"Comparison of Adsorption Characteristics between Granular Activated Carbon (GAC) and Activated Carbon Fibers (ACFs) for Toluene"

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Abstract

Granular activated carbon (GAC) has been the standard adsorbent used in respirators for several gases and vapors because of its efficiency, low cost, and available technology. However, GAC has some drawbacks, including poor selectivity, high pressure drop through the packed media, and requirement for containment. Activated carbon fiber (ACF) is an alternate adsorbent that overcomes some of the drawbacks of GAC. It is obtained from the carbonization and activation of polymeric fibers, and has a narrow pore size distribution in the micropore range. The advantages of ACF over GAC include larger surface area, larger adsorption capacities, ease in handling due to its form, and lower pressure drop through the adsorption units. Such advantages give ACF a great potential for application in the development of better respirators that are efficient in removing air pollutants and are more comfortable and easy to use. Such improved respirators may also be used for short-term protection by first responders and emergency personnel in case of catastrophic events, such as chemical accidents and terrorism. The purpose of this study is to compare the critical bed depths and adsorption capacities between GAC and ACF. GAC and ACF in cloth (ACFC) and felt (ACFF) forms were challenged with a constant concentration of toluene at 500 ppm, at constant air temperature (23°C), relative humidity (50%) and air flow (3 LPM) at a minimum of 5 different adsorbent weights and bed depths. Breakthrough data were obtained for each adsorbent using gas chromatography with flame ionization detector. The surface areas of each adsorbent were determined using a physisorption analyzer. The results showed that the critical bed depth for GAC, ACFC and ACFF are 0.30, 0.18 and 0.50 cm; the adsorption capacities are 520.02, 416.64 and 455.48 mg/g; and the surface areas are 1834.75, 1692.93 and 1650.09 m^2/g, respectively. The critical bed depth of the GAC is comparable to that of the ACFF but is higher than that of the ACFC. The GAC analyzed in the study has higher adsorption capacity than the ACF which may be due to its higher surface area. It is concluded that ACF still has great potential for application in respiratory protection considering its advantages over GAC.

Statement of Purpose

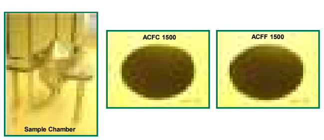
The purpose of this study is to compare the critical bed depths, adsorption capacities and surface areas between granular activated carbon (GAC) and activated carbon fibers (ACFs).

Materials & Methods

Three (3) types of adsorbents were analyzed: GAC, ACF in cloth (ACFC) and felt (ACFF) forms. Both ACF forms have manufacturer-specified surface area of 1500 m^2/g. The adsorbents were treated in an oven at 150 °C overnight prior to testing.

The materials were challenged in a stainless steel sample chamber with a constant concentration of toluene at 500 ppm, at constant air temperature (23°C), relative humidity (50%) and air flow (3 LPM) at a minimum of 5 different adsorbent weights and bed depths. Breakthrough data were obtained for each adsorbent using gas chromatography with flame ionization detector (Agilent 6850®).

The surface areas of each adsorbent were determined by an automatic physisorption analyzer (Micromeritics ASAP 2020®) using high purity nitrogen (99.99%) at 77 K.



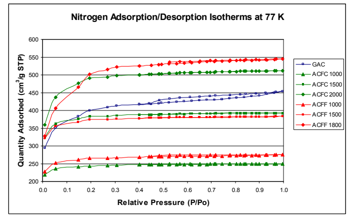
The time (min) at 50% breakthrough was plotted against the adsorbent mass (g) to obtain a regression line for the calculation of the adsorption capacity (W_e) of each adsorbent at 500 ppm using the modified Wheeler equation.

$$t_b = \frac{W_e}{C_0 Q}\left[W - \frac{\rho_B Q}{k_v}\ln\left(C_0 / C_x\right)\right]$$

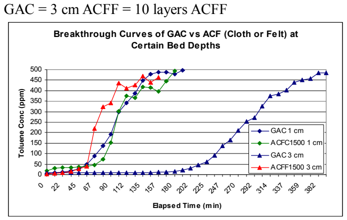
Wherein:
- t_b – breakthrough time (min)
- C_x – exit concentration (g/cm^3)
- C_0 – inlet concentration (g/cm^3)
- Q – volumetric flow rate (cm^3/min)
- W – weight of adsorbent (g)
- ρ_B – bulk density of packed bed (g/cm^3)
- k_v – first order rate constant of adsorption (min^{-1})
- W_e – kinetic adsorption capacity (g/g)

Results

- The adsorption/desorption isotherms for nitrogen of 7 types of adsorbents using an automatic physisorption analyzer are shown in the graph below. The adsorbent types include the 3 types of adsorbents analyzed in this study.



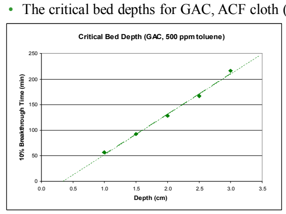
- The graph below shows sample breakthrough curves of the adsorbents for toluene.
- 1 cm GAC = 1 cm ACFC = 16 layers ACFC
- 3 cm GAC = 3 cm ACFF = 10 layers ACFF

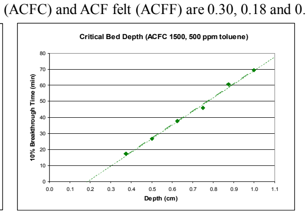


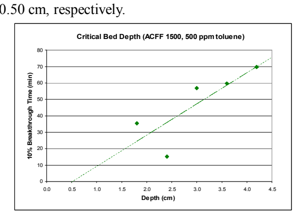
Breakthrough Time of Toluene by Adsorbent and Bed Depth

Bed Depth (cm)	Adsorbent	Breakthrough Time (min)		
		0+%	50%	100%
1	GAC	22	96	191
	ACFC 1500	79	97	168
3	GAC	168	281	382
	ACFF 1500	56	71	135

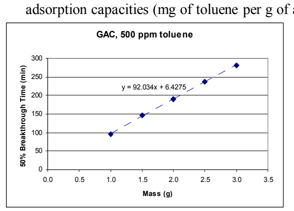
- The critical bed depths for GAC, ACF cloth (ACFC) and ACF felt (ACFF) are 0.30, 0.18 and 0.50 cm, respectively.

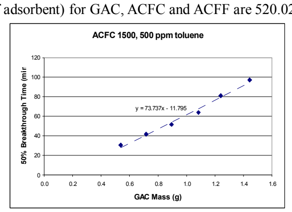


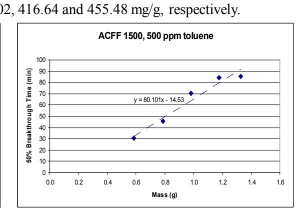




- The following graphs show the regression lines of 50% breakthrough time (min) plotted against the mass (g) of the adsorbents. The calculated adsorption capacities (mg of toluene per g of adsorbent) for GAC, ACFC and ACFF are 520.02, 416.64 and 455.48 mg/g, respectively.







- The surface areas for GAC, ACFC and ACFF are 1834.75, 1692.93 and 1650.09 m^2/g, respectively.

Summary of Characteristics of the Types of Adsorbents

Characteristics	GAC	ACFC 1500	ACFF 1500
Langmuir Surface Area (m^2/g)	1834.75	1692.93	1650.09
Critical Bed Depth (cm)	0.25	0.18	0.25
Adsorption Capacity (mg/g)	520.02	416.64	455.48

Discussion

Breakthrough

- Breakthrough curves for ACFs are steeper than that for the GAC, which may be attributed to the nature of the material.
- At 1 cm bed depth, GAC, has a comparable breakthrough profile for toluene with ACFC, which has a lower surface area, particularly at 50% breakthrough.
- At 3 cm bed depth, GAC has a much later breakthrough time for toluene compared to that of ACFF. However, ACFF at this bed depth may still give respiratory protection from airborne toluene for approximately 1 hour.

Critical Bed Depth

- Critical bed depth is defined as the minimum bed depth of the adsorbent required to reduce the concentration of toluene by 90%.
- The critical bed depth of the GAC is lower than that of the ACFF but is higher than that of the ACFC. → ACFF > GAC > ACFC

Adsorption Capacity

- The adsorption capacity of the GAC is higher than those of the 2 forms of ACF, while the adsorption capacity of ACFF is higher than that of ACFC.
- One reason for this is the higher surface area of GAC (~1800 m^2/g) compared to the ACF (~1600 m^2/g), since the extent of adsorption is proportional to the specific surface area.
- ACFs with higher surface area (i.e. 1800-2000 m^2/g) are commercially available and may have adsorption capacities that are comparable or even higher than that of the GAC. This assumption is based on the results of the nitrogen adsorption/desorption isotherms of ACFs with higher surface areas (ACFC 2000 and ACFF 1800) which shows higher quantity of nitrogen adsorbed per gram of adsorbent than that of the GAC with equivalent surface area.

Conclusions

- Both the ACF cloth and felt forms used in this study have good potential for the removal of airborne toluene, considering their critical bed depth and adsorption capacities.
- Given its advantages over GAC, ACF is a promising alternative as an adsorbent for use in respiratory protection.
- ACF shows promise in the development of disposable respirators or masks for short-term protection against toluene, and probably similar volatile organic compounds (VOCs).
- Further studies are aimed to be conducted to compare the performance of similar surface area GAC and ACF for the adsorption of VOCs and other gases, such as sulfur dioxide and chlorine.

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Acknowledgements

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