The characteristics purifying formaldehyde of air purification system for haze-absorbing wall

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Abstract. Formaldehyde in indoor air is very harmful to human body. In this paper, a haze-absorbing wall air purification system was constructed based on assembly buildings. The experimental device was set up with bulk activated carbon as adsorption material. The purification performance for formaldehyde of the system was studied experimentally. The effects of air velocity and air passage size on formaldehyde purification efficiency were analysed. It was found that the haze-absorbing wall system can effectively purify the formaldehyde in the air. After the experiment, the purification efficiency of the system to formaldehyde is more than 90% under all conditions of the experiment. With the increase of inlet air velocity, the purification efficiency of haze-absorbing wall to formaldehyde increases first and then decreases, and the peak value appears when the air velocity is 0.4 m/s. When the air passage is 20 cm and the air velocity is 0.4 m/s, the haze-absorbing wall has the best purification performance for formaldehyde.

1. Introduction
Formaldehyde is a colorless gas with a strong pungent odor. It is easily soluble in water. It is gaseous at room temperature and volatile.[1-3] Formaldehyde is very harmful to human body and has been classified as carcinogenic and teratogenic substance by WHO. Even low concentrations of formaldehyde can cause eye pain and headaches if people are exposed to it for a long time, and can cause atopic dermatitis, asthma, memory loss and neurological disorders, and even cancers such as nasopharyngeal and colon cancers. Formaldehyde is more harmful to children and pregnant women, causing a series of major diseases such as fetal chromosomal abnormalities, childhood leukemia and pregnancy syndrome in pregnant women.[4-9] The formaldehyde in indoor air mainly comes from building materials, furniture, various adhesive coatings and synthetic textiles. The glue and adhesive in plywood, particleboard and MDF in general decoration materials all contain formaldehyde, and formaldehyde will be released when damp or heated.[10-11]

At present, the common methods of removing formaldehyde are chemical method, photocatalyst decomposition method and adsorption method.[12-13] Chemical method is to spray chemical reagent stain in the air or furniture and formaldehyde chemical reaction to achieve the purpose of removal. However, because indoor formaldehyde is released slowly, chemical removal requires constant spraying, so the effect is not ideal. The photocatalyst decomposition method requires the use of ultraviolet light, which is cumbersome and costly to implement, so its application is not widespread. Because of its simple operation, ideal effect and good economy, it is relatively common to use the
adsorption of activated carbon to remove indoor formaldehyde. In this paper, based on prefabricated buildings, a haze-absorbing wall air purification system is constructed with built-in adsorptive materials, which can effectively remove harmful substances such as inhalable particles and formaldehyde in indoor air. Its structure is shown in Figure 1. On the basis of previous studies,[14] this paper set up an experimental device for air purification system of haze-absorbing wall, and tested the purification characteristics of formaldehyde of the system under different experimental conditions by using block activated carbon as adsorption material.

![Figure 1. Structure diagram of air purification system of haze-absorbing wall](image)

Where: 1—wall; 2—wire; 3—battery; 4—fan; 5—metal net; 6—adsorption material; 7—frame; 8—air flow channel.

2. Theory

The adsorption of formaldehyde by adsorbing materials involves two kinds of forces: physical force and chemical force. Physical forces include dipole moment, polarization force, dispersion force and short-range repulsive force. Chemical forces are the resultant force from the redistribution of electrons between the solid surface and the adsorbed atoms. Ordinary activated carbon mainly absorbs formaldehyde through the action of physical force. The process is more significant at low temperature, and the adsorption decreases with the increase of temperature. Formaldehyde molecules and the surface of the fiber layer of activated carbon are combined with relatively weak van der Waals force (similar to the cohesive molecular force). The adsorption of formaldehyde by activated carbon fiber with higher specific surface area is determined by physical and chemical forces. The physical adsorption performance is mainly determined by the micropore structure of the activated carbon fibers, and the chemical adsorption performance is determined by the number of acidic oxygen-containing functional groups on the surface of the activated carbon fibers. In this study, the adsorption of formaldehyde by the haze-absorbing wall system is mainly physical adsorption, and its adsorption process can be fitted theoretically by a quasi-first-order kinetic model.[15]

\[
q_t = q_e - q_e \cdot e^{-tk_t}
\]

Where: 
- \( q_t \) is the adsorption capacity of activated carbon at time \( t \) (mg/g);
- \( q_e \) is the equilibrium adsorption capacity of activated carbon (mg/g);
- \( k_t \) is the adsorption rate constant of the quasi-first-order model (min\(^{-1}\)).
3. Materials and Method

![Figure 2. Schematic diagram of air purification system of haze-absorbing wall](image)

The experimental device shown in Figure 2 was built. The experimental device was composed of a transparent experimental cabin and a haze-absorbing wall system model. The experimental cabin was made of tempered glass, and the system model was assembled by acrylic panels. The system model has a height of 1.1m, a width of 0.6m and a thickness of 0.2m. The air inlet and outlet sizes are the same, with a length, width and height of 0.6m, 0.1m and 0.05m respectively. The system is equipped with 3 layers of activated carbon modules (the average filling particle size is 1.5mm, the porosity is 67%, and the specific surface area is 2000m²), which are placed on a steel frame, 5 in each layer, with a thickness of 10cm. The airflow channel is in the shape of “S”, and the distance between each layer of activated carbon is the airflow channel size, which can be manually adjusted. There are two sets of size parameters of 10cm and 20cm. Two fans with adjustable speed are placed at the corresponding outlets in the system. After the fans are started, the upper outlet of the system begins to deliver air volume. At this time, the lower inlet of the system generates negative pressure, and then the air in the experimental cabin is inhaled from the haze-absorbing wall system model. By adjusting the speed of the fan at the outlet, an inlet air flow rate of 0.1~0.5m/s can be generated. The point velocity at the middle position of the entrance section of the system is used as the air velocity at the entrance of the experiment, which is measured by the testo401-1 anemometer. The test cabin is 1.5m high and 1m long and wide. The formaldehyde in the experiment was obtained by volatilizing a quantitative formaldehyde solution,[16-17] the volatilization time was about 1 minute, and the initial concentration was about 1.36mg/m³ (the formaldehyde in the experimental cabin was exceeded), and the deviation of each experiment did not exceed 0.03mg/m³. The total duration of the experiment was 115 minutes. The DT-9851M air quality detector was used to measure the change in the concentration of formaldehyde during the experiment. The data was measured every 5 minutes. Under the same experimental conditions (10 experimental conditions), the average was taken for three tests. In the experimental research of this paper, the purification efficiency of the haze-absorbing wall system at a certain time can be calculated by equation (2).

$$\eta = \frac{C_i - C_{i+\tau}}{C_i}$$ (2)

Where: \(C_i\) is the initial concentration of formaldehyde in the experimental cabin during the experiment; \(C_{i+\tau}\) is the concentration of formaldehyde in the experimental cabin at time \(\tau\).
4. Results and Discussion

In this paper, the total experimental time of purifying formaldehyde by the haze-absorbing wall system was 115 minutes, and the drop of formaldehyde concentration under each experimental condition mainly occurs in the first 30 minutes of the experiment. In the subsequent time period, due to the fact that formaldehyde is too sparse, it is difficult for activated carbon to adsorb it, and the decrease of formaldehyde concentration is very small, even remaining unchanged for 10 to 20 minutes continuously. Therefore, Figure 3 shows the purification efficiency of formaldehyde by the haze-absorbing wall system under different experimental conditions after purification for 30 minutes. As can be seen from Figure 3, with the increase of inlet air velocity, the purification efficiency of formaldehyde in the haze-absorbing wall system first increases and then decreases. When the air velocity is 0.4m/s, it peaks. The maximum purification efficiency under 10cm and 20cm airflow channels is 92.6% and 93.3%, and the minimum is 84.3% and 86.7%, respectively. The purification efficiency of formaldehyde under the 10cm air channel is greater than 20cm, but the difference between the two is small, and the maximum difference is only 2.4%.

Figure 3. Purification efficiency of formaldehyde under different experimental conditions

As shown in Figure 4(a), when the airflow channel is 10cm, the corresponding formaldehyde concentration curve trends under the five groups of air flow rates are basically the same. The decrease of formaldehyde concentration mainly occurred in the first half of the experiment. When the formaldehyde concentration was reduced to 0.1mg/m³, it was difficult for the activated carbon to adsorb it quickly due to its too small concentration, and the concentration of formaldehyde in the experimental cabin began to stabilize. After that, it takes at least 10 minutes for the formaldehyde concentration to drop by 0.01mg/m³. At five groups of air flow rates (0.1~0.5m/s), the time required for the formaldehyde concentration to decrease to 0.1mg/m³ is 60, 50, 35, 30 and 35 minutes respectively. At the end of the experiment, the concentration of formaldehyde at the four air flow rates of 0.1m/s, 0.2m/s, 0.3m/s and 0.4m/s were 0.08mg/m³, 0.07mg/m³, 0.06mg/m³ and 0.07mg/m³ respectively, all reached the 0.08mg/m³ stipulated in the "Hygienic standard for formaldehyde in indoor air of house". The formaldehyde concentration at 0.5m/s was 0.09mg/m³ at the end of the experiment, which did not meet the standard. As shown in Figure 4 (a), when the channel size is 20cm, the trend of formaldehyde concentration change curves under the five groups of air velocity in Figure 4 (b) is basically the same. The drop in the concentration of formaldehyde mainly occurred in the first half of the experiment. When the concentration of formaldehyde was reduced to 0.1mg/m³, the concentration of formaldehyde in the experimental cabin began to stabilize. Under the five groups of air flow rates, the time required for the concentration of formaldehyde to decrease to 0.1mg/m³ is 60 minutes, 50 minutes, 35 minutes, 20 minutes and 20 minutes respectively. At the end of the experiment, the formaldehyde concentrations of the five groups at the air velocity were 0.07mg/m³, 0.06mg/m³, 0.05mg/m³, 0.07mg/m³ and 0.08mg/m³, respectively. The formaldehyde concentrations in the experimental cabin all met the standard, and the time taken to reach the standard was 85 minutes, 75 minutes, 65 minutes, 60 minutes and 80 minutes, respectively. Comparing Figure 4 (a) and (b), it
can be found that when the channel is 20cm, the drop rate of the formaldehyde concentration under the five groups of air flow velocity is greater than 10cm, and all meet the specification requirements at the end of the experiment.

Figure 4. Change of formaldehyde concentration under different experimental conditions

As shown in Figure 5, when the air velocity was 0.1m/s, the formaldehyde concentration in the 20cm channel decreased at a rate greater than that in the 10cm channel in the first 30 minutes of the experiment, and the difference was obvious. The maximum decline of formaldehyde concentration in each 5 minutes interval was 0.55mg/m$^3$ and 0.29mg/m$^3$, respectively. Within a period of 30 to 55 minutes, the descent rate under the 10cm channel is slightly greater than 20cm. Since then, the formaldehyde concentration in the two groups of channels decreased to 0.1mg/m$^3$, and the formaldehyde concentration in the experimental cabin began to stabilize. After 60 minutes, the formaldehyde concentration in the 20cm and 10cm channels decreased only 0.03mg/m$^3$ and 0.02mg/m$^3$, respectively.

Figure 5. Change of formaldehyde concentration under different airflow channel sizes when the air velocity is 0.1m/s

5. Conclusion
1) The haze-absorbing wall system can effectively remove formaldehyde in the air. After the experiment, the purification efficiency of the system for formaldehyde under all experimental conditions is greater than 90%.

2) With the increase of the inlet air velocity, the purification efficiency of the haze-absorbing wall system for formaldehyde first increases and then decreases, and the air velocity peaks when the air velocity is 0.4m/s.

3) In the 115-minute experiment, the drop in formaldehyde concentration mainly occurred in the first 60 minutes of the experiment. When the formaldehyde concentration decreased to 0.1mg/m$^3$, the formaldehyde concentration in the simulated cabin began to stabilize.
4) When the airflow channel is 20cm wide and the air velocity is 0.4m/s, the haze-absorbing wall system has the best formaldehyde purification performance.

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