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A cost-effective porous carbon derived from pomelo peel for the removal of methyl orange from aqueous solution

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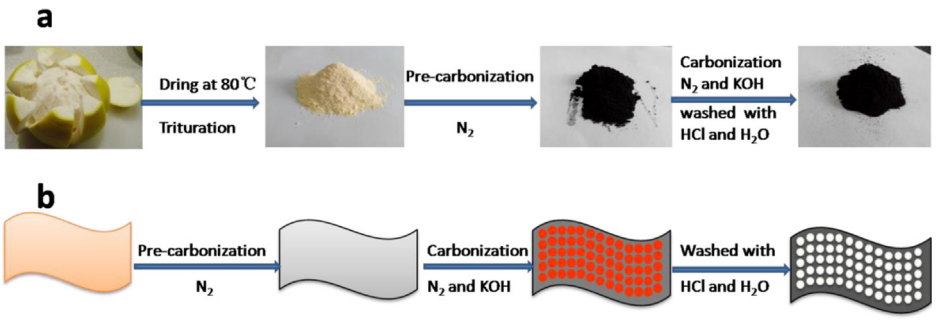
HIGHLIGHTS

- Porous carbon (PCs) was prepared by carbonization pomelo peel and KOH activation.
- The dose of KOH was researched in the material activation process.
- PCs prepared by us possess abundant micropores and mesopores.
- PCs-2 showed high adsorption efficiency for methyl orange (MO).
- The adsorption process for MO was studied in detail.
- The reusability of PCs-2 was high.

GRAPHICAL ABSTRACT



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ABSTRACT

A cost-effective approach was developed to prepare a porous carbon samples (PCs) by the simple carbonization of pomelo peel followed by KOH activation. The resulting materials were characterized by different techniques, such as SEM, XRD, FTIR, XPS, and BET surface area measurement. And the prepared PCs with high special surface area were first used as adsorbent materials for removal of methyl orange (MO) and experimental results indicated that PCs-2 activated by the mixture of KOH and precarbonization product (weight ratio 2:1) possesses the best adsorption performance among different weight ratio samples. The kinetic adsorption of different initial concentrations could be accurately described by the pseudo-second-order model and overall rate process was apparently influenced by external mass transfer and intraparticle diffusion. Furthermore, the Langmuir isotherm model showed a better fit with experimental data than Freundlich model and the maximum adsorption capacity was determined to be 680.2 mg/g. Moreover, the thermodynamic parameters indicated that the adsorption process was spontaneous and exothermic. Results of this work are of great significance for environmental applications of PCs as promising adsorbent materials for organic pollutant from aqueous solutions.

1. Introduction

With the recent enormous industrialization of especially developing countries, organic dyes have become widespread pollutants in the surface water due to their extensive use in a wide range of industries such as textile, leather, paper, printing and other industries [1–3]. And the color wastewater is rather difficult to treat because of the non-degradable synthetic origins and aromatic structures of the pollutants [4]. Meanwhile, the presence of dyes highly influences water quality because many of dyes and their metabolites have been reported to be toxic and carcinogenic [5]. The world water resources are becoming more and more scarce due

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to the emission of dye wastewater. Thus, it is imperative to treat the dyes in their wastes to an acceptable level before discharging them into the environment.

For the sake of human health and ecological security, various techniques including chemical oxidation, photochemical degradation, ultrasonic degradation, reverse osmosis, flotation and adsorption procedures have been developed for dye effluent treatment [6–11]. Among them, adsorption is considered to be the most popular method due to its low cost, easy operation and high removal efficiency [12–14].

Among various available adsorbents, carbon materials including activated carbons (ACs) and nanocarbons like carbon nanotubes, graphene, etc., which have a large specific surface area and chemical stability have been extensively exploited as adsorbents for pollutants removal from wastewaters [10,11,15]. Although many recent reports show that nanocarbons have great potential for future applications, PCs, especially activated carbons, remain the first choice because of their advantages of low cost, easy preparation and outstanding adsorption characteristics. Therefore, activated carbon is one of the materials mostly used for the treatment of industrial wastewaters. However, the generation and regeneration of activated carbons are relatively costly, thus limiting their application. Therefore, preparing activated carbon from low-cost organic waste materials for treatment of wastewater is worth considering. Recently, low-cost organic waste materials have received an increasing attention for the production of activated carbons that used for dyes removal. For example, several nonconventional biobased products such as oil palm empty fruit bunch fibers, cocoa shell, waste apricot, succinylated sugarcane bagasse and banana peel were previously used by other researchers to prepare activated carbon adsorbents and were studied for their ability to remove dyes from aqueous solutions [16–20]. Activated carbons derived from organic sources have a large specific surface area, meso to microporous characteristics and high adsorption performance. Based on these advantages, they are widely used to be adsorbents for the wastewater treatment.

Pomelo peel is a low-cost agricultural waste residue that is readily available in large quantities. In the present work, a novel porous carbon (PCs) was prepared by carbonizing pomelo peel followed by KOH activation. This activated carbon possesses a high specific surface area and displays a remarkable adsorption performance for removal organic dyes. And its adsorption capability for organic pollutants was investigated using methyl orange (MO) as a model. The PCs were characterized by scanning electron microscopy (SEM), X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR) analysis, Brunauer, Emmett, and Teller surface area measurement (BET) analyses, and X-ray photoelectron spectroscopy (XPS). The adsorption capacities of different materials, effects of pH, contact time at different initial concentrations and temperature were examined in bath experiments. Moreover, the adsorption kinetics, rate-controlling mechanisms, and thermodynamics of the adsorbents were also comprehensively investigated.

2. Experimental

2.1. Materials

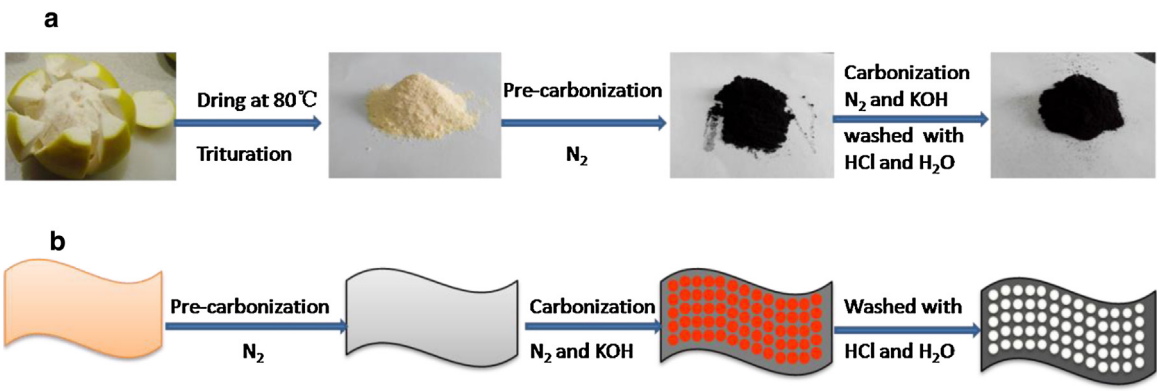
All reagents such as potassium hydroxide (KOH), sodium hydroxide (NaOH), concentrated HCl and methyl orange (MO) were purchased from Kelong chemical company (Chengdu, China). All chemicals are of analytical grade and used without further purification. And deionized water was used in all experiments.

2.2. Preparation of porous carbon samples (PCs)

The PC samples were fabricated by calcination. And the detailed preparation procedure and formation mechanism are illustrated in Scheme 1. In a typical procedure, pomelo peel was diced and dried at 80 °C for 24 h, and was then disintegrated into powder in an agate mortar. The white powder was pre-carbonized at 450 °C with a heating rate of 5 °C min^{-1} for 2 h under N_2 flow. Afterwards, the resulting black powder was further grounded and thoroughly mixed with different volume of 1 M KOH aqueous solution. Then, the black paste was dried at 80 °C for 4 h to remove redundant water, and was further grounded manually in a mortar with a pestle for 20 min to ensure KOH was mixed evenly. This mixed powder was then placed in a nickel crucible and activated in a tubular furnace first at 450 °C for 1.5 h and then at 800 °C for 2.5 h (ramp rate: 5 °C min^{-1}) under nitrogen conditions. The activated samples were washed with 1 M HCl to remove any inorganic salts (KOH) and then washed with distilled water until the pH of solution reach to about 6–7. Finally, these PCs were dried at 60 °C in an oven for 12 h. A series of experiments were similarly carried out to investigate the amount of KOH on the microstructure and adsorption performance of the PCs. The obtained PCs were marked as PCs-0, PCs-1, PCs-2 and PCs-3 when the weight ratio of KOH and pre-carbonization product is 0:1, 1:1, 2:1 and 3:1, respectively.

2.3. Material characterizations

The morphology and microstructure of the as-prepared PCs were analyzed with scanning electron microscopy (SEM, JSM-6701F). The crystallinity of the sample was investigated by X-ray diffraction (XRD, XRD-6000, Shimadzu, Japan). Fourier transform infrared spectra (FTIR) were carried out using a NEXUS 670 FTIR equipped with a pressed KBr pellets in wavenumber range of 400–4000 cm^{-1}. The BET surface area, pore volume, and



Scheme 1. Schematic presentation of the preparation procedure and formation mechanism of PCs.