Air purification in confined spaces

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Abstract: How to provide clean, healthy and fresh indoor air in the process of controlling atmospheric pollution is one of the major challenges facing the present and the future. At present, people mostly use air purification technology to optimize indoor air quality. Air purification technology can effectively remove indoor pollutants and improve indoor air quality. By considering the types of pollutants, the improvement of air quality, the filtration performance of purifiers, the current research progress and advantages, limitations and challenges of air filtration technology are discussed, and the development trend of air purification technology is forecasted. This article reviews the synergy between different air purification technologies, air filtration theory and purification technology.

1. Introduction

Even if you can't see it, the air is always affecting human health. Contaminated air can cause difficulty breathing, allergies or asthma attacks, and other lung problems. Long-term exposure to air pollution increases the risk of other diseases, including heart disease and cancer. Some people think that air pollution mainly occurs outdoors. They may imagine the idling of a car or the chimney of a power plant, but air pollution also occurs indoors in homes, offices, and even schools. With the development of the economy and the progress of society, the level of civilization of human life has continuously improved. Indoors have become the main place for human life, work and social activities. According to statistics, more than 80% of human time is spent indoors. Therefore, when the indoor air is polluted relative to outdoor air pollution, the impact on human health is more serious.

Indoor air pollution refers to the contamination of indoor air by particulate matter and other harmful substances. According to new data from the World Health Organization, 9 out of 10 people breathe high concentrations of pollutants in the air; new estimates indicate that 7 million people die each year from environmental (outdoor) and domestic air pollution, including pollution. Household air pollution caused by fuel, etc. caused about 3.8 million deaths. Indoor air pollution has become a serious threat to human health. The various types of buses and trains operated in China, due to the relatively small space, airtightness, large passenger flow and interior decoration, will produce certain air pollution to different extents. The types of pollutants have certain industry characteristics, and the concentration of pollutants factors such as passenger flow, season, regional environment, and vehicle service life have changed greatly and are uncertain. The main pollutants are carbon dioxide, carbon monoxide, airborne microorganisms, volatile organic compounds, odors, particulate matter and the like.

At present, although air filtration technology based on object ventilation can remove air pollutants and improve indoor air quality, it will increase system energy consumption during the use of the filter and may generate harmful substances. The amount of energy consumed is related to the amount of...
resistance of the filter to the air; when the filter collects dust, an increase in resistance results in higher energy consumption. The generation of hazardous substances is related to the maturity of purification technology. This paper reviews the theory, historical process and development of air purification technology, as well as the synergistic effects of different air purification technologies. By summarizing the technology of air purification products, the development trend of purification technology is forecasted.

2. Air purification technology theory
Most indoor air purification technologies come from industrial waste gas and related gas treatment technologies. The technology is divided into three main categories: dust removal technology, gas purification and sterilization technology. The main indoor air purification technologies include filtration purification, activated carbon adsorption purification, water washing purification, electrostatic purification, plasma purification, photocatalytic purification and other purification technologies. Indoor air dust removal technology is derived from atmospheric dust removal technology. Most indoor methods are fiber filtration and electrostatic dust removal. Activated carbon filtration is still the most common method for gas purification, and ozone and ultraviolet radiation are the most commonly used sterilization techniques.

3. Type of air purification technology

3.1 Filtration purification technology
Indoor particulate pollutants are the main source of indoor pollution, accounting for about 76% of indoor pollutants, and in developing countries, the situation in developing countries is even more serious. Filtration and purification technology mainly filters particulate matter. The most common filter is a fiber filter. Air purifiers are classified into four types based on the filtering effect on particulate matter: pre-filter, medium efficiency filter, high efficiency particulate air (HEPA) filter and ultra low particulate air (ULPA) filter. HEPA materials have a strong ability to capture particles because they remove 99.97% of particulate matter, smoke, and bacteria over 0.3 μm in size, while medium efficiency filters are only 60% to 90% efficient. The ULPA filter has been found to have a filtration efficiency of over 99.999% for particles with a diameter of 0.12 μm to 0.17 μm. Nonwoven nanofiber materials are an emerging filtration technology with extremely high filtration efficiency. Research on non-woven fiber filtration technology has found that its filtration effect is comparable to that of HEPA filters, and its filtration efficiency is superior to HEPA filters for filtering smaller particles. The glass fiber filter is another well-established high-efficiency filtration technology (99.0%) with a filtration principle similar to that of a HEPA filter.

However, the disadvantages of this filtration technique are also obvious. For example, during the use of the HEPA type air purifier, the particulate matter accumulates in the filter membrane, accompanied by the generation of microorganisms, and in the severe case, the harmful microbial aerosol can be released into the air. Therefore, the filter needs to be replaced continuously during use, which increases maintenance costs. At the same time, according to research, the filtration efficiency of the fiber filter is affected by the airtightness of the installation, and the indoor air distribution also affects the filtration effect of the fiber filter on the particles.

3.2 Activated carbon adsorption purification technology
The most common method currently used for the treatment of VOCs is the adsorption method, especially for the treatment of low concentrations of VOCs. Adsorption-based granular activated carbon filter (GAC) is a common technique for removing vapor phase contaminants. The GAC filter removes VOCs in the order of toluene, n-hexane and methyl ethyl ketone.

Compared to GAC filters to remove single gas performance, GAC filters have significantly reduced the removal performance of mixed gas phase contaminants because the different compounds of the gas mixture will compete for the same free space on the carbon media. Among the different physical
properties of indoor pollutants, the removal performance and service life of the tested GAC filters are directly proportional to the molecular weight of the contaminants. At the same time, the adsorption of activated carbon still has problems such as low adsorption capacity, basically no regeneration ability of activated carbon after adsorption, and environmental impact on its adsorption function.

3.3 Washing and purifying technology
In the water purification technology, the indoor contaminated air is sucked into the air purification equipment during operation. The air is then rotationally cut into the water under the relative rotation of the water curtain convection combination to allow sufficient contact between the air and the water so that the harmful substances in the air are sufficiently dissolved by the water. However, the water tank is prone to pollution problems. There is now a silver ion sterilization water tank, which can effectively kill bacteria in the water, effectively avoiding the bacteria in the water from being blown into the room again to ensure the quality of air purification. Washing and purifying technology reduces PM2.5 and formaldehyde levels in the air. The price of an air purifier using a single water purification technology is also relatively cheap.

3.4 Plasma purification technology
Plasma purification technology can be divided into thermal plasma purification technology and low temperature plasma purification technology. Thermal plasma is one of the processes for removing toxic compounds (especially VOCs) from industrial applications. It has proven to be suitable for wastes with high concentrations of organic components, but is not economical at low levels. Therefore, some experts pointed out that the application of thermal plasma to indoor air treatment and integration with building mechanical ventilation systems is almost impossible. At normal temperature, a low temperature plasma can be obtained by a high voltage, high frequency pulse discharge or the like. It has been found that low temperature plasma (or non-thermal plasma) air filtration can effectively remove fungal spores or bacteria in the air. Even if the exposure time is very short (0.06 s), its removal efficiency can reach 85%–98%. Therefore, low temperature plasma purification technology is commonly used in high-risk hospital areas.

However, ozone and nitrogen oxides are generated during the operation of the low-temperature plasma. When using a cold plasma filter, it should be paid to the influence of the chemical substances generated on the indoor environment. The experimental results show that increasing the length of the internal electrode increases the residence time of the ionized oxygen atoms and increases the energy input, thereby forming a larger amount of ozone.

3.5 Photocatalytic technology
Photocatalytic purification technology is based on the theory of photogenerated electrons and photogenerated holes, which generate electron-hole pairs under illumination. It can improve indoor air quality and provide energy saving solutions for HVAC applications. It not only effectively kills bacteria and viruses, but also has a high removal rate for VOCs. Photocatalytic energy is used to destroy pathogens, including Lactobacillus acidophilus, Saccharomyces cerevisiae and Escherichia coli. Some experts have conducted pioneering research on photocatalysts to destroy liquid organic compounds, including polychlorinated biphenyls, methyl chloride and organic compounds, through semiconductor photocatalysts (TiO2).

However, PCO air purifiers produce toxic by-products such as formaldehyde and acetaldehyde, so it is necessary to combine other technologies or develop new photocatalytic technologies to reduce potential health risks and improve indoor air quality. According to reports, UV-catalytic oxidation (UV-PCO) is recognized as an effective decomposition of indoor volatile organic compounds, and this technology can also reduce building energy consumption. Aghighi developed a new nano-TiO2 photocatalyst to improve the performance of UV-PCO systems in indoor air applications. The results show that the new nano-TiO2 photocatalyst has better removal efficiency than other catalysts under the
same experimental conditions. Experiments have shown that by-products are reduced at higher flow rates, but at the same time their efficiency in removing organic compounds is reduced.

4. The development trend of air purification technology

The development of indoor air purification technology can not only be the use of purifiers, but also the comprehensive application of various new building materials, science and technology, and effective methods. The combination of filtration technology and sterilization system can effectively solve the problem of filtration technology. Because the purifier captures dust and other organic particles, the filter often becomes a medium for the growth of bacteria and fungi. This process turns the filter into a secondary source of contaminants. When combined with an antimicrobial agent, the filter can exhibit anti-microbial properties.

5. Conclusion

Conventional fiber filters have the advantages of high removal efficiency, low initial cost, and simple structure. Theoretically, the electrostatic air filter is a very effective purification technology, and the filtration efficiency of the particles can reach 82% to 94%. Cold plasma air filtration can effectively remove fungal spores and bacteria in the air. Even after a short exposure time (0.06 s), the decontamination rate can reach 85%~98%.

At present, due to imperfect technology, indoor air purification cannot completely remove pollutants; substances that are harmful to the human body may be produced during the purification process; and the materials to be cleaned need to be replaced frequently. When a variety of pollutants exist, the effect of a single purification technology is not obvious. Therefore, the strategic combination of filtration technology and other purification technologies can improve the purification performance through synergistic effects.

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