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RESEARCH PAPER

# Microwave-assisted preparation of peanut shell-based activated carbons and their use in electrochemical capacitors

**Ming-bo Wu[1]*, Ru-chun Li[2], Xiao-jun He[2]*, He-bao Zhang[2], Wu-bin Sui[1], Ming-hui Tan[1]**

[1]State Key Laboratory of Heavy Oil Processing, College of Chemical Engineering, China University of Petroleum, Qingdao 266580, China;
[2]School of Chemistry and Chemical Engineering, Anhui Key Laboratory of Coal Clean Conversion and Utilization, Anhui University of Technology, Maanshan 243002, China

**Abstract:** Activated carbons (ACs) were prepared from peanut shells by KOH activation under microwave heating and were used as electrode materials for electrochemical capacitors (ECs). The pore structure of the ACs was characterized by nitrogen adsorption and the electrochemical performance by galvanostatic charge-discharge and cyclic voltammetry. Results show that the ACs' specific surface area, total pore volume, specific capacitance, as well as energy density are maximized using an activation time from 6 to 10 min or KOH/peanut shell mass ratio from 0.6 to 2.0 under otherwise identical conditions. When the KOH/peanut shell mass ratio was 1.0, microwave power was 600 W and activation time was 8 min, the specific surface area of the resulting AC was 1277 $m^2/g$ and its energy density was 8.38 Wh/kg after 1000 cycles. The KOH activation of peanut shells with microwave heating is an efficient approach for the rapid preparation of low cost ACs for ECs.
**Key Words**: Peanut shell; Microwave heating; Activated carbon; Electrochemical capacitor

## 1 Introduction

China is the world's largest peanut producer with a capacity of 5 million metric tons of peanut shells each year. As a byproduct of peanut production, peanut shell is normally used as animal feed or fuel without any value and technology-added applications. On the other hand, activated carbons (ACs) with sufficient pores and good adsorptivity have been widely used in various fields[1], e.g. industrial purification, chemical recovery and electrode materials for electrochemical capacitors (ECs). The fact that peanut shell is cost-competitive, readily available in such large quantity, leads us to believe that converting peanut shell into useful technology-added ACs should be highly beneficial and meaningful[2]. Traditionally, ACs are usually prepared by physical or chemical activations via conventional heating. Among the chemical activation methods, KOH activation is a rather efficient activation agent for preparation of microporous carbons[3-7]. However, the biggest economic barrier to convert peanut shell to ACs is the high cost of activation, which usually requires extended activation time, high energy consumption and excessive activation agents. This being the case, it would be imperative to invent a rapid and efficient approach to make low-cost ACs.

In terms of heating means, microwave heating has lots of advantages over conventional heating means, e.g. high heating efficiency, easy control of the heating process, rapid temperature rise at low energy consumption[8,9]. For these reasons, the microwave heating has received extensive attention over the past few years for AC preparation[10-15]. To date, little has been reported on an efficient and straight-forward preparation of ACs from renewable peanut shell for use as ECs electrode materials.

Herein, the prospect in deriving ACs from peanut shell using microwave heating for ECs was investigated at lowered KOH/peanut shell mass ratios with shortened activation times. The effects of the key determining factors, such as KOH/peanut shell mass ratio and activation time, on the pore structure and electrochemical performance of ACs in ECs were studied.

## 2 Experimental

### 2.1 Preparation and characterization of ACs

Peanut shell was obtained from Huaian in Jiangsu, China. Peanut shell particles with a size of about 3×10 $mm^2$ were cleaned by water scrubbing and then dried at 383 K for 24 h. The analysis results of peanut shell on air dry basis by mass fraction are as follows: 9.52% of moisture, 1.30% of ash, 68.34% of volatile matter and 20.84% of fixed carbon.

Dried peanut shell (9 g) was mixed with KOH solution at

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***Corresponding author.** E-mail: wumb@upc.edu. cn; xjhe@ahut.edu.cn

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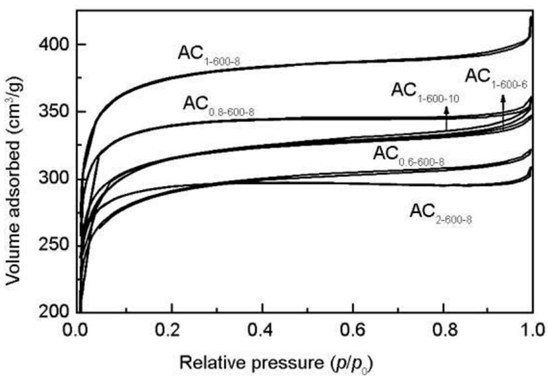


Fig. 1 $N_2$ adsorption-desorption isotherms of ACs.

different KOH/peanut shell mass ratios. The mixture was dried at 383 K for 24 h after being impregnated for 12 h at room temperature, and then transferred to a crucible. The crucible was heated in a LWMC-205-type microwave oven with a microwave power of 600 W from 6 to 10 min of activation to prepare the ACs. The temperature of reactants in the crucible was measured by an armor-type thermocouple during microwave heating.

ACs were successively washed with 0.5 mol/L HCl solution and distilled water, until pH=7.0 was reached. ACs were then dried at 383 K for 24 h. The resultant AC is designated as $AC_{x\text{-}y\text{-}z}$, where x refers to the KOH/peanut shell mass ratio, y the microwave power, and z the activation time. For example, $AC_{1\text{-}600\text{-}8}$ refers to the AC prepared with a KOH/peanut shell mass ratio of 1, a microwave power of 600 W and an activation time of 8 min. Characterization of the pore structure of ACs was performed on the basis of nitrogen adsorption-desorption isotherms measured on a sorptometer ASAP2010 at liquid nitrogen temperature.

### 2.2 Preparation and electrochemical measurements of AC electrodes

The electrode slurry was made by mixing AC, carbon black (CB) and poly(tetrafluoroethylene) (PTFE) in a mass ratio of 87:5:8. The slurry was coated onto nickel foam with a diameter of 12 mm. Prior to packaging and test, two disk electrodes with an active mass of about 40 mg were dried at 393 K for 2 h under vacuum. One cell was composed of two similar electrodes separated by polypropylene membrane. The cell was tested in 6 mol/L KOH solution using a symmetrical button cell configuration by cyclic voltammetry on an electrochemical workstation (CHI-760C, Chenghua, Shanghai). The electrochemical performance of AC electrodes in the cell was investigated on a land cell tester (Land, CT-2001A).

## 3 Results and discussion

### 3.1 Pore structure of ACs

The $N_2$ adsorption-desorption isotherms of the ACs are shown in Fig. 1. It is found that all the ACs are microporous as evidenced by the Type I isotherm. The pore structure parameters of the ACs are shown in Table 1. It can be seen that the specific surface area, total pore volume, micropore volume of the AC all exhibit maxima with activation time for 8 min or with KOH/peanut shell mass ratio of 0.8 under otherwise identical conditions investigated. At a KOH/peanut shell mass ratio of 1.0 with a microwave power of 600 W and an activation time of 8 min, the $S_{BET}$ of $AC_{1\text{-}600\text{-}8}$ reach 1 277 $m^2/g$. The $S_{BET}$ of ACs produced by microwave heating is larger than that from biomass using conventional heating methods even at a longer activation time[16], which is ascribed to the efficiency of microwave heating at molecular level. The yields of $AC_{1\text{-}600\text{-}6}$, $AC_{1\text{-}600\text{-}8}$ and $AC_{1\text{-}600\text{-}10}$ are 24.4%, 21.8% and 18.0%, respectively, showing the same trend in the yields of ACs with activation temperature[17]. The final activation temperature of $AC_{1\text{-}600\text{-}6}$,

**Table 1 Pore structure parameters of ACs.**

| AC sample | $D_{ap}$ | $S_{BET}$ | $V_t$ | $V_{mic}$ | $S_{mic}$ | $S_{ext}$ | Yield |
|---|---|---|---|---|---|---|---|
| $AC_{1\text{-}600\text{-}6}$ | 1.99 | 1065 | 0.53 | 0.38 | 839 | 226 | 24.4 |
| $AC_{1\text{-}600\text{-}8}$ | 1.98 | 1277 | 0.63 | 0.47 | 1028 | 249 | 21.8 |
| $AC_{1\text{-}600\text{-}10}$ | 2.03 | 1082 | 0.55 | 0.36 | 786 | 296 | 18.0 |
| $AC_{0.6\text{-}600\text{-}8}$ | 2.00 | 990 | 0.50 | 0.34 | 733 | 256 | 23.1 |
| $AC_{0.8\text{-}600\text{-}8}$ | 1.92 | 1145 | 0.55 | 0.45 | 967 | 178 | 24.5 |
| $AC_{2\text{-}600\text{-}8}$ | 1.90 | 995 | 0.47 | 0.39 | 850 | 145 | 14.2 |

*$D_{ap}$, average pore diameter; $S_{BET}$, specific surface area; $S_{mic}$, micropore surface area (<2 nm); $S_{ext}$, external surface area (>2 nm); $V_t$, total pore volume; $V_{mic}$, micropore volume (<2 nm).