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2540 Research Park Drive, Lexington KY 40511-8410, USA.
under

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OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
Managed by
LOCKHEED MARTIN ENERGY RESEARCH CORP.
for the
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ACTIVATION AND MICROPORE STRUCTURE DETERMINATION OF
ACTIVATED CARBON-FIBER COMPOSITES

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SYNOPSIS

Previous work focused on the production of carbon fiber composites and subsequently activating them to induce adsorbent properties. One problem related to this approach is the difficulty of uniformly activating large composites. In order to overcome this problem, composites have been made from pre-activated fibers. The loss of surface area upon forming the composites after activation of the fibers was investigated. The electrical resistivity and strength of these composites were compared to those made by activation after forming. It was found that the surface area is reduced by about 35% by forming the composite from pre-activated fibers. However, the properties of the activated sample are very uniform: the variation in surface area is less than $\pm 0.5\%$. So, although the surface area is somewhat reduced, it is believed that making composites from pre-activated fibers could be useful in applications where the BET surface area is not required to be very high.

The strength of the composites produced from pre-activated fibers is lower than for composites activated after forming when the carbon burnoff is below 45 %. For higher burnoffs, the strength of composites made with pre-activated fibers is as good or better. In both cases, there is a dramatic decrease in strength when the fiber:binder ratio is reduced below 4:1.

The electrical resistivity is slightly higher for composites made from pre-activated fibers than for composites that are activated after forming, other parameters being constant (P-200 fibers, similar carbon burnoffs). For both types of composite the resistivity was also found to increase with carbon burnoff. This is attributed to breakage of the fiber causing shorter conductive paths. The electrical resistivity also increases when the binder content is lowered, which suggests that there are fewer solid contact points between the fibers.

The applications of activated carbon fiber composites are in areas of water and air purification. One particularly unique property of the composites is the high rates of adsorption that can be achieved. They should therefore be effective for removing pollutants from air at high flowrates. An example is in the removal of VOC's from process effluent air streams. We have investigated the removal of 20 ppm of butane from air at flow rates up to 50 lpm. For equal volume beds of activated carbon fiber composite and a commercial coconutshell granular activated carbon it was found that the composite will last 8 hours before any detectable breakthrough, while the granular bed starts to break through after 4 hours.

The connectivity between individual fibers in the composites provides a pathway for electrical conduction which can be employed to drive the desorption stage of a

cyclic adsorption process by direct electrical heating. In solvent recovery and VOC adsorption the adsorbent bed is usually regenerated by heating to $\sim 200^{\circ}\text{C}$ with steam, a procedure that can take several hours, depending on the size of the bed. In this work, regeneration was achieved by electrical heating, in which it only took a few minutes to heat the bed to 150°C . This technique can produce rapid and uniform heating and could be very energy efficient, since heat transfer losses will be minimized. This process also eliminates the need for an expensive steam generator.

INTRODUCTION

Activated carbon fibers are of interest in several areas of adsorption and environmental protection due to their novel properties that make them more attractive than conventional forms (powder or large-size carbons) for certain applications^{1,2}. Among the possible applications, activated carbon fibers are of interest for the adsorption and recovery of organic vapors; the clean up of landfill gas i.e separation of methane and carbon dioxide, the removal of SO_x and NO_x from flue gases; the improvement of air quality; and water treatment^{5,6}.

Difficulties in handling and utilizing activated fibers can be surmounted by their incorporation into composites, such as woven and non-woven fabrics, felt, and paper. This research is concerned with the development of a rigid activated carbon fiber composite material that can be produced in single pieces to a given size and shape. The work involves a collaboration between the Oak Ridge National Laboratory (ORNL) and the Center for Applied Energy Research (CAER), University of Kentucky ¹⁻⁴.

The unusual properties of the composites offer potentially unique solutions to a range of environmental and catalytic applications. An open structure, combined with the presentation of the reactive surfaces for adsorption or catalysis in the form of narrow diameter fibers allows direct access of the contacting fluid with minimal mass transfer limitations, and very high rates of adsorption, desorption, and reaction. Hence, efficient adsorption or desorption can be achieved at short contact times and with low pressure energy requirements.

The composites are made by filtration of a water slurry containing chopped carbon fibers (typically 400 micron long) and a powdered phenolic resin binder. The resulting shape is dried and then cured to set the binder. One approach to producing an adsorbent composite is to activate the cured shapes by reaction with steam or CO₂. However, a difficulty in making large samples is the lack of uniformity of surface area development through the composites. In 2" and 4" diameter samples, the heat transfer to the center of the composite is slow such that there is a temperature gradient between the inside and outside. The cooler zone in the middle leads to lower activation rates and less surface area development than in the outer parts of the composite. Stresses caused by differential burnoff can lead to cracking of the samples. In order to overcome this effect, composites have been made from pre-activated fibers. We have investigated the effect of forming the composites after activation of the fibers in relation to the loss of surface area due to the binder particles occluding open pores. We have also compared the electrical conductivity and strength of these composites to those made by activation after forming. Information is also provided on the effects of fiber length, binder content and burnoff on electrical conductivity and surface area.

The specific objectives of this component of the research are to:

- * investigate the manufacture of composites from pre-activated fibers
- * determine the changes in pore structure, electrical conductivity, and other properties as a function of:
 - fiber length,
 - extent of activation,
 - binder content
 - heat treatment conditions.

The incorporation of activated carbon fibers (ACF) into permeable monoliths provides a connectivity between individual fibers allowing their pore structure and other characteristics to be combined with a pathway for electrical and thermal conduction. The general aims of the continuing research are to investigate the possibilities for utilizing this unique combination of properties in adsorption and catalysis in the gas and liquid phases. Both ORNL and the CAER have examined the prospect of driving the desorption stage of a cyclic process by direct electrical heating. In solvent recovery and VOC adsorption the adsorbent bed is usually regenerated by heating to $\sim 200^{\circ}\text{C}$ with steam, a procedure that can take several hours, depending on the size of the bed. In this work, the regeneration is achieved by electrical heating. The technique can produce rapid and uniform heating and can be very energy efficient since heat transfer losses are minimized.

Another objective is to examine the relative merits of butane adsorption at low concentrations (20-300 ppm) over activated carbon fiber composites (ACFCs) and granular activated carbon (GAC). In previous work^{7,8}, the density of the ACFC was about 0.2 g/cc, whereas that of the GAC bed was ~ 0.4 g/cc. In the present work we increased the density of the composite to 0.3 g/cc so that it is closer to that of the GAC bed. Earlier comparisons with GAC beds used coal-based Calgon F-400. As the solvent recovery industry uses a coconutshell based activated carbon, a commercial coconutshell activated carbon was also obtained for comparative studies.

EXPERIMENTAL

Preparation of pre-activated composites

Preactivated composites were made using three different length fibers, P-200, P-400 and P-800 from Anshan Carbon Fibers, China. The P number indicates the average fiber length in microns. The powdered resin used in forming the composites is a one-step Varcuum phenolic resin binder made by Oxychem, with an average particle size of 20 microns.

P-800: A batch of pre-activated fibers was made from 430 g of P-800 carbon fibers by activation in steam at 900°C for 12 hours and 40 minutes to 46.1% burnoff. A cylindrical composite was formed from 97.0 g of the pre-activated fibers, 48.5 g resin and 4000 cc water. The composite was formed in a 4" mold. The green cake was dried and then cured at 200°C for 12 hours. The diameter of the cured composite was 102.01 mm (4.02"), length 100.45 mm (3.96") and the density was 0.127 g/cc. The composite was carbonized at 650°C for 3.5 hours. The weight loss on carbonization was 12.6%.

P-400: A batch of pre-activated fibers was obtained from Anshan Carbon Fibers, Inc. These fibers have an approximate burnoff of 75%.

Two composites were made, each using 12 g of the fibers, 12 g resin, and 250 cc water. The composites were formed in a 1" diameter cylindrical mold. The green cakes were dried and cured at 200°C for 12 hours, and then carbonized at 650°C for 3.5 hours.

P-200: A batch of pre-activated fibers was made from 200 g of P-200 carbon fibers by activation in steam at 877°C for 14 hours to 78% burnoff. A second batch of 332 g was activated for 14 hours to 45% burnoff.

Composites were made from both batches; 24 g of the 45% burnoff fibers, 6 g resin, 120 cc water; and 7.1 g of 78% burnoff fibers, 1.9 g resin and 120 cc water. The composites were formed in a 1" diameter mold. The green cakes were dried and cured at 200°C for 12 hours, and then carbonized at 650°C for 3.5 hours.

For all of the composites made from pre-activated fibers, the reported ratio of fiber:binder is based on the weight of non-activated fiber to binder.

Preparation of carbon fiber composites: activation after forming.

24 g of P-200 carbon fibers were mixed with 6 g of resin and 120 cc of water. The composites were formed in a 1" diameter mold. The green cakes were cured at 200°C for 12 hours and then activated in steam at 877°C for 2 hours. During the activation, carbon atoms are removed by gasification:

The removal of carbon creates a network of pores and simultaneously reduces the yield of material. The rate of reaction is dependent upon the concentration of the reactant gas and the temperature. In order to effect uniform activation of composites it is therefore important to ensure that the gas concentration and temperature are maintained uniformly throughout the sample.

A high temperature furnace (CM Furnaces Inc.) with an inconel chamber of dimensions 9.5" x 10" x 10" is used for activation. Water is pumped into the reaction chamber through a manifold that is perforated to distribute steam uniformly throughout the area of the chamber.

A summary of the composites made from pre activated fibers and those activated after forming are given in Table 1.

Table 1: Composites from pre activated fibers and composites activated after forming.

Composite #	Fiber		Fiber:Binder Ratio(wt)	composite burnoff(%)
	burnoff(%)	length(micron)		
Composites from pre-activated fiber				
F 637	46	P-800	4:1	-
F 1565	45	P-200	7.2:1	-
F 1566	45	P-200	7.2:1	-
F 1567	78	P-200	18:1	-
F 1622	45	P-200	4:1	-
F 1623	75	P-400	4:1	-
F 1624	75	P-400	4:1	-
Composites activated after forming				
F 1586	-	P-200	4:1	-
F 1464	-	P-200	4:1	45
F 1625	-	P-200	4:1	49
F 1626	-	P-200	4:1	57
F 669		P-400	4:1	

Characterization

Porosity measurements: BET surface areas were measured for the composites from pre-activated fibers and compared to the initial surface area of the fibers. Surface area and pore size distributions were measured on a 10 port automated surface area analyzer, OMNISORB 610. The high efficiency of the instrument allows the measurement of surface areas, as well as the characterization of pore sizes down to 4 Å diameter, using nitrogen at 77K as the adsorbate. Surface areas were determined from the isotherms by the BET method⁹.

Resistivity Testing of Carbon Composites: The experimental arrangement for the resistivity measurement is shown in Figure 1. A section of the carbon fiber composite ranging in length from 5-13 cm is placed between two conductive plates. Care is taken to ensure that good contact is made between the composite and the conductive plates. A voltage of 1.0 V is applied across the composite using a Tektronix PS2520G Programmable Power Supply. The voltage drop across a length, l of the composite was measured by a Craftsman Autoranging Multimeter 982018. The current through the composite was read using a Fluke 45 Dual Display Multimeter. Using the current given on the ampmeter, I , the voltage drop measured by the voltmeter, V , the length between the probes, l , and the crosssectional area of the composite, A_c , the resistivity can be calculated by the following equation:

$$\text{Resistivity (Ohm.cm)} = (V/l)/(I/A_c)$$

The resistivity was calculated at different points around the circumference of the composite, and the length between the probes was varied. The average resistivity was determined from four different measurements.

Flexural Testing of Carbon Composites: Break stress measurements were performed using a three point bend test. Two quarter inch wide slices were cut from the center of a composite as shown in Figure 2. The width and depth of these slices were accurately measured using a digital caliper. The composite slices were centered across the 50 mm beam in the in the QTest QT/1L flexural testing machine. The flexural test is performed according to the American Society for Testing and Materials (ASTM) D 790M standard. The crosshead speed is set to 10.00 mm/min and the percent strain limit is 100%. The average break stress is determined from two separate measurements.

RESISTIVITY

Figure 1: Experimental arrangement for resistivity tests.

Flexural Testing

Figure 2: Experimental arrangement for resistivity test and carbon fiber composites

Butane adsorption test: The adsorption of low concentrations of butane (20 ppm) was studied at high flow rates (25 and 50 lpm) over activated carbon fiber composites (ACFCs) and granular activated carbon (GAC). The GAC was a commercial coconutshell carbon, SXO 4x8 from Carbon Link, Inc. The density of the ACFC was 0.3 g/cc in one experiment and 0.37g/cc in a second experiment. The density of the GAC bed was 0.41 g/cc.

Test 1: Composite of density 0.3 g/cc, flow rate 20 ppm butane at 25 lpm:

Adsorption over a bed of composite 1.4 " diameter by 1.6" long was compared to an equal size bed of the coconutshell based activated carbon. The properties of the two carbons are shown in Table 2. A gas flow of 25 liters per minute of 20 ppm butane in nitrogen was passed through the beds, at an equivalent contact time of 0.09 seconds.

Test 2: Composite of density 0.37g/cc, flow rate 20 ppm butane at 50 lpm:

Adsorption over a bed of 1.4 " diameter by 4.57" long was compared to an equal size bed of coconutshell based activated carbon. The weight of the composite was 42.2 g and the density was 0.37 g/cc. The weight of the granular bed was 47.4 g and the density was 0.41 g/cc. The properties of the two carbons are shown in Table 2. A flow of 50 liters per minute of 20 ppm butane in nitrogen was passed through the beds at an equivalent contact time of 0.13 seconds.

Table 2. Carbon Properties and Experimental Parameters

Sample	BET s. area(m ² /g)	Mass of carbon(g)	Density (g/cc)	Contact time (s ⁻¹)
CFC 1	1130	12.1	0.30	0.09
Coconut shell 1	1250	17.9	0.42	0.09
CFC 2		42.2	0.37	0.13
Coconut shell 2	1250	47.4	0.41	0.13

Regeneration of carbon bed by electrical heating: To investigate the heating/cooling cycle time of a composite block, a sample measuring 3 inch x 1.3 inch in cross section, by 7 inches long, was heated to 150°C by an alternating current of 9.5 A at 14 V. The heating time to 150°C was measured. The composite was then cooled to 30°C, and the cooling time was determined.

RESULTS AND DISCUSSION

Surface area of pre-activated composites

One of the most important issues when making composites from pre-activated fibers is the reduction in surface area due to the occlusion of pores by the binder. We investigated the loss of surface area on a composite made from pre-activated P-800 fibers with 46% burnoff. The BET surface areas of the pre-activated fibers and the formed composite are shown in Table 3. Samples for surface area measurement were taken from two different positions to check uniformity, one was taken from the middle of the sample and the other one from around the edges (B). As can be seen from the table, the reduction in surface area upon forming the composite is 34.5%. However, the uniformity of the activated sample is high, with a variation in surface area less than $\pm 0.5\%$.

Although the surface area is somewhat reduced, it is believed that making composites from pre-activated fibers could be useful in applications where the total BET surface area is not required to be extremely high.

Table 3: BET surface area of pre-activated fibers and formed composites (see Tab 1)

Sample	BET surface area (m ² /g)
Activated fiber (sa-338)	824.9
composite F 637 A	536.2
composite F 637 B	541.1

Flexural Testing of Carbon Composites:

Composite strength is important to many prospective applications. Another important factor is to minimize the loss of fines from the composite when in service. If the composites are weak, the stresses imposed by high fluid flow could cause abrasion and pullout of short fibers, or debonding of binder-fiber joints.

The strength of cylindrical composites 1" diameter and 3.5" long were measured by a three point bend test which gives the break stress measured in the direction perpendicular to the composite length. Since these materials are isotropic the strength should be similar in the other direction.

The break stresses of the composites formed from pre-activated fibers are compared to those of composites activated after forming in Table 4 and Figure 3. As a general trend the composite strength decreases with carbon burnoff. This is expected as the fibers themselves get weaker when carbon is removed. For composites made from the short P-200 fibers and at burnoffs below 45%, the composites activated after forming show higher break stress than the pre-activated composites. At burnoffs above 45% the composites from pre-activated

fibers are similar or better. The preactivated composite made from P-400 fibers at a burnoff of about 75% has higher strength than the composite made from P-200 fibers. This could be due to easier pull out of the shorter fibers from the composite structure.

It is therefore concluded that for composites of burnoff below 45 % it is desirable from a strength perspective to use the production technique of activating the composite after production. For composites with higher burnoffs the technique using pre-activated fibers seems as good or better. The strength of P-400 pre-activated composites is superior to that of P-200 composites at similar burnoffs.

Resistivity Testing of Carbon Composites:

The electrical resistivity was measured for the composites from pre-activated P-200 and P-400 fibers, Table 4 and Figure 4. The electrical resistivity is slightly higher for the composite made from pre-activated fibers than for a composite that was activated after forming, keeping other parameters constant (P-200 fibers activated to the same burnoff). It is also found that the electrical resistivity increases with carbon burnoff. This is probably due to weakening of fibers and fiber breakage causing shorter conductive paths. The electrical resistivity increases when the binder content is lowered, which suggests that there are fewer solid contact points between the fibers.

Figure 3: Break Stress of composites from pre-activated fibers and composites activated after forming. (Fiber length P-200 and P-400, one set of data has low binder content)

Figure 4: Electrical resistivity of composites from pre-activated fibers and composites activated after forming. (Fiber length P-200 and P-400, one set of data has low binder content)

Composite Number and Burn Off	Cured Weight (g)	Carbonized or Activated Weight (g)	Density (g/cc)	Crossectional Area (cm ²)	Volts (mV)	Current (mA)	Length (mm)	Resistivity (Ohm.cm)	Break Stress (MPa)
Preactivated Fibers								Average in Bold	
F1565 45%	14.09	13.07	.2958	5.07	155.5 156.2 161.9 171.8	64.59 64.51 64.61 64.65	63.94 65.31 65.41 66.40	1.91 1.88 1.94 2.03 1.94	.158 .264 .211
F1566 45%	17.19	16.04	.2893	5.22	219.1 208.3 217.2 212.9	64.42 64.36 64.40 64.41	93.56 90.85 92.04 92.83	1.90 1.86 1.91 1.86 1.88	.222 .236 .229
F1567 78%	6.86	6.36	.2139	5.20	317.6 304.5 300.3 300.3	51.05 50.96 50.97 50.92	45.94 46.21 46.18 45.83	7.04 6.72 6.63 6.76 6.79	Data not available
F1622 45%	21.5	19.12	.3042	5.11	370 380 360 410	51.73 51.67 51.69 51.73	96.38 96.96 93.50 103.63	3.79 3.88 3.81 3.91 3.85	.364 .321 .343
F1623 75%	21.5	17.87	.2743	4.59	430 420 430 460	46.87 46.79 46.83 46.84	123.54 119.26 120.91 124.13	3.41 3.45 3.49 3.63 3.50	.525 .541 .533
F1624 75%	20.4	17.16	.2629	4.63	390 360 390 440	47.72 47.73 47.77 47.69	121.53 116.17 120.87 129.60	3.11 3.01 3.13 3.30 3.14	.570 .567 .569

Nonactivated Fibers (activated after composite formation)

F1464 43.4%	23.87	13.50	.2999	4.58	41.5 39.7 39.1 40.7	82.59 83.01 82.95 82.95	82.76 82.45 80.91 84.08	.278 .266 .267 .267 .270	.697 .744 .721
F1568 0%	21.02	19.53	.3901	5.10	31.6 30.9 31.1 32.4	81.75 81.42 81.57 81.72	87.76 86.38 85.35 85.09	.225 .224 .228 .238 .229	1.069 2.040 1.55
F1625 49.0%	10.4	5.10	.1182	4.75	840 800 870 860	196 196 196 196	67.12 63.68 66.24 65.91	3.03 3.04 3.18 3.16 3.10	.082 .080 .081
F1626 57.0%	10.0	5.70	.1146	4.64	820 830 680 800	153 153 153 153	64.98 64.60 58.54 61.48	3.83 3.90 3.52 3.95 3.80	.117 .107 .112

VOC Adsorption: Butane

In work reported previously^{7,8} we examined the relative merits of butane adsorption at low concentrations (20-100 ppm) and high flow rates (25 lpm) over activated carbon fiber composites (ACFCs) and beds of granular activated carbon (GAC). The butane uptake by equal weight beds of activated carbon fiber composites and granular activated carbon (Calgon F-400) is shown in Table 5. At breakthrough, the composites take up 2.3-2.7 % of their weight of butane, while the granular bed only adsorbs 1-1.6%. The composites have higher efficiencies of butane adsorption because of the higher intrinsic rate of adsorption. The composites used in this study all had a low density ~0.2 g/cc while that of the granular bed was 0.45 g/cc. Hence, in this comparison using equal bed weight, the composite bed would have a larger volume.

Table 5: Butane Uptake per Weight of Carbon.

Butane Conc(ppm)	Butane Uptake (wt %)		
	Composite	GAC	Ratio
20	2.27	0.96	2.4
50	2.47	1.26	2.0
100	2.67	1.66	1.6

In recent work, we increased the density of the composite to 0.3 g/cc and to 0.4 g/cc to give a closer correspondence to the GAC bed. Also, previous comparisons were made with coal based Calgon F-400 GAC. The solvent recovery industry uses mostly coconutshell based activated carbon. Therefore a commercial coconutshell carbon (from Carbon Link, Inc.) was obtained for comparison with the composites.

Test 1: Composite of density 0.3 g/cc, flow rate 20 ppm butane at 25 lpm: A bed of composite 1.5 " diameter by 1.6" long was compared to an equal size bed of coconutshell based activated carbon. The properties of the two carbons are shown in Table 2. A gas flow of 25 liters per minute of 20 ppm butane in nitrogen was run through the beds with an equivalent contact time of 0.09 seconds. The breakthrough curves are shown in Figure 5. The butane breaks through the GAC bed immediately, presumably due to channeling. Due to the unique structure of the composite, it is ~ 120 minutes before any butane breaks through. The composite is therefore superior to the commercial coconutshell carbon under these conditions of low butane concentration and high flow rate.

Figure 5: Breakthrough of butane over bed of composite and GAC coconutshell carbon. (Flow rate of 20 ppm butane: 25lpm)

Test 2: Composite of density 0.37g/cc, flow rate 20 ppm butane at 50 lpm: In the second test an even denser composite was compared to the coconut shell carbon. The length of both beds was 4.57". A longer bed was selected to minimize channeling in the GAC bed. The bed diameter was 1.4 ". The weight of the composite was 42.2 g and its density was 0.37 g/cc. The weight of the granular bed was 47.4 g and its density was 0.41 g/cc. The properties of the two carbons are shown in Table 2. A gas flow of 50 liters per minute of 20 ppm butane in nitrogen was run through the beds.

The breakthrough curves for butane are shown in Figure 6. It can be seen from the Figure that the composite lasts 8 hours before there is any detectable breakthrough, while the granular bed starts to break through after ~ 4 hours. At about 6 hours the outlet concentration of butane is 0.25 ppm and at 7 hours is about 0.6 ppm. At about 8 hours there is a crossover point where the composite breaks through very rapidly while the GAC bed has a much slower breakthrough profile.

Again, it can be concluded that the carbon fiber composites have superior performance in applications where little or no breakthrough of the contaminant is tolerated.

Butane Adsorption, 20 ppm

Figure 6: Breakthrough curve for 20 ppm butane over carbon fiber composite and GAC bed.
(equal volume bed of composite and GAC, GAC is commercial coconut shell activated carbon).

Electrical Regeneration of Carbon Fiber Composites

The incorporation of activated carbon fibers (ACF) into permeable monoliths provides a connectivity between individual fibers allowing their pore structure and other characteristics to be combined with a pathway for electrical and thermal conduction. This gives possibilities for utilizing this unique combination of properties in adsorption and catalysis in the gas and liquid phases. Both ORNL and the CAER have examined those properties in relation to driving the desorption stage of a cyclic adsorption-desorption process by direct electrical heating.

In solvent recovery and VOC adsorption the adsorbent bed is usually regenerated by heating to $\sim 200^{\circ}\text{C}$ with steam, a procedure that can take several hours, depending on the size of the bed. While the bed is being regenerated, a second adsorbent bed is brought on stream. In this work, regeneration was achieved by electrical heating. This technique can produce rapid and uniform heating and can be very energy efficient since heat transfer losses are minimized.

To investigate the heating/cooling cycle time of a composite block, a sample measuring 3 inch x 1.3 inch in cross section, by 7 inches long, was heated to 150°C by an alternating current of 9.5 A at 14 V. The heating time to 150°C was 2.5 minutes. The composite was then cooled to 30°C in 14 minutes, Figure 7. This gives a total cycle time for bed desorption of 16.5 minutes. Other experiments have shown that butane desorption occurs almost immediately when the ACFC temperature is raised. Using the data for butane uptake per weight of carbon reported in Table 5, and assuming a butane heel of 10 %, it is calculated that the block could be held on stream for 81 minutes before breakthrough, at an inlet butane concentration of 100 ppm. The bed would last 350 minutes at a concentration of 20 ppm. This novel regeneration method could allow economies in commercial operation because the adsorber system could be made up of one large bed and a second smaller bed for adsorption during the short duration of the regeneration of the large bed. Current systems are made up of two large beds of carbon because the heating/cooling cycle is very long. This process also eliminates the need for an expensive steam generator.

Figure 7: Heating cooling cycle of carbon fiber composite when heated by a 9.5 A current at 14 V. (Composite dimensions: 3" x 1/2" x 7")

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