

DYNAMICS OF BUTANE ADSORPTION ON ACTIVATED CARBON-FIBER COMPOSITES

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Introduction

Activated carbon is a logical choice for the removal and recovery of volatile organic compounds (VOCs) from air streams emanating from a range of industrial sources. The requirements of the carbon adsorbent are especially demanding in those applications with high flow rates and low VOC concentrations. In such situations, beds of granular activated carbon (GAC) must be relatively deep in order to provide sufficient contact time for the adequate removal of the adsorbates. An attendant disadvantage is the pressure drop over the bed. The rate of adsorption can be greatly increased by using narrow diameter activated carbons (micron vs millimeter dimensions), and can be achieved by using small particles or fibers. However, in order to circumvent problems of unacceptably high pressure drop, handling, and containment, the particles or fibers must be incorporated into a more tractable flexible or rigid structure. At this laboratory we have been studying the production, properties and behavior of rigid activated carbon fiber composites that were originally developed in collaboration with researchers at the Oak Ridge National Laboratory¹. The composites possess an open internal structure which presents little resistance to the flow of fluids, and allows direct access of a contacting fluid to the activated fiber surfaces. Consequently, they offer a potential solution to the problems of removing low concentrations of VOCs from large volumes of air. In this paper we describe a study that was made to compare the characteristics of beds of GAC and activated carbon composites for the adsorption of low concentrations of butane at high space velocities.

Experimental

Carbon fiber composites were prepared using petroleum pitch-based carbon fibers (P200 fibers, Ashland Carbon Fibers Division, Ashland Inc.) and powdered phenolic resin, using methods that have been described elsewhere². The composites were activated in steam (877°C) to a burn-off of ~45 wt% and then fitted into stainless steel tubes to produce beds of diameter 3.8 cm and depth 3.8 cm. Comparisons were made with beds of a commercial GAC (F-400, Calgon Carbon Corporation, 0.6-0.84 mm) which was also packed into tubes and supported by a stainless steel grid. Physical properties of

the GAC and the composites are given in Table 1, where it can be seen that they have comparable surface areas.

Breakthrough plots for butane adsorption were obtained for both types of activated carbon bed by passing a stream of dry nitrogen containing a metered concentration of butane through the bed. Because of the differences in bulk density, comparisons were made on the basis of equal bed mass and equal bed volume. The concentration of butane at the outlet of the carbon bed was measured using a quadrupole mass spectrometer. At the start of each experiment the air flow by-passed the carbon bed to acquire a baseline reading for the butane concentration before directing the flow through the bed. The range of butane concentration was 415 - 1244 ppm by weight, and the flow rates were 48 and 96 l.min⁻¹, giving contact times between 0.008 - 0.048 sec.

Table 1: Properties of activated carbons

Sample	S. area (m ² /g)	Pore vol. (cc/g)	Bulk dens. (g/cc)
F-400	1014	0.44	0.46
Composite	789	0.39	0.15

Results and Discussion

For beds of equal mass, the superficial contact time is about three times longer for the composite than the GAC. Typical butane breakthrough plots for this situation are shown in Figure 1. Breakthrough has been arbitrarily

defined as the point where $C/C_0 = 0.1$. It can be seen that the time to breakthrough is significantly longer for the composite, and that the profile is much steeper. The breakthrough profile essentially describes the shape of the adsorption front as it passes through the bed. The region between the activated carbon that is already saturated and the point where the concentration of the unadsorbed compound is at the breakthrough concentration is the mass transfer zone (MTZ).

By integration, the dynamic adsorptive capacity and the amount of butane adsorbed at breakthrough can be calculated, and the length of the MTZ can be determined as a percentage of the bed depth, Table 2³. As shown, the MTZ is much shorter for the composite under all

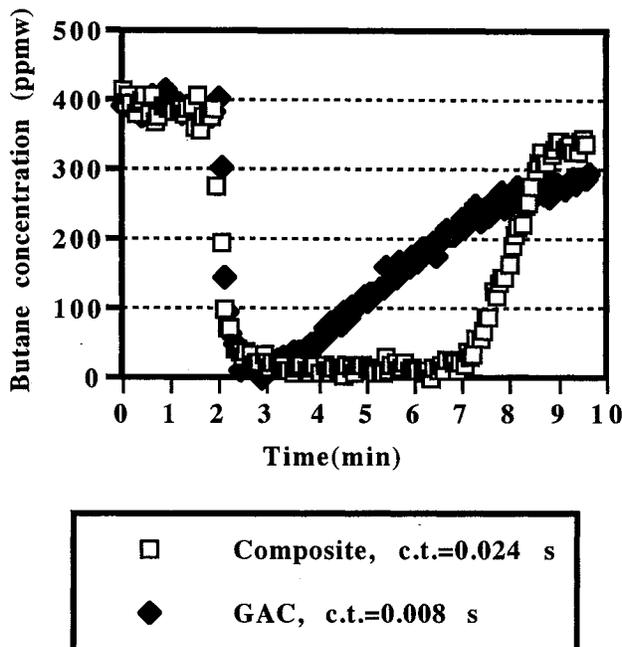


Figure 1: Breakthrough plot for butane over beds of carbon fiber composite and GAC (c.t = contact time).

Table 2. Dependence of MTZ on adsorption conditions

Butane conc. (ppmw)	MTZ (% bed depth)	
	Composite	F-400
<u>equal bed mass¹</u>		
415	22	155
830	16	188
1000	38	198
1244	45	156
<u>equal bed volume</u>		
2415	34	86
31447	45	70

¹ contact time: GAC 0.008 sec; composite 0.024 sec

² contact time 0.048 sec, ³ contact time 0.024 sec

capacity is utilized before breakthrough. At equal bed mass, the composite clearly excels over the GAC: the overall adsorption rate is 5-10 times higher; the amount of C_4H_{10} adsorbed at breakthrough is about 2.5 times higher; and the bed utilization efficiency (fraction of dynamic equilibrium capacity used at breakthrough) is 75-85% vs 20-40%. For the shallow GAC beds used under this condition, the MTZ is actually longer than the bed itself, and the prospect of channeling cannot be eliminated.

At equal bed volume, the mass of GAC is about

three times that of the composite. Under these conditions, the pressure drop is about the same over the two beds. The GAC bed out-performs the composite with respect to longer breakthrough times, and the mass of C_4H_{10} adsorbed at breakthrough. At the same time, the MTZ is still appreciably longer than for the composite and the bed utilization efficiency is lower (55-70% vs 70-85%). If it is assumed that a desorption cycle would take the same time as adsorption, the rate of adsorbent removal and recovery would be the same for both beds. However, if desorption is thermally driven, this part of the cycle will be longer for the GAC to allow for heating and cooling of the greater mass of carbon.

Synopsis

Because of its structure, the activated carbon fiber composites allow more effective contact with the gas stream than GAC, allowing faster rates of adsorption, and a much shorter MTZ, which translates to more efficient use of the adsorptive capacity before breakthrough. The relative merits of the activated composite become more apparent as the contact time and butane concentration are reduced. Comparisons have been made on the basis of equal bed mass and equal bed volume. Both circumstances represent extremes that bracket the range of interest for industrial applications. In the latter case, GAC presents certain advantages. However, in many applications, performance would be determined through repeated adsorption - desorption cycles. The optimum bed size will be determined by several parameters, and the two types of adsorbent should not be considered as interchangeable.

References

1. Jagtoyen, M., Kimber, G. and Derbyshire F., Proceedings, 10th Annual Conference on Fossil Energy Materials, Oak Ridge, Tennessee, May 12-15, 1996.
2. G. M. Kimber, M. Jagtoyen, Y.Q. Fei and F. J. Derbyshire, Gas. Sep. Purif., Vol. 10 (2), pp. 131-136, 1996.
3. In "Air Pollution and Control Equipment", eds. L. Theodore and A. J. Buonicore, ETS Inc. 1992, p.93.

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