

COMBINED PARTICULATE AND VAPOUR FILTRATION (CPVF) USING ACTIVATED CARBON FIBRES: INFLUENCE OF CARBON FIBRE LENGTH ON DYNAMIC FILTRATION PERFORMANCE

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Introduction

Respiratory protection filters are generally comprised of a dual filter media which includes a glass fibre particulate material to remove aerosols, followed downstream by a layer of granular activated carbon to remove toxic vapours. Whilst this is an effective filter media for providing protection, there is a drawback in the form of a pressure drop across the filter leading to a breathing resistance. A reduction in this pressure drop, whilst maintaining or improving the effectiveness of the filter, is therefore highly desirable in order to reduce the user burden. The successful identification of a material that could be utilised for both particulate and vapour filtration would have great implications for the future redesign of individual respiratory protection. Carbon fibres are potential candidates for this, as their fibrous form can be utilised to remove aerosols, and in addition, they can be modified to impart vapour adsorptive properties. In general, activated carbon fibres offer a number of advantages over conventional granular activated carbons. These include (i) very high adsorption rates, (ii) they avoid problems arising from channelling and settling, and (iii) they retain some of the mechanical properties of the original carbon fibre [1].

This work describes an element of the research carried out into the development of an activated carbon fibre filter medium capable of providing protection against both aerosols and toxic vapours [2]. The main focus of this part of the study was to determine the influence of the length of the carbon fibre on the filter mats ability to remove physisorbed vapours.

Experimental

A variety of different types of activated carbon fibre were studied. These materials varied in terms of both their length (0.1 and 50 mm) and their specific surface area (1503 to 2270 m² g⁻¹). Two series of activated carbon fibres were investigated:

- Series B1 to B3 were formed from the same base pitch-based carbon fibre and activated under the same conditions (850 °C, CO₂, 12 hours), their length varied from 0.1 to 6 mm.
- Series A1 to A3 varied in their length (0.1 to 50 mm) however their surface areas were similar.

Table 1 shows the characterisation data for the two series of activated carbon fibres.

Table 1. Characterisation data for two activated carbon fibre series as determined by nitrogen adsorption at 77K

Sample	Nominal Length (mm)	Specific Surface Area (m ² g ⁻¹)	Total Pore Volume (cm ³ g ⁻¹)	Micropore Volume (cm ³ g ⁻¹)	Mesopore Volume (cm ³ g ⁻¹)
Same base fibre and activation conditions (850 °C, CO ₂ , 12 hours), varying length					
B1	0.1	1608	0.665	0.637	0.028
B2	3	1851	0.812	0.771	0.041
B3	6	2270	1.030	0.958	0.072
Similar surface area, varying length					
A1	0.1	1608	0.665	0.637	0.028
A2	6	1503	0.660	0.615	0.045
A3	50	1551	0.656	0.615	0.041

The ability of the activated carbon fibres to remove a physisorbed challenge (hexane) was carried out under dynamic conditions. Initially, the activated pitch-based carbon fibres were mixed with water and drawn into a volume analysis (VA) tube (2 cm diameter x 2.5 cm length) using a modified Büchner funnel technique. The samples were then dried in a vacuum oven for 4 hours at 120 °C. A hexane/ air mixture of concentration 8000 mg m⁻³ was prepared using dry (RH<5%) air.

The VA tube containing the fibres was placed in-line (Figure 1) and air containing 8000 mg m⁻³ of hexane was pulled through the sample at a flow rate of 1 l min⁻¹. The effluent was monitored using a quadrupole mass spectrometer (ESS instruments). Adsorbent testing was carried out at 22°C under dry (RH<5%) conditions for all experiments

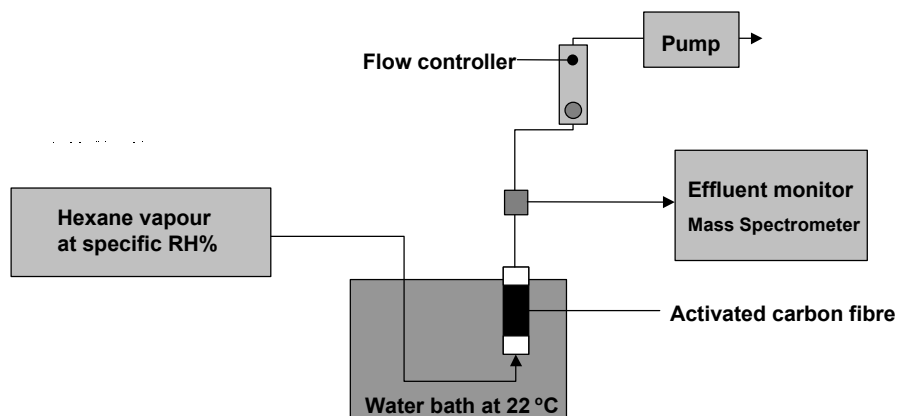


Figure 1; Schematic diagram of the dynamic filter test line

Results and Discussion

Regarding series B1 to B3. Nitrogen adsorption isotherms for the CO₂ activated carbon fibres are shown in Figure 2. All are BET type I in appearance. As indicated in Table 1 the specific surface area varied between 1608 m² g⁻¹ and 2270 m² g⁻¹ suggesting that the larger length, 6 mm fibre was activated to a greater extent compared to the shorter, 0.1 mm fibres.

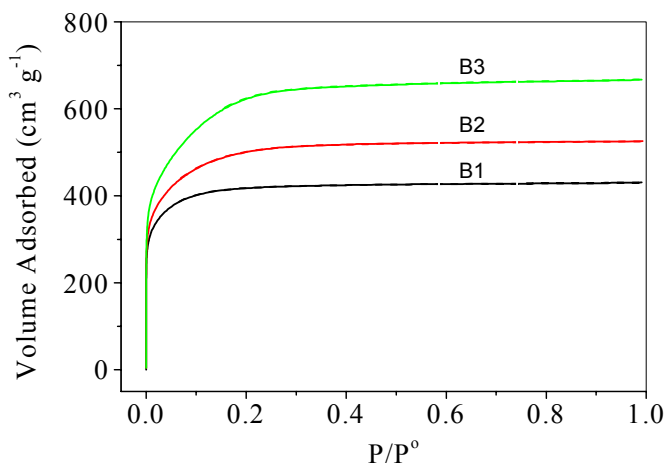


Figure 2. Nitrogen adsorption isotherms determined at 77 K for series B1 to B3 activated in CO₂ at 950 °C for 12 hours

The ability of the activated carbon fibres to remove a hexane challenge under 'dry' conditions (RH<5%) was assessed. Figure 3 shows the dynamic hexane breakthrough profiles for the pitch-based activated carbon fibres B1 to B3.

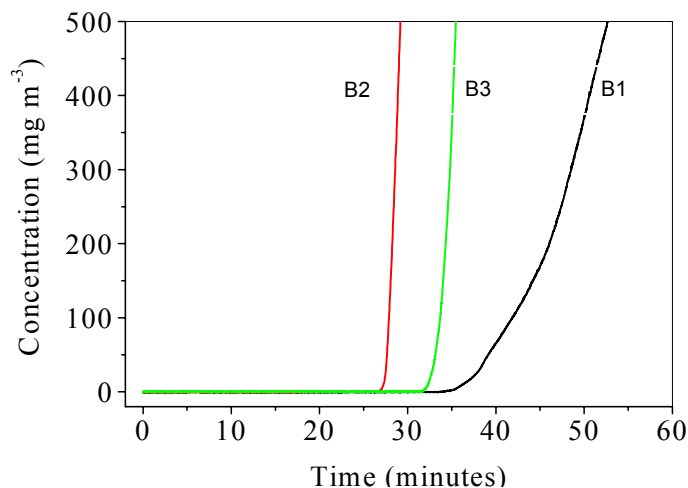


Figure 3 Dynamic hexane breakthrough profiles for the pitch-based carbon fibres B1 to B3 of varying lengths, activated in CO₂, 950 °C for 12 hours, at 22 °C (8000 mg m⁻³, 1000 cm³ min⁻¹, RH<5%)

The shape of the dynamic breakthrough profiles suggests that for the B2 and B3 activated carbon fibres, maximum breakthrough is achieved following a relatively short time after the initial breakthrough. For the B1 activated carbon fibre, however, following initial breakthrough, maximum breakthrough is attained after a much greater period of time, suggesting that the adsorption capacity of the bed was not fully utilised before breakthrough occurred.

From the times to 1 % breakthrough of hexane it is apparent that the B1 activated carbon fibre offers a greater amount of protection compared to the higher surface area B2 and B3 fibres. This is due to the much greater mass of the smaller, 0.1 mm B1 fibres that it is possible to pack into the VA tube, ~2 g as opposed to ~0.95 g for both the B2 and B3 fibres. Between the B2 and B3 fibres, the B3 fibre offers the greatest level of protection. Similar amounts of both B2 and B3 fibre, ~0.95 g, could be packed into the VA tube and therefore the ability to remove hexane was governed primarily by available surface for adsorption. The pressure drop across the B1 carbon fibres however is considerably higher than that of the B2 and B3 carbon fibres, which negates any benefits found in filtration performance for respiratory protection.

For the series A1 to A3 dynamic filter testing under dry conditions (RH<5%) gave times to 1% breakthrough of hexane of 41 minutes for A1, 24 minutes for A2 and 25 minutes for A3. Similar to the studies for series B the A1 fibre has a size of approximately 0.1 mm and therefore approximately twice as much adsorbent can be packed into the VA tube. For fibres A2 and A3 similar amounts of activated carbon fibre were placed in the VA tube and as such similar breakthrough times were recorded. The calculated Wheeler-Jonas Static Adsorption Capacities for the activated carbon fibres were 0.18 g g⁻¹ for A1, 0.25 g g⁻¹ for A2 and 0.28 g g⁻¹ for A3. Activated carbon fibres A3 has a slightly higher surface area compared to A2 and this is reflected in the W-J adsorption capacity. For A1 the value is reduced even though this fibre has the highest surface area of the three. This supports the breakthrough profile that suggests that the total adsorption capacity of the bed is not consumed before breakthrough occurs.

Conclusions

For very small activated carbon fibres (0.1 mm) more material can be packed into the filter and hence the adsorption capacity of the mat is greater. The pressure drop across the filter is however significantly higher. The results suggest however that for fibres of 3, 6 and 50 mm similar masses can be packed into more or less a similar volume and therefore the surface area of the fibre is the most dominating aspect governing the performance of the filter mat. Any benefit therefore in terms of pressure drop, aerosol removal or fibre mat integrity that can be gained from larger fibres can therefore be utilised without any loss of vapour filtration performance.

References

- [1] Mays, TJ, in 'Carbon Materials for Advanced Technologies' (Ed. Burchell, T.D.), Oxford, Pergamon, 1999.
- [2] Chinn MJ, Hindmarsh CJ, and Pears LA, Carbon Fibres for Combined Particulate and Vapour Filtration, Journal of the International Society for Respiratory Protection, 2003, 19, Issue III&IV