Progress in Preparation and Application of Organic Waste Based Activated Carbon

To cite this article: Chengyong Wang et al 2018 IOP Conf. Ser.: Mater. Sci. Eng. 392 042004

You may also like

- The Effect of Biofertilizer of Azolla, Phosphate and Nitrogen Fertilizers on some Growth Traits of Rice Sajjad H. J. Al-Bdairi and Jawad A. Kamal

- Ecological and agrochemical assessment of the effect of fertilizers on the behavior of cadmium and lead in soil T S Morozova, V I Geltukhina, L A Manokhina et al.

- Synergy of application fertilizer leaves and organic growth regulatory for growth and production potential of eggplant plants (Solanum melongena L.) W Widiwurjani, N Augustien and P Nurfikaini
Progress in Preparation and Application of Organic Waste Based Activated Carbon

WANG Chengyong1,*, CHEN Peng1, LI Ziwen1
1 School of Chemistry and Materials Engineering, Liupanshui Normal University, Liupanshui 553004, China
* Corresponding author email address: wangchengyong87@163.com

Abstract. The organic waste of the preparation activated carbon is the city solid organic waste and agricultural waste. Organic waste with the characteristics of wide source, low price, and environmental friendly, is an ideal material for preparation of activated carbon. The research status and new progress of activated carbon were reviewed from the aspects of selection, preparation and application of activated carbon. The preparation methods of activated carbon and the new progress in the research of organic waste based activated carbon were summarized. The physical activation method, chemical activation method, chemical-physical method, and other methods were introduced. The application of the adsorption capacity of traditional activated carbon and the application of activated carbon in medicine, catalytic load and electrode materials were introduced. The future development direction of activated carbon industry was put forward.

1. Introduction
Activated carbon, as a functional carbon material, has the characteristics of large specific surface area, strong adsorption capacity, stable physical and chemical properties, renewable and so on. It has been widely used in the fields of petrochemical, medical and health, environmental protection, power electronics and even Aeronautics and Astronautics, and the demand is increasing day by day [1]. The output and export volume of activated carbon have continued to rise in recent years [2]. It is particularly important for the development of activated carbon industry to prepare activated carbon from raw materials, which are widely distributed, cheap and environment-friendly organic wastes.

2. Preparation methods
At present, about 60% of China's activated carbon is coal based activated carbon. Coal based activated carbon is made from single high quality coal or coal blending as raw material. It is prepared by carbonization, cooling, activation, washing and other processes [3]. The common coal preparation of active carbon is anthracite, non-caking coal and candle coal. Although China's coal reserves are rich, the reserves of high quality coal are less, and the coal mining, washing and processing, and the preparation of coal based activated carbon have brought serious damage to the environment, which restricts the production of activated carbon, especially the coal based activated carbon industry [4].

Organic waste has the characteristics of wide source, low price and friendly environment. The activated carbon has good adsorption properties and reliable mechanical strength. It is an ideal material for the preparation of activated carbon. The main sources of organic waste are urban solid organic waste and agricultural organic waste [5]. The municipal solid organic wastes that can be used for the preparation of activated carbon include wood, plastic, rubber, paper, kitchen waste and so on [6].
The ideal activated carbon can be prepared from peanut shell, walnut shell, coconut shell, hazelnut shell, rice husk, straw stalk, lotus rod, ramie rod, tobacco rod, cotton stalk, cattail, corn cob, Luffa complex, cow dung, and bamboo\cite{7}. There are physical activation method, chemical activation method, chemical-physical method and other methods for the preparation of activated carbon from organic wastes.

2.1. **Physical activation method**

The physical activation is usually carbonized at the temperature of 400~700℃, and then the carbonized materials react with the activated gas at the high temperature of 800~1000℃ to produce activated carbon, and the activated gases include water vapor, N2, CO2 and the mixture of gas above\cite{8}. The reaction is mainly carbon oxidation in the process of activation. The reaction formula is (1)\textendash(2).

\[
C + H_2O \rightarrow H_2 + CO (\Delta H = +117 \text{kJ/mol}) \quad (1)
\]

\[
C + CO_2 \rightarrow 2CO (\Delta H = +159 \text{kJ/mol}) \quad (2)
\]

The disordered carbon atom and the heteroatom first react with the high temperature activated gas to expose the surface of the carbonized microcrystal, and the carbon atoms on the surface of the microcrystal continue to react with the activated gas and make the pores expand\cite{9}.

The basic process of physical activation method is shown in Figure 1, mainly including carbonization, activation, impurity removal, crushing, refining and drying. The process of physical activation is simple. The heat produced by the activation process can be used for drying and steam generation. The waste gases such as steam and CO2 are less polluted to the environment. The activated carbon has a developed pore and large specific surface area, so the physical activation method has been widely used in industry.

![Figure 1. Basic process flow chart of physical activation method](image1)

2.2. **Chemical activation method**

The basic process of chemical activation method is shown in Figure 2. The organic waste is mixed with activator, and then activated carbon is made by carbonization, activation, rinsing and drying at a certain temperature, in which activators include H$_3$PO$_4$, ZnCl$_2$, KOH, H$_2$SO$_4$, (NH$_4$)$_2$HPO$_4$ and so on. The activator will erode the cellulose and decompose hydrocarbon in the raw material\cite{10}.

![Figure 2. Basic process flow chart of chemical activation method](image2)
2.3. Chemical-physical method
Chemical-physical method is a method of combining physical activation and chemical activation. In general, organic waste is treated with activator first, and then it is treated by physical method by high temperature activated gas. Chemical activators increase the reactivity of raw materials, facilitate the activation of gases into the raw materials, and make the porous activated carbon more developed.

2.4. Other preparation and modification methods
In recent years, new preparation methods and modification technologies have been developed on the basis of traditional activated carbon preparation methods. The catalytic activation method uses metal and its compounds as catalysts to regulate the pore size of activated carbon. Microwave activation method is used to replace the traditional heating method in the preparation of activated carbon by microwave heating[11]. Activated carbon modification technology mainly includes chemical modification, physical modification, microbial modification and other methods. Chemical modification is modified by means of acid base soaking, metal or compound load and plasma technology to modify the surface functional groups and pore structure of activated carbon. Physical modification is mainly using heating to change the physical properties of activated carbon. Microorganism modification uses activated carbon to adsorb microorganism and use the characteristics of microorganism to change the adsorption properties of activated carbon[12].

3. Organic waste based activated carbon

3.1. Activated carbon from urban organic waste
The composition of urban organic wastes is more complex, and the composition changes with the changes of regions and seasons. The properties of the activated carbons are also different. From Figure 3, it can be seen that there are more differences in the nature of organic waste in every city, high ash content in household kitchen, high volatile of paper and wood, low fixed carbon content of foam plastic and high calorific value of plastic. The adsorption property and specific surface area of activated carbon have a great relationship with the ash content of organic waste. When the ash content is high, the pore structure and adsorption properties of activated carbon are poor, and the size of the volatile and the precipitation in the process of pyrolysis affect the pore development and pore structure of the activated carbon. Therefore, the ideal activated carbon is difficult to be prepared by using the organic waste of a single city.

![Figure 3. Proximate analysis of organic waste in cities](image)

At present, many scholars have made many researches on the preparation of activated carbon from urban organic wastes. Xie Liping et al[13] in sawdust, waste paper and plastic packaging three city solid waste as raw material for preparation of activated carbon. The raw materials were broken up to 100 mesh and pressed into strips, and activated carbon was prepared by steam physical activation. The activation temperature was 900°C. The pore volume of the activated carbon is 0.357cm³/g.
mesoporous rate is 45%, the iodine adsorption value is above 900mg/g, and the macromolecule dioxin can be adsorbed effectively in the process of waste incineration.

Laszlo K. et al\textsuperscript{[14]} take home kitchen residue as raw material and use physical activation method to obtain activated carbon. The results show that the activated carbon has certain adsorption properties to phenol and three chlorophenol in the solution. Nagano S et al\textsuperscript{[15]} with urban waste as raw material, obtained the developed activated carbon by pyrolysis and steam activation. The specific surface area of the activated carbon was 378m\textsuperscript{2}/g, the pore volume was 0.21cm\textsuperscript{3}/g, the pore volume was 0.18cm\textsuperscript{3}/g, and the mesoporous rate was 53.8%.

3.2. Activated carbon from agricultural organic waste

The agricultural organic wastes are mostly biomass, and the biomass contains a large amount of cellulose and lignin, and has a rich network structure and pore structure. In the process of preparation of activated carbon, cellulose and other biopolymers break up and form carbon skeleton. At the same time, due to the role of carbon oxidation, activated carbon has abundant pores and large specific surface area. Agricultural organic wastes also contain functional groups such as carboxyl, hydroxyl, amine or amino compounds. The existence of these functional groups improves the adsorption efficiency of activated carbon.

3.2.1. Activated carbon from shell. Wang Limin et al\textsuperscript{[16]} used peanut shell as raw material to prepare activated carbon. The adsorption capacity of peanut shell activated carbon to aqueous solution of brilliant blue dye was studied. The activated carbon was prepared by chemical activation. First, the peanut shell was soaked, dried and crushed as the raw material. The activator was H\textsubscript{3}PO\textsubscript{4}, the activation temperature was 400°C, and the activation time was 4 hours. The activated carbon of peanut shell has good adsorption property to the active brilliant orchid. Zhang Manman et al\textsuperscript{[17]} took walnut shell as raw material, ZnCl\textsubscript{2} and H\textsubscript{2}SO\textsubscript{4} as activators. Activated carbon was obtained by microwave heating and physical method. The adsorption property of walnut shell activated carbon to malachite green and 4-chlorophenol in water body was better, and the adsorption rate of methyl orange solution (200mg/L) was 99.76%. Milan G et al\textsuperscript{[18]} used rice husk as raw material to prepare activated carbon by boiling and formaldehyde treatment. When pH is 2 and the dosage is 20mg/L, the removal rate of Cr\textsuperscript{6+} solution is the highest.

3.2.2. Activated carbon from plant rod. Xiong Huizhen et al\textsuperscript{[19]} used eggplant straw as raw material, carbonized at 300–400°C for a certain time, ZnCl\textsubscript{2} was used as activator, and activated carbon was activated under nitrogen for a certain time. The pore size of the activated carbon is mainly distributed in the range of 2–10nm. The equilibrium adsorption capacity of the activated red X-3B dye wastewater is larger than that of the acid blue RL dye wastewater. The removal rate of COD for these two dyes is 94.5% and 86.4%, respectively. Zhang Shuguang et al\textsuperscript{[20]} used the lotus rod as the raw material. The activated carbon was prepared by H\textsubscript{3}PO\textsubscript{4} activation and ultrasonic degradation, and the activated carbon of lotus rod was modified with Cu(NO\textsubscript{3})\textsubscript{2} and Fe(NO\textsubscript{3})\textsubscript{3} Impregnated activation method. Fe(NO\textsubscript{3})\textsubscript{3} modified activated carbon has good adsorption effect on cephalosporin in water, and the adsorption capacity is 75.1180mg/g.

3.2.3. Activated carbon from other organic wastes. Badie S. Girgis et al\textsuperscript{[21]} take the jujube core as the raw material and use the phosphoric acid as the activator with the volume concentration of 30%-70%. The activation condition is 700°C and the ratio of phosphoric acid to the raw material is 1.20-1.44, and the pore of activated carbon is developed. Guo Xiang et al\textsuperscript{[22]} made activated carbon from cow dung and (NH\textsubscript{4})\textsubscript{2}HPO\textsubscript{4} as activator. The optimum preparation conditions were as follows: (NH\textsubscript{4})\textsubscript{2}HPO\textsubscript{4} solution mass fraction 30%, solid liquid mass ratio 1:3, activation time 60min, activation temperature 700°C. The average yield of activated carbon from cow dung was 47.18%, the average value of iodine adsorption value was 671.39mg/g, and the average value of methylene blue adsorption value was 81.2mL/g.
4. New progress in the application of activated carbon

The application of traditional activated carbon mainly is the application of adsorption properties, which are mainly divided into gas adsorption and liquid adsorption, such as industrial waste water treatment, domestic water purification, indoor air purification, air separation and rich oxygen, and storage of combustible gas.

With the continuous development of functional activated carbon, many new applications have appeared. Using selectivity and tropism of activated carbon to some pathological tissues of human body, activated carbon can be used as a drug carrier to target the pathological tissue, which can reduce the side effect of the drug on the intact tissue and improve the efficiency of the drug. The use of the adsorbability and functional sustained-release effect of nanoscale activated carbon can increase the time of drug action and reduce the toxicity caused by the high concentration of drug. As shown in Figure 4, the drug adsorbed by particle activated carbon maintains a dynamic balance between the free drugs and the surrounding free drugs. When the free drug is metabolized or diluted, the concentration is reduced, and the drug adsorbed on the activated carbon is released to maintain the stability of the drug concentration so that the drug is maintained at the effective concentration and does not change violently. Due to its good conductivity, stable chemical properties and large surface area, activated carbon is the preferred material for supercapacitor. The supercapacitor made of activated carbon has large capacitance and good charging and discharging cycle performance.

![Figure 4. Slow-release effect of nanoscale activated carbon](image)

5. Conclusions

Coal based activated carbon raw materials are non-renewable, with high cost, few varieties, low price and low profits, which weakens the competitiveness of China's active carbon in the field of international activated carbon. Organic waste based activated carbon has solved these problems, and its comprehensive development can be considered from the following points.

- To expand the source of raw materials, explore the kinds of organic waste that can be used to prepare active carbon, reduce the cost of the preparation of activated carbon, take into account the environmental protection and take the road of sustainable development.
- Research and development of new organic waste based activated carbon preparation methods and equipment, which improve the quality of activated carbon, will increase the yield and proportion of activated carbon for special purposes.
- To expand the application of organic waste based activated carbon to meet the needs of some special materials in various fields, promote the development of organic waste based activated carbon industry, establish an effective market regulation mechanism, and make the development, production, import and export and popularization of various links coordinated development.

Acknowledgements

This research was financially supported by National Natural Science Foundation of China (No. 51504134), Guizhou Provincial Education Department Youth Science and technology talent growth project (Qian Jiao he KY zi [2017]263). Guizhou Key supported discipline (Qian Xue wei he zi
ZDXK[2016]24) and Guizhou Institutions of Higher Education innovation team (Qian Jiao he rctdz [2015]69).

References
[1] Sun Longmei, Zhang Liping, Xue Jianhua, et al. Progress in the preparation and application of activated carbon[J]. Chemistry & Bioengineering, 2016, 33 (3): 5-8.
[2] Cao Xuping, Liang Lin. Analysis of the export trade structure and competitiveness of China's activated carbon products, 2002 -2015[J]. Prices Monthly, 2017 (7): 36-41.
[3] Xiong Yinwu. Status quo and development trend of coal based activated carbon production equipment in China[J]. Clean Coal Technology, 2014, 20 (3): 39-42.
[4] Luo Peng, Jia Zhigang, Yan Ming. Production status and development of coal based activated carbon in China[J]. Contemporary Chemical Industry, 2014, 43 (7): 1277-1279.
[5] Li Runxia. Study on the mechanism of solid organic waste in the preparation of activated carbon[D]. Tianjin: Tianjin University of Science and Technology, 2011.
[6] Wang Jiaqi, Yuan Meng, Tian Yuan Yu. Study on the preparation of high porosity powdered activated carbon from waste wood chips of poplar wood[J]. Chemical Research and Application, 2017, 29 (10): 1574-1578.
[7] Wu Chen, Liang Yanli, Ding Yidan, et al. Research progress on the utilization of agricultural waste rice husk resource utilization[J]. Environmental Protection and Circular Economy, 2017 (6): 16-19.
[8] Cui Jicheng, Yang Ying. Research on the development of active carbon preparation technology[J]. Forestry Machinery & Woodworking Equipment, 2016, 44 (9): 8-12.
[9] LÓPEZ CH T, JANNA F C, BHATIA S K. Effect of activating agents: Flue gas and CO2 on the preparation of activated carbon for methane storage[J]. Energy & Fuels, 2015, 29(10): 6296-6305.
[10] SABIO E, GONZÁLEZ E, GONZÁLEZ J F, et al. Thermal regeneration of activated carbon saturated with p-nitrophenol[J]. Carbon, 2004, 42(11): 2285-2293.
[11] Jiang Jianchun, Sun Kang. Review of the preparation technology and application of activated carbon[J]. Chemistry and Industry of Forest Products, 2017, 37 (1): 1-13.
[12] Yang Xing, Lin Jian Qing. Research progress on modification of activated carbon and its application[J]. Journal of Anhui Agricultural Sciences, 2014, 42 (9): 2712-2715.
[13] Xie Liping. Study on the preparation of activated carbon from municipal solid organic waste[D]. Beijing: Institute of Process Engineering, Chinese Academy of Sciences, 2003.
[14] Laszlo K, Bota A, Nagy L G. Characterization of Activated Carbons from Waste Materials by Adsorption from Aqueous Solutions[J]. Carbon, 1997, 35(4): 593-598.
[15] Nagano S, Tamon H, Adzumi T, et al. Activated Carbon from Municipal Waste[J]. Carbon, 2000, 38(2): 915-920.
[16] Wang Limin, Zhang Yong Le. The adsorption of reactive brilliant blue dye in aqueous solution by peanut shell activated carbon[J]. Journal of Jilin Institute of Chemical Technology, 2013, 30 (11): 100-103.
[17] Zhang Manman. Preparation of Juan walnut shell based activated carbon and adsorption of malachite green and 4- chlorophenol in water[D]. Zhengzhou: Zhengzhou University, 2012.
[18] Milan G, Dragana B, Velizar S, et al. Kinetics, equilibrium and mechanism of Cu2+, Ni2+ and Zn2+ ions biosorption using wheatstraw[J]. Ecological Engineering, 2013, 58:113-122.
[19] Xiong Huizhen. Study on the preparation of activated carbon from Solanum culm and the adsorption of dye wastewater[D]. Shanghai: Donghua University, 2011.
[20] Zhang Shuguang. Study on the preparation of lotus rod activated carbon and its adsorption properties for cephalamaxine[D]. Ji'nan: Shandong University, 2011.
[21] Badie S, Girgis, Abdel-Nasser A. El-Hendawy, Porosity development in activated carbons obtained from date pits under chemical activation with phosphoric acid[J]. Microporous and Mesoporous Materials, 2002, 52: 105-117.
[22] Guo Xiang. Study on the preparation and properties of cow dung activated carbon[D]. Chongqing: Southwestern University, 2013.