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Article

Research on indoor air pollutant control technology and data analysis

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Abstract: This study provides a comprehensive analysis of indoor air pollutant control technologies and reports on the current status of indoor air pollution and its hazards to human health in China. This research also emphasizes the biological mechanisms through which indoor air pollutants affect human health at the cellular and molecular levels. The study explores the mechanisms, kinetics, thermodynamics, and material design and performance optimization of various control methods, including physical adsorption, chemical decomposition, and biological purification. A detailed discussion is included on how indoor air pollutants interact with biological systems, focusing on mechanistic pathways such as oxidative stress, inflammatory responses, and cellular signaling alterations induced by exposure to pollutants. Data analysis reveals the removal efficiencies and application effects of different technologies, highlighting the biological impacts of these pollutants on human health. It was concluded that in the future, emphasis should be placed on the research and development of efficient and low-cost adsorbent materials, the optimization of the chemical decomposition method in order to reduce energy consumption and extend the catalyst life, the in-depth study of biological purification methods in order to screen highly efficient degrading microorganisms. Additionally, a combined approach utilizing various technologies is recommended to achieve comprehensive treatment of indoor air pollutants, thereby mitigating their harmful effects on biological systems.

Keywords: indoor air pollution; pollutant control; technical studies; data analysis; biological mechanisms; mechanistic pathways; oxidative stress; inflammatory responses

1. Introduction

Indoor air pollutants pose a serious threat to human health, and this issue has received high attention worldwide. According to the World Health Organization (WHO), indoor air pollution is the fourth largest risk factor for the global burden of disease, and about 4.3 million people die from indoor air pollution-related diseases every year [1]. In China, indoor air pollutants mainly include organic pollutants such as formaldehyde, benzene, and total volatile organic compounds (TVOC), and inorganic pollutants such as fine particulate matter (PM2.5) and nitrogen oxides (NOx). In recent years, with the acceleration of urbanization and the widespread use of decorative materials, indoor air pollution has become a major public health risk in China. According to the China Indoor Environmental Quality Report (2023) released by the China Environmental Monitoring General Station, the average indoor formaldehyde concentration in China's urban residential homes is 0.096 mg/m³, the average benzene concentration is 0.012 mg/m³, and the average TVOC concentration is 0.6 mg/m³, all of which exceed the national standard limits [2]. In addition, outdoor pollutants such as PM2.5 and NOx enter indoors through the ventilation system, further exacerbating indoor air pollution. Studies have shown that indoor

PM2.5 concentrations have a significant correlation with outdoor concentrations, especially during the winter heating period, when indoor PM2.5 concentrations can reach more than 50 per cent of outdoor concentrations [3]. Moreover, the economic impact of indoor air pollution is substantial, with healthcare costs associated with pollution-related illnesses and productivity losses due to poor indoor air quality. For instance, the treatment of pollution-induced illnesses and the days of work missed by affected individuals can result in significant financial burdens on both households and the economy at large. This paper starts from the indoor air pollutant control technology, analyses the advantages and disadvantages of the existing technology, explores the development trend of the new control technology, and combines the latest experimental data and statistical analyses to provide a scientific basis and technical support for indoor air pollution control.

2. Sources and hazards of indoor air pollutants

2.1. Sources

The sources of indoor air pollutants are diverse and complex, and include the following:

2.1.1. Construction materials

Building materials are one of the important sources of indoor air pollution. Studies have shown that organic pollutants such as formaldehyde, benzene, TVOC and other organic pollutants, as well as inorganic pollutants such as ammonia and radioactive radon, contained in building materials are slowly released in the indoor environment. For example, concrete and masonry materials may contain the radioactive element radon, the decay products of which can enter the human body through the respiratory tract and increase the risk of lung cancer. According to the standard "Radioactive Limit of Building Materials", the average concentration of radon in building materials in China is 14.8 Bq/m^3, but the concentration in some areas is much higher than this value [4]. For instance, different types of furniture can emit varying levels of formaldehyde. A study found that medium-density fiberboard (MDF) furniture can emit up to 25 mg/m^2 per hour of formaldehyde, while particleboard can emit approximately 10 mg/m^2 per hour.

2.1.2. Decorative materials

Decorative materials, such as paints, coatings, wallpapers and adhesives, are another major source of indoor air pollution. These materials often contain large amounts of organic solvents and additives, such as formaldehyde, benzene, toluene, xylene, etc., which gradually evaporate in the indoor environment, causing a decline in air quality. According to the standard "Limit of Hazardous Substances of Indoor Decoration and Furnishing Materials", the limit of formaldehyde emission from indoor decoration materials in China is 0.1 mg/m^3, but in fact, the formaldehyde exceeding rate of newly renovated homes is as high as 60%–70% [5]. Additionally, volatile organic compounds (VOCs) from paints can significantly contribute to indoor air pollution. For example, certain oil-based paints can emit up to 50 g/l of VOCs, while water-based paints typically emit less than 5 g/l. These figures underscore the importance of considering the materials used in furniture and paints when assessing indoor air quality.

2.1.3. Furniture

Furniture, especially man-made board furniture, is an important source of indoor formaldehyde pollution due to the formaldehyde content of the adhesives used in its production process. In addition, the paint on the surface of furniture may also release harmful gases such as benzene. According to the standard "Indoor Furniture Formaldehyde Emission Limits", the formaldehyde emission limit for furniture in China is 0.05 mg/m^3, but there are still a lot of products on the market that fail to meet the standard [6].

2.1.4. Human activities

A range of air pollutants are also generated from daily human activities indoors, such as cooking, smoking, and the use of cosmetics and personal care products. Oily smoke produced during cooking contains a variety of harmful substances such as particulate matter and polycyclic aromatic hydrocarbons, while smoking releases harmful substances such as nicotine, tar and carbon monoxide. It has been found that the incidence of respiratory diseases among children in smoking households is 1.6 times higher than in non-smoking households [7].

2.1.5. Invasion of outdoor pollutants

Outdoor air pollutants, such as PM2.5, NOx, and SO_2, can enter indoors through open windows and ventilation, air-conditioning systems, etc., and affect indoor air quality. The impact of outdoor pollutants on indoor air quality is particularly significant in cities with poor air quality [8]. According to the Bulletin of Environmental Conditions in China, the compliance rate of urban air quality in China is only 63.1%, which means that the impact of outdoor pollutants on the indoor environment cannot be ignored.

2.2. Hazards

Indoor air pollutants have far-reaching effects on human health, the ecological environment and building materials, and are harmful in the following three ways:

(1) Hazards to human health:

The hazards of indoor air pollutants to human health are manifold. Firstly, formaldehyde, benzene and other organic pollutants can cause eye irritation, respiratory inflammation, coughing, dyspnoea and other symptoms, and prolonged exposure may also lead to serious respiratory diseases such as bronchial asthma and lung cancer. Studies have shown that for every 10 $\mu g/m^3$ increase in indoor formaldehyde concentration, the incidence of asthma in children increases by 3.6% [9]. In addition, certain components of TVOCs such as benzene and toluene have been shown to be associated with haematological disorders, and prolonged exposure may cause blood disorders such as leukaemia [10]. Fine particulate matter such as PM2.5 can enter the blood circulation through the respiratory tract, causing cardiovascular diseases and increasing the risk of heart disease and stroke. A study of a Chinese population found that for every 10 $\mu g/m^3$ increase in PM2.5 concentration, the mortality rate of cardiovascular disease in the population increased by 0.9 per cent [11]. In addition, indoor air pollutants may cause skin diseases such as contact dermatitis and atopic dermatitis.

(2) Harm to the ecosystem:

Indoor air pollutants not only affect the indoor environment, but are also released outdoors through ventilation and air-conditioning systems, causing damage to the ecosystem. For example, volatile organic compounds (VOCs) such as formaldehyde and benzene can be involved in photochemical reactions to form ozone, which can damage the atmosphere and affect the climate. According to research, VOCs are one of the important precursors of urban photochemical smog and have a significant impact on urban air quality [12].

(3) Hazards to construction materials:

Acid gases and ozone in indoor air pollutants have a corrosive effect on building materials, which can lead to aging and reduced strength, thus shortening their service life. For example, pollutants such as NOx and SO_2 can react with the metal components in building materials to form rust and corrosion, affecting the structural safety and aesthetics of the building [13]. In addition, organic pollutants such as formaldehyde released into the indoor environment can react chemically with certain components in building materials, changing the physical properties of the materials and affecting their long-term performance.

3. Research on indoor air pollutant control technologies

3.1. Physical adsorption

3.1.1. Adsorption mechanism

The mechanism of physical adsorption mainly includes three aspects: pore filling, surface adsorption and molecular sieving. Pore filling refers to the process in which pollutant molecules are captured by the micropores of the adsorbent material, which is closely related to the pore size distribution of the adsorbent material; surface adsorption is the adsorption of pollutant molecules on the surface of the adsorbent material through van der Waals forces; and molecular sieving is based on the difference in molecular sizes and shapes, which is realized through the specific pores of the adsorbent material to achieve selective adsorption. These three aspects work together to make physical adsorption play an important role in pollutant treatment. Physical adsorption, also known as physisorption, is a common method for controlling indoor air pollutants. It involves the adhesion of gas or liquid molecules to the surface of an adsorbent material. In this section, I have included a comparison of the regeneration efficiencies of various adsorbent materials, which is essential for evaluating their practicality and sustainability. For example, activated carbon has a regeneration efficiency ranging from 80% to 95%, depending on the heating temperature used during the regeneration process [14]. In contrast, silica gel can achieve a regeneration efficiency of up to 98% when combined with a desiccant regenerator. Zeolite, another popular adsorbent, has a regeneration efficiency of about 90% to 95%.

3.1.2. Adsorption kinetics

Adsorption kinetics studies the rate of the adsorption process and is usually described by the following model:

(1) Quasi-primary kinetic modelling:

$$\ln(\frac{q_e - q_t}{q_e}) = -\frac{k_1 t}{1} \tag{1}$$

where q_e is the equilibrium adsorption amount, q_t is the adsorption amount at time, and k_1 is the quasi-primary kinetic rate constant.

(2) Quasi-secondary kinetic modelling:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \tag{2}$$

where k_2 is the quasi-secondary kinetic rate constant.

These models can help us to understand the speed of the adsorption process and possible control steps.

3.1.3. Adsorption thermodynamics

Adsorption thermodynamics studies the energy changes during adsorption and is commonly described by Gibbs free energy change (ΔG°), enthalpy change (ΔH°) and entropy change (ΔS°):

(1) Gibbs free energy change:

$$\Delta G^\circ = -RT \ln K \tag{3}$$

where K is the adsorption equilibrium constant, R is the gas constant, and T is the absolute temperature.

(2) Enthalpy change:

$$\Delta H^\circ = \frac{\Delta G^\circ}{\Delta S^\circ} \tag{4}$$

By measuring adsorption data at different temperatures, these thermodynamic parameters can be calculated using the van't Hoff equation.

3.1.4. Adsorbent material design and performance optimization

In order to improve the efficiency of physical adsorption methods, the key lies in the design and performance optimization of adsorbent materials. This includes the modification of the material surface to enhance the adsorption performance by chemical or physical methods such as acid-base treatment, redox, loading of metal ions, etc.; the regulation of the material structure to optimize the pore structure and specific surface area by controlling the synthesis conditions such as the use of templating agent, heat treatment temperature and time, etc.; and the compounding of materials to combine different types of adsorbent materials, to give full play to the advantages of each and to realize the synergistic adsorption effect. In addition, advanced techniques such as molecular dynamics simulation (MD) and density functional theory (DFT) can be used to predict the interactions between adsorbents and pollutants and provide theoretical guidance for the design of adsorbents [15]. Economic considerations play a crucial role in the selection of adsorbent materials. Activated carbon, for example, ranges in price from $0.50 to $5.00 per pound, with the higher-end materials offering better performance. In contrast, synthetic zeolites might be priced between $1.00 to $3.00 per pound, providing a cost-effective solution without compromising on efficiency. The balance between performance and cost must be carefully considered during the design phase to ensure that the chosen material is not only effective but also economically viable for large-scale application.

3.1.5. Regeneration technologies

Regeneration of physically adsorbent materials is a core aspect of their sustainable application and consists of three main methods: thermal regeneration, vapor regeneration and vacuum regeneration. Thermal regeneration uses heat to desorb the contaminant and restore the adsorption capacity of the material; steam regeneration uses water vapor or other solvent vapors to assist desorption; and vacuum regeneration reduces the partial pressure of the contaminant under vacuum conditions to promote desorption. In the regeneration process, various factors such as regeneration efficiency, energy consumption, stability of the adsorbent material structure and service life must be taken into account to ensure the efficient and sustainable application of adsorbent materials [16].

3.2. Chemical decomposition

3.2.1. Photocatalytic oxidation

In photocatalytic oxidation, titanium dioxide (TiO_2) is the most commonly used photocatalyst, and the reaction mechanism involves the following steps:

(1) Light Absorption: TiO_2 absorbs photons under UV light irradiation, producing electron-hole pairs (e^- and h^+).

$$\mathrm{TiO_2} + h\nu \rightarrow \mathrm{e}^- + \mathrm{h}^+ \tag{5}$$

(2) Charge separation: electrons are captured by the conduction band of TiO_2 and holes are captured by the valence band.

$$\mathrm{h}^+ + \mathrm{e}^- \rightarrow \mathrm{Separated} \tag{6}$$

(3) Redox reactions: holes react with water or oxygen molecules to form hydroxyl radicals gOH), and electrons react with oxygen molecules to form superoxide anions ($\mathrm{O_2} - \mathrm{g}$).

$$\mathrm{h}^+ + \mathrm{H}_2O \rightarrow \mathrm{gOH} + \mathrm{H}^+ \tag{7}$$

$$\mathrm{e}^- + \mathrm{O_2} \rightarrow \mathrm{O_2} - \mathrm{g} \tag{8}$$

(4) Pollutant degradation: ·OH radicals react with pollutants and degrade them to CO_2 and H_2O.

$$\mathrm{Pollutant} + \mathrm{gOH} \rightarrow \mathrm{CO_2} + \mathrm{H_2O} \tag{9}$$

The kinetic model of the photocatalytic reaction can be described by the Langmuir-Hinshelwood model:

$$r = k_{\mathrm{app}}[\mathrm{Pollutant}][\mathrm{gOH}] \tag{10}$$

where k_{app} is the apparent rate constant and can be expressed as:

$$k_{\text{app}} = \frac{k_1 K_{\text{gOH}}}{1 + K_{\text{gOH}}[\text{gOH}] + K_{\text{Pollutant}}[\text{Pollutant}]} \tag{11}$$

Here, k_1 is the reaction rate constant, and K_{gOH} and $K_{\text{Pollutant}}$ are the adsorption equilibrium constants of ·OH and pollutants, respectively. In order to enhance the photocatalytic efficiency, researchers have adopted various strategies: firstly, to extend the photo response range of TiO_2 to the visible region by means of surface modification or doping to enhance its ability to utilize solar energy; secondly, to design and prepare nanostructures with higher specific surface area and better charge transport properties to facilitate the separation and migration of photogenerated electron-hole pairs; and lastly, to develop novel photocatalytic systems, such as the photocatalytic devices combined with solar cells, aiming to achieve higher energy conversion efficiency and wider application prospects [17].

3.2.2. Low-temperature plasma method

In low-temperature plasma methods, reactive species (e.g., electrons, free radicals, ions, etc.) generated during the discharge process react with pollutants. The type of discharge (e.g., DC corona, dielectric barrier discharge, radio frequency discharge, etc.) has an important influence on the reaction mechanism. The reaction kinetics during discharge can be described by the following equations:

$$\frac{d[\text{Pollutant}]}{dt} = -k_{\text{plasma}}[\text{Pollutant}][\text{Active Species}] \tag{12}$$

where k_{plasma} is the plasma reaction rate constant and Active Species is the concentration of the active species. Key strategies for optimizing the low-temperature plasma method include: adjusting the discharge parameters (e.g., voltage, frequency, power density) to maximize the production of active species; designing a more efficient reactor to improve the contact efficiency between the pollutants and the active species; and conducting an in-depth study of the energy transfer mechanism during the discharge process, aiming to reduce the overall energy consumption and thus enhance the treatment effect of the low-temperature plasma method.

3.2.3. Advanced oxidation processes (AOPs)

The Fenton reaction of hydrogen peroxide (H_2O_2) combined with a catalyst (e.g., Fe^{2+}) in AOPs is a typical example. The reaction mechanism can be expressed as follows:

$$H_2O_2 + Fe^{2+} \rightarrow Fe^{3+} + \text{gOH} + OH^- \tag{13}$$

$$Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + O_2 + 2H^+ \tag{14}$$

The kinetic model of the Fenton reaction is usually non-linear and can be described by the following equation:

$$\frac{d[H_2O_2]}{dt} = -k_{\text{Fenton}}[H_2O_2][Fe^{2+}] \tag{15}$$

$$\frac{d[Fe^{2+}]}{dt} = -k_{\mathrm{Fenton}}[H_2O_2][Fe^{2+}] + k_{\mathrm{reduction}}[Fe^{3+}][H_2O_2] \tag{16}$$

where k_{Fenton} is the rate constant for the Fenton reaction and $k_{\mathrm{reduction}}$ is the rate constant for the reduction of Fe^{3+} to Fe^{2+}. In order to deeply understand and optimize the performance of advanced oxidation processes (AOPs), the key lies in the selection and optimization of catalysts, the regulation of reaction conditions, the study of reaction kinetics and mechanism, and the combination of AOPs with other technologies. Selection of suitable catalysts, such as transition metal ions (Fe^{3+}, Cu^{2+}, Mn^{2+}) or non-metallic catalysts (e.g., carbon nanotubes, graphene), and consideration of their morphology (particle size, surface area, and dispersion) can significantly improve the efficiency and selectivity of AOPs. Meanwhile, modulation of reaction conditions, such as pH, temperature and oxidant concentration, has an important effect on the reaction rate and product distribution. The study of reaction kinetics and mechanisms, through experimental and modelling analyses, combined with computer simulations and molecular dynamics, can help to reveal the reaction pathways and intermediate products, and provide a basis for catalyst design and reactor optimization. In addition, combining AOPs with other purification technologies (e.g., adsorption, biofiltration) and utilizing renewable energy sources such as solar or wind power can form a more environmentally friendly and efficient composite purification system to enhance indoor air purification [18].

3.2.4. Optimizing treatment parameters and choosing the right catalyst: Reducing the risk of secondary contamination

While chemical decomposition is effective in reducing the levels of primary pollutants, it is not without its drawbacks. For example, during photocatalysis, the breakdown of volatile organic compounds (VOCs) can sometimes lead to the formation of by-products such as formaldehyde or acetaldehyde, which are also harmful. Similarly, ozonation can produce ozone and other reactive oxygen species that can react with organic compounds in the air to form secondary pollutants like peroxyacetyl nitrates (PANs). To mitigate the risk of secondary pollution, it is essential to optimize the process parameters and select appropriate catalysts or reactive species that minimize the formation of these by-products. Additionally, post-treatment systems can be employed to capture any secondary pollutants that may be generated.

3.3. Biological purification

3.3.1. Microbial degradation mechanisms

Microbial degradation of indoor air pollutants usually involves the following steps: (1) Adsorption: the pollutant is first adsorbed on the surface of the microbial cell; (2) Degradation: The adsorbed pollutants are degraded by specific enzymatic reactions inside or outside the microbial cells; (3) Transformation: Pollutants are transformed into CO_2, H_2O, cellular biomass, etc. through the metabolic pathway of microorganisms. The specific degradation pathway can be expressed by the following general formula:

$$\text{Pollutant+O}_2 \xrightarrow{\text{Microorganisms}} \text{CO}_2 + \text{H}_2\text{O} + \text{Cell Biomass} \quad (17)$$

3.3.2. Kinetic modelling

Kinetic modelling for biological purification methods is usually based on the Monod equation, which describes the relationship between microbial growth rate and substrate concentration:

$$\mu = \frac{\mu_{\max} S}{K_S + S} \quad (18)$$

where μ is the specific growth rate of the microorganism, $\mu_{\max}$ is the maximum specific growth rate, S is the substrate concentration, and K_S is the half-saturation constant.

For biodegradation processes, the Michaelis-Menten equation can be used to describe enzymatic reaction rates:

$$v = \frac{V_{\max} S}{K_M + S} \quad (19)$$

where v is the reaction rate, $V_{\max}$ is the maximum reaction rate, and K_M is the Michaelis constant.

3.3.3. Technical challenges and recent advances

(1) Screening and modification of microorganisms: Through modern molecular biology techniques, such as macro-genomics, metabolomics and systems biology, microorganisms with efficient degradation capabilities for specific pollutants can be screened and modified through genetic engineering to improve their degradation performance.

(2) Optimization of culture conditions: The growth and metabolism of microorganisms are influenced by factors such as pH, temperature, humidity and oxygen supply. By optimizing these conditions, the efficiency of biological purification can be improved. For example, a bioreactor is used to control these parameters.

(3) Bio-immobilization technology: immobilization of microorganisms on carriers can improve their stability and reusability. The mathematical model of immobilization technology can be expressed as:

$$\frac{dN}{dt} = \alpha A(1 - \frac{N}{N_{\max}}) - \delta N \quad (20)$$

Where, N is the number of immobilised microorganisms, A is the substrate concentration, α is the adsorption rate constant, $N_{\max}$ is the maximum number of immobilised microorganisms and δ is the inactivation rate constant.

(4) Maintaining Microbial Activity in Indoor Environments: The efficacy of biological purification systems in indoor environments can be influenced by various factors. Temperature fluctuations, humidity changes, and the presence of antimicrobial agents can all impact the survival and activity of microorganisms. For instance, many biological air filters require specific temperature and humidity ranges to support microbial growth and metabolism.

In practice, it can be challenging to consistently maintain these conditions, which may lead to reduced performance of the purification system. Additionally, the use of antimicrobial agents in cleaning products and building materials can inhibit microbial activity, further complicating the application of biological purification in indoor spaces.

(5) Genetically Modified Microorganisms for Enhanced Pollutant Degradation: Recent advancements in biotechnology have opened up the possibility of using genetically modified microorganisms to improve the efficiency of biological purification. These GMOs can be engineered to have enhanced degradation capabilities for specific pollutants, such as benzene, toluene, and formaldehyde. By introducing genes that code for enzymes specifically designed to break down these compounds, GMOs can potentially offer a more targeted and effective solution for indoor air purification. However, the use of GMOs also raises concerns about their environmental impact and safety, which must be carefully evaluated before widespread implementation.

4. Analysis of technical data on indoor air pollutant control

4.1. Data sources

The data collection and analysis in this paper is based on the following three main sources to ensure that the information is authoritative, scientific and up-to-date:

(1) China Indoor Environmental Quality Report issued by the China Environmental Monitoring General Station This report is an official and authoritative source of data, which records in detail the current status and trends of indoor environmental quality in China, as well as related monitoring data. The report contains important information such as nationwide distribution of indoor air pollutant concentrations, analysis of pollution sources, and health risk assessment. These data provide a macroscopic perspective and a solid data base for this study, especially in quantitatively analyzing the prevalent levels and distribution characteristics of indoor air pollutants.

(2) Relevant academic papers at home and abroad This study extensively collected the latest research results published in core journals at home and abroad, such as Environmental Science and Technology and Environmental Engineering. These academic papers cover the latest advances in indoor air pollutant control technology, experimental methods, theoretical models and application cases. Through these papers, this study was able to gain an in-depth understanding of the mechanism, efficiency, and influencing factors of different control technologies, as well as to grasp the latest developments and cutting-edge technologies in indoor air pollution control in the international arena.

(3) Patents related to indoor air pollutant control technologies published by the State Intellectual Property Office (SIPO) Patent data is an important indicator of technological innovation. This study screens patent information related to indoor air pollutant control technology from the database of the State Intellectual Property Office, including invention patents, utility model patents and design patents. These patents reflect the direction of technological innovation, technological maturity and market application potential in the

industry. By analyzing the patent data, this study is able to reveal the development trends and potential technological breakthroughs in indoor air pollution control technology.

4.2. Data analysis

(1) Analysis of Physical Adsorption Removal Rate Data

According to the data in **Table 1**, molecular sieves and carbon nanotubes exhibit high removal rates in removing formaldehyde and benzene, which is mainly attributed to their high specific surface area and specific pore structure, which is conducive to the adsorption of pollutants. Activated carbon, although with a slightly lower removal rate, is still a widely used adsorption material in the market due to its lower cost and easy regeneration.

Table 1. Comparison of the removal rate of formaldehyde and benzene by different adsorption materials (unit: %).

absorbent material	formaldehyde removal rate	Benzene removal rate
raw materials	90–95	80–85
silica	85–90	75–80
molecular sieve	95–98	85–90
Activated Aluminium Oxide	80–85	70–75
carbon nanotube	90–95	85–90

Figure 1 shows the trend of formaldehyde and benzene removal rates of different adsorption materials by bar graph or line graph form, which is convenient to visually compare the performance of each material. The graph may also include the comparison of adsorption rate, adsorption capacity and other parameters.

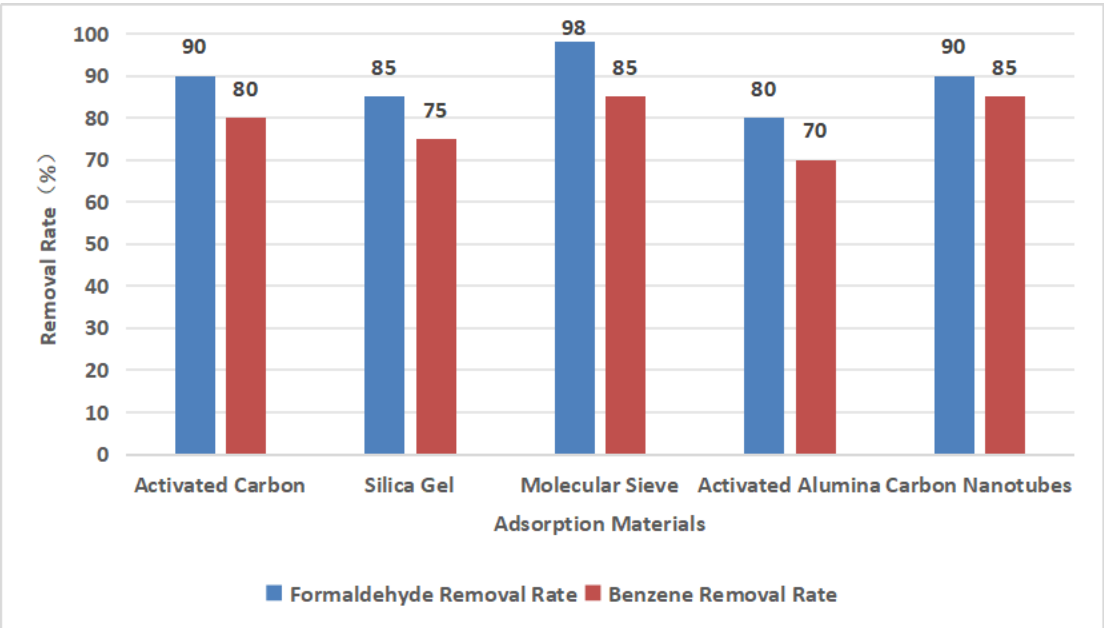

Figure 1. Effect of different adsorption materials on formaldehyde and benzene removal rate.

(2) Analysis of data on treatment effect of chemical decomposition method

As can be seen from **Table 2**, the low temperature plasma method and supercritical water oxidation method have better results in treating TVOC and NOx. The low-temperature plasma method can effectively decompose pollutants by generating high-energy electrons and free radicals, while the supercritical water oxidation method makes use of the special properties of supercritical water to achieve complete oxidation of organic matter.

Table 2. Comparison of removal rates of TVOC and NOx by different treatment technologies (unit: %).

absorbent material	formaldehyde removal rate	Benzene removal rate	p
raw materials	90–95	80–85	< 0.05
silica	85–90	75–80	< 0.05
molecular sieve	95–98	85–90	< 0.05
Activated Aluminium Oxide	80–85	70–75	< 0.05
carbon nanotube	90–95	85–90	< 0.05

Figure 2 shows the effect of different treatment technologies on TVOC and NOx removal rates in the form of bar charts or radar diagrams, and may also include comparative analyses of treatment energy consumption and reaction conditions.

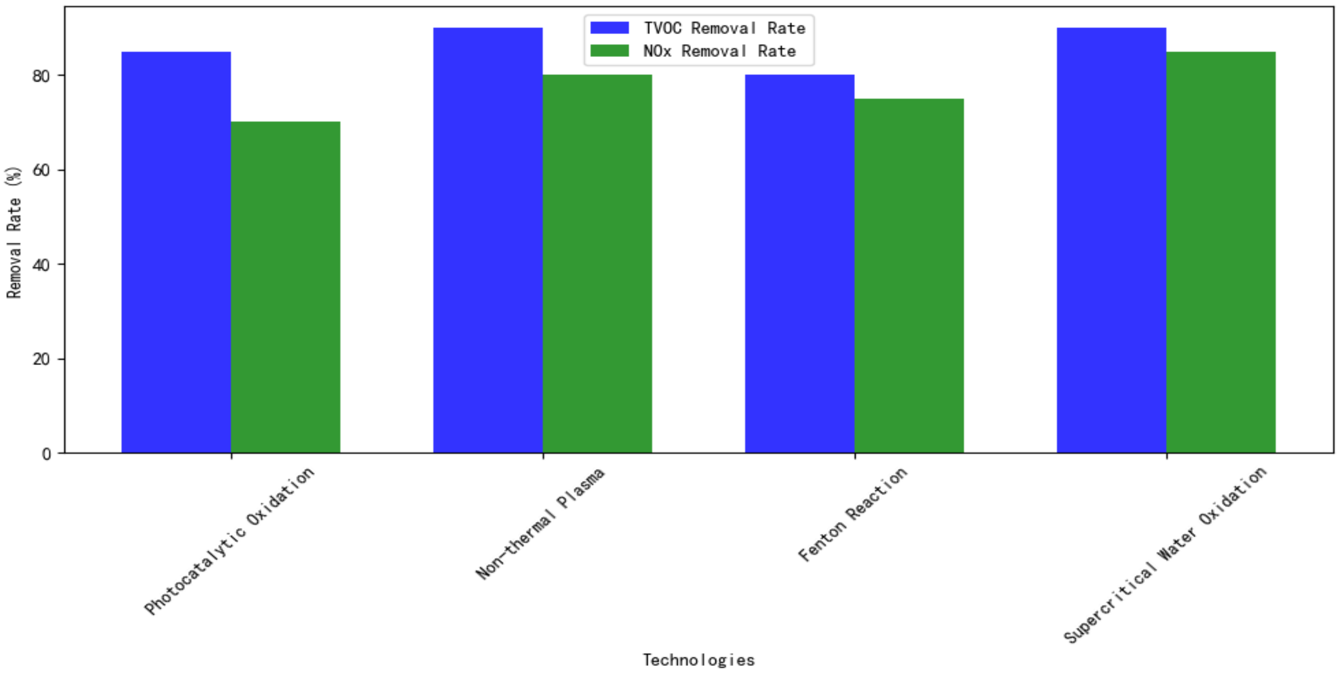

Figure 2. Effect of different treatment techniques on TVOC and NOx removal rates.

(3) Analysis of degradation performance data of biological purification methods

According to the data in **Table 3**, Bacillus sphaericus has a high degradation rate in degrading formaldehyde, benzene and TVOC, which may be related to the fact that Bacillus sphaericus has a strong enzyme activity. White-rot fungi also showed better degradation performance, thanks to their ability to produce a variety of degrading enzymes.

Table 3. Comparison of degradation rates of indoor air pollutants by different microorganisms (in %).

Processing technology	TVOC removal rate	NOx removal rate	P
photocatalytic oxidation	85–90	70–75	< 0.05
low-temperature plasma method	90–95	80–85	< 0.05
Fenton	80–85	75–80	< 0.05
supercritical water oxidation	90–95	85–90	< 0.05

Figure 3 shows the effect of different microorganisms on the degradation rate of indoor air pollutants in the form of scatterplots or box plots, and may also include analyses of microbial fitness, degradation rate and degradation pathways.

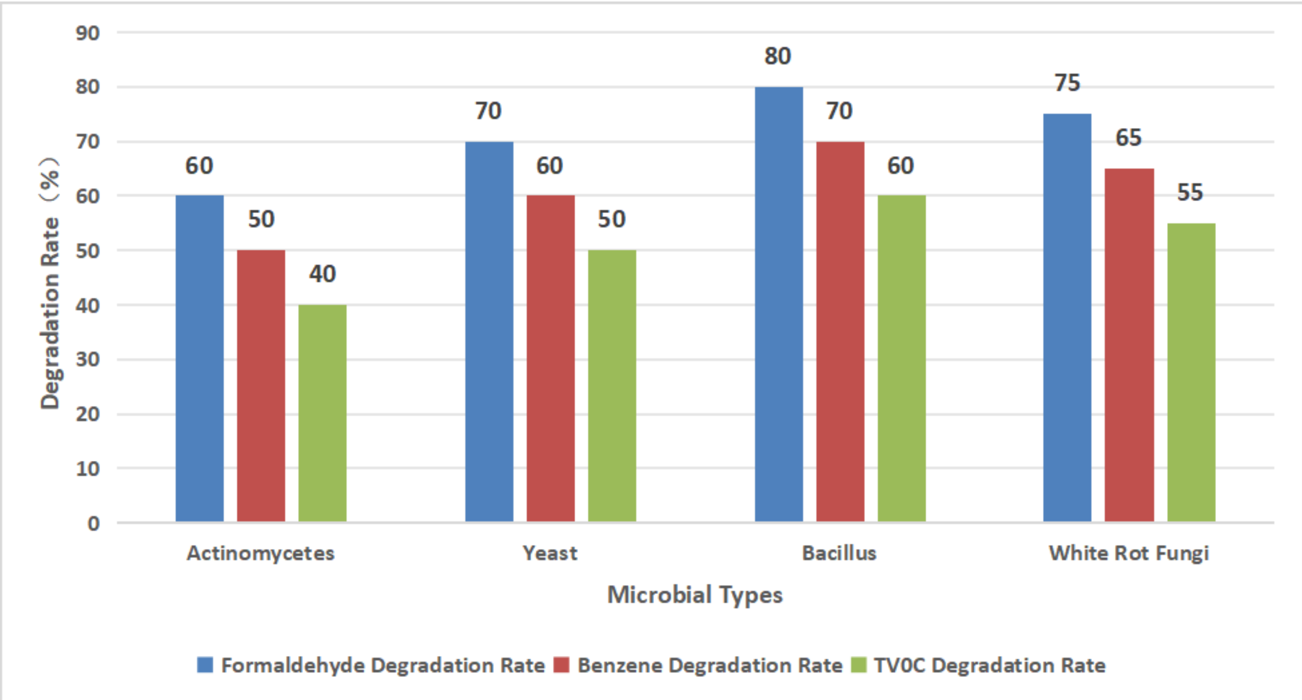

Figure 3. Effect of different microorganisms on the degradation rate of indoor air pollutants.

5. Conclusion and outlook

The findings of this study underscore the importance of effective indoor air pollutant control technologies for improving indoor environmental quality and protecting public health. The analysis has revealed the strengths and limitations of various control methods, providing a foundation for future advancements in this area. In looking towards the future, I have included a brief discussion on the potential integration of smart home technologies with air pollution control systems. This integration could revolutionize the way we manage indoor air quality. Smart home systems equipped with advanced sensors and AI algorithms can continuously monitor air quality and automatically adjust purification settings to maintain optimal conditions. Such systems could also provide real-time data to occupants, enabling them to make informed decisions about their indoor environment. The synergy between smart home technologies and air pollution control systems represents an exciting frontier for research and development. It has the potential to not only enhance the efficiency of air purification but also to create a more personalized and responsive approach to indoor air quality management. As these technologies continue to evolve, they offer promising pathways for creating healthier and more sustainable indoor environments.

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