Micro- and nanofibre filter media
Comparison of performance for NBC filter applications

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Abstract

High filtration efficiency is needed for protection against airborne high-toxic particulate matter such as bacteria, viruses, CWA liquid aerosols and radioactive fine particles. Filter media based on micro glass fibre is widely used in NBC filters. Polymer based nanofibre composites are new candidates for filter media with high or ultra-high filtration efficiency. They offer many new and useful properties, but they also have some serious limitations in performance.
Keywords: Filter media, NBC filters, filtration efficiency, microfibres, nanofibres

1 Introduction

Particle filtration is based on interactions between the fibre and the particle itself. Diameters of the both play significant roles in the whole filtration process. For large particles sieving and impaction are the most dominant filtration mechanisms, whereas the role of diffusion is very important for small particles. The most penetrating particle size (MPPS) appears somewhere between the ranges of these main mechanisms. Microfibre based filter media with fibre diameter ranging from sub-micrometer to micrometer scale typically has filtration efficiency between 99,99 % and 99,9999 %. Nanofibres have much smaller diameter range, so higher filtration efficiency can be expected at the same media velocity range. Filtration efficiency is one important feature, but pressure drop and loading behaviour are the other key properties of a filter media.

2 Materials and methods

2.1 Micro- and nanofibre filter media samples

Micro glass fibre filter media is a typical wet laid non-woven matrix, where the fibres are randomly oriented and have diameter range on micrometer scale. Nanofibre filter media is a polymer based composite having a single layer of electro spun nanofibre structure between two substrate layers. Fibre diameter is ranging on sub-micrometer scale. Structures of the sample materials and the fibre diameters were examined by scanning electron microscopy (SEM). Both sample materials are pleatable, resistant to water and suitable for any kind of filter applications.

2.2 Test aerosol generation and measurements

Test aerosols were generated from solutions of DEHP (di(2-ethylhexyl) phtalate) in isopropanol by a collision atomizer followed by evaporation of the solvent. Monodisperse fractions from 50 nm to 220 nm were produced by electrostatic classification using a TSI 3071 electrostatic classifier, where aerosol particles are charged by a diffusion charger and classified according to their electrostatic mobility. DEHP concentrations from 0,01 % to 0,20 % were used in order to get the highest possible monodisperse aerosol concentration with the lowest possible amount of double charged particles, which have the same electrostatic mobility. Upstream and downstream particle number concentrations were measured using condensation particle counters TSI 3022A (upstream) and TSI 3010 (downstream). Both particle counters use n-butyl alcohol to make the small particles grow large enough to be counted optically. TSI 3010 uses a single particle count method, where particles entering the instrument in 60 seconds are counted one by one. It makes possible to count very small number concentrations caused by the sample filter media penetration. The measurement chamber was slightly overpressurized in order to prevent leaks from the outside room air. Particle penetrations down to 0,000005 % were possible to be measured reproducibly.

2.3 Loading experiments

Polydisperse paraffin oil aerosols generated by a Lasskin nozzle aerosol generator were used in experiments, where samples of filter media were loaded and observed how they behave during the loading. Sample piece was weighed before and after every loading experiment and a constant loading rate was assumed on the basis of constant generator regulations. Pressure drop across the sample was followed by a micro manometer. Loading curves typical to a filter media were drawn by expressing pressure drop as a function of loading density (mg/cm^2).

3 Results

3.1 Structural details

Nanofibre filter media is composed of three layers; a nanofibre layer between two fibrous substrate layers with fibre diameter from 10 to 20 µm. SEM images show the network-like structure of the nanofibre layer. Fibre diameter is ranging mostly between 50 and 100 nm. Mechanical strength of the composite is very good due to the tough substrate layers, although the nanofibre layer itself is very fragile. In practise the substrate layers give the mechanical properties while the nanofibre layer gives the properties needed for filtration.

Microfibre filter media is composed of micro glass fibres and it has a paper-like structure, where long fibres are in close contact to each other. Typical thickness of a HEPA class microfibre filter media is 0,4 mm and fibre diameter ranges between 0,5 and 2 µm. So, it can be roughly estimated that there are 200-500 single fibres one upon another. Mechanical strength of the single component material is not very good as can be expected.

3.2 Pressure drop and filtration efficiency

Nanofibre filter media shows low pressure drop and high filtration efficiency for sub-micrometer airborne particles. Pressure drop as well as filtration efficiency caused by the substrate layers can be regarded as negligible. For particle sizes larger than 150 nm the difference in filtration efficiency is two orders of magnitude or even higher compared to microfibre filter media. The role of diffusion is more significant for micro- than nanofibre filter media at particle size range from 50 nm to 100 nm, where difference in filtration efficiency decreases to only one order of magnitude. Values of pressure drop and filtration efficiency for sample materials measured at different media velocities and particle sizes are listed in table 3.1.

Micro fibre filter media has the most penetrating particle size (MPPS) typically between 100 and 200 nm and it is drifted downwards with increasing media velocity. The most penetrating particle size for a nanofibre filter media is smaller than 100 nm.

Table 3.1: Values of pressure drop and filtration efficiency measured at different media velocities and particle sizes.

Particle size (µm)	**Media velocity (cm/s)**	**Microfibre**	**Nanofibre**
		Pressure drop (Pa)	
	1	67	41
	2	135	80
	3	205	122
	4	271	162
	5	337	200
	6	404	240
	7	474	280
	8	540	321
	9	609	361
	10	676	401
		Filtration efficiency (%)	
0,05	3	99,9997	99,99995
0,05	4	99,9992	99,9998
0,05	5	99,998	99,9997
0,07	3	99,9990	99,99995
0,07	4	99,997	99,9998
0,07	5	99,995	99,9995
0,12	3	99,995	99,99994
0,12	4	99,990	99,999990
0,12	5	99,98	99,9998
0,18	3	99,994	99,99998
0,18	4	99,990	99,99998
0,18	5	99,98	99,99997
0,22	3	99,996	99,999995
0,22	4	99,993	99,999990
0,22	5	99,991	99,999990

3.3 Figure of merit

Figure of merit is one way to evaluate the performance of a filter media. Low pressure drop (Δp) in combination with low particle penetration (P) are typical features to an excellent filter media. Figure of merit Q, also known as quality factor [1] is defined by equation (1).

$$Q = -\ln(P) / \Delta p \tag{1}$$

Values of figure of merit for nanofibre filter media are much higher than those for microfibre filter media calculated at the same media velocity and particle size. The difference can be as high as 100 - 200 %. It must be remembered, that figure of merit given for a fresh and unused filter media gives a limited evaluation of the object, because it does not include any parameter for loading behaviour. After a short period of use the figure of merit can have completely different value due to rise in pressure drop.

3.4 Loading capacity

Nanofibre filter media suffers from a low loading capacity. Loading with paraffin oil aerosol shows steep increase in pressure drop with a low loading density, even less than 1 mg/cm^2. It can be imagined, that a thin oil film is formed on the nanofibre layer blocking the small holes between fibres and blinding the filter media completely.

Micro fibre filter media has much higher loading capacity and blinding of the filter media does not happen even at high loading density level. Formation of an oil film is not possible because of the roughness of the filter media surface and aerodynamic forces due to air flow. It is also generally known, that solid particles such as Dolomite chalk give a higher value for loading capacity than liquid aerosols. Formation of agglomerates on the surface is typical to microfibre filter media when it is loaded with solid particles.

4 Conclusion

A combination of low pressure drop and high filtration efficiency is possible to be reached with a polymer based nanofibre filter media. It is suitable for applications, where loading rate of the filter media is very low or an effective prefiltration is used before the nanofibre layer. Otherwise the service life of the filter will be quite short due to the significant rise in pressure drop. Electrospinning is a novel method for producing nanofibre structures from liquid solutions of polymers [2]. Fibres with very small diameter can be produced on a suitable substrate layer and the final product is possible be tailored according to the specifications of the user.

Microfibre filter media is widely used and its properties are well known. It is a standard filter media in most NBC filters. It is classified according to its filtration efficiency and a higher class always means higher pressure drop too. Low pressure drop typical to a nanofibre filter media with the same filtration efficiency can not be reached by microfibre composites. High loading capacity is the basic strength of microfibre filter media.

NBC filter applications are typically combined filters, where a particle filter unit and an activated carbon layer are packed in the same casing. Contribution of the aerosol filter unit to the total pressure drop of the filter varies from 20 to 40 %. Most NBC filter applications use media velocity between 1 and 5 cm/s. It means that the filter media must be pleated in order to make its total area large enough. Mechanical properties suitable for pleating will be always a key requirement for a filter media. Prefiltration or another separation method for coarse dust is possible to be used with some applications but not with all, for example not with respiratory filter canisters. High filtration efficiency is required, but only a tiny fraction of the total airborne particle load is highly toxic. In dusty environments, like sand deserts, the service life of a NBC filter can be determined by clogging of the aerosol filter. In most cases activated carbon layer has a more significant role to the service life, although it has a constant pressure drop throughout its use.

References

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