A Fundamental Understanding Of The Filtration Of Volatile Toxicants In Cigarette Smoke By Active Carbons

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INTRODUCTION

Active carbons (ACs) are effective adsorbents for many volatile toxic compounds encountered in domestic and industrial situations and they are used in a wide range of separation and recovery processes. In the present work their performance as cigarette filter additives has been investigated with respect to the adsorption of toxic volatile constituents of tobacco smoke.

The challenges encountered in this use are considerable, requiring rapid adsorption kinetics for the non-specific reduction of a broad range of organic and inorganic toxicant species, in a humid smoke-stream.

In the current study we have examined the adsorption of a range of vapours present in cigarette smoke by two carbon adsorbents with very different pore characteristics; one coconut shell-derived (with micropores) and one polymer-derived (with a bimodal distribution of micropores and meso/macropores).

EXPERIMENTAL

The coconut shell-derived activated carbon was produced from coconut shell charring at 300-500˚C followed by activation in a rotary kiln at 900-950ºC using steam.

The spherical particle shape polymer-derived carbon was prepared by a proprietary process (Blücher GmbH), involving indirect heating of a polymer under reduced pressure and in an inert atmosphere. Material was thermally stabilised using an excess of oleum. Subsequently, the material is slowly heated to 500˚C, resulting in the release of predominantly SO_2 and H_2O and the carbonisation of the polymer. Finally the material was further heated to 900 – 1000˚C for activation with steam and a second activation step with CO_2.

Carbons were characterised using nitrogen adsorption at 77 K and the adsorption of a range of vapours at 298 K.

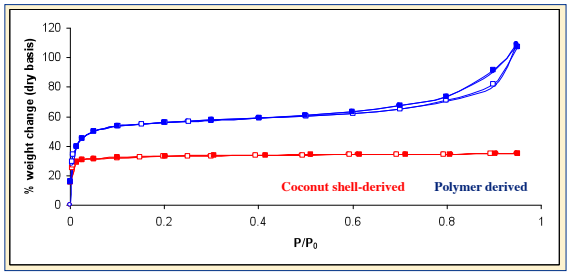
To measure dynamic breakthrough times and volumes, a stainless steel flow system incorporating carrier flow gas, toxicant feed, Relative Humidity (RH) control, active carbon bed and bed-effluent analysis has been used.

Assessment of the performance of the carbons is described under different smoking regimes and using a 24.6 mm circumference cigarette, made up of a 56 mm tobacco rod containing a Virginia style tobacco blend (tobacco rod density of 255 mg/cm^3 at a moisture content of 13%) and a 27 mm length three-part cavity filter (10 mm cellulose acetate at the rod end, 4 mm cavity and 13 mm cellulose acetate at the mouth end) containing 60±1 mg of each granular carbon in the filter cavity. Cigarette filters were all unventilated. As a control, cigarettes of the same dimensions and composition were also prepared with an empty 4mm filter cavity section. All cigarettes were smoked following conditioning at 22ºC and 60% Relative Humidity for a period of three weeks following the inclusion of AC in the cigarette filter.

RESULTS AND DISCUSSION

The adsorption of benzene on both carbons at 298 K is shown in Figure 1. The difference in isotherm shape is due to the presence of additional mesopores for the polymer-derived carbon. It can clearly be seen that the uptake of benzene is greater using the polymer-derived carbon.

Figure 1 - Adsorption of Benzene Vapour at 298 K



Breakthrough measurements of three toxicant vapours through both carbons under different humidities are shown in Table 1. It can clearly be seen that using the polymer-based carbon results in the longest breakthrough times and that the presence of water vapour causes a decrease in the breakthrough times (through competing adsorption). The breakthrough volumes were in good agreement with the micropore volumes determined from the adsorption isotherms.

Table 1 - Breakthrough Time and Volume for Active Carbons at 298 K and 0% and 60% RH. (Measured at a flow of 2 L/min using 3.2 g Coconut-derived Carbon or 2.3 g Polymer-derived Carbon beds; Toxicant Challenge 0.20 cm^3/min)

	Breakthrough Time (min)		Breakthrough Volume (cm^3/g)	
	0% RH	60% RH	0% RH	60% RH
Vapour	Polymer-derived Carbon			
Benzene	7.2	6.7	0.63	0.59
Acrylonitrile	5.9	5.7	0.52	0.50
2-Butanone	7.0	6.8	0.61	0.60
	Coconut-derived Carbon			
Benzene	5.7	5.4	0.36	0.34
Acrylonitrile	5.4	5.2	0.34	0.32
2-Butanone	5.6	5.3	0.35	0.33

Table 2 shows smoke data for a range of vapours measured using the carbons in the cigarette filter.

Table 2 - Mainstream Smoke Data using 60mg Carbon in a 24.6 mm Circumference Cigarette

Carbon filter type (60mg)	Control	Coconut-derived		Polymer-derived		Control	Coconut-derived		Polymer-derived	
Smoking regime	ISO	ISO		ISO		HCI	HCI		HCI	
	Yield per cig	Yield per cig	% removed	Yield per cig	% removed	Yield per cig	Yield per cig	% removed	Yield per cig	% removed
Puff No	7.1	6.8		7.1		9.1	9.9		9.8	
NFDPM (mg)	11.8	10.3		10.0		25.6	24.3		24.1	
Nicotine (mg)	0.94	0.85		0.83		2.02	1.99		1.87	
Water (mg)	3.1	2.3		1.7		16.3	16.1		15.7	
CO (mg)	11.4	11.5		11.5		21.4	21.6		22.8	
Acetaldehyde (µg)	584	384	34	289	51	1030	863	16	860	17
Acrolein (µg)	78.4	39.0	50	11.9	85	144.2	93.7	35	53.7	63
Formaldehyde (µg)	59.3	35.5	40	27.0	54	119.1	68.7	42	52.3	56
HCN (µg)	118.6	66.1	44	54.9	54	260.6	195.9	25	180.1	31
1,3-butadiene (µg)	20.0	16.0	20	3.4	83	53.7	41.7	22	22.8	58
Benzene (µg)	32.0	18.2	43	5.1	84	59.8	42.6	29	12.1	80

A 6 month ageing study was conducted on cigarettes with the different carbons. Some small increases in selected toxicants were found over this time period with a slightly greater ageing effect for the polymer-derived carbon. However, the extent of ageing in each case was small in comparison to the differences in toxicant removal efficiencies between the two carbons.

CONCLUSION

Measurements of adsorption isotherms and breakthrough profiles on activated carbons give valuable information that can be used to estimate their performance in cigarette smoke; the greatest toxicant reductions in cigarette smoke were achieved where the micropore volumes obtained from adsorption isotherms and breakthrough times from dynamic tests were the greatest.

A new polymer-derived material was found to be approximately twice as effective, in general, at removing volatile cigarette smoke toxicants than the coconut shell-derived carbon commonly used in contemporary carbon filtered cigarette products. The polymer-derived carbon performed well at both ISO and HCI smoking regimes.

REFERENCE

Branton PJ, McAdam KG, Duke MG, Liu C, Curle M, Mola M, Proctor CJ, Bradley RH: *Adsorption Science & Technology*: 2011, 29(2), 117-138.