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A simple route for consecutive production of activated carbon and liquid compound fertilizer from rice husk

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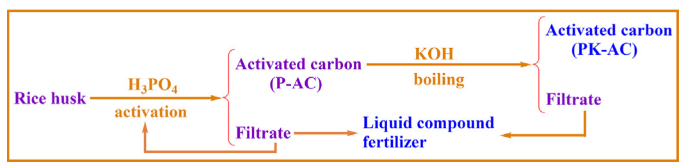
HIGHLIGHTS

- Two useful materials (activated carbon and liquid compound fertilizer) were produced from rice husk.
- This simple route combined the advantages of H_3PO_4 activation and KOH etching.
- Activated carbon exhibited excellent adsorption and electrochemical performances.
- All the chemicals involved in this route have been effectively used.

GRAPHICAL ABSTRACT



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ABSTRACT

Two useful materials (activated carbon and liquid compound fertilizer) were obtained from rice husk by a simple route which combined the processes of H_3PO_4 activation and KOH etching. The resulting activated carbon exhibited excellent performances, including low ash content, large surface area, high adsorption and electrochemical performances. The advantage of this route is that the waste water produced in this process was used to produce compound fertilizer containing Si, K and P. This technique provided an environmentally friendly production process for conversion of waste rice husk to high performance materials.

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1. Introduction

Utilization of abundant renewable rice husk to produce useful materials is of great significance. It not only avoids the environment pollution produced from combustion of rice husk, but also produces enormous economic benefits. Rice husk contains approximately 80% organic materials and 20% silica. The organic components are the precursor of carbonaceous materials. Among various carbonaceous materials, activated carbons are the most promising materials as they have large surface area, highly developed pore structures and wide applications in many areas, including energy storage [1], adsorption [2] and catalysis [3]. H_3PO_4 and KOH activation are two established approaches for the production of activated carbon [4,5]. The H_3PO_4 activation has the advantages of high yield and low pollution, while the corresponding activated carbon suffers from high ash content. Compared with H_3PO_4 activation, activated carbon produced using KOH exhibits some attractive properties, such as high surface area and low ash content. However, the high cost and low yield limit the application of KOH activation. Thus, designing a process with the elegant combination of the advantages of H_3PO_4 and KOH activation is of high significance. In the activation

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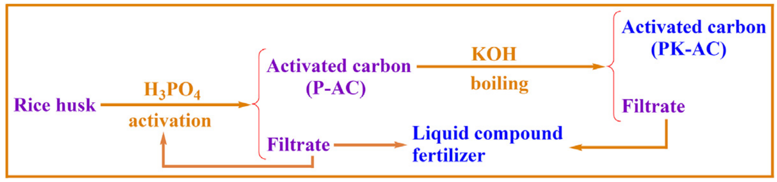

Fig. 1. Schematic diagram of the production processes of activated carbon and liquid compound fertilizer.

processes of rice husk, silicon usually acts as a useless material. A large number of silicon has been wasted. In fact, siliceous materials have wide application in drug delivery [6], Li-ion battery [7], catalysts [8], ceramics and electronics [9]. Utilization of the untapped silicon in the activation processes of rice husk is being considered. In addition, the discharge of waste water containing acid or basic in the activation processes should not be ignored, because the waste water usually causes serious environmental pollution if it is not treated properly. It is desirable to make a deep research about the full use of waste water for production of valuable materials.

Here, we propose a simple route to convert rice husk to useful activated carbon and liquid compound fertilizer by H_3PO_4 activation and KOH etching. All the chemicals involved in this process have been effectively used. The advantages of this route are that recycling of H_3PO_4 can reduce the production cost, the function of KOH etching can reduce the ash content and improve the adsorption properties and electrochemical properties of activated carbon, the fertilizer obtained by this route not only contains silicon, but also contains phosphorus and potassium. The main objective of this paper is to achieve effective utilization of rice husk.

2. Methods

2.1. Materials and reagents

Rice husk was obtained from a rice mill and washed with distilled water. Rice husk was dried at 105 °C for 12 h. Phosphoric acid, potassium hydroxide and Rhodamine B (RhB) were analytical grade.

2.2. Production of activated carbon by H_3PO_4 activation

Fig. 1 shows the schematic diagram of the production processes of activated carbon and liquid compound fertilizer. Rice husk was mixed with 50 wt% phosphoric acid, the mass ratios of phosphoric acid to rice husk were from 3:1 to 6:1. The activation reactions were conducted at the high temperature ranging from 400 to 600 °C, and maintained for 0.5–2 h. The solid product was washed

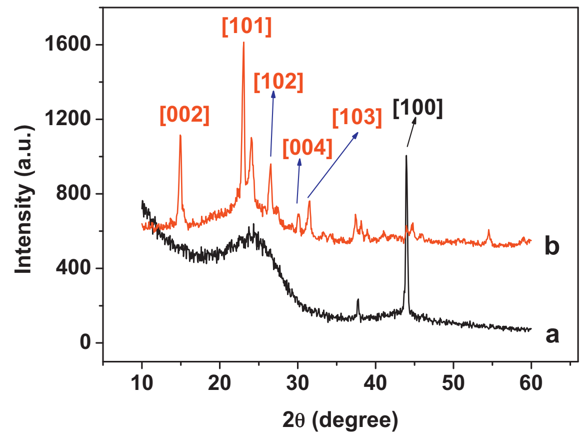

Fig. 2. XRD patterns of (a) P-AC/4:1/500/1 and (b) PK-AC/4:1/500/1.

with distilled water several times until neutral pH, and then dried at 105 °C for 12 h. The liquid product (washing solution) was separated from solid product by filtration. The liquid product was collected and named filtrate-*n* according the washing times (*n* represents the washing times). For example, after the first washing and filtration, the collected liquid product was named filtrate-1. The filtrate containing a high concentration of acid was returned to the activation processes. The filtrate containing a low concentration of acid was used to produce fertilizer. The above obtained solid products were activated carbons, they were denoted as P-AC. The activated carbons will be denoted according to the expression: P-AC/H_3PO_4:rice husk/temperature (°C)/time (h). For example, the activated carbon obtained at 500 °C 1 h when the H_3PO_4:rice husk ratio was 4:1, the activated carbon is denoted as P-AC/4:1/500/1.

2.3. Production of activated carbon by KOH etching

P-AC was mixed with a certain amount of potassium hydroxide solution in the three necked flask. The concentration of potassium hydroxide solution was varied from 3 to 7 wt%. The mixture was

Table 1
Texture properties of the activated carbons.

Sample	S_{BET}[a] (m^2/g)	V_t[b] (cm^3/g)	D_{ave}[c] (nm)	S_{mic}[d] (m^2/g)	S_{ext}[e] (m^2/g)
P-AC/4:1/500/1	892	1.48	7.12	0	829
PK-AC/4:1/500/1	1803	3.20	7.11	32	1771
PK-AC/4:1/500/0.5	1734	3.37	8.39	0	1734
PK-AC/4:1/500/2	1448	2.74	7.58	44	1404
PK-AC/4:1/400/1	1749	1.88	4.29	518	1230
PK-AC/4:1/600/1	1398	2.96	8.34	0	1398
PK-AC/3:1/500/1	1529	3.01	7.86	49	1481
PK-AC/5:1/500/1	1638	3.26	7.96	29	1609

[a] BET surface area.
[b] Total pore volume.
[c] Average pore diameter.
[d] t-method micropore surface area.
[e] t-method external surface area.

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