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Preparation of pore-size controllable activated carbon fibers from bamboo fibers with superior performance for xenon storage

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HIGHLIGHTS

- Bamboo fiber is proposed for the first time as precursor to prepare activated carbon fiber.
- Pore-size controllable bamboo activated carbon fibers (BACFs) are prepared.
- A novel gas carrying moisture activation technique is developed for preparing BACFs.
- The specific surface area of the as-prepared BACFs is as high as 2169 m^2/g.
- The as-prepared BACFs are very effective for xenon storage.

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ABSTRACT

Bamboo fiber (BF) is proposed for the first time as precursor to prepare pore-size controllable bamboo activated carbon fiber (BACF) by a novel but facile gas carrying moisture activation technique for xenon storage. This activation technique consists of two major steps: carbonization of BFs and physical activation of carbonized BFs. The as-prepared BACF samples are characterized by Raman, SEM and nitrogen adsorption at 77 K. The effects of the activation temperature, activation time and agent concentration are systematically investigated on the porous texture of the BACF samples and thus on their xenon adsorption capacity. The specific surface area of BACF is up to 2169 m^2/g. The dependence of the xenon adsorption capacity on the pore volume or surface area is examined. And the results show that the micropore of the as-prepared BACFs is very effective for xenon storage due to the fact that the micropore (especially ultrafine micropore) shows a very high xenon adsorption density. The maximum xenon uptake has a high value of 158.49 cm^3/g for the sample activated at 900 °C for 2 h when the activation agent concentration is equal to 402.6 g/m^3.

1. Introduction

In the last decade, there has been an increasing interest in developing gas storage systems for H_2 storage, CO_2 capture and volatile organic compound absorption, etc [1]. There are several ways including liquefaction, compression, usage of metallic compound and porous adsorbents for storage of gases. Porous carbon materials for gas storage attracted extensive attention due to their advantages associated with its light weight, complete reversibility, low cost and high surface area [2,3]. Activated carbon fibers (ACFs) are a comparatively modern form of porous carbon materials with a number of significant advantages over the traditional powder or granular forms of carbon materials, which have relatively higher specific surface area and higher adsorption capacity for ACFs, etc [4]. Nowadays, more and more researches are focused on preparation of ACFs from biomass materials from the recycling and sustainable view point. Bamboo is a type of biomass material and has been widely cultivated in the west and south of China. Currently, bamboo resources are very abundant and the total area of bamboo is about five million hectares and that of moso-bamboo (*Phyllostachys heterocycla*) is about 4.84 million hectares in China [5]. Bamboo fibers (BFs) are the cellulose fibers extracted and fabricated from natural bamboo which has been widely used in textile industry. Therefore, herein BFs are proposed for preparation of ACFs.

Xenon is described as having many characteristics of an ideal anesthetic agent, offering many medical and environmental advantages over the nowadays used nitrous oxide [6]. The positive medical effects of xenon include cardiovascular stability, neuroprotection and favorable pharmacokinetics [7]. However, the high cost of xenon prevents its wide application in clinical application [8]. Thus, xenon recycling becomes the only economically acceptable technique for clinically anesthetic purposes using conventional

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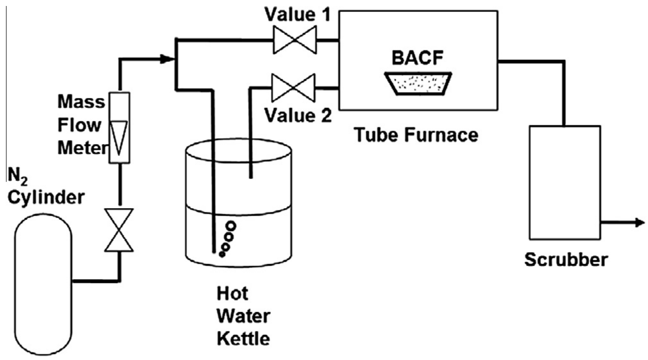

Fig. 1. Schematic diagram of the apparatus for preparing BACFs.

breathing circuits [9]. Several technological solutions have been proposed for xenon recycling. For example, a group at Ulm University [10] developed a device where the anesthetic gas passes through a cooling trap, activated carbon and a molecular sieve filter to remove all volatile substances. A group at Botkin Hospital [11] developed a device composing of several containers of adsorbent such as charcoal cooled in liquid N_2 and being evacuated by a pump. The high xenon purity was obtained by these methods. Storage of xenon is important in the recycling process. Nonetheless, to our knowledge, little work has been reported on the storage of xenon using ACFs.

The most common procedure for preparation of ACFs is physical activation with supercritical water steam or superheated water steam [12,13]. However, it is difficult to get a steady steam flow in physical activation, which may cause an inconsistent quality of ACFs for different batches. In this work, a novel but facile gas carrying steam activation (GCSA) technology is proposed for preparation of pore-size controllable activated carbon fibers (BACFs) from BFs with superior performance for xenon storage. This new approach consists of two major steps: carbonization of BFs and physical activation of carbonized BFs. The effects of the activation conditions are systematically investigated on the pore structure and texture of the BACFs. The dependence of the xenon storage density is examined on the porous structure of the as-obtained samples and the xenon adsorption mechanism is then clarified.

2. Experimental

2.1. Materials and equipment

The as-spun commercial bamboo fibers (BFs) with a diameter of about 11 μm were used as feedstock to prepare BACFs. BACF surfaces were investigated by scanning electron microscopy (Hitachi S-4300). Raman spectra were acquired with a Raman spectroscopy (inVia-Reflex) equipped with an air cooled CCD detector for signal recording. The porous texture of the as-prepared BACFs was characterized by physisorption of nitrogen at 77 K, which was measured in volumetric adsorption apparatus (Quadrasorb SI-MP). Xenon adsorption measurement was performed by volumetric methods (Micromeritics ASAP 2020) under the pressure range of 0–1 bar at 273 K. Elemental analysis was conducted with a Vario EL III element analyzer to obtain the mass percentage of C, H, N, S and O. The ash content of the samples was measured using thermal analyzer (NETZCH STA 409 PC) under air atmosphere at a heating rate of 10 °C/min. The heating temperature ranged from 30 to 500 °C.

2.2. Sample preparation

The gas carrying steam activation (GCSA) technology proposed in this study is depicted in Fig. 1. It comprises two major steps: (1) the BF is carbonized in a horizontal tube furnace at a carbonization temperature under N_2, for which valve 1 is open while valve 2 is close; (2) the followed physical activation is performed using nitrogen carrying moisture as activating agent, in which valve 1 is close while valve 2 is open, and the moisture is carried by nitrogen flowing through the tube furnace. The nitrogen here is served not only as a carrier gas but also a shielding gas. The control in moisture content (i.e. activation agent content) can be achieved by adjusting hot water kettle temperature. The influencing factors for preparation of the BACF samples include hot water kettle temperature, activation temperature and activation time. One BACF prepared at the hot water kettle temperature *A* and the activation temperature *B* within the time *C* is denoted by BACF-*A*-*B*-*C* while one carbonized bamboo fiber at the temperature *T* before activation process is named BCF-*T*.

3. Results and discussion

Bamboo fibers (BFs) are the cellulose fibers extracted and fabricated from natural bamboo as shown in Fig. 2. It shows that the BFs have uniform sizes. The BFs are employed for preparation of BACFs via the GCSA process. It has been indicated that the carbonization process has a significant effect on the final product quality and eventually influences the product yield and textural properties [14]. The effects of carbonization temperature on the yields of BCFs are shown in Table 1. It is found that the yield decreases with increasing the carbonization temperature. This result is consistent with the literature [15]. A higher carbonization temperature leads

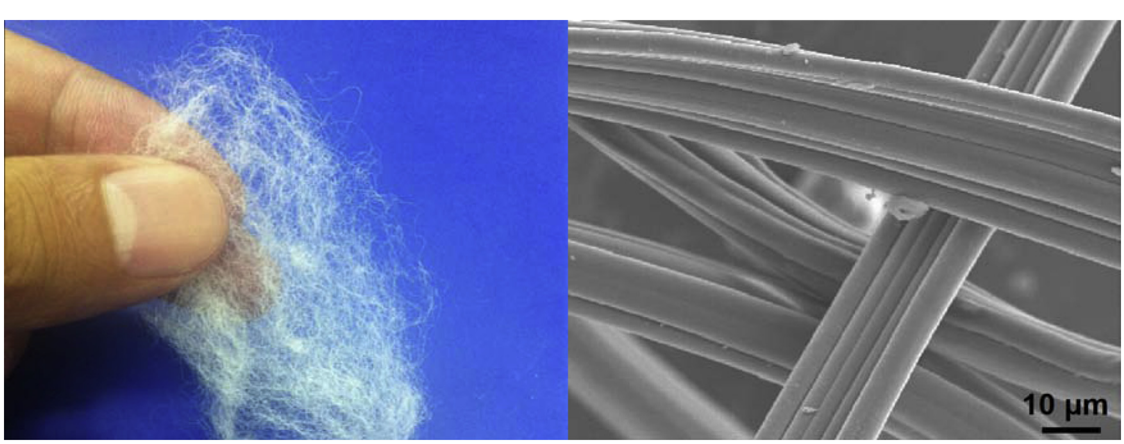

Fig. 2. Optical and SEM images of bamboo fibers.