CARBON FIBERS FOR COMBINED VAPOR AND PARTICULATE FILTRATION

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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 granular activated carbon to remove toxic vapours. While this is an effective method for providing protection, there is an associated pressure drop over the filter leading to significant breathing resistance. A reduction in this pressure drop, while maintaining, or improving, the effectiveness of the filter is therefore highly desirable in order to reduce the user burden. A single filter media, which could remove both particulate and vapour challenges, could be one possible way to overcoming this problem. Carbon fibres are potential candidates for this, their fibrous form can be utilised to remove aerosols and in addition they can be modified to impart vapour adsorptive properties. 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.

In this study a range of pitch-based or PAN-based carbon fibres have been combined with varying proportions of vapour grown carbon fibres (VGCF’s) and formed into mats using a technique employed in the paper making industry. The mats have been subjected to a salt aerosol. The influence of fibre type, fibre diameter and proportion of VGCF in the mat on particulate trapping efficiency and pressure drop have been investigated. The carbon fibres have been activated by physical activation methods in order to impart vapour-adsorbing properties. Characterisation of their porous structure has been carried out using gas adsorption techniques. The effect of activation on the structural integrity of the carbon fibres has also been assessed.

Experimental

Carbon fibre mats were prepared from varying proportions of both pitch-based (12-15 µm diameter), or PAN-based (6.9 µm diameter), carbon fibres and vapour grown carbon fibres (0.08-0.3 µm diameter). A mixed slurry of fibres and water was poured into a standard sheet former (Messmer Buchel), drained, and the resulting fibre mat removed. The fibre mat was dried in a vacuum oven at 120°C for 3 hours. The fibre mats were then placed in a brass sample cell and subjected to a salt aerosol. Salt penetration was measured using a sodium flame photometer (Moores). A manometer attached to either side of the sample cell was used to ascertain the pressure drop created by the filter mat.

Pitch-based or PAN-based carbon fibre (10 g) was activated using either CO₂ or steam (flow rate = 1000 cm³ min⁻¹). The furnace (carbolite) was heated at a rate of 5 °C min⁻¹ to the required temperature (600 - 950 °C) and left at that temperature for a specific duration (6 – 16 hours), after which the furnace was cooled to room temperature and the fibre removed. The activated carbon fibres were characterised using gas adsorption techniques. To obtain an indication of the strength of the carbon fibres following activation the fibres were shaken in a vibratory mill for 10 mins. Scanning Electron microscopy (SEM) studies were carried out on the fibres before and after milling.

Results and Discussion

In order to ascertain the particulate trapping performance of the carbon fibres, filter mats were made up of varying proportions of both pitch-based or PAN-based carbon fibres and vapour grown carbon fibre (VGCF). The smaller diameter VGCF was added in order to determine whether they could aid aerosol capture due to their small diameter.

Figure 1 illustrates that as the proportion of pitch-based carbon fibre was increased the pressure drop across the filter mat was decreased. Salt penetration followed a similar trend to pressure drop, which was unexpected. Fibre mats with greater proportions of VGCF were denser and more brittle than those composed almost entirely of pitch-based fibres. Fractures in the mats may cause leak paths, resulting in greater penetration of salt.
Similar to the observations for the pitch-based fibre/ VGCF mats, as the proportion of PAN-based fibre in the mat was increased there was a corresponding decrease in pressure drop (Figure 2). In contrast to the observations for the Pitch-based fibre/ VGCF mats salt capture was very good for all combinations of PAN-based fibre and VGCF.

The results indicated that the PAN-based carbon fibres were more effective at removing salt particles than the pitch-based carbon fibres. This was probably due to the smaller diameter of the PAN-based fibres (6.9 µm compared to 12-15 µm for the pitch-based fibres). The importance of fibre diameter for effective aerosol filtration has been shown previously for glass fibre filters[1] The studies also showed that VGCF is not necessarily required in the filter media to enhance particulate trapping.

The physical activation of the PAN-based carbon fibres in both CO$_2$ and steam proved ineffective. For the pitch-based carbon fibres activation produced fibres with surface areas up to ~2000 m$^2$g$^{-1}$. Activation using CO$_2$ produced more microporous carbons than activation using steam. The variation in specific surface area with activation temperature for the CO$_2$ and steam activated pitch-based carbon fibres is shown in Figure 3 and Figure 4 respectively. The results suggest that activation using CO$_2$ is easier to control than activation using steam.
randomly distributed over the fibre surface. The steam-activated fibres have a much smoother surface, however they appear to be thinner than the base fibre.

Figure 5 SEM micrographs for the pitch based carbon fibre activated in (a) CO\textsubscript{2} and (b) steam, at 900°C for 12 hours.

The CO\textsubscript{2} activated fibres were much smaller than the corresponding steam activated fibres following milling for 10 minutes. This indicated that CO\textsubscript{2} activation weakened the structural integrity of the fibre to a greater extent than steam activation. This is in agreement with previous studies by Alcañiz-Monge et al.[2]

Conclusions

The studies have shown that carbon fibre mats have the potential to effectively remove aerosols from air streams. VGCF’s are not necessary for enhanced particulate removal performance. Vapour adsorbing properties have been successfully introduced to some of the carbon fibres. Structural integrity studies have revealed that CO\textsubscript{2} activated carbon fibres are weaker than steam activated fibres.

References


Acknowledgements

This research was carried out under UK MoD funding.