

CO₂ ADSORPTION ON BANANA-PEEL DERIVED HIERARCHICAL POROUS CARBON FOAMS

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INTRODUCTION

Carbon foams with high void volumes, hierarchical porous structures, low bulk density, and good thermal and electrical conductivity have been reported for a range of significant applications including catalyst supports, energy storage electrodes, insulation and adsorption applications. [1, 2] Renewable biomass materials for carbon foams may offer long-term environmental and economic advantages to fossil-fuel sources such as pitch, plus biomass materials can provide interesting natural macroporous structures that can utilize to create novel foam properties.

Banana peel (BP) is an agricultural waste available in large volumes as bananas are a very popular and nutritionally important fruit for a wide population of the world - the global production of bananas is more than 100 million tonnes annually [3]. Banana peels contain a mixture of biopolymers including pectins and containing various surface functional groups; and these compounds may serve as interesting precursors for carbon foams. In this study, carbon foams were prepared from banana peel by a procedure based on Lv et al. [4] self-templating method with zinc nitrate, furfural and 2-aminophenol. We added a post-foam carbonization step of CO₂ activation to enhance the microporosity of the carbon foams as adsorbents for CO₂ capture.

METHODOLOGY

The procedure to prepare carbon foams was based on the self-template method proposed by Lv et al. [1] using zinc ions coordinated with carboxylic and hydroxyl groups on the BP's pore surfaces. The key process steps in this procedure, as summarized in Figure 1, were (1) The BP particles were soaked in 2 mol.L⁻¹ zinc nitrate solution at 343 K in a closed vessel for 7 days to form zinc complexes. (2) The reaction vessel was opened and the excess water was evaporated over 14 days at 333 K to obtain brown zinc complexes. (3) The zinc complexes were soaked in a mixture of furfural and 2-aminophenol at 343 K for 7 days. This step produces slurry of banana peel zinc complexes impregnated with a 2-aminophenol-furfural resin, which subsequently provide a N-rich carbon source during pyrolysis. (4) 7 g of the slurry was pressed by hand into a cylindrical quartz crucible (2.54 cm diameter × 2.54 cm height) and carbonized in a horizontal tube furnace at 1273 K for carbonization times of 3 hrs. In addition, we extended on Lv et al.'s procedures [1] to produce a CO₂ activated carbon foam by switching the gas flow from argon to CO₂ once the carbonization temperature had been reached and kept it in that condition for 1 hour. The heating rate in all experiments was 10 K.min⁻¹. Carbons produced from the banana peel zinc complexes are labelled as CBF-Ar and CBF-CO₂, based on the gas atmosphere of the carbonization step, Ar and CO₂, respectively.

Pore textural properties of the carbon foams were characterised by mercury intrusion porosimetry (MIP) measured at pressure of (20 – 414000) kPa (Micromeritics PoreSizer 9320) and sorption analyses with CO₂ at 273 K and N₂ at 77 K (Micromeritics TriStar II 3020). Adsorption isotherms of pure fluids CO₂ and N₂ on carbons were measured at (298, 313 and 323) K and pressures up to 4000 kPa using a BELSORP-BG instrument (BEL Japan) equipped with a RUBOTHERM magnetic floating balance.

RESULTS AND DISCUSSION

An aim of this study was to produce monolithic carbon foams with a mechanically stable, open cellular structure and the chemically-modified banana foams synthesis method successfully produced monoliths of CBF, as it can be seen in Figure 1. Table 1 shows the specific surface areas (S_{BET} , calculated by the Brunauer-Emmett-Teller method at the relative pressures in the range of $P/P_0 = 0.05 - 0.30$); total pore volumes (estimated at $P/P_0 = 0.98$); and micropores surface area (calculated from 273 K CO₂ isotherms using the Dubinin- Radushkevich (D-R) equation). As indicated in this table, the calculated BET surface area and total pore volume in CBF-CO₂ are, respectively, more than seven and four times greater than CBF-Ar because of extra activation and pore opening under CO₂ atmosphere. However this increase in the micropore surface area measured by CO₂ sorption is from 620.9 m²·g⁻¹ for CBF-Ar to 881.9 m²·g⁻¹ CBF-CO₂. The evaporation of ZnO (derived from the zinc nitrate) particles from the carbon structure at temperature above 1100 K is likely to be the main reason for the close small micropores produced at a carbonization temperature of 1273 K [5].

The total nitrogen concentration of the BP determined by CHNS Elemental Analyzer was 1.9 %wt while this value for the intermediate composite BPC is 8.0 %wt. The source of the additional N in the chemically-modified CBF is the 2-aminophenol (C₆H₇NO) that contains 12.83 %wt N. Carbonization at high temperature (1273 K) decomposed some N-functional groups on the carbon surface to reduce total N concentrations in the CBFs to 4.6 -4.2 %wt. However nitrogen functionalities on the CBFs surface still is high enough to affect the CO₂ adsorption performance of the activated carbon [6].

To evaluate the potential of these carbon foams as adsorbents for gas separation, the adsorption capacity of the carbon foams for CO₂ and N₂ were measured by a gravimetric sorption. Figure 2 present the absolute adsorption capacities of CO₂ and N₂ on the CBFs measured with the BelsORP apparatus at 298 K. As expected, the adsorption capacities on the carbon foam prepared under argon were lower than the capacities on the CO₂ activated carbon foam CBF-CO₂. The adsorption capacities for CO₂ and N₂ on CBF-CO₂ measured at 298 K and 4000 KPa were about 63 % and 34% higher, respectively, than the capacities on CBF-Ar. This comparative results highlights that the CO₂ activation of the foam has improved the selectivity of the CBF for CO₂ over N₂.

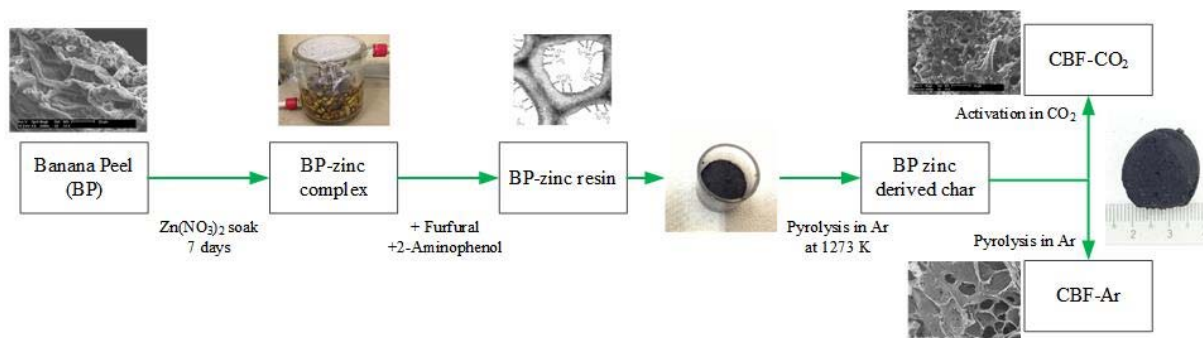


Figure 1. Process block flow diagrams of zinc complex templated furfural + 2-aminophenol procedures to produce activated carbons

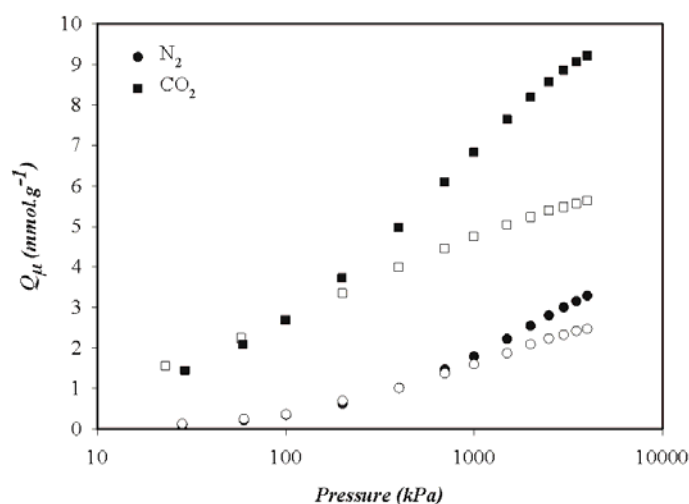


Figure 2. Measured N₂ and CO₂ adsorption capacities on chemically-modified banana foam CBF-Ar (solid symbols) and CBF-CO₂ (empty symbols) at 298 K.

Table 1 Surface textural properties of zinc complex templated carbon foams from banana peel (CBFs) determined from sorption isotherms of N₂ at 77 K and CO₂ at 273 K and elemental composition measured by CHNS/O analyser.

Sample	N ₂		CO ₂	Elemental Composition (%)		
	BET surface area (m ² ·g ⁻¹)	Pore volume (cm ³ ·g ⁻¹)	D-R Micropore Surface area (m ² ·g ⁻¹)	N	C	H
BP-Raw	-	-	-	1.9	42.0	5.6
BPC	-	-	-	8.0	32.4	3.6
CBF-Ar	169	0.18	620.9	4.6	70.0	1.3
CBF-CO ₂	1426.1	0.83	881.9	4.2	43.5	2.2

ACKNOWLEDGMENT

This research was funded by the Australian Research Council (DE140100569, FT120100720) with additional scholarship support for Mr Arami-Niya provided through a UQ International Postgraduate Research Scholarship.

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