Adsorption Characteristics of Various Types of Activated Carbon Fibers (ACFs) for Toluene

Jo Anne Balanay, Shaun Crawford and Claudiu Lungu
Department of Environmental Health Sciences, School of Public Health, University of Alabama at Birmingham

Introduction

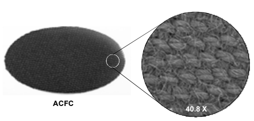
Granular activated carbon (GAC) is currently the standard adsorbent in respirators against several gases and vapors because of its efficiency, low cost and available technology. However, a drawback of GAC due to its granular form is its need for containment, adding weight and bulkiness to respirators. This makes respirators uncomfortable to wear, resulting to poor compliance in its use.

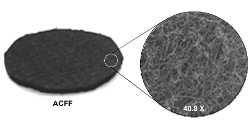
Activated carbon fibers (ACFs) are considered viable alternative adsorbent materials for developing thinner, light-weight and efficient respirators because of their larger surface area, lighter weight and fabric form.

The purpose of this study is to determine the critical bed depth and adsorption capacity of different types of commercially available ACFs for toluene to understand how thin a respirator can be and the service life of the adsorbents, respectively.

Materials & Methods

ACF in cloth (ACFC) and felt (ACFF) forms with 3 different surface areas (1000, 1500, 1800 or 2000 m^2/g) per form were challenged with 6 concentrations of toluene (50, 100, 200, 300, 400 and 500 ppm) at constant air temperature (23°C), relative humidity (50%) and air flow (16 LPM) at different adsorbent weights and bed depths.





Breakthrough data were obtained for each adsorbent using gas chromatography with flame ionization detector (Agilent 6850®). The time (min) at 10% and 50% breakthrough of toluene were obtained to calculate the critical bed depth and adsorption capacity, respectively, for different ACF types at different toluene concentrations.

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

Results

Table 1. Surface Area by ACF Type

ACF Type	Measured Surface Area, m^2/g ($x \pm SD$)
ACFC 1000	753 ± 37
ACFC 1500	1181 ± 64
ACFC 2000	1467 ± 83
ACFF 1000	810 ± 41
ACFF 1500	1129 ± 59
ACFF 1800	1541 ± 83

Table 2. 10% Breakthrough Time of Toluene by ACF Type

Bed Depth (cm)	ACF Type	Toluene Concentration (ppm)					
		50	100	200	300	400	500
0.5	ACFC 1000	133.7	56.9	31.1	16.0	13.3	10.6
	ACFC 1500	159.2	82.4	38.1	24.5	19.5	14.1
	ACFC 2000	190.3	97.5	52.6	39.0	25.4	19.2
1.5	ACFF 1000	41.4	17.6	9.1	5.1	4.4	2.6
	ACFF 1500	95.7	49.9	28.0	15.6	11.9	12.2
	ACFF 1800	95.5	50.3	32.7	20.4	15.8	15.3

Table 3. Adsorption Characteristics by ACF Type Adjusted for Toluene Concentration

ACF Type	Mean Critical Bed Depth (cm)	Mean Adsorption Capacity (mg/g)
ACFC 1000	0.216 ± 0.022	375.17 ± 29.40
ACFC 1500	0.137 ± 0.022	476.91 ± 51.20
ACFC 2000	0.147 ± 0.039	715.78 ± 93.87
ACFF 1000	0.727 ± 0.193	291.39 ± 45.63
ACFF 1500	0.286 ± 0.033	385.80 ± 36.83
ACFF 1800	0.258 ± 0.072	455.87 ± 91.00

Surface Area

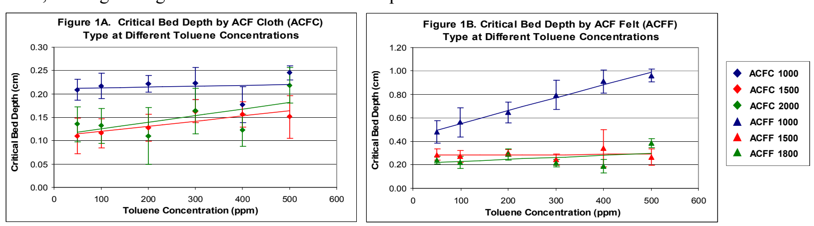
- The measured surface areas (BET) of the ACF were slightly less than those specified by the manufacturer (table 1).
- ACFC 2000 and ACFF 1800 have similar measured surface area and thus may be compared to each other.

10% Breakthrough Time

- Time (min) when 10% of the challenge concentration is breaking through the adsorbent
- At an adsorbent thickness of 0.5 cm, the ACFCs in a respirator may give protection to the wearer from 10.6 – 19.2 min before 10% breakthrough of 500 ppm toluene occurs, and from 133.7 – 190.3 min for 50 ppm toluene (table 2).
- At an adsorbent thickness of 1.5 cm, the ACFFs may give protection from 2.6 – 15.3 min before 10% breakthrough of 500 ppm toluene occurs, and from 41.4 – 95.7 min for 50 ppm toluene (table 2).

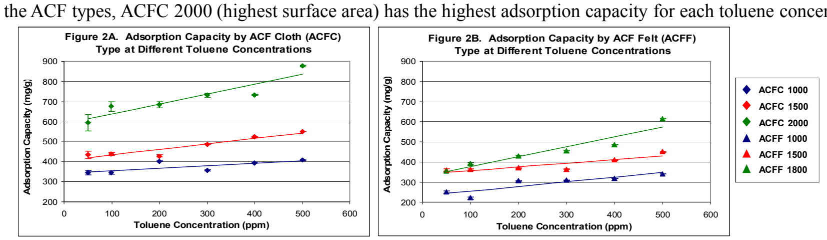
Critical Bed Depth

- Figures 1A and 1B show the critical bed depth of the 6 ACF types for different toluene challenge concentrations.
- The critical bed depth of ACFC is significantly lower than that of ACFF with similar surface area for each toluene concentration (table 3), as well as the mean critical bed depth of ACFC (0.1668 cm) in general than that of the ACFF (0.4239 cm).
- Among the ACF types, ACFC 1500 and 2000 (2 highest surface areas) have the lowest critical bed depths for each toluene concentrations, making them good candidates for thinner respirators.



Adsorption Capacity

- The adsorption capacity increases as the toluene challenge concentration increases for all of the ACF types. The adsorption capacity has an increasing trend as the surface area increases for both ACFC and ACFF (figures 2A and 2B).
- The adsorption capacity for ACFC is higher than that of ACFF with similar surface area for each toluene concentration (table 3), as well as the mean adsorption capacity of ACFC (522.62 mg/g) in general than that of the ACFF (377.69 mg/g).
- Among the ACF types, ACFC 2000 (highest surface area) has the highest adsorption capacity for each toluene concentration.



Conclusions

- ACF, when used as adsorbents in respirators, may provide short term protection against toluene based on 10% breakthrough time.
- The surface area and physical form of the ACF are both determinants of the critical bed depth and adsorption capacity.
  - The higher the surface area → the lower the critical bed depth → the higher the adsorption capacity
  - The ACFC forms have lower critical bed depths and higher adsorption capacities than the ACFF forms.
- Activated carbon fiber has a great potential for application in respiratory protection for toluene, particularly the ACFC with the highest surface area (ACFC 2000) which was shown to be the best ACF type based on its critical bed depth and adsorption capacity.
- The ACFC's lower critical bed depth and higher adsorption capacity for toluene, as compared to ACFF's, show that they are better candidates for thinner and efficient respirators that may be more comfortable to wear and thus, improving compliance in its use among workers.
- Further studies are aimed to investigate more on the adsorption characteristics of ACF:
  - To determine the critical bed depth and adsorption capacity of different ACF types for other VOCs and gases (sulfur dioxide and chlorine)
  - To determine the applicability of adsorption models (i.e. Dubinin-Radushkevich equation) in predicting the adsorption capacity of ACFs

Acknowledgements

This study was supported by Grant # 2T42OH008436-03 and ROI grant # OH 008080 from NIOSH. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of NIOSH.