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Removal of volatile organic compounds over bagasse ash derived activated carbons and monoliths

Anjali Bajwa[a], Malini Balakrishnan[a,b], Gunnar Svensson[c], Vidya S. Batra[a,b,*]

[a] Centre for Energy and Environment, TERI University, 10 Institutional Area Vasant Kunj, New Delhi 110 070, India
[b] The Energy and Resources Institute (TERI), IHC Complex, Lodi Road, New Delhi 110003, India
[c] Department of Materials and Environmental Chemistry, Stockholm University, SE-106 91 Stockholm, Sweden

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ABSTRACT

The unburned carbon in bagasse ash was separated and used as a starting material for activated carbon and carbon monolith preparation. The separated carbon was steam activated in a rotary kiln under different conditions and compared with carbon activated in limited supply of air. The activated carbon from the rotary kiln showed surface areas ranging from 324 to 601 m^2/g. Different phenolic resins and cellulosic binders were used to prepare the monoliths using slurry casting method. The effects of different preparation conditions on the properties of the monolith were studied. Upon monolith formation, the surface area was reduced slightly and surface areas in the range 92–479 m^2/g were achieved. The activated carbons and monoliths were tested for static adsorption of volatile organic compounds (VOCs) using benzene, xylene, hexane and toluene as model compounds. With the activated carbons, adsorption capacities as high as 22.5, 31.1, 27.5 and 25.0 g/100 g sample were obtained for toluene, benzene, xylene and hexane, respectively. The adsorption capacities were reduced for the corresponding monoliths. The waste derived activated carbons and monoliths show promising results as adsorbents for the removal of volatile organic compounds.

1. Introduction

Bagasse ash waste is generated in sugar mills from the use of bagasse as a fuel. This waste usually find its way to landfilled sites where it is disposed. The large quantities of ash generated every year creates disposal problem since it is difficult to provide large land area. Also, due to the presence of light carbon particles in this ash, the water has to be sprayed over it regularly so that it does not catch fire. To get rid of disposal problems associated with this waste, alternate strategies are being looked into to utilize this waste in an efficient manner. This ash contains 16–35 wt% unburned carbon that can be easily separated and utilized in many applications [1–3]. The bagasse ash has been widely studied as an adsorbent for the removal of pollutants [4–6] but very few other studies have examined the utilization of unburned carbon in bagasse ash. The utilization of unburned carbon from coal fly ash as an adsorbent has however been examined [7–9]. We have recently reported the synthesis of activated carbon monoliths by utilizing unburned carbon of bagasse ash and their applications towards phenol removal, a liquid phase pollutant [10] have been tested successfully. Similarly, such waste derived monoliths can also be tested for other applications such as removal of volatile organic compounds (VOCs).

The presence of VOCs in indoor and outdoor system is of great concern because of their harmful effects on human health. For example, formaldehydes, ketones and benzene are present in building materials, furniture and office equipments, while presence of toluene could be seen in paints, detergents and cleaners and xylene is found in synthetic rubber and polyester clothing. Xylene and hexane are also most commonly used solvents in petroleum industry [11]. Adsorption is a well-studied method [12] for removing these volatile organic compounds and many adsorbents in different forms such as activated carbon fiber [13], granular activated carbon [14], zeolites [15] and monoliths [16] have been tested for its removal. Dynamic [14,15] and static [13,16] adsorption studies have been reported in literature for the removal of volatile organic compounds and significant adsorption capacities and extent of removal has been achieved. The present study examines the performance of waste derived monoliths and activated carbons for the removal of volatile organic compounds using static adsorption method. Due to the large number of samples involved in this study (three types of activated carbons

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[*] Corresponding author at: The Energy and Resources Institute (TERI), India Habitat Centre, Lodhi Road, New Delhi 110 003, India. Fax: +91 11 24682144.
E-mail address: vidyasb@teri.res.in (V.S. Batra).

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(AC) and different monoliths made of them), a simple static adsorption method was used to test their adsorption capacities.

2. Experimental

2.1. Preparation of separated and activated carbons

The bagasse ash was collected from a sugar mill in Uttar Pradesh, India. A carbon rich fraction was collected by sieving and floatation as reported before [2]. The resulting separated carbon was then crushed and sieved (through 38 microns) before utilizing it for monolith preparation. This carbon is hereby referred to as SC38.

This separated carbon was activated in a rotary kiln mounted on a tilting frame. The activation was carried out under steam atmosphere at 900 °C and an inclination of 8°, which led to a sample exit rate of approximately 7 g/min. To obtain a higher degree of activation, one sample was prepared at 950 °C and an inclination of 4°. An alternative method to activate the separated unburned carbon was also carried out, by mixing separated carbon and water in 1:7 ratio followed by heating at 800 °C for 3 h, in a limited supply of air [2], thereafter the obtained activated carbons were crushed and sieved through 38 microns. The three samples of activated carbons were named AC8, AC4 and 7AC38. The first two samples were named based on their degree of inclination during activation (4 in case of AC4 and 8 in case of AC8) whereas 7AC38 was named as it was activated using carbon and water ratio of 1:7 and was sieved through 38 microns after activation.

2.2. Monolith preparation

The starting carbons (SC38 and 7AC38) were mixed with different phenolic resin binders [Sumitomo PR311 (solid) (P3), PR-50273 (liquid) (P5) and Satya Cashew novolac resin (liquid) (S)] and cellulosic binder (solid) (CMC), in different ratios (ranging from 20–50 wt%) using appropriate solvents (ethanol for phenolic resins and water for cellulosic binder) to obtain a slurry. The slurry was then poured into a square mold (5 × 5 cm) placed on a smooth glass surface and kept for drying overnight. The square shaped flat monoliths were further dried and carbonized at 550 °C for 4 h, in a partially sealed box with a limited supply of air. Additional monoliths using AC8, AC4 and commercial activated carbon with surface area of 685 m^2/g (CC) were prepared with P3 binder, based on its better performance. Since AC8 and AC4 were available in smaller quantities, only the best performing binder was used. The samples prepared are shown in Table 1.

Table 1
Sample preparation conditions (samples carbonized at 550 °C in air free atmosphere). The sample code (e.g. SC38P320) is carbon (SC38), binder (P3), percentage of binder (20).

Carbon	Binder	Binder amount (wt%)	Sample code
SC38	P3[a]	20	SC38P320
		30	SC38P330
		40	SC38P340
SC38	P5[b]	20	SC38P520
		30	SC38P530
		40	SC38P540
7AC38	P3	20	7AC38P320
		30	7AC38P330
		40	7AC38P340
AC4		40	AC4P340
AC8		40	AC8P340
CC		40	CCP340
7AC38	P5	20	7AC38P520
		30	7AC38P530
		40	7AC38P540
		50	7AC38P550
7AC38	S[c]	20	7AC38S20
		30	7AC38S30
		40	7AC38S40
		50	7AC38S40
		20	7AC38CMC20
		30	7AC38CMC30
7AC38	CMC	40	7AC38CMC40

[a] P3 = PR311.
[b] P5 = PR 50273.
[c] S = Satya.

Table 2
BET values[a] of carbonized binders.

Binder	BET surface area (m^2/g)
P3	221
P5	4
S	43
CMC	575

[a] single point measurements.

2.3. Characterization of activated carbons and carbon monoliths

Detailed adsorption properties of activated carbons and monoliths were determined using single point (Smart Instruments, results in Tables 2 and 3) and multipoint nitrogen adsorption (Micromeritics ASAP 2020, results in Tables 4 and 5) at 77 K. In case of single point adsorption, the sample was degassed at 150 °C for 1 h before analysis and Brunauer–Emmett–Teller (BET) method was used to obtain surface area. For multipoint nitrogen adsorptions, the samples were degassed at 200 °C for 10 h in vacuum prior to analysis and BET, Dubinin–Radushkevich (DR) and Density Functional Theory (DFT) methods were used to determine the apparent surface area, pore volume and pore size distributions, respectively.

The characterization of activated carbons and monoliths was done through Scanning Electron Microscopy (SEM) using JEOL JSM7000 equipped with an Oxford INCAx SIGHT energy dispersive detector (EDS) and Transmission Electron Microscopy (TEM) with a JEOL3010 and a JEOL 2000FX equipped with EDS analyzer. For the TEM studies of activated carbons, the powders were dispersed in butanol and thereafter a drop of the suspension was placed on a holey carbon film supported by a copper grid.

The thermal analysis of binders and carbon monoliths was performed using thermogravimetric analyzer (PerkinElmer 519 N). The sample was placed in a platinum crucible and heated at the rate of 10 °C/min in nitrogen atmosphere in the temperature range of 20–900 °C.

Infrared spectroscopic analyses of pressed pellets of powder samples mixed with KBr, (1:100 ratio) were performed in a FTIR spectrometer (PerkinElmer, India) at room temperature over the frequency range of 400–4000 cm^{-1}.

Boehm titration [17] was performed to identify the amount of acidic (carboxyl, hydroxyl and lactonic groups) and basic

Table 3
BET values[a] of carbonized monoliths.

Sample	BET surface area (m^2/g)
AC4P340	445
AC8P340	277
7AC38P340	179
CCP340	395

[a] single point measurements.