Research progress of indoor air purification technology

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Abstract. Filtration, adsorption and photocatalysis are widely used in the purification of indoor air pollutants as three commonly used air purification methods. The methods to improve the purification efficiency of air purifiers and the factors affecting the purification efficiency have been widely studied. This paper briefly describes the main purification principles of the three air purification technologies and reviews the influence of filter size, filtration wind speed, particle size, particle size of adsorbed material and filling amount on purification efficiency and the amount of clean air produced by photocatalysis. Coupling the use of single purification technology with other new building technologies, as well as simplifying the regeneration process of adsorption and catalytic materials, and achieving the recycling of filter materials are the future research directions.

1. Introduction
Indoor environment is one of the important places for human beings to work and live for a long time. Some data show that most people spend 70%~90% of their time indoors. [1-2] In recent years, the problem of air pollution has become more serious. At the same time, people's demand for indoor air quality has also increased accordingly.[3] Under this background, finding effective methods to remove all kinds of solid particles and gaseous pollutants widely distributed indoors has become a widely studied problem. Among these methods, filtration, adsorption [4-5] and photocatalysis are widely used. This paper summarizes the research status of these three air purification methods, discusses the effects of particle size, filter type, adsorbent materials and catalyst on the purification effect, and proposes the development direction of related research.

2. Filtration
2.1. Main mechanism
Filtration is a traditional air purification method, which mainly uses inertial collision, Brownian diffusion, interception effect, gravity effect and electrostatic effect to capture pollutants such as particulate matter.[6] In general, particles with larger particle size are mainly captured due to inertial collision, particles with medium size are captured due to interception effect, and particles with smaller particle size have obvious Brownian diffusion effect, and are usually adhered and captured due to diffusion to the surface of filter material.[7] At present, the research on filtration technology is mainly focused on the filtration efficiency and filtration materials of air filters.
2.2. Research status
Siamak R. Ardkapan et al.[8] studied the relationship between filtration efficiency of electrostatic fiber filters and particle concentration. The results show that the filtration efficiency of the electrostatic fiber filter increases as the contact area of the fibers with the particles increases. In addition, the study also shows that with the continuous deposition of particulate matter, chain-like agglomerates called dendrites will form on the filter fibers, which help the filter fibers to further capture other particles.

Huang Zheng et al.[9] experimentally studied the filtration efficiency and filtration resistance of polyimide nanofiber membranes doped with polytetrafluoroethylene (PTFE) nanoparticles after electret treatment. The results show that the fiber membrane treated by electret has good filtration efficiency due to its charge and electrostatic adsorption effect on passing particles. In addition, compared with the pure polyimide fiber membrane without electret treatment, it has a larger pore diameter and therefore has lower filter resistance. However, electret filter materials also have their disadvantages. Studies by Stephens[10], Balazy et al.[11] and Li et al.[12] show that electret filter materials have general filtration efficiency for nano-sized fine particles. In response to this problem, Tang Min[13] proposed to combine the electret filter material with the ultrafine fiber layer to compensate each other for the disadvantages of the two filter materials, thereby improving the filtration efficiency of the composite filter material.

Pavel Bulejkoa et al.[14] studied the filtration performance of an air filter using polypropylene Hollow-fiber membranes (HFM) as a filter module. The filtration efficiency and permeability of the module were tested by the most penetrating particle size (MPPS) method. The results show that the filter with HFM as the filter material has a good filtering effect on the fine particles with particle size of 15~600nm under the condition of low filtration speed ignoring inertial collision. Experiments on permeability show that the pressure drop rate of HFM is slow even under high-concentration particles. Therefore, compared with the traditional fiber filter, HFM has a higher ability to withstand particulate pollution.

Through the study of different kinds of filters, it can be found that the factors that affect the filter efficiency mainly include particle size, filter area, filter wind speed, filter material aperture, filter material type and property, etc. Reducing the filter size, increasing the filter area and selecting a moderate wind speed are all conducive to the improvement of filtration efficiency. On the basis of interception, the filter material treated by electret can also enhance the further attraction and adhesion of particles by electrostatic force, so as to increase the filtration efficiency. In addition, in order to overcome the disadvantages of a single type of filter, the filter efficiency can be improved by using several filters superimposed on each other.

3. Adsorption

3.1. Main mechanism
The adsorption method uses porous solid materials with rich pores and large specific surface area to process the gas mixture so that one or more components contained in it can be adsorbed on the surface of the adsorbed materials to achieve the purpose of separation. [15]

3.2. Research status
Peng Peng et al.[16] studied and prepared a composite structural filtering material composed of polypropylene ultrafine fibers and activated carbon particles. Mechanical embedding and bonding are adopted between the two materials, and no adhesive is used. The purification effect of the filter material was tested by adding different amounts of activated carbon between the ultrafine fiber materials. In the purification performance test, MPPS in the European standard (EN1882-1:1998) was also used to test the purification efficiency of particles with a diameter of 0.3μm. Test results are shown in Table 1.
Table 1. Test results of filtration efficiency of materials on 0.3μm particles [16]

| Experimental sample                                | Purification efficiency /% | Purification resistance /mm H₂O |
|----------------------------------------------------|----------------------------|---------------------------------|
| polypropylene ultrafine fiber                      | 23.7                       | 6.6                             |
| double layer polypropylene ultrafine fiber         | 45.2                       | 10.8                            |
| ultrafine fiber and activated carbon composite material | 60.8                     | 9.9                             |

The results show that the ultrafine fiber & activated carbon composite material has an improved filtration efficiency compared with ordinary ultrafine fiber materials without activated carbon; at the same time, the filter material with activated carbon particles has a lower resistance than the ordinary double-layer filter material without activated carbon, because the addition of activated carbon increases the porosity inside the composite material and reduces the filtration resistance. This result shows that the development of filters in the future can be changed from a single type to a composite type integrating adsorption and filtration.

Xing Yi et al.[17] also studied the effects of porous materials with different particle sizes, different filter thickness and wind speed on the filtration effect of porous materials for fine particles. The results showed that when other conditions are unchanged, the excessive wind speed will reduce the purification efficiency, which is not conducive to the full adsorption of particulate matter by activated carbon. The effect of the thickness of the filter layer on the purification efficiency is that the increase in the thickness of the filter layer increases the purification efficiency. This is because the thickness of activated carbon layer increases, which not only increases the number of porous structures, but also increases the residence time of particles in the activated carbon layer, which is conducive to the removal of fine particles[18].

The research on the purification of pollutants by adsorption is similar to the use of fiber filters. The factors that affect the purification efficiency are mainly the specific surface area of porous materials, the thickness of porous materials, and air velocity. Increasing the specific surface area and thickness of the porous material and reducing the velocity of the air flow are conducive to the adsorption process and increase the purification efficiency. Unlike fiber filters, the use of porous materials can also purify indoor gaseous pollutants, such as Volatile Organic Compounds (VOCs). Therefore, the purification effect of the purifier can be enhanced by using a fiber & adsorption composite filter.

4. Photocatalysis

4.1. Main mechanism
Photocatalytic technology means that under the condition of light, organic pollutants in the room are oxidized on the surface of the catalyst into inorganic water, carbon dioxide and other substances, so as to achieve the purpose of purifying indoor air. Common photocatalysts include: precious metal catalysts, such as Pt, Pd, Rh, Ru and Au[19]; metal oxide catalysts, such as TiO₂, ZnO, WO₃, Fe₂O₃, SnO₂, CdS, etc. of which TiO₂ is the most widely used. The essence of photocatalytic technology is the redox reaction of air pollutants. Research shows that the purification efficiency of photocatalytic technology is related to pollutant concentration, air velocity, temperature and humidity, ultraviolet intensity, catalyst type, catalyst carrier, etc. [20]

4.2. Research status
Yu et al.[21] coated the thermocatalytic material MnOₓ-CeO₂ on the wall surface and studied the thermodynamic properties and pollutant degradation properties of the system. The results showed that the heating efficiency of the system was 41.3%, the degradation of formaldehyde was 208.4 mg/ (m²•day), and the fresh air was 249.2 m³/ (m²•day).

Yu et al.[22] proposed a new Trombe wall that can degrade indoor VOCs, heating and ventilation. The wall surface is covered with ceramic fiber paper-TiO₂ film prepared by impregnation method. The
effects of pollutant concentration, ultraviolet intensity, temperature and humidity on the catalytic rate of the system were studied experimentally. The results show that the model has better performance in winter and can be combined with air conditioning in summer, which has great potential for indoor air purification.

Duan Yanan[23] based on the theoretical basis of TiO$_2$ photocatalytic purification of indoor VOCs, studied the purification effect of TiO$_2$ and activated carbon fiber (ACF) composite photocatalytic materials on formaldehyde under different conditions such as different formaldehyde concentrations, different relative humidity, and different air flow rates. The results showed that when the initial concentration was less than 8.04mg/m$^3$, the purification efficiency of the system for formaldehyde could reach above 75%. When the relative humidity is higher than 55%, the degradation rate of formaldehyde decreases, which indicates that the environment with high humidity is unfavorable to the photocatalytic reaction. The effect of flow rate on the purification efficiency is mainly reflected in the residence time of formaldehyde molecules on the surface of the catalyst. An appropriate gas flow rate can make the reaction fully occur.

The photocatalytic method can directly oxidize pollutants into water, carbon dioxide and other inorganic substances. Various studies have shown that the photocatalytic method can show a better purification effect when there is sufficient ultraviolet radiation and the catalyst has sufficient contact with the air. By studying the properties of the catalyst and making a composite or modified catalyst [24], the activation energy can be further reduced, and the purification efficiency can be enhanced.

5. Conclusion
In summary, different studies have shown that filtration purification, adsorption purification and photocatalytic method have good removal effects on pollutants such as particulate matter and VOCs in the air, and have the advantages of low cost, convenient use and mature technology. Therefore, these three methods will be the mainstream air purification methods in the future.

For filtration, high-efficiency filters are currently mainly used to filter fine particles in the air. In order to improve the filtration efficiency of the filter, a primary-effect filter can usually be installed in front of the high-efficiency filter to pre-filter larger particles and dust. In addition, the filtration efficiency can be improved by designing appropriate filtration wind speed and increasing the surface area of the filter. At present, porous media such as activated carbon are widely used as filter materials for adsorption method. Different from filtration method, adsorption method can not only remove fine particles in air, but also remove gaseous pollutants such as formaldehyde. The adsorption efficiency can be increased by reducing the particle size of the porous medium and increasing the filling amount of the porous medium. For photocatalysis, it is necessary to solve the adhesion problem of the catalytic material on the medium, prolong the activity of the catalyst, and search for the appropriate reaction wind speed and relative humidity.

With the continuous development of air purification technology and people's increasing attention to air pollution issues, future research on this type of purification technology should be changed from a single direction to coupling it with other new technologies, to manufacture multi-technology composite purification materials, simplify the regeneration process of adsorbent materials and catalysts, and achieve recycling and other aspects.

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