. 7. Purification efficiency of PM10 under different relative humidity.

Figure 7 shows the comparison of the purification efficiency of the sponge activated carbon purification system for PM10 after 30min under different humidity. It can be seen that in the working condition except 30% relative humidity, the purification efficiency of the system for PM10 is about 85%, when the relative humidity is higher than 50%, the purification efficiency has been significantly improved, and the highest purification efficiency appears in the working condition of 50% relative humidity, which is 94%.

Figure 8 shows the relationship between PM10 concentration and time in the experimental chamber. It can be seen that under all experimental conditions, the decreasing relationship of particulate matter concentration with time presents a trend of first fast and then slow, and the fastest decreasing trend is concentrated within 20min after the start of the experiment. Under the condition of 20%-70% relative humidity, the decreasing trend of PM10 concentration in the cabin has no obvious relationship with the change of relative humidity.

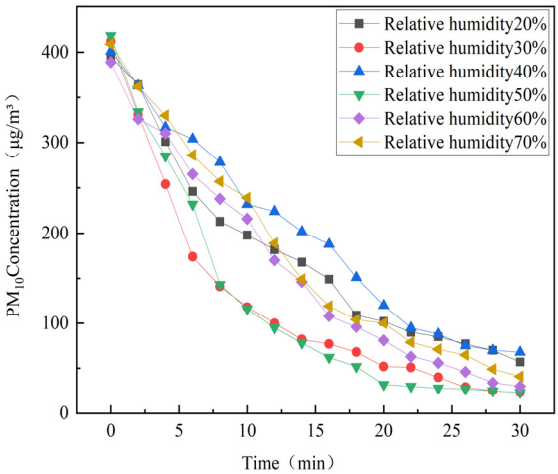

Fig. 8. PM10 concentration in cabin with different relative humidity.

The experiment found that under the condition of 20%-70% relative humidity, the purification efficiency of the purification system for PM2.5 showed a trend of increasing with the increase of relative humidity. This is mainly because saturated water vapor has condensation phenomenon. First, water vapor takes fine particles as condensation nuclei to produce embryonic droplets with critical size. Then the water vapor diffuses to the surface of the critical embryo droplet, condenses into larger droplets, and further grows the dust-containing droplet through the collision condensation of gravity, Brownian, thermal swimming, diffusion swimming and turbulence. After the growth stage, the particle size increases and the mass increases, and the fine particles have become particles with larger sizes, which are easy to be adsorbed and purified by sponge activated carbon in the purification device, thus improving the capture and purification efficiency of the purification system for particles. The purification efficiency of the system for PM10 does not change significantly with the humidity trend, which is because the particle size and mass of PM10 are larger than that of PM2.5, and the collisional coalescence effect of gravity, brownian, thermal, diffusive, and turbulent swimming and the change of particle size do not change significantly on the deposition and trapping effect when the water vapor combines with it.

4 Conclusion

Based on the results and discussions presented above, the conclusions are obtained as below:

(1) In the range of 20%-70% relative humidity, the purification efficiency of the sponge activated carbon purification system for PM2.5 shows a trend of increasing with the increase of relative humidity. After the 30-minute purification experiment, the highest purification efficiency appeared in the condition of 70% relative humidity.

(2) In the range of 20%-70% relative humidity, the purification efficiency of the sponge activated carbon purification system for PM10 does not change significantly with the increase of relative humidit.

Acknowledgments

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