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ACTIVATED CARBON FOR FORMALDEHYDE CAPTURE IN NEW BUILDINGS

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ABSTRACT

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Over time, formaldehyde and activated carbon are well known in daily life, and everyone can always be exposed to relevant derivatives. After you decorate a new building, it will always be wary of formaldehyde exceeding the standard and place activated carbon to achieve the purpose of making the formaldehyde concentration up to the standard and not affecting people's health. Due to the relationship between adsorption and adsorption, this paper explores the efficiency of the reaction in this process, combined with the relevant experimental data to support, and briefly describes its real practical and effective mechanism.

Key words
Activated carbon, Formaldehyde, Efficiency, New building

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1 INTRODUCTION

Activated carbon, is black powder or granular amorphous carbon. In addition to carbon, its main components include oxygen, hydrogen, and other elements. Activated carbon is a kind of porous carbon with low bulk density, large specific surface area due to its irregular arrangement of microcrystalline carbon and fine pores between cross connections (Kubyshkin 2010). Activated carbon is tasteless, sand free and insoluble in any solvent. It has selective adsorption capacity for various gases and high-capacity adsorption capacity for organic pigments and nitrogen-containing bases. (Yakovleva 2010).

Formaldehyde is an organic chemical substance with the chemical formula of HCHO or CH ν o, molecular weight of 30.03, also known as formic aldehyde. It is a colourless and irritating gas, which can attack human eyes and nose. On October 27, 2017, formaldehyde was included in the list of class I carcinogens in the list of carcinogens published by the international agency for research on cancer of the World Health Organization (Rengga, Sudibandriyo & Nasi kin, 2012). On July 23, 2019, formaldehyde was listed in the list of toxic and harmful water pollutants (the first batch) (WHO 2010).

The main purpose of this research report is to show the adsorption of formaldehyde on activated carbon. In daily life, we can often learn the most information that many people will place activated carbon to remove formaldehyde and other harmful substances in the room after buying new house decoration. The most heard is the removal of formaldehyde, which is also known as formaldehyde.

2 THE INFLUENCE OF FORMALDEHYDE AND ACTIVATED CARBON

Formaldehyde (CHO) is one of the typical pollutants in the indoor environment. In a residential survey in California, the average indoor formaldehyde concentration reached a dreadful 17 ppbv, which is much higher than the 8 h reference exposure level recommended by the Environmental Protection Agency: 7 ppbv(An & Wang 2022). Another poll in China likewise demonstrated similar results, because all kinds of furniture and ornamental coatings are releasing formaldehyde all the time, and the release period can be up to 15 years. This shows that our attention to formaldehyde treatment is still far from sufficient. According to statistics, people spend 88% of their life indoors (Yang, Qu & Sun 2022).

Accordingly, as a class I carcinogen identified by the International Agency for Research on Cancer, if formaldehyde cannot be effectively eliminated, it will pose a huge threat to human health (Zhou & Zhao 2022). At present, formaldehyde-caused indoor pollution affects approximately 2.8 million people in the world every year (Yang & Zhou 2022). The development of an efficient formaldehyde treatment technology is of significant importance for protecting human health and satisfying indoor environmental requirements. The activated carbon adsorption is a common technology of removing formaldehyde which is easy to operate, and low investment required. However, although activated carbon exhibits a high adsorption ability for most pollutants, it cannot effectively adsorb formaldehyde, and even desorption occurs (Qu & Zhou 2022).

2.1 Details of formaldehyde

Formaldehyde is a highly toxic substance, ranking second in the priority control list of toxic chemicals in China, and has been identified by the World Health Organization as carcinogenic and teratogenic substance. Formaldehyde is recognized as an allergen and one of the potential strong mutagens (Tang 2009). Research shows that formaldehyde has strong carcinogenic and cancer-promoting effects. Among all contacts, children and pregnant women are particularly sensitive to formaldehyde, and the harm is greater. The effects of formaldehyde on human health are manifested in abnormal olfaction, stimulation, allergy, lung function, liver function and immune function (Kim & Kim 2005).

When its concentration reaches 0.06-0.07 mg/m3 in the air, children will have slight asthma. When the formaldehyde content in the indoor air is 0.1 mg/m3, there is a peculiar smell and people feel uncomfortable. When it reaches 0.5 mg/m3, it can irritate eyes and cause tears. When it reaches 0.6 mg/m3, it can cause throat discomfort or pain. When the concentration is higher, it can cause nausea and vomiting, cough, chest tightness, asthma and even pulmonary enema. When it reaches 30 mg/m3, it will cause death immediately (Zhang 2009).

2.2 Effect of activated carbon

Activated carbon is a small carbon particle with a larger area, which contains small capillaries. Such capillaries have extremely strong adsorption capacity. Because of the large area of carbon particles, it can fully touch the vapor (residue) (Zhang 2015). So, when the vapor (residue) touches the capillary, it will be absorbed and purified. The results can be seen in the wastewater treatment project. Activated carbon (AC) can be added to the membrane bioreactor (MBR) to treat wastewater (Skouteris, Saroj., Melidis, Hai & Ouki 2015).

This process combines adsorption, biodegradation, and membrane filtration using AC assisted MBR. This can lead to advanced removal of stubborn pollutants and reduce membrane fouling. The sludge retention time (SRT) determines the frequency of AC extraction and fresh AC addition, and is an important parameter that significantly affects the performance of AC assisted MBR. The most important thing is the AC dosage, as excessive AC may exacerbate membrane fouling, increase sludge viscosity, damage mass transfer, and reduce sludge dewatering ability (Skouteris et al. 2015)

Activated carbon is used to absorb harmful substances, filter out insoluble substances, and absorb some soluble substances. The main part of activated carbon is charcoal. It is made by a series of processes by using various fruit stones and high-quality coal as raw materials, crushing raw materials, screening powder, metal catalyst activity, soaking, drying and choice according to physical methods (Lee & Miyawaki 2013). The first role of activated carbon in the world is to produce anti-gas masks. After that, activated carbon is used for door removal of activated carbon in waterworks. Activated carbon can eliminate residual chlorine, colloidal solution, organic compounds, and heavy metals in water that exceed the standard (such as mercury, silver, cadmium, chromium, lead, and nickel) (Yoon & Jang 2013). Radioactive elements are the earliest substances used in water purifiers. Water treatment materials are the most widely used. The porous structure of activated carbon is developed, and its adsorption capacity is strong (Miyawaki 2013).

2.2.1 The effect of activated carbon on wastewater treatment

Environmental protection enterprises use wastewater treatment, organic waste gas and harmful substances treatment methods, purification gas, the key air pollution source discharged from the coal combustion process in China. Activated carbon flue gas desulfurization and flue gas denigration, with obvious solution effect, low cost of development and operation, and easy recovery and utilization (Zhang 2005). In a study, a method combining microalgae biological treatment with sludge cultivation and physical absorption of activated carbon was used to remediate weak wastewater. The influences of each factor on the process efficiency have been studied in detail by statistical analysis (Zahmatkesh & Pirouzi 2020).

The experimental design was carried out using Taguchi arrangement. Chemical oxygen demand (COD) and biological oxygen demand (BOD) were measured as responses over 16 h of the treatment. It was found that the physical absorption was controlled the treatment with the highest contribution ($> 71\%$) (Pirouzi 2020). It found that the second and third ranks correspond to the microalgae and activated sludge, respectively. The optimal conditions to minimize COD were obtained at the activated carbon of 0.2 g/l, microalgae of 1 ml/l and activated sludge of 1 ml/l. The study shows that the reductions in COD and BOD are more than 90% and 93%, respectively. The validity of the predicted mathematical model also has been confirmed by measuring the responses at the optimal conditions, resulting in low deviation (Zahmatkesh & Pirouzi 2020).

2.2.2 Activated carbon has adsorption effect

The activated carbon adsorption method for removing indoor air pollution is one of the most widely used, perfect, safe, practical, and valuable methods for absorbing substances. Using activated carbon is a kind of high-quality methods. People paid more attention to organic chemical adsorbent (Lee, Miyawaki & Shiratori 2013). The activated carbon can absorb the molecular structure of indoor formaldehyde, ammonia, benzene, xylene, radon, and other harmful substances in the air, and can quickly remove the smell after decoration. Newly renovated houses and newly purchased furniture can be deodorized with activated carbon. New cars will contain many harmful things. The pungent smell can be removed with activated carbon (Yoon & Jang 2013).

2.3 Popularity of activated carbon

The advantages of activated carbon are manifested in four aspects: first, the adsorption range is wide, and the adsorption performance is good. Second, the physical and chemical properties are stable, and the intensity is high, which can adapt to various working environments. Third, flexible use, simple production process. Fourth, it is highly efficient and recyclable. The superior application characteristics and economic efficiency of production and utilization of activated carbon make it an irreplaceable product in many industries (Cao, Han & Yang 2017). The main application fields of activated carbon cover food and beverage, chemical industry, metallurgy, light textile, water treatment, medicine, and other industries. In recent years, with environmental protection and energy conservation becoming the core concept of economic and social development, the application value of activated carbon in water treatment, air pollution prevention and other fields is also increasingly prominent (Shi, Jia & Geng 2005). In addition, with the technological progress in the fields of new material technology and medical science, the application of activated carbon in energy storage, natural gas recovery, blood purification and other aspects is gradually expanded, which will inject new vitality into the prospects of the industry.

3 STRUCTURE OF ACTIVATED CARBON

Activated carbon uses the structure with many pores for adsorption, which is a kind of physical adsorption. In fact, the molecular structure of activated carbon is special. It contains very developed pores. When gas or liquid passes through activated carbon, it can be adsorbed by ac-riveted carbon, and then it cannot be released. It is because there are many airs interval, so the adsorption capacity is extraordinarily strong. (Cai Z 2011). The activated carbon uses the static adsorption method. However, if the formaldehyde in a space does not diffuse near the activated carbon, there is no way to be absorbed by the activated carbon, so the adsorption range has been affected.

The chemical structure of activated carbon is in the form of disordered graphite. The basic chemical structure of activated carbon is closely approximated by the structure of pure graphite. The graphite crystal is composed of layers of fused hexagons held by weak van de Waals forces. The layers are held by carbon–carbon bonds (Nasikin 2012). The activated carbon can only be fixed in one place and cannot move freely for adsorption. Some activated carbon were prepared by specific activation methods to improve the surface area. Some researchers also used modified activated carbon by adding specific additive to improve its performance in attracting formaldehyde molecules (Rengga & Sudibandriyo 2012). The greater the capacity, the more contaminants the activated carbon will be able to adsorb in volume.

Activated carbon is a kind of specially treated carbon, which heats organic raw materials (fruit shell, coal, wood). Under the condition of isolating air to reduce non-carbon components. This process is called carbonization. Then the activated carbon reacts with the gas, and the surface is subsequently eroded to produce a microporous structure, which is called activation. (Jawad & Ismail 2019). Because the activation process is a microscopic process, that is, the surface erosion of many molecular carbides is pitting, resulting in numerous small pores on the surface of activated carbon. The diameter of micropores on the surface of activated carbon is mostly between 2 and 50 nm. Even a small amount of activated carbon has a huge surface area. The surface area of each gram of activated carbon is 500~1500 m2. All applications of activated carbon are based on this feature of activated carbon (Ishak & Wilson 2019). The microporous specific surface area of activated carbon accounts for more than 95% of the specific surface area of activated carbon, which determines the adsorption capacity of activated carbon. The specific surface area of mesopore accounts for about 5% of the specific surface area of activated carbon, which is the adsorption site of larger molecules that cannot enter the micropores and generates capillary condensation under high relative pressure (Li & Xiao 2019). The specific surface area of macropores is not more than 0.5m2/g, which is only the channel for adsorbate molecules to reach micropores and mesopores and has influence on the adsorption process.

3.1 Classification of activated carbon

Activated carbon can be divided into coal activated carbon, wood activated carbon, fruit shell carbon, coconut shell carbon, petroleum activated carbon, bone carbon and mineral raw material carbon according to its source of raw materials (Moreno-Marenc 2019). According to the manufacturing method, it can be divided into physical method, chemical method, and the combination of chemical and physical methods. According to its morphology, it can be divided into spherical activated carbon, columnar activated carbon, powdered activated carbon, granular activated carbon, fibrous activated carbon, and amorphous activated carbon (Giraldo 2019). Plant chitin activated carbon has developed microporous structure compared with other activated carbon, wood activated carbon has rich mesoporous structure compared with other activated carbon, and coal activated carbon has all kinds of pore structure (Moreno 2019)

3.2 Activated carbon fibre

The industrial development of activated carbon fibre began in the 1960s. Because of its high specific surface area, good conductivity, thermal conductivity and other graphitization characteristics, high strength, good elasticity, and plasticity, activated carbon fibre has become a new type of efficient adsorption material and plays a significant role in the field of air purification (Song & Qiao 2007). It is prepared by carbonization and activation of cellulose (rayon with cellulose as raw material), polymeric fibre (polyacrylonitrile, phenolic resin, polyethylene), asphalt Activated carbon fibre is a porous adsorption material with small and uniform pore size and rich micropores, accounting for more than 90% of the total pore volume. The adsorption of gaseous pollutants by activated carbon fibre is a process of filling micropores (Yoon 2007). The surface of activated carbon fibre contains many micropores, which can effectively adsorb low concentration pollutants and transfer pollutants to activated carbon fibre in large quantities.

The carbon content of activated carbon fibre is about 90%, and contains a small amount of hydrogen, oxygen, sulphur, nitrogen, chlorine, and other elements. The surface of activated carbon fibre contains a series of active oxygen-containing functional groups, such as carboxyl, carbonyl, phenol, ether, ester. Some activated carbon fibres, such as polyacrylonitrile activated carbon fibres, also contain functional groups such as amine group, amino group, and sulfonic group. These activated carbon fibres containing N functional groups have extremely strong adsorption capacity for compounds containing N, S and other elements. Researchers mixed the commercially available activated carbon powder into the AN-VDC copolymer spinning stock solution to make the activated carbon-containing acrylonitrile-chlorinated fibre adsorption fibre (Jin & Hua Z 2015). When the concentration of formaldehyde does not exceed 8mg/L, under the optimal conditions for formaldehyde removal, the removal rate of formaldehyde by the activated carbon-containing acrylonitrile-chlorinated fibre adsorption fibre is more than 95%. Other researchers used organic fibre as the precursor and adopted a wet forming technology to prepare activated carbon fibre filter cake, which has the characteristics of large porosity, three-dimensional network structure and high mechanical strength (Aixu & Zhang 2015).

The activated fibre has certain adsorption efficiency and adsorption capacity for methanol and formaldehyde, which is superior to the common activated carbon fibre materials on the market. Researchers have electro spun polyacrylonitrile nanofibers of about 800 nm, which are carbonized and activated by water vapor to produce carbon nanofibers with many micropores and rich nitrogen-containing functional groups (Kyung, Jin & Lee 2019). Its adsorption of formaldehyde is twice that of traditional activated carbon. It also has a good adsorption effect on formaldehyde when the concentration of formaldehyde is exceptionally low in a humid environment. Other researchers found that the biological enzyme obtained from the hydrolysis of soybean protein was loaded on activated carbon fibre (Hongmei & Zuo 2019).

Formaldehyde can combine with the amino group on the protein and undergo chemical reaction, the protein denatured and solidified, thus achieving the purpose of removing formaldehyde.
It was found that the morphology of the activated carbon fibre loaded with biological enzyme was like the untreated activated carbon fibre, which maintained the original pore and specific surface area, and played a synergistic role in promoting the adsorption of formaldehyde. The removal rate was up to 80%. Some researchers added activated carbon powder to nonwovens through processes such as dip rolling, coating, airbrush, and carbon bag to make nonwovens containing activated carbon powder (Ying, Gang & Jiang 2018).

3.3 Activated carbon modification

The surface of activated carbon has rich pore structure, high specific surface area and active groups. Compared with other types of adsorbents, it has the characteristics of fast adsorption rate, large adsorption capacity and easy regeneration, and has a good application prospect in the treatment of gaseous pollutants. (Rengga & Sudibandriyo 2012) However, when activated carbon alone adsorbs meteorological pollutants, it adsorbs gaseous pollutants through physical adsorption. Due to the limited number of micropores and mesopores on the surface of activated carbon, depending on the physical adsorption of micropores and mesopores in its structure on gaseous pollutants, with the extension of adsorption time, the adsorption of activated carbon on meteorological pollutants reaches saturation, and it is easy to lose its adsorption performance. (Nasikin 2012)

In addition, the activated carbon is low in strength and fragile, and it is easy to cause secondary pollution when adsorbing gaseous pollutants (Carter 2011). In recent years, the modification of the pore structure, specific surface area and surface chemical properties of activated carbon has become a research focus of researchers, and researchers at home and abroad have done a lot of experimental research (Speitel & Ramirez 2011). The surface of activated carbon is modified to make the adsorption of gaseous pollutants on activated carbon change from single physical adsorption to physical-chemical combined adsorption, which creates conditions for the development of activated carbon in the adsorption of gaseous pollutants (Katz 2011).

3.3.1 Modification of surface physical structure of activated carbon

The modification of surface physical structure of activated carbon refers to the modification of pore volume, pore structure and distribution, and specific surface area of activated carbon. There are two methods to modify the physical structure of activated carbon surface (Bhatnagar & Hogland 2013). One is physical modification, the modification of activated carbon raw materials. The physical structure of activated carbon is modified by changing the carbonization and activation conditions during the preparation of activated carbon to change the specific surface area, pore structure and distribution (Marques & Sillanpää 2013).

The other method is chemical modification, which refers to the secondary carbonization and activation of activated carbon by adding chemical substances during the preparation of activated carbon, to increase the pore volume of activated carbon and increase the micropore content and specific surface area of activated carbon (Marques & Sillanpää 2013). Researchers found that during the preparation of coal-based activated carbon, HCL and NaOH of certain concentration were added to the activated carbon for acid-base modification to remove its acid-base soluble substances and reduce its ash content, so as to keep the pore structure unchanged and improve the specific surface area and adsorption capacity of the activated carbon (Zhang, Li & dan 2014). Other researchers modified the activated carbon by the combination of physical and chemical methods (Cater 2014). After the activated carbon was activated by ZnC12 chemical activation, carbon dioxide was used for physical activation, further opening, and expanding the pores, and the activated carbon with a specific surface area of up to 3 OOOm2/g could be obtained.

3.3.2 Modification of surface chemical structure of activated carbon

The chemical composition of activated carbon and the chemical functional groups and quantity contained on the surface have an important impact on the adsorption (Lu & Jiang 2014). The surface of ordinary activated carbon is non-polar, which can effectively adsorb non-polar compounds. The surface of activated carbon is modified according to the characteristics of adsorbate, and some surface chemical functional groups are introduced or removed (Sun, Wang & Zhang 2014). To change the acidity and alkalinity of the surface of activated carbon, increase the non-carbon element groups on the surface of activated carbon, and make it have specific adsorption properties.

3.3.3 Oxidation modification

Oxidative modification refers to the increase of oxygen-containing acidic groups on the surface of activated carbon after treatment with strong oxidant, such as carboxyl, phenolic hydroxyl, ester, carbonyl, etc., thus enhancing the polarity and hydrophilicity of the surface of activated carbon (Feng, Xing, Du & Shen 2023). It is common to use oxidants such as H2O2 and HNO3 to treat activated carbon, while diverse types of oxidants to modify activated carbon produce diverse types and quantities of oxygen-containing functional groups. The higher the degree of oxidation, the more oxygen-containing functional groups on the surface of activated carbon (Zhang, Yang & Lv 2023).

Researchers found that the activated carbon prepared from corn stalk was modified with H2O2/H2SO4. The results showed that the average pore size of the modified activated carbon increased, the content of acidic oxygen-containing functional groups on the surface increased significantly, the saturated adsorption capacity of formaldehyde extended by 50%, and the saturated adsorption capacity increased by 94%, the desorption peak area and peak height were increased. (Liu 2013). At the same time, it was also found that the adsorption of formaldehyde on the activated carbon modified by oxidation was a combination of physical adsorption and chemical adsorption.

3.3.4 Strong reduction modification

Strong reduction modification refers to the reduction treatment of functional groups on the surface of activated carbon with H2, N2, NaOH, ammonia and other reducing agents at appropriate temperature to improve the relative content of oxygen-containing basic groups on the surface of activated carbon, enhance the non-polarity of the surface of activated carbon, and improve the adsorption performance of non-polar substances (Yang & Wang 2019). Among them, the elevated temperature treatment of activated carbon by inert gases such as H2 and N2 and the impregnation treatment with ammonia water are common strong reductive treatment methods (Liu, H., Liu, C. & Xie 2019). Researchers found that the surface of activated carbon fibre was impregnated with different concentrations of ammonia water to determine the content of acid and alkali groups on the surface of activated carbon fibre and the change of pore structure (Pan 2019).

The results showed that the content of oxygen-containing basic groups, micropore volume and specific surface area of the activated carbon fibre impregnated with 6ml/L ammonia water were the largest, which increased the adsorption capacity of the activated carbon fibre to styrene in the experiment. Searchers used corn stalk as raw material to prepare activated carbon, modified it with NaOH, and determined the pore structure and surface properties of activated carbon by BET model and Boehm titration (Liu, et al. 2019).The results showed that the activated carbon prepared from corn stalk modified with NaOH could prolong the saturated adsorption time of formaldehyde by 62% and increase the saturated adsorption capacity by 33%, increased by 30.2%, micropore volume increased by 60%, the desorption peak area and peak height increased significantly, and the content of surface alkali increased about 11.85%, acid functional groups increased about 5.51%, indicating that NaOH modification an improve the content of surface acid and basic groups of activated carbon (Xu & Liu 2019). Increase the specific surface area and micropore volume of activated carbon, and thus increase the adsorption capacity of activated carbon for polar substances such as formaldehyde.

3.3.5 High temperature heat treatment

After the activated carbon is heat treated at elevated temperature in an inert atmosphere, the active groups on the surface of the activated carbon will change. Because at high temperature, the oxygen-containing functional groups on the surface of activated carbon can be decomposed into carbon oxides and water. Some studies have shown that the change of the number of phenolic hydroxyl and carbonyl groups on the unit surface of activated carbon can better explain the change trend of phenol adsorption on activated carbon (Tian, Song, Tang, Guo, & Liu, 2008). Researchers found that the specific surface area and pore area of activated carbon were significantly increased at 723 and 1123 degrees (Rong 2009). And after high-temperature heat treatment in an inert atmosphere, the increase of macromolecular carboxylic acid groups, the interaction between dipoles, and the structural collaboration of hydrogen bonds in activated carbon increase the specific surface area and pore area. The increase of carboxylic acid groups on the surface is more conducive to the adsorption of formaldehyde molecules (Song & Guo 2008).

3.3.6 Low-temperature plasma treatment

The introduction of basic functional groups on the surface of activated carbon is usually achieved by reducing substances such as ammonia immersion or elevated temperature deoxidation. In recent years, low-temperature plasma treatment technology has gradually become a research hotspot (Yamamoto 2020). The modification of activated carbon by oxygen nitrogen plasma, CF4 plasma and other commonly used plasma technologies can change the chemical characteristics of the surface of activated carbon, and at the same time can control the interface characteristics of activated carbon performance to remain unchanged (Ohzawa 2020).

Guo Lina and others connected the plasma reactor with the granular activated carbon adsorption device and carried out reduction modification on the granular activated carbon and tested its adsorption effect on formaldehyde and the removal ability of ozone in automobile exhaust (Iwata 2020). It was found that the adsorption rate of formaldehyde increased significantly, showing an upward trend with the increase of gas flow.

3.3.7 Modification of loaded metal ions

Some transition metal substances or metal compounds are loaded into the activated carbon by using the adsorb ability and reducibility of activated carbon, and metal ions are reduced to simple or low valent ions due to the reducibility of activated carbon, thus increasing the chemical reaction and catalytic reaction capacity of activated carbon (Ghaedi & Noormohamadi 2016). The commonly used loading metals include copper ion, zinc ion, iron ion and silver ion. Some researchers used the splash method to load silver nanoparticles onto granular coal-based activated carbon (Shin & Song 2016). The results showed that the deposition of modified nanoparticles reduced the effective surface area of activated carbon and blocked the microporous openings of activated carbon. The activated carbon loaded with silver nanoparticles has a formaldehyde removal ability of 3, which is 5 times that of a single activated carbon. Within a retention time of 5 seconds, the adsorption amount of formaldehyde reaches 156 mg/g (Tashkhourian & Soylak 2016).

Researchers found that the preparation of activated carbon-supported platinum catalyst by sodium borohydride liquid-phase reduction method has high formaldehyde removal activity (Huang & Liu 2019). And the researchers observed different platinum loading (0.1%, 0 5% and 1%) on formaldehyde removal rate (Wang & Chen 2020). The results show that the platinum loading of activated carbon is 0 at 5%, the formaldehyde removal rate is about 98% within the range of 5 h reaction. Formaldehyde can be completely oxidized to carbon dioxide (Li, Cao & Lee 2020).

3.3.8 Liquid deposition method

Activated carbon loaded heteroatoms or compounds are loaded onto the surface of activated carbon by liquid phase deposition. These substances can combine with adsorbate, thus increasing the adsorption performance of activated carbon. Ti02, Mn02, Zn0. are common loaded compounds (Sun & Fatemi 2015). Researchers found that KM-nO4 with different concentrations was loaded on activated carbon by impregnation, and then transformed into manganese oxide (MnOx) by different heat treatment temperatures (Jiang 2018). The experimental results show that the heat treatment temperature is 650 ℃ and the concentration of KMnO4 solution is 0 At 08mol/L, the adsorption capacity of activated carbon for formaldehyde is the highest. XPS and FTIR tests show that formaldehyde can be chemically adsorbed on carbon and manganese atoms on the surface of activated carbon during the adsorption of formaldehyde on activated carbon loaded with manganese oxide (Bigdeli & Fatemi 2015).

Researchers studied the photocatalytic degradation of gaseous formaldehyde in the air by the photocatalyst (TiO_2/activated carbon) prepared by Ti02 loaded on activated carbon during the preparation process (Sun 2015). It is found that after Ti02 is loaded on activated carbon, Ti02 is loaded in the macropores and mesopores of activated carbon, while the adsorption of formaldehyde by activated carbon occurs in micropores, so the loaded activated carbon still has strong adsorption performance. It was found that when the film thickness reached 300 nm, the photocatalytic degradation rate of formaldehyde decreased with the increase of the film thickness (Bigdeli & Fatemi 2015). The photocatalytic degradation efficiency of formaldehyde will increase with the increase of air flow (Sun, Bigdeli & Fatemi 2015).

3.4 Executive summary

To sum up, activated carbon is widely used in various fields of environmental protection due to its high specific surface area, large pore structure, uniform pore size distribution, fast adsorption and desorption rate and large adsorption capacity. Activated carbon has a good application prospect in purifying gaseous pollutants and removing volatile organic compounds. At present, the research focus should be on the following aspects.

According to the diverse types of activated carbon, the preparation process of activated carbon is optimized to develop activated carbon with high specific surface area and large pore volume. Researchers have strengthened their in-depth research on the modification methods and processes of activated carbon, revealed the modification mechanism of activated carbon, and optimized the modification conditions. Activated carbon fibre and activated carbon nonwovens with high specific surface area and high adsorption capacity have been developed and applied to activated carbon fibre and activated carbon fibre nonwovens in combination with activated carbon modification process. To reduce the consumption of resources and improve the economic feasibility, the best adsorption conditions of activated carbon should be deeply studied when multiple gaseous pollutants coexist.

4 ACTIVATED CARBON ADSORBED FORMALDEHYDE

Adsorption using activated carbon is one of the most common methods for the removal of formaldehyde at low concentrations in indoor air. The activated carbon is characterized by a strong adsorption capacity which is attributed to its large internal surface area, porosity, and high degree of surface reactivity. The activated carbons with higher nitrogen content show a great ability to absorb formaldehyde because of their increased affinity with polar pollutants. Nitrogen functional groups that neighbour oxygen atoms play a significant role in maximizing adsorption capability (Lee 2013). Activated carbon not only adsorbs formaldehyde, but also absorbs any odours or gases near it. Therefore, activated carbon can easily reach the saturated state, and the adsorbed formaldehyde is still exceedingly small. The adsorption of formaldehyde by activated carbon has a clear drawback (Wang & Chen 2020). When activated carbon adsorbs a large amount of formaldehyde, it will also be released again when the indoor temperature rises (Huang, Wang, Chen & Lee 2020).

4.1 Adsorption mode and efficiency

Preparation of activated carbon from sugarcane bagasse (SCBAC) is a promising approach to produce cheap and efficient adsorbent for gas pollutants removal. It may be also a solution for the agricultural wastes’ problems in big cities, particularly in Egypt. MB adsorption tests suggest that the SCBAC have high adsorption capacity (Abdel & Shetaya 2015). Formaldehyde gas removal in the plant chambers indicates that the SCBAC have potential to recover volatile gases. The results confirmed that the activated carbon produced from sugarcane bagasse waste raw materials can be used as an applicable adsorbent for treating a variety of gas pollutants from the indoor environment (Mohamed & Mael 2015). If activated carbon is placed in the air, there is formaldehyde in the surrounding environment and it encounters activated carbon, this part of formaldehyde will be adsorbed by activated carbon.

4.2 Adsorption mechanism of activated carbon adsorption of gaseous formaldehyde

The adsorption of gaseous formaldehyde on activated carbon comes from its rich pore structure, high specific surface area and oxygen-containing functional groups on the surface. When adsorbate molecules are adsorbed, their molecules gather on the surface of carbon fibre (Wen, Li & Zhao 2011). According to the different adsorption forces, the adsorption of activated carbon can be divided into two types: one is physical adsorption, which refers to the adsorption of the adsorbate on the surface of activated carbon due to the van der Waals force generated by the asymmetric dipole effect (Cai & Zhang 2011).

During the adsorption process, the chemical properties of the adsorbate and the molecule itself of the adsorbent will not change. At the same time, the adsorption heat generated by physical adsorption is exceedingly small, with the increase of temperature, the adsorption capacity of activated carbon to adsorbate is weakened, so physical adsorption is usually carried out at low temperature in favour of adsorbate adsorption. In addition, desorption of adsorbate molecules will also occur (Gao & Chen 2011). The other is chemical adsorption, which comes from the chemical reaction between the oxygen-containing functional group on the surface of activated carbon and the adsorbate, thus adsorbing it on the surface of activated carbon. This kind of adsorption is irreversible, so the adsorption is stable, and there will be no desorption (Li, Zhen & Chen 2011).

4.3 Adsorption of meteorological formaldehyde by different activated carbons

With the increasingly prominent problem of indoor air formaldehyde pollution, the adsorption of gaseous formaldehyde by diverse types of adsorbents has been widely reported. Due to its rich pore structure and high specific surface area, activated carbon is superior to other adsorbents in the adsorption of gaseous formaldehyde (Ma & Yang 2010). Although the adsorption performance of activated carbon for formaldehyde in the air is higher than that of activated alumina, zeolite, molecular sieve and other adsorbents, the adsorption performance of activated carbon for formaldehyde is also different due to the different pore size distribution and surface chemical properties of varied materials of activated carbon (Lu & Wang 2010). Researchers found that the adsorption rate of formaldehyde gas on granular activated carbon is better than that on powdered activated carbon through the comparative study of the adsorption performance of powdered activated carbon and granular activated carbon (Dong 2010).

However, there are few reports on the effect of activated carbon particle size on formaldehyde gas adsorption performance. Lin Lili and others studied the adsorption of gaseous formaldehyde on activated carbon made of coconut shell, fruit shell, coal and technology through static adsorption and dynamic penetration experiments (Lin, Carter & Katz 2011). The study found that the adsorption of activated carbon for formaldehyde conforms to the Freundlich isotherm adsorption equation. The surface of coconut shell activated carbon contains many micropores, as well as many nitrogen and oxygen groups, which are conducive to the adsorption of small molecules **(**Speitel & Ramirez 2011). Therefore, coconut shell activated carbon has the best adsorption performance for formaldehyde, and the actual adsorption capacity and adsorption capacity utilization rate can reach 9 88 mg/g and 84 37%. It is found that the activated carbon with small particles has higher adsorption capacity within a certain range of particle size (Carter et al. 2011).

4.4 Activated carbon with additional functions

Researchers conducted an experiment about studying the effect of activated carbon on formaldehyde purification in the return air purification device of a clean workshop and its influencing factors (Cha 2010&Seredich 2008). From May to June 2018, researchers selected four different types of commercial activated carbon (bamboo charcoal, 1-3 mm, 3-5 mm; coconut shell charcoal, 6-12 mesh, 8-16 mesh) to produce five types of activated carbon purification nets. In the simulated clean plant laboratory, the detection of occupational disease hazards was used to test the purification effect of diverse types of activated carbon purification nets on formaldehyde. (Wang, Niu, Xu, Wang, Xie & Li 2019).

The affinity coefficient of activated carbon for formaldehyde is not high, but higher for benzene. Moreover, the activated carbon originally adopts the physical adsorption method, so if it can adsorb formaldehyde to the interior of the activated carbon, and then reduce the indoor formaldehyde concentration. However, this effect is not effective. It is difficult to absorb all formaldehyde in the whole space (Boonamnuayvitaya 2005). Results is the purification effect of several types of activated carbon increased with the prolongation of purification time, and the difference was statistically significant ($P<0.05$) (Li 2008 & Lee 2010). Compared with other types of activated carbon, coconut shell charcoal (8-16 mesh, double layer) had the best purification effect, 15 min and 30 min purification efficiency were 58.72% and 85.20% respectively, and the difference was statistically significant ($P<0.05$). The purification effect of double-layer coconut shell charcoal was better than single layer ($P<0.05$) (Gratuito 2008).

The purification effect of double-layer coconut shell charcoal (8-16 mesh) was better than double-layer coconut shell charcoal (6-12 mesh), the difference was statistically significant ($P<0.05$). Coconut shell charcoal (8-16 mesh, double layer) had better purification effect than bamboo charcoal ($P<0.05$) (Wang et al. 2019). Conclusion is different specific surface area, particle size, and thickness of activated carbon have a certain effect on the purification effect of formaldehyde, and its selection has a certain significance in improving the occupational health protection level in the clean plant, solving the safe use of return air, and reducing energy consumption. (Xie et al. 2019). Unless activated carbon is filled in every place indoors, formaldehyde cannot be absorbed if it cannot diffuse near the activated carbon.

4.5 Photocatalysis

Photocatalysis is a new and promising indoor air purification technology (Liang, Li & Jin 2012). This photocatalysis method is effective when the concentration of pollutants is high, but its wide application in indoor air purification is limited due to the low level of indoor air pollutants. To improve the removal of pollutants in the indoor air, it evaluated the photocatalytic performance of nano-TiO2 particles fixed on the surface of activated carbon (AC) filter for the removal of formaldehyde (HCHO). (Liang, Li J, Li J-X, Zhu & Jin 2010). The results show that the photocatalytic reaction rate increased since activated carbon can absorb pollutants in the diluting air stream and produce high concentration of pollutants on the catalyst surface. With the increase of flow rate, the photocatalytic reaction changes from diffusion control process to photocatalytic reaction control process (Rozada 2008). In the former process, the photocatalytic reaction rate increases, while in the latter process, the photocatalytic reaction rate changes little with the increase of flow rate. The flow rate is lower than that of TiO2, 2/AC catalyst is higher than that of TiO2, 2/glass catalyst when the photocatalytic reaction is switched from diffusion control process to photocatalytic reaction control process. It was also observed that the indoor low concentration of HCHO could photocatalytic degrade 2/AC on TiO2, and the concentration of HCHO in the product mixture fell into the standard range specified by the Chinese indoor air quality standard (Apopei, Orha, Popescu, Lazau, Manea, Catrinescu, & Teodosiu, 2020.)

4.6 Oxygen vacancy engineering

Oxygen vacancy (OV) is usually used as the adsorption/active site in the catalytic oxidation of formaldehyde (HCHO), which strongly affects the catalyst activity. However, it is still challenging to control and convert them into scale-up products for practical application. In this article, δ- Mnx/activated carbon is synthesized by in-situ reduction combined with ammonia modification. It is found that the developed method is easy to control OV in large-scale production (Huang & Liu 2020). By adjusting Mn, effectively adjusting the concentration of OV 3+content and the role of OV in catalytic reaction explored through several technologies. The optimized catalyst has excellent HCHO removal efficiency and CO2 selectivity at room temperature, due to the rich OV activated oxygen to form active oxygen (Wang & Li 2020). The intermediates and ways to remove HCHO were studied. Therefore, this work provides insights for enhancing active site exposure through OV control of a single bulk catalyst and proves its applicability in the efficient and commercially feasible room temperature oxidation of HCHO (Huang, Liu, Wang, Li, Chen, Lee & Cao 2020).

4.7 Nanocrystalline manganese dioxide 2

Three distinct types of nanocrystalline MnO2, namely α- Manganese 2, c-manganese 2 and δ- Manganese dioxide 2, successfully synthesized by coprecipitation, has the advantages of simple preparation, low cost, uniform particle size, and excellent crystallinity (Chen, Lu & Guo 2019). It also avoids operating at elevated temperatures and pressures. Nanocrystalline MnO2 was then tested for catalytic oxidation of formaldehyde at 25 ° C. The results show that δ- MnO2 has the highest catalytic activity. Therefore, δ- Manganese 2 used the same method to synthesize the modified activated carbon fiber (ACF) substrate. Further tests show that the prepared MnO2/ACF sample can significantly improve the formaldehyde removal rate at room temperature (Zhu & Lu 2019). The content 2/ACF in Manganese Min 2 has a significant impact on the breakthrough time. It found that the content of MnO2 is poor in a wide range, but the best performance is 16.12% by weight (Song 2019). The formation method developed in this study may become a promising technology for improving the catalytic activity of formaldehyde removal.

5 CONCLUSIONS

Therefore, the conclusion drawn is that activated carbon can effectively absorb formaldehyde. However, an important aspect of absorption efficiency is that the desired effect can be achieved by adding different surfactants and changing the capacity of activated carbon. Of course, activated carbon will not adsorb formaldehyde indefinitely. Activated carbon needs to be replaced after a period of use. It is recommended to place it outdoors in the scorching sun, with good ventilation, and expose it to sunlight for a period after 7-15 days. This method will evaporate the water vapor adsorbed inside the activated carbon, making room for further adsorption of formaldehyde, and improving the adsorption performance of the activated carbon for formaldehyde.

For the practical and effective application of activated carbon adsorption of formaldehyde: The effect of activated carbon adsorption on the photocatalytic removal of formaldehyde (Lu, Wang, Ma & Yang 2010). Oxygen vacancy–engineered δ-MN Ox/activated carbon for room-temperature catalytic oxidation of formaldehyde (Huang, Liu, Wang & Chen 2020). Nanocrystalline MnO2 on an activated carbon fibre for catalytic formaldehyde removal (Dai, Yu, Huang & Li 2016).

These three practical applications typically show the impact on improving the efficiency of formaldehyde absorption by activated carbon. It includes the simplest change to the activated carbon to affect the absorption efficiency of the activated carbon. Such as photocatalysis, the degradation rate of formaldehyde in the presence of activated carbon is observed by discussing the intensity of ultraviolet light. Ultraviolet light is an extremely popular and easy to operate equipment, which is convenient for popularization and use. The latter two practical and effective applications are obviously. The purpose of degrading formaldehyde is achieved by adding chemicals on activated carbon and oxidizing formaldehyde. The conditions at room temperature are not harsh, and the chemicals as catalysts will not cause poor environmental changes. Activated carbon is widely used to adsorb formaldehyde in all aspects, and it is also improving the efficiency of adsorbing formaldehyde to varying degrees.

The study on the structure of activated carbon and its arrangement can be further improved. It will be effective to deepen the research in these two aspects in the future to see the changes caused by the addition of surfactants to activate carbon and the different efficiency under different catalytic methods.

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