CHAPTER 5

Air and Gas Filter Media

There have already been occasions in parts of this Handbook where it has proved difficult to draw hard and fast boundaries between categories of filter media. This chapter is an especially difficult one to classify, partly because it concerns filter elements or complete filters as well as media, and partly because it deals with media covered by other chapters in the special applications featured in this one. The most important feature of this chapter is that it deals with filter media applications, rather than media types.

Thus, the range of ventilation filters, employed for cleaning or protecting living and working spaces, uses many of the media discussed in Chapter 3, as does the section on dust removal in industrial processes, here also including woven media.

The two special cases of compressed air and hot gas filtration could have been included in other sections of this chapter, but are separated because of their importance.

5.1 Introduction

This chapter is basically concerned with three distinct classes of filter: those for ventilation systems, dust collection and demisting. Ventilation filters are intended to deal with low concentrations of contaminants in air, and are usually expected to remove these contaminants to extremely low outlet concentrations. They function primarily by depth filtration mechanisms, and are therefore mostly difficult or impossible to clean, so that when fully loaded with contaminant they are discarded.

By contrast, those filters used in industrial dust collection are expected to handle much higher inlet dust concentrations. They function primarily by surface filtration, so that they can be cleaned automatically at frequent intervals. They function on a cyclic basis that enables them to remain in operation for very long periods before replacement is necessary.

Demisters differ from the other two classes by virtue of the fact that they deal with liquid droplets in suspension in a gas, rather than solid particles. The droplets are removed in special depth filtration media, in which they are trapped and then coalesce.

Recent years have seen a great increase in demand for clean air in all applications, and this further justifies the keeping of these topics in a separate chapter in the Handbook.

5.2 Living and Working Space Filters

A significant part of the filter media market is concerned with cleaning normal atmospheric air, either as part of the air conditioning of living and office spaces, or more especially in the cleaning of air before it is drawn into working areas that may be sensitive to dust, such as clean rooms for semiconductor manufacture. A smaller component is that which protects the ambient air from harmful gases or particles that might be released within working spaces.

Also concerned in cleaning atmospheric air are those filters used to clean the air intakes of engines, whether internal combustion engines for automobiles or gas turbines for power generation, and the filters used to keep vehicle cabins free of atmospheric pollutants. Another air cleaning duty is in the respirator worn by people subjected to dusty atmospheres, and the final coverage here is of the filter media used in domestic and industrial vacuum cleaners.

5.2.1 Classification of air filters

Air filters are classified on the basis of their filtration efficiency measured under defined standard conditions in relation to a defined test dust or aerosol. The situation is complicated by the number of different classification systems, test procedures and aerosols used for tests, which have evolved in various countries (as is discussed in Chapter 11).

To some extent, this already complex situation has been compounded during recent years as the increasingly stringent standards of cleanliness demanded, for example in the microchip industry, have stimulated the development of more sensitive testing methods. Simultaneously, there have been strong moves towards establishing international standards, notably within Europe under the leadership of CEN (Comité Européen de Normalisation) and Eurovent.

This international cooperation is evident from Table 5.1, adapted from Morris(1). The parallel Eurovent and CEN classifications distinguish among a total of 17 classes of air filter; the first nine are for coarse and fine dusts, while the five HEPA (High Efficiency Particulate Air) and three ULPA (Ultra Low Penetration Air) filters are for submicrometre particles. As indicated, these classifications draw together standards not only from Europe but also from the USA (ASHRAE being the American Society of Heating, Refrigeration and Airconditioning Engineers).

An alternative classification has been developed as part of an American project, jointly sponsored by ASHRAE and the US Environmental Protection Agency. The project was aimed at developing a new standard to replace ASHRAE

52-76, a revised version of which was approved as an American national standard in 1992 as ANSI/ASHRAE 52.1-1992. The new standard, ASHRAE 52.2-1999, includes the classification system reproduced as Table 5.2(2). The appropriate test method (using a KCl aerosol) establishes minimum efficiency curves for filters in bands over the size range 0.3–10 µm. A shorthand version of the filter's efficiency performance is the minimum efficiency reporting value (MERV), which is based on the lowest removal efficiencies for different particles in the test. The average removal efficiencies over the three size bands (0.3–1.0 µm, 1–3 µm and 3–10 µm) are calculated, and designated E_1, E_2, and E_3 respectively. From Table 5.2, the filter is then assigned an MERV value.

The efficiency ratings cited in Tables 5.1 and 5.2 relate specifically to the actual filters, such as those in Figure 5.1, which are the critical working components in an effective filtration system. However, the efficiency that they achieve in practice depends on the combined effect of the filter medium (including any pin holes in it due to manufacturing faults), and any fluid flow that bypasses the filter medium through leaks between the edge of the medium and the casing into which it is sealed.

Therefore, unless all such leaks are eliminated, which is generally unrealistic both technically and economically, the efficiency of an actual filter will inevitably tend to be less than the specified rating of the filter medium that it incorporates. The avoidance of leaks, or at least the minimizing of them, is consequently of crucial importance to the filter manufacturer, especially when the products are intended for the top-grade ULPA ratings (Eurovent 16 and 17).

Table 5.1 Eurovent and CEN classifications of ventilation air filter

Type	Eurovent class	CEN EN779 class	Efficiency (%)	Measured by:	Standards
Coarse dust filter	EU1	G1	<65	Synthetic dust weight arrestance	ASHRAE 52-76
	EU2	G2	65<80		
	EU3	G3	80<90		Eurovent 4/5
	EU4	G4	>90		
Fine dust filter	EU5	F5	40<60	Atmospheric dust spot efficiency	BS 6540
	EU6	F6	60<80		
	EU7	F7	80<90		DIN 24 185
	EU8	F8	90<95		
	EU9	F9	>95		EN 779
High efficient particulate air filter (HEPA)	EU10	H10	85	Sodium chloride or liquid aerosol	BS 3928
	EU11	H11	95		Eurovent 4/5
	EU12	H12	99.5		DIN 24 184
	EU13	H13	99.95		(DIN 24 183)
	EU14	H14	99.995		
Ultra low penetration air filter (ULPA)	EU15	U15	99.9995	Liquid aerosol	DIN 24 184
	EU16	U16	99.99995		(DIN 24 183)
	EU17	U17	99.999995		

The rigorous manufacturing and monitoring techniques that have been developed include automatic scanning of filters with CNC (Condensation Nuclei Counting) testing, using an oil-based aerosol.

One of the complications of these various standard test procedures is the diversity of particulate materials specified for them. They range from atmospheric dust to synthetic dusts, and from aerosols of oil to aqueous solutions that rapidly evaporate to leave a residue of fine crystals, with inevitable significant differences in the shape and size distribution of the resultant particles. The characteristics of the more common test materials are summarized in Table 5.3.

Wepfer(3) points out that, rather than a filter being characterized in terms of its efficiency against a particle of some specific size, it is more relevant to the user to know its efficiency for the Most Penetrating Particle Size (i.e. its MPPS efficiency), since it is this which ultimately determines the level of contamination in a clean room. The significance of this is brought out by Figure 5.1, which illustrates how the amount of contaminant penetrating may depend on the filtration velocity, the filter medium and the particle size: this arises from the nature of the depth filtration mechanisms by which HEPA and ULPA filters function. A test method and appropriate standard based on the MPPS has been developed by CEN as EN1822.

As Wepfer warns, filter efficiency is sometimes wrongly considered to be a physical constant, thus ignoring the variations of the wet-laid papermaking process with its own probability distribution. Figure 5.2 shows an example of such efficiency variations of a widely used ULPA medium from a leading manufacturer. A medium with a typical efficiency of 99.9999% (50% probability value) may therefore also have an efficiency of 99.9995% with a probability of 1%. That would

Table 5.2 MERV ratings from ASHRAE 52.2

Group number	MERV rating	Average efficiency in size range (%)		
		0.3–1.0 µm	1–3 µm	3–10 µm
1	1	–	–	$E_3<20$
	2	–	–	$E_3<20$
	3	–	–	$E_3<20$
	4	–	–	$E_3<20$
2	5	–	–	$20 \le E_3<35$
	6	–	–	$35 \le E_3<50$
	7	–	–	$50 \le E_3<70$
	8	–	–	$70 \le E_3$
3	9	–	$E_2<50$	$85 \le E_3$
	10	–	$50 \le E_2<65$	$85 \le E_3$
	11	–	$65 \le E_2<80$	$85 \le E_3$
	12	–	$80 \le E_2$	$90 \le E_3$
4	13	$E_1<75$	$90 \le E_2$	$90 \le E_3$
	14	$75 \le E_1<85$	$90 \le E_2$	$90 \le E_3$
	15	$85 \le E_1<95$	$90 \le E_2$	$90 \le E_3$
	16	$95 \le E_1$	$95 \le E_2$	$95 \le E_3$

give five times more penetration and five times more particles in the clean room. Thus, if the manufacturer of ULPA filters has to guarantee a maximum penetration (or minimum efficiency), the average value of penetration of this production lot could typically be about five times smaller than the guaranteed maximum.

5.2.2 Types of ventilation filter

Ventilation filters, such as those that are used to control the cleanliness of the air supply in office buildings or clean rooms, usually comprise a rectangular frame containing a sheet, pad or other array of filter medium. In the simplest form, the filter medium is flat as in Figure 5.3(a). The active surface area can be greatly increased by pleating the sheet as in Figure 5.3(b), especially if the pleats are

Table 5.3 Some dusts and aerosols for testing air filters

Designation	Material	Particle size (%wt.)	Range (μm)
Dusts[a]			
Air cleaner test dusts (Arizona road dust)	Quartz mineral		
AC coarse[b]			
			0–200
		10–14	0–5
		9–15	5–10
		11–18	10–20
		20–26	20–40
		27–33	40–80
		6–12	80–200
AC fine[b]			0–80
		37–41	0–5
		15–21	5–10
		13–19	10–20
		15–21	20–40
		6–12	40–80
ASHRAE 52/76	Molacco black	23	
	SAE J 726 fine	72	0–80
	Cotton linters	5	
BS2831 No. 3	Fused alumina		8–32
BS2831 No. 2	Fused alumina		0–10
Aerosols			
BS2831 No. 1	Methylene blue (solid[c])		0.6 (median)
BS3928 NaCl	Sodium chloride (solid[c])		0.6 (median)
DOP (USA)	Dioctylphthalate (liquid)		0.3 (median)
Uranine (France)	Sodium salt of fluoroscein (solid[c])		0.12 (median)

[a] Dusts to these and many other specifications are manufactured by Particle Technology Limited.

[b] Formerly products of AC Spark Plus Division of General Motors marketed by A.C. Delco. Equivalent dusts are included in the nine grades of a new ISO specification due to be approved early in 1997.

[c] Generated as a dilute solution in water. Evaporation leaves solid particles for filtration.

deep as in Figure 5.3(c): with very deep pleats, the sheet effectively becomes a series of linked pockets as in Figure 5.3(d). There is also a very different format providing a sheet of filter medium, the roll filter, which enables the renewal of the active sheet by incorporating automatic indexing of a roll of medium, triggered by a pressure drop monitor.

Where a sheet or pad is used in a simple frame, then this can be of any suitable medium, from the simplest felt to a multi-layered construction, such as an active layer of synthetic medium or glass microfibres sandwiched between protective outer coverings of open spunbonded fabric.

The nature and diameter of the fibres in the active layer, and in some instances of their density of packing, determine the filtration efficiency and other performance characteristics of the filter. By judicious selection and control of these parameters, ventilation filters are produced in a wide variety of grades, ranging from coarse filters down to the finest with an efficiency greater than 99.999999% against 0.12 μm particles.

Most manufacturers of air filter media supply their media in these various ventilation filter formats. Thus, Freudenberg, one of the leading suppliers of nonwovens, under its Viledon brand name, has a product portfolio that includes:

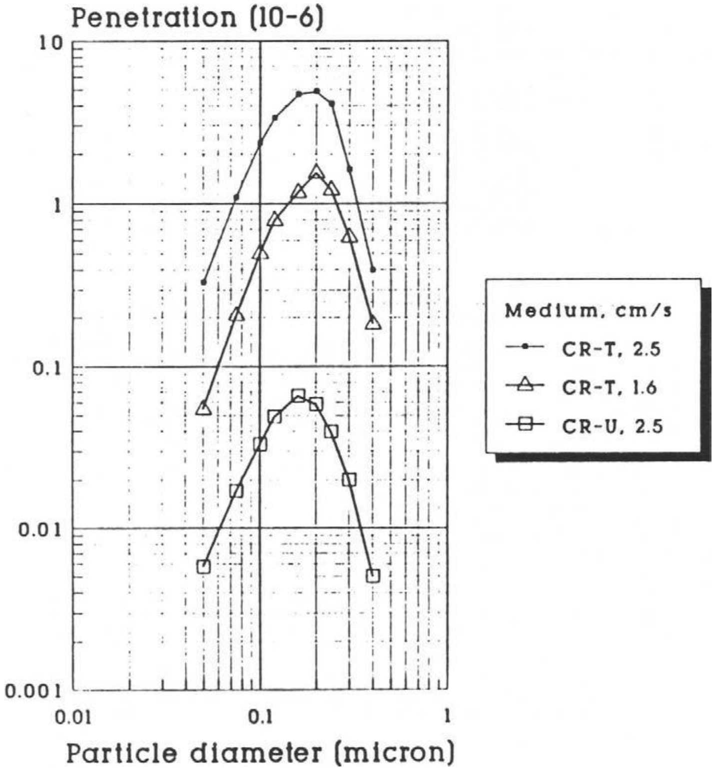


Figure 5.1. Medium penetration versus particle size depends on face velocity and nature of the medium. Tests on Luwa Ultrafilter CR with DEHS aerosol and CNC detection.

- a range of roll goods intended for cutting into specific shapes by the filter maker – these cover EU2 to EU5 (in particular to make simple sheet filters, although the range includes the R/260 material for roll filters);
- a large range of compact pocket filters (as in Figure 5.3(d)), which cover EU3 to EU9, and which are made from needlefelts and spunbonded materials, mostly with a multilayer structure;
- a range of MaxiPleat deep pleated filters, made from bonded glass fibres, for finer filtration, covering EU6 to EU11; and
- a range of specially pleated glass paper filters for HEPA and ULPA usage, covering EU10 to EU17.

5.2.3 Media for ventilation filters

As shown in Figure 5.3, ventilation filters are made either as sheets or pads of fibrous media, as flat arrays of corrugated (pleated) paper-like media, or as sets of filter pockets mounted in the same type of frame – so that any can be fitted into the same housings in the partition wall of a living or work room, or in an air

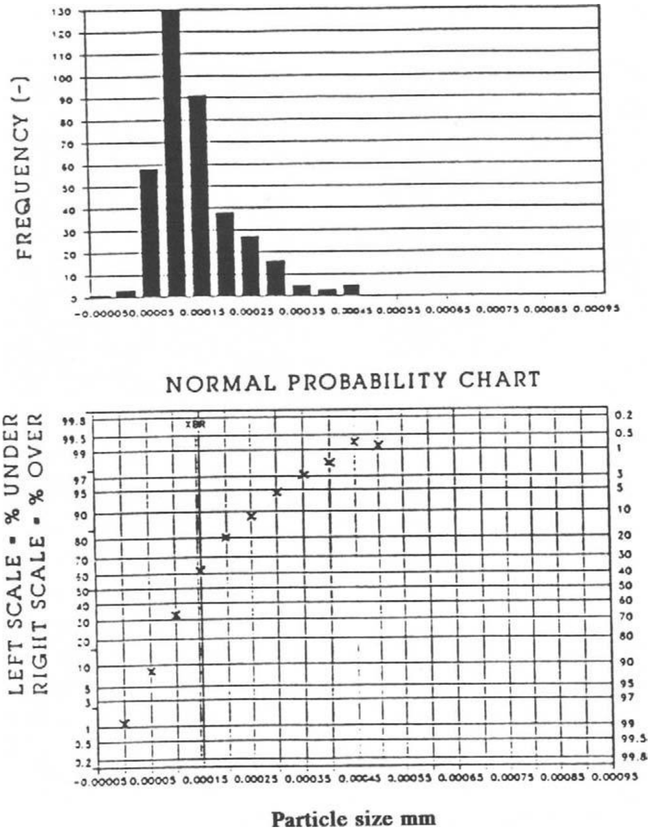


Figure 5.2. Statistical analysis of penetration of 370 production lots of ULPA filters. Penetration measured with laser particle counter at 0.12 μm.

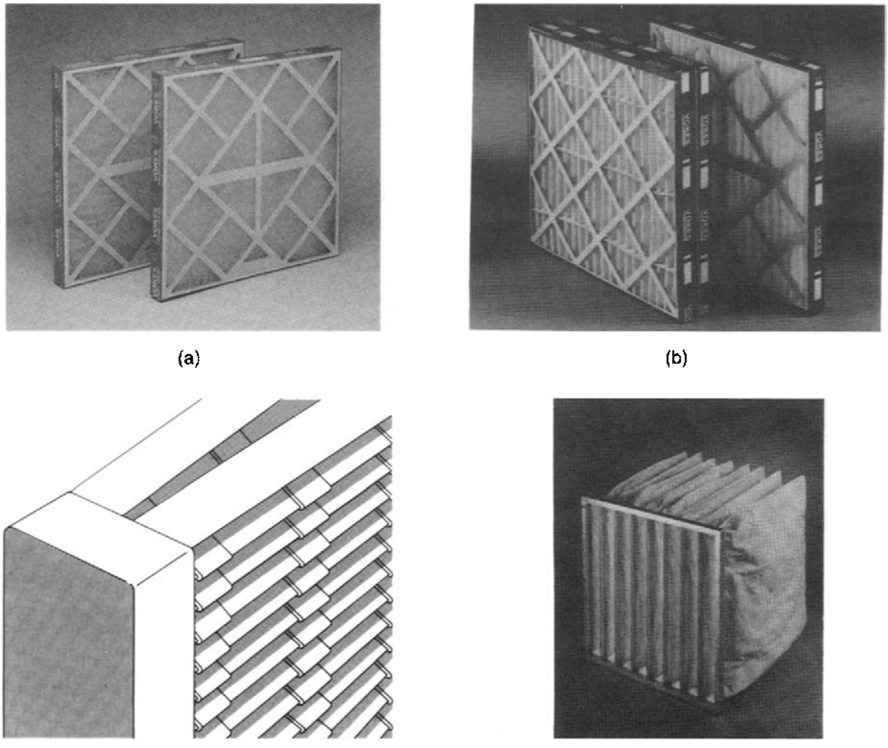
conditioning unit. Although, in principle, any kind of medium could be used for ventilation purposes, the following notes indicate the main media used. These notes supplement the comments on these media made elsewhere in the Handbook.

For a considerable period of time, ventilation filters largely employed simple or needled felts, or pleated papers. Nowadays, the demand for high levels of purity in the filtered air has led to the use of the more recently developed glass and polymeric media.

5.2.3.1 Glass fibre pads

Glass fibres provide a uniquely versatile source of filter media since, in addition to being very inert, they can be produced in controlled degrees of fineness down to exceptionally small diameters. This latter characteristic is of particular importance because the interception/diffusion mechanisms involved in air filtration result in the need for increasingly fine fibres as the size of particles to be captured is reduced.

The various processes for manufacturing glass fibres are briefly summarized in Chapter 4. One of these is the 'rotary' process used by Johns Manville to



(a) (b)

(c) (d)

Figure 5.3. (a) Simple flat panels; (b) shallow pleated panels; (c) deep pleats (for HEPA filters); (d) multipocket bag filters.

manufacture the relatively short and coarse fibres of their Micro-Aire products, of which the six basic grades are identified in Table 5.4. They are available in roll form (in widths up to 2.3 m and lengths up to 150 m), ready for in-plant cutting and sewing to fabricate into filters; they are colour coded for convenience, and can be supplied either with or without a choice of backing materials to provide extra strength. These media contain about 12 or 14% of phenolic resin as a binder; this gives the structure some resilience, so that it compresses when vacuum-packed for shipping, but recovers its full thickness as soon as a pack is opened.

The Micro-Aire range embraces ASHRAE efficiencies from 30 to 95%, nominally covering Eurovent classes up to EU9; in practice, Johns Manville is commercially focused on classes EU5 to EU9, with the coarse dust sector served by lower-cost materials. Examples of single- and dual-layer media are illustrated in Figure 5.4; typical performance curves are reproduced in Figure 5.5.

An alternative low-cost form of glass medium, illustrated in Figure 5.6, comprises continuous monofilament glass fibre of relatively coarse diameter (10–12 μm) bonded with a thermosetting resin. Thicknesses available range from 12 to 100 mm, the corresponding flow resistance and filtration efficiency characteristics of which are indicated in Table 5.5; the efficiency range extends up to Eurovent class EU4. The material is available in widths up to 2 m and roll lengths up to 100 m, and can be supplied with scrim backing.

5.2.3.2 Glass microfibre papers

Papers made from glass microfibres, as shown in Figure 5.7, with diameters as small as 0.3 μm or less, form the heart of the HEPA and ULPA filters that correspond to Eurovent classes from EU10 to EU17.

A major source of these papers is the 100 Series Micro-Strand Micro-Fibers produced by Johns Manville's pot and marble process as described in Chapter 4. There are 10 grades of these fibres, their corresponding spread of diameters being given in Table 4.7, while Table 4.6 identifies their chemical composition.

Examples of papers based on these fibres are the four classes of Lydair products summarized in Table 5.6, with typical data for the media in each class given in Tables 5.7–5.10. All of these media are available either plain or laminated to various scrims on one or both sides; the laminate options and identification system are listed in Table 5.11.

5.2.3.3 Spunbonded polymers

Confusion can arise (as further discussed in Chapter 3) from the term 'spunbonded media', since it is quite widely used both to embrace the three different categories of polymeric media made from extruded filaments (with fibres of distinctly different fineness), and also, much more often now, to identify one specific category. These media are taking an ever-increasing proportion of the general ventilation media market.

The one specific category, also once known as melt spun, is widely used to make relatively coarse continuous fibres, with diameters in the range 15–40 μm. Development of the original spinning process resulted in the finer (5–10 μm) fibres

Table 5.4 'Micro-Aire' glass fibre media[a]

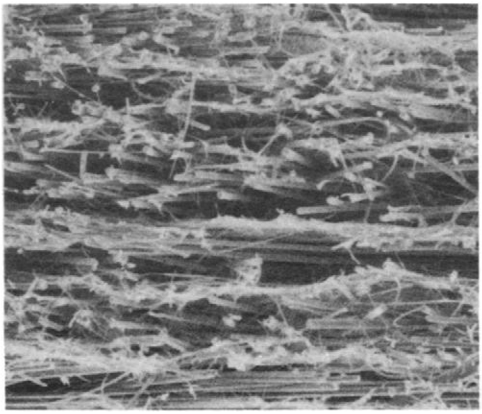
Grade	Colour	Thickness (mm)	Backing[b]	Weight (gm/m²)	Permeability[c] (mm of water)	Filtration efficiency (%)		Flammability[e] class
						Flat sheet[d]	Ashrae 52.1	
AFS-3	Yellow	6.9	None	65	8.8	68–78	90–95	1
		6.9	B2	73	8.8	68–78	90–95	2
		6.9	B1GS	139	8.8	68–78	90–95	1
		6.9	B1NW	105	8.8	68–78	90–95	1
AFS-4	Pink	6.9	None	54	4.4	48–58	80–85	1
		6.9	B2	66	4.4	48–58	80–85	2
		6.9	B1GS	131	4.4	48–58	80–85	1
		6.9	B1NW	98	4.4	48–58	80–85	1
AF-11	Orange	6.4	None	61	1.6	18–28	55–65	1
		6.4	B2	75	1.9	18–28	55–65	2
		6.4	B1GS	141	1.6	18–28	55–65	1
		6.4	B1NW	108	1.9	18–28	55–65	1
AF-18	Yellow/tan	6.4	None	97	1.6	10–20	50–55	1
		6.4	B2	111	1.9	10–20	55–65	2
		6.4	B1GS	176	1.6	10–20	55–65	1
		6.4	B1NW	143	2.1	10–20	55–65	1
AMF-30	Yellow/tan	4.1	B2	62	0.8	5–15	30–40	2
		4.1	B1GS	128	0.8	5–15	30–40	1
		4.1	B1NW	95	1.0	5–15	30–40	1
G.P.	Yellow/tan	6.4	None	76	0.9	8–18	40–50	1
		6.4	B2	90	1.3	8–18	40–50	2
		6.4	B1GS	156	0.9	8–18	40–50	1
		6.4	B1NW	123	1.5	8–18	40–50	1

[a] Johns Manville Inc. [b] Backings: B1GS. woven glass scrim: recommended maximum air temperature is 167°C: B1NW. non-woven mat: recommended maximum air temperature is 121°C; B2. non-woven polyester or nylon: maximum air temperature is 121°C. [c] Nominal pressure drop at an air velocity of 7.6 m/min through a flat sheet. [d] For 0.3–0.5 μm particles at an air velocity of 7.6 m/min through a flat sheet. [e] Underwriters Laboratories Class 1 or 2 for specific flame and smoke requirements.

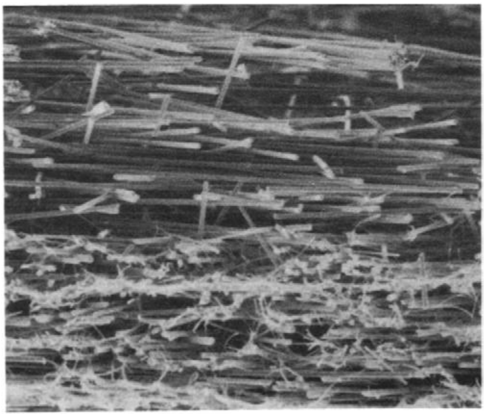
of melt blown media; yet further development has led to Du Pont's even finer flash spun fibres. More information on this set of media types is given in Chapter 3.

Because of the relative coarseness of their continuous fibres, the main role in air filtration for spunbonded media, such as BBA's Reemay, is as protective or support layers in combination with finer media of higher efficiency, and they would normally be used as pleated sheets. They also serve as prefilters in which to trap larger particles, and in composite media such as BBA's Qualiflo, to achieve efficiencies equivalent to EU9 and higher. For further information on these media, see Chapter 3.

The company Irema Ireland has developed a patented version of melt spinning that enables it to produce a wide range of fibre sizes, from 40 µm down to microfibres of the order of 0.5 µm. Irema attributes its success to the flexibility of the very small scale of the original production facilities, which were focused exclusively on the specialist needs of surgical masks. Subsequently the range of 100% polypropylene binderless Micro 2000 Plus media was developed for air



(a)



(b)

Figure 5.4. ASHRAE grade glass filter media: (a) single layer, (b) dual layer. (Photograph: Lydall, Inc)

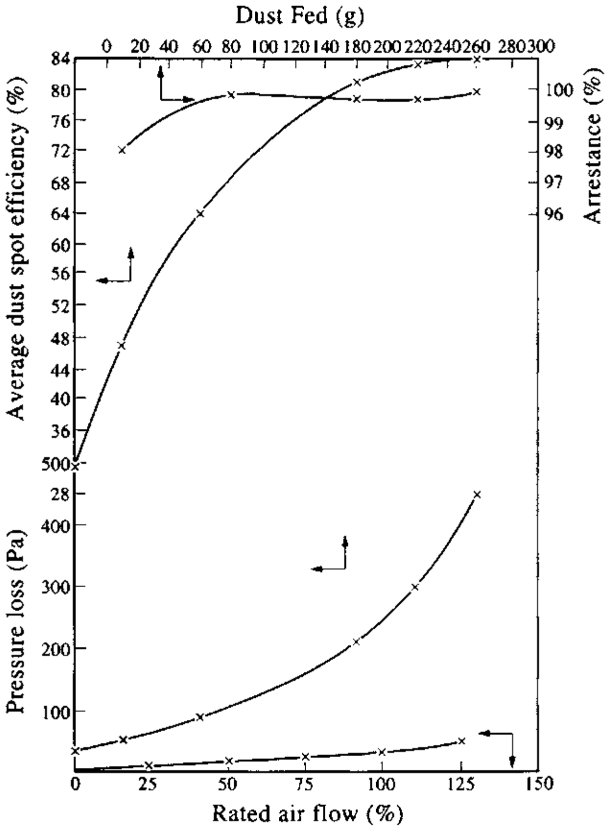


Figure 5.5. Typical ASHRAE test curves.

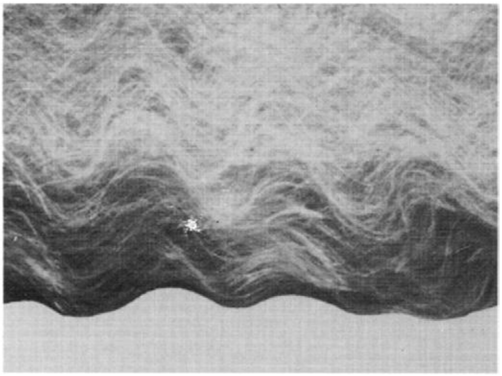


Figure 5.6. Continuous monofibre glass filter medium. (Photograph: Lancaster Glass Fibre Ltd)

filtration. These lofted uncalendered media are in the form of 5–10 mm sandwiches, comprising 60/65 g/m^2 of graded fibres enclosed between cover and backing scrim. They may be used as flat sheets or deep pleated arrays. The characteristics of standard products are given in Table 5.12; filtration efficiencies extend from Eurovent class EU5 to EU9.

5.2.3.4 Meltblown media

The sophisticated techniques of melt blowing permit the production of graded fine short fibres with diameters in the size range 5–10 μm. These form the basis of filters for finer dusts, corresponding to Eurovent classes EU5 to EU8 and beyond; but note that initial efficiencies tend to be inflated by unstable static charges induced by the manufacturing process. Examples of these are the range of polypropylene media with colour-coded scrim backing summarized in Table 5.13.

Other polymers are also available in meltblown form: Hollingsworth and Vose, for example, supplies polyester, nylon and polyphenylene sulphone as meltblown webs, in both simple and composite forms.

Table 5.5 Resin bonded continuous monofilament glass filter media[a]

Thickness (mm)	Clean resistance to air flow (mm WG)			Average efficiency[b] (%)	Arrestance load[b] (g/m^2)
	1.0 m/s	1.5 m/s	2.0 m/s		
12	–	–	4.50	75	650
25	–	–	5.00	80	750
50	0.80	1.50	5.00	86	850
75	1.60	3.00	6.00	90	1050
100	2.60	4.00	6.50	92	1200

[a] Lancaster Glass Fibre Limited.

[b] Test velocity 2 m/s.

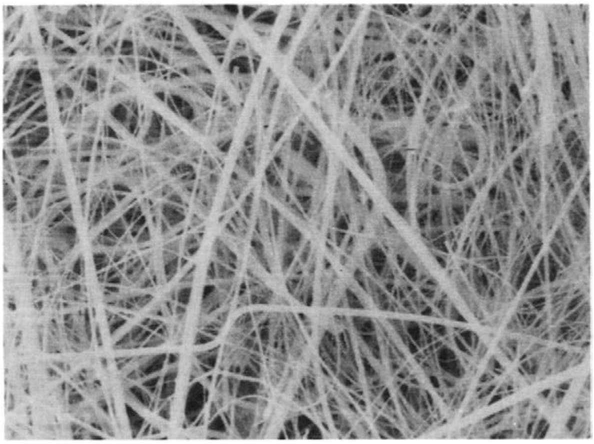


Figure 5.7. Magnified view of microfibre glass paper. (Photograph: Whatman International Ltd)

5.2.3.5 Plastic foam

Reticulated polyurethane foams are available in a range of pore size grades and sheet thicknesses, which can achieve Eurovent ratings from EU1 to EU3. For example, Figure 5.8 shows an efficiency of almost 90% for a 10 mm thick sheet of the finest grade (80 ppi, pores per linear inch). An advantage of plastic foam is that it can be readily washed and reused repeatedly. (More information on plastic foams as filter media is given in Chapter 7.)

5.2.3.6 Expanded metal mesh

Expanded metal mesh may be used dry as a grease trap or demister. It may also be used when wetted with a replaceable oil or adhesive for particular collection, with efficiencies corresponding to Eurovent ratings of EU1 or EU2, as illustrated by the typical performance data given in Table 5.14. In any of these roles, it has the advantage of being readily washed and reused repeatedly. (More detail on expanded metal mesh as a filter medium is given in Chapter 6.)

5.2.4 Electrostatically charged media

It is well known that the efficiency of a filter can be enhanced significantly by an electrostatic charge on the fibres of the medium. The earliest practical example of this was the resin/wool mixture used by Hansen(4) as the basis of the military gas mask patented by him in 1931. An account of this, and of some of the secrecy that understandably surrounded it, was given by Feltham(5), who commented on the notable absence from the patent of any reference to electrical action on which its function depends.

Table 5.6 Summary of 'Lydair' glass filter media[a]

Class	Number of standard grades	Filtration efficiency range (%)		Typical applications
		ASHRAE	DOP[b]	
1000	13	30–95	15–65	Heating and ventilating, inlets to compressors and turbines, paint spray booths
2000	4	–	86–98.5	Prefilter for HEPA, hospital air, computer disc drive, chemical and pharmaceutical processing
3000	6	–	99.91–99.99	HEPA for clean rooms for hospitals, microelectronics industry, processing industries, aerospace, film manufacturing
5000	7	–	99.999 up	ULPA for clean rooms for pharmaceutical processing, microelectronics industry, genetic research, mainframe computers

[a] Lydall, Inc.

[b] 0.3 μm DOP particles @ 3.2 m/min for Classes 1000, 2000 and 3000.
0.12 μm DOP particles @ 1.07 m/min for Class 5000.

Table 5.7 Class 1000 'Lydair' glass paper media[a]

Grade number	1224	1224B	1235[b]	1229	1229A	1229B	1272[b]	1381	1232	1232a	1251[b]	1254	1254A
DOP penetration[c] (%) 0.3 μm particle @ 3.2 m/min	35	35	35	50	50	50	50	75	85	85	85	–	–
DOP efficiency[c] (%) 0.3 μm particle @ 3.2 m/min	65	65	65	50	50	50	50	25	15	15	15	–	–
ASHRAE efficiency (%)	90–95	90–95	90–95	80–90	80–90	80–90	80–90	60–70	55–60	55–60	55–60	40–45	30–40
Air permeability (l/s @ 12.5 mm WG)	13	13	13	20	20	20	20	43	60	69	64	116	162
Pressure drop with air @ 3.2 m/min (mm WG)	5.0	5.0	5.0	3.5	3.5	3.5	3.5	1.5	0.8	0.8	0.8	–	–
Basis weight (g/m^2)	73	81	76	73	68	81	76	73	70	63	76	63	49
Thickness (mm)	0.38	0.43	0.38	0.38	0.36	0.43	0.38	0.38	0.36	0.33	0.38	0.33	0.25
Tensile strength (kgf/cm)													
MD (machine direction)	1.35	1.42	1.35	1.35	1.27	1.42	1.35	1.35	1.27	1.23	1.35	0.96	0.77
CD (cross direction)	0.77	0.84	0.77	0.77	0.77	0.84	0.77	0.77	0.77	0.69	0.77	0.69	0.65
Water repellancy (mm)	381	381	254	381	381	381	254	254	254	254	127	–	–
Yield (m^2/kg)	13.7	12.6	13.1	13.7	15.0	12.6	13.1	13.7	14.7	16.2	13.1	16.21	21.0

[a] Lydall, Inc.

[b] Denotes dual layer for higher dust holding capacity and longer life.

[c] % penetration = 100 – % efficiency.

Table 5.8 Class 2000 'Lydair' glass paper media[a]

Grade number	2233	2221	2220	2400
DOP penetration[b] (%) 0.3 μm particle @ 3.2 m/min	1.5	4.0	7.0	14.0
DOP efficiency[b] (%) 0.3 μm particle @ 3.2 m/min	98.5	96.0	93.0	86.0
Pressure drop with air @ 3.2 m/min (mm WG)	17	15	12	9
Basis weight (g/m^2)	73	83	73	73
Thickness (mm)	0.38	0.38	0.38	0.38
Tensile strength (kgf/cm)				
MD (machine direction)	1.15	1.15	1.15	1.15
CD (cross direction)	0.69	0.69	0.69	0.69
Water repellancy (mm)	254	635	254	254
Combustibles (%)	5	5	5	5
Yield (m^2/kg)	13.7	13.7	13.7	13.7

[a] Lydall, Inc.
[b] % penetration = 100 − % efficiency.

Table 5.9 Class 3000 'Lydair' glass paper media[a]

Grade number	3215	3428	3255[b]	3255-N	3514	3248
DOP penetration[c] (%) 0.3 μm particle @ 3.2 m/min	0.015	0.015	0.015	0.015	0.030	0.060
DOP efficiency[c] (%) 0.3 μm particle @ 3.2 m/min	99.985	99.985	99.985	99.985	99.97	99.94
Pressure drop with air @ 3.2 m/min (mm WG)	36	31	36	36	32	30
Basis weight (g/m^2)	73	73	86	86	49	73
Thickness (mm)	0.38	0.38	0.46	0.46	0.25	0.38
Tensile strength (kgf/cm)						
MD (machine direction)	1.35	1.04	1.47	1.47	0.96	1.15
CD (cross direction)	0.69	0.61	0.96	0.96	0.54	0.69
Water repellancy (mm)	381	254	762	762	254	254
Combustibles (%)	5	5	5	10	5	5
Yield (m^2/kg)	13.7	13.7	11.6	11.6	20.5	13.7

[a] Lydall, Inc.
[b] Denotes dual layer for higher dust holding capacity and longer life.
[c] % penetration = 100 − % efficiency.

The key to the Hansen filter is the friction generated during carding of a mixture of wool and particles of amber (fossilized resin). This induces a positive charge on the wool and a negative one on the resin; moreover, the charge is stable because of the very low conductivity of resin, even though wool is a comparatively good conductor. British military respirators were based on this technology through the 1940s and into the 1950s, with some use also of asbestos fibres, until the development of glass microfibres provided an alternative. Even today, Hansen-type material (without asbestos) still finds limited use in some industrial face masks.

Table 5.10 Class 500 'Lydair' glass paper media[a]

Grade number	5721	5588	5373	5471	5252	5470	5375
DOP penetration[b](%) 0.12 μm particle @ 1.07 m/min	0.000001	0.00001	0.0001	0.0001	<0.001	<0.001	<0.001
DOP efficiency[b] (%) 0.12 μm particle @ 1.07 m/min	99.999999	99.99999	99.9999	99.9999	>99.999	>99.999	99.999
Pressure drop with air @ 3.2 m/min (mm WG)	80	63	63	50	50	42	42
Basis weight (g/m^2)	78	78	73	73	73	73	73
Thickness (mm)	0.41	0.41	0.38	0.38	0.38	0.38	0.38
Tensile strength (kgf/cm)							
MD (machine direction)	1.35	1.35	1.35	1.04	1.35	1.04	1.35
CD (cross direction)	0.77	0.77	0.69	0.61	0.69	0.61	0.69
Water repellancy (mm)	254	254	508	254	508	254	381
Combustibles (%)	5	5	5	5	5	5	5
Yield (m^2/kg)	12.8	12.8	13.7	13.7	13.7	13.7	13.7

[a] Lydall, Inc.

[b] % penetration = 100 − % efficiency.

Table 5.11 Laminated options for 'Lydair' glass filter media[a]

Scrim material	Basis weight (g/m^2)	Letter code[b]
Reemay	18	A
Woven glass cloth	98	B
Hollitex (calendered Reemay)	16	C
Cerex	28	D
Reemay	32	E
Cerex	32	F
No scrim	–	O

[a] Lydall, Inc.

[b] Example: 1224 A/A specifies – standard grade 1224.
– wire side scrim 18 g/m^2 Reemay.
– felt side scrim 18 g/m^2 Reemay.

Because of the high resistivity of synthetic polymers, and because of the nature of the spinning process, fibres as produced tend initially to have a static charge that enhances the initial filtration efficiency; for example, Irema Ireland specifically refers to this feature in respect of its Micro 2000 Plus media in Table 5.12. However, this 'natural static' is generally not stable and soon decays.

5.2.4.1 Corona charged media

A stable static charge can be applied to polymer fibres by a corona discharge. This develops rapidly into a dipole configuration, with each fibre comprising a multitude of frozen-in electric polarization cells or 'electrets', analogous to a series of magnets, so that particles are attracted to the fibres. As shown

Table 5.12 'Micro 2000 Plus' continous fibre synthetic media[a]

Reference no.	Weight (gm/m^2)	Grade/class		Initial NaCl 0.4 µm (%)	Clean pressure drop (Pa)	Dust holding[b] capacity (gm/m^2)	Face velocity (m/s)
		ASHRAE efficiency (%)	Eurovent				
50.1F.19E.a	120	45	EU5	25	25 maximum	60	0.15
60.1A.19E.a	120	60/65	EU6	35	25 maximum	50	0.15
80.1C.19E.a	110	80/85	EU7	65	55 maximum	55	0.15
90.1D.18E.a	120	90/95	EU8	80	35 maximum	45	0.15
95.1F.19E.a	120	95	EU9	85	85 maximum	40	0.15

[a] Irema Ireland.

[b] Dust holding capacity of flat sheet to pressure drop of 250 Pa

Table 5.13 'Poly-Aire' melt blown polypropylene filter media[a]

Grade number	PF-95	PF-85	PF-65	PF-45
Colour	Yellow	Magenta	Orange	White
Maximum thickness (mm)	6.5	6.5	6.5	6.5
Basis weight (g/m^2)	160–194	135–188	118–160	80–135
Air permeability[b] (mm WG)	3.8–6.4	2.5–5.1	0.7–2.3	0.2–1.0
Initial flat sheet particle efficiency[c] (%)	60–70	50–60	15–25	6–14
Average ASHRAE efficiency[d] (%)	90–95	80–85	60–65	40–45
Eurovent class[e]	EU8	EU7	EU6	EU5
Dust capacity (g/m^2)	55–65	79–95	120–150	170–215
Flammability class[f]	2	2	2	2

[a] Johns Manville Inc.

[b] Nominal pressure drop measured at an air velocity of 12.7 cm/s through a flat sheet.

[c] Measured at an air velocity of 12.7 cm/s through a flat sheet with 0.3–0.5 µm particles.

[d] Applicable to finished air cleaning devices, based on ASHRAE-52.1. Efficiency depends on the filter design and construction.

[e] Filter media alone will meet Class 2 rating when tested in accordance with UL-900 'Standard for air filter units'.

[f] Available in 710 mm wide rolls; lengths 68 m for PF-95, 76 m for other grades.

schematically in Figure 5.9 and described by Van Turnhout and Albers(6), negatively or positively charged particles are directly attracted by a coulombic force, while uncharged particles may be polarized into dipoles prior to attraction.

The magnitude of enhancement achievable depends on the nature and the geometry of the fibres. Thus, the charge density achievable with 3M's Filtrete Type S media, comprising round 5–10 μm diameter meltblown fibres of low-density polypropylene, is twice that for polycarbonate fibres (8 as compared with 4 nC/cm^2); but it is an order of magnitude smaller than the 75 nC/cm^2 surface charge of 3M's split-film high-density polypropylene Filtrete Type G, which comprises coarse fibres of relatively large rectangular cross section (10 μm × 60 μm). This results in significant differences in the electromagnetic field

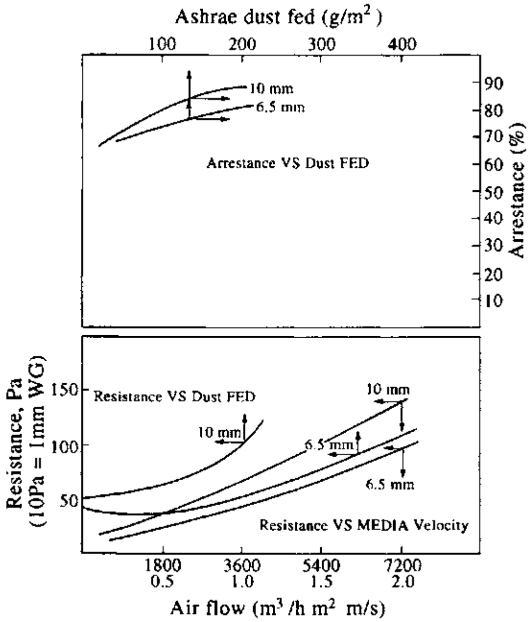


Figure 5.8. Filtration performance of 80 ppi 'Poret' reticulated foam based on ASHRAE 52-68 procedure at a face velocity of 0.8 m/s.

Table 5.14 Typical results of tests[a] of expanded metal air filter[b]

Filter type	Type E		Type SP		Type SS	
Thickness (mm)	25	50	25	50	25	50
Air velocity (m/s)	2	2	2	2	2	2
Clean resistance (Pa)	37	39	54	78	34	39
Final resistance (Pa)	287	289	304	328	284	289
Average synthetic dust arrestance (%)	72	74	78	85	66	77

[a] BS 6540 Part I: Section 3.

[b] The Expanded Metal Company Limited.

surrounding the two types of fibre, with the stronger distorted field of the split fibres of Type G being more able to polarize uncharged particles.

Whilst there are grades manufactured frequently tailored to order, there are three standard grades of the Filtrete Type S media, all of which combine 40 g/m^2 of meltblown fibres with a 30 g/m^2 polypropylene fleece substrate. Their initial atmospheric dust spot efficiencies based on ASHRAE 52.1 are: 84% for SBMF-40V, and 89% for SBMF-40PF and SBMF-40VF, corresponding to Eurovent class EU7. Relationships between particle diameter and efficiency, face velocity and efficiency, and face velocity and pressure drop are given in Figures 5.10–5.12.

The Filtrete Type G media are produced not by any form of spinning but by needling the flat fibres generated by a film stretching process as outlined in Chapter 3. Stretching a film of polypropylene causes the molecules to realign in the direction of the force; the film thereby becomes strong in this direction and weak across it, and can then be split into fibres. These fibres are subjected to the needling process used for manufacturing needlefelts, as described in Chapter 3;

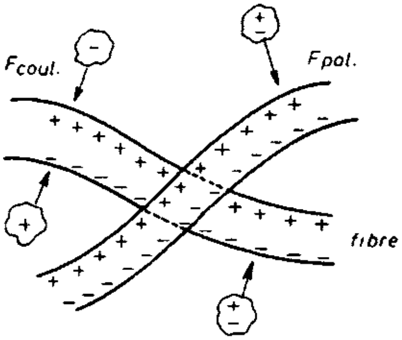


Figure 5.9. Schematic illustration of two modes of attraction of particles to charged fibres. The two charged particles on the left are attached by a Coulombic force. Those on the right are converted into dipoles and attracted by a polarization force.

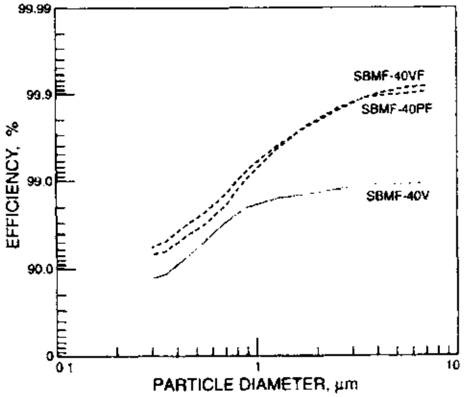


Figure 5.10. Efficiency versus particle size (@ 40 ft/m) for Filtrete Type S. (Illustration: 3M Filtration Products)

sometimes this involves combining the fibres with an open woven scrim located either in the centre of the layer of fibres (denoted by GS) or beneath it (GSB).

These media are produced in a range of basis weights extending from 30 to 300 g/m^2 (indicated by a corresponding suffix, such as GS-100). ASHRAE initial dust spot ratings for a representative number are listed in Table 5.15, corresponding to Eurovent classes between EU5 and EU9. Relationships between particle diameter and efficiency, face velocity and efficiency, and face velocity and pressure drop are given in Figures 5.13–5.15. The impact of the basis weight of the media (g/m^2) on filtration efficiency and on pressure drop is indicated in Figures 5.16 and 5.17.

Comparison of the face velocity versus pressure drop diagrams for Type S and Type G Filtrete shows that the latter has a major advantage in this respect, as a consequence of the high charge density permitting a very open structure, whilst still achieving high filtration efficiencies.

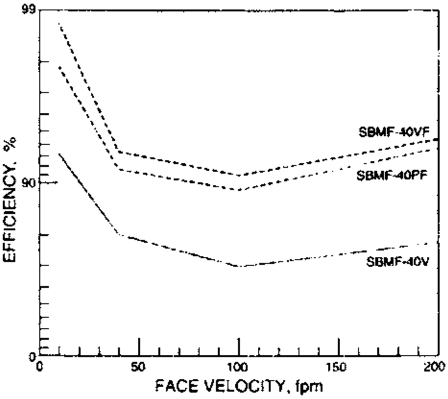


Figure 5.11. Efficiency versus face velocity for Filtrete Type S. (Illustration: 3M Filtration Products)

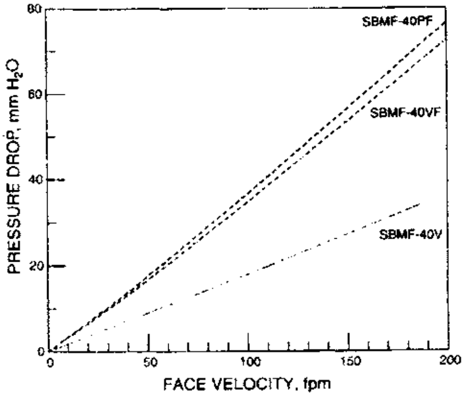


Figure 5.12. Pressure drop versus face velocity for Filtrete Type S. (Illustration: 3M Filtration Products)

Extended tests are reported to demonstrate the high charge stability of Filtrete in respect of time (a decrease of no more than 1.2% over a shelf-life of 4 years), temperature (lengthy stability at up to 80°C, safe for short periods at up to 100°C), and humidity (a very long service life at tropical conditions of 100% humidity at 45°C).

5.2.4.2 Triboelectric media

Electrostatic charges can also be generated by triboelectric means when fibres of different polymers are rubbed together, one becoming positively charged and the other negatively: Table 5.16 lists textile materials in a triboelectric series, where one higher in the series will become positively charged if rubbed with any of those below(7).

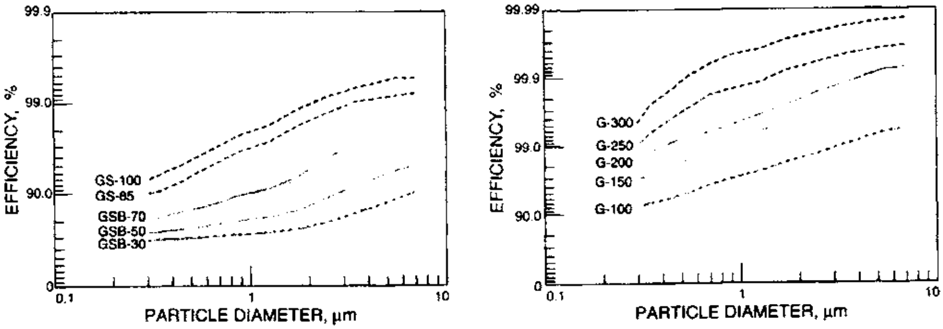
Table 5.15 'Filtrete' Type G media[a]

Grade	Basis weight (g/m²)	Scrim location		Filtration efficiency	
		Centre	Backing	ASHRAE[b]	Eurovent class[c]
GSB-30	30	No	Yes	52	–
GSB-50	50	No	Yes	64	–
GSB-70	70	No	Yes	74	–
GS-85	85	Yes	No	78	–
GS-100	100	Yes	No	80	–
G-100	100	Yes	No	80	–
G-150	150	No	No	92	6
G-200	200	No	No	95	7
G-250	250	No	No	96	8
G-300	300	No	No	99	9

[a] 3M Filtration Products.

[b] 'Initial atmospheric dust spot' according to ASHRAE 52.1-1992.

[c] Eurovent ratings are only given where full tests have been completed @ 0.20 m/s.



5.13. *Efficiency versus particle size (@ 0.2 m/s) for Filtrete Type G. (Illustration: 3M Filtration Products)*

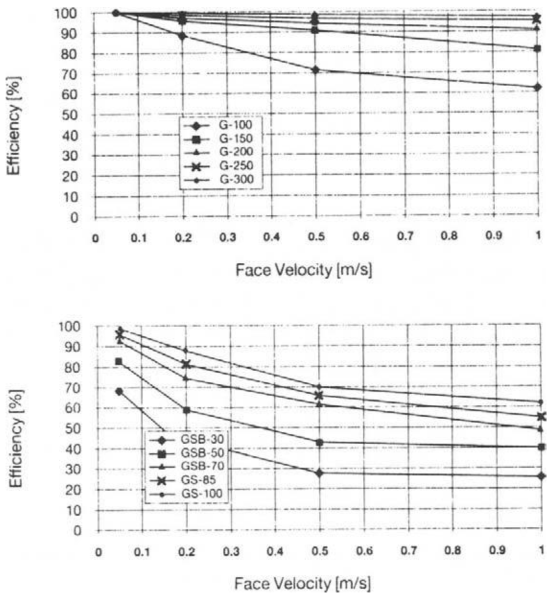


Figure 5.14. Efficiency versus face velocity for Filtrete Type G. (Illustration: 3M Filtration Products)

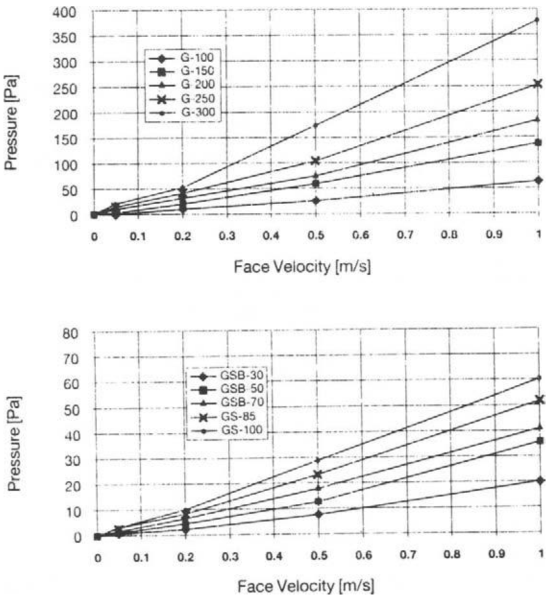


Figure 5.15. Pressure drop versus face velocity for Filtrete Type G. (Illustration: 3M Filtration Products)

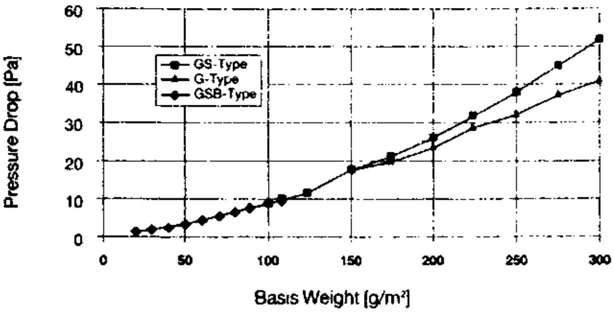


Figure 5.16. Pressure drop versus basis weight for Filtrete Type G. (Illustration: 3M Filtration Products)

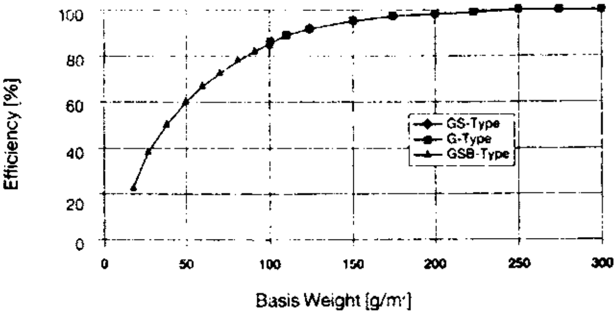


Figure 5.17. Efficiency versus basis weight for Filtrete Type G. (Illustration: 3M filtration Products)

Table 5.16 Triboelectric series of textile materials

Positive

Wool
Nylon 66
Nylon 6
Silk
Regenerated cellulose
Cotton
Polyvinyl alcohol
Chlorinated wool
Cellulose triacetate
Calcium alginate
Acrylic
Cellulose diacetate
Polytetrafluorothylene
Polyethylene
Polypropylene
Poly(ethylene terephthalate)
Poly(butylene terephthalate)
Modacrylic
Chlorofibre

Negative

Media designed to carry triboelectric charges need careful selection of their component fibres to achieve efficient charge creation and retention. The needs for a good electrostatically charged medium are that it should:

- have as high an amount of charge as possible;
- have as high an electrostatic field intensity as possible; and
- hold its charge for a long time, preferably for the life of the filter.

The main triboelectric fibre couple for some time was polypropylene and modacrylic, and this is still exemplified by Hollingsworth and Vose's Technostat media (formally Hepworth)(8).

A newer fibre grouping is polypropylene with polymetaphenylene isophthalamide, supplied as Tribo media by Texel(9), with claims for superior performance. These fibre mixtures are well suited to needle punching technology, and there is evidence that they have much better charge characteristics than corona charged material(10).

5.2.5 Combination filters

The filters and their associated media discussed so far in this chapter have all been concerned with the removal of dusts, i.e. solid granules, from suspension in atmospheric air. It may also be necessary, however, in an air conditioning operation, to remove gaseous impurities, in particular odorous chemicals. This can be done at the same time as the removal of dust if the filter medium contains (or is made up of) an adsorptive substance such as activated carbon.

It is, of course, perfectly possible to have activated carbon 'filters', whose sole purpose is to remove gaseous impurities, and which provide no filtration of particles at all (or not intentionally). However, most activated carbon filters for contaminated air are made in much the same way as dust filters, and the combined duty is now a common feature of air conditioning. Thus, Freudenberg supplies its Viledon DuoPleat Filter in a range of standard AC frame sizes, as a rigid deep pleated design, capable of EU7-rated filtration. The medium is a combination of activated carbon and a triple-layered synthetic fibre non-woven, with microfibres forming the central layer(11). (The similar Viledon CarboPleat Filter is for odour removal only.) BBA's Qualiflo media (see Chapter 3, Section 3.6) can include activated carbon particles in the matrix of a resin-bonded polyester fibre material, also to provide odour removal combined with fine dust filtration.

It is normally intended that very fine ('absolute') air cleaning filters should remove bacteria and viruses by direct filtration, so that air can be sterilized by such action. However, there is now a growing range of combination media where the fibres have been treated in some way with a range of anti-bacterial coatings, to provide an alternative (or supplementary) means of pathogen removal. These treatments may work by physical action (damaging the impinging cells) or chemical destruction on the pathogen particles, and may be 'permanent' or have a definite active life, after which the filter is discarded or retreated.

Another combination activity is the combination of filtration with some kind of chemical activity, such as the catalytic destruction of gaseous impurities, like dioxins and furans. Thus, W L Gore has its Remedia D/F catalyst filter system(12), which is intended to remove dioxins from an exhaust gas stream to well below acceptable discharge values, by contact with catalyst particles held in a fibre matrix, and, at the same time, remove fine solid particles, on which dioxin may also have become adsorbed.

5.3 Other Atmospheric Air Filtration

The previous section was concerned with the conditioning of air in large spaces, but there are several other applications of filters to ambient air, which impose special requirements upon their associated media. These include the air intake filters on engines of all types (mobile or stationary), the respirators or filters used to protect individual people or the occupants of vehicles from the impurities in the atmosphere, and finally the filters used to prevent the emission of collected dust from suction (vacuum) cleaners back into the living space.

5.3.1 Engine air filters

The air drawn in to engines of all kinds for the purpose of combustion needs to be cleaned of dust particles, which might otherwise damage the moving parts of the engine – the pistons and cylinders, or turbine blades. As engines improve in design and performance, so the need for ever-cleaner air has driven the demand for increasing efficiencies in the intake air filters.

The filter used in mobile internal combustion engines has changed little over the years, apart from increased use of pleated media. However the material of the filter medium improved markedly with the arrival of synthetic needlefelts and the spun polymeric media, which are steadily taking market share from the older paper media, although the latter still holds the major share (estimated at 79% of the market in 2000(13) for both treated and untreated paper).

The automobile engine filter is well known to most vehicle owners, as a shallow, drum-shaped item containing a ring of radially pleated medium, which has to be changed at regular intervals. The turbine air intake filter, on the other hand, may be a huge array of panel filters, made from the same kinds of media as are used in air conditioning systems. Pocket and deep pleat filters are frequently used for this application.

5.3.2 Respirators

Individual respirators (or face masks) are essential safety equipment in many dust-generating industrial applications, and are increasingly being worn by people walking or cycling in congested town centres. They are simple structures –

a device to hold a small piece of filter medium, which can comfortably be held firmly against the mouth and nose, and the medium itself.

The chief characteristics of the medium for respirators are efficient removal of solid particles and lowest possible resistance to flow, so as to restrict the breathing process as little as possible. Bearing in mind the current concern over the emission of PM2.5 (2.5 μm) dust particles by vehicle diesel engines, it can be seen that the respirator has quite a task to keep soot particles out of the lungs.

Typical of the media used in respirators are the needlefelts described in Table 5.17: relatively thick sheets of needlefelts, made mainly from a mixture of polypropylene and polyacrylonitryl fibres. These have low breathing resistances, allowing the making of a small mask, and avoiding the fitting of a bypass valve used when breathing resistance rises too high.

5.3.3 Cabin air filtration

The cabins of vehicles used for personal and public transport are as much in need of clean air as are living and working spaces, although manufacturers were a lot slower to realize and supply this need. People are tending to spend longer times in vehicles of all kinds, and there is currently wide acceptance of the need to provide clean air, especially inside automobiles driving in polluted areas, and in aircraft to reduce the transfer of illnesses.

Road vehicles are increasingly being fitted with cabin filters, mainly in the form of pads of needlefelts or spun polymers, cut to fit the channels available in the confined spaces of the vehicle's ventilation system. These need to be efficient enough to keep out the exhaust fumes and pollen that can be so much a nuisance within the vehicle.

Packed aircraft, often travelling long distances, form a good breeding ground for bacteria and viruses, and the air circulation systems of aircraft are increasingly being required to filter out submicrometre particles, to ensure that their passengers reach their destinations without acquiring diseases en route.

Table 5.17 Viledon needlefelts for respirators[a]

Type	Basis weight[b]	Thickness (mm)	Fibre types[c]	NaCl penetration[d]	Flow resist[e]
2396	160	2.5	PP + PAN	6	8
2397	250	3.0	PP + PAN	2.5	14
2398	350	3.5	PP + PAN	1	25
2402	210	2.4	PES + PP + PAN	0.9	15

[a] Freudenberg Vliesstoffe KG.

[b] In g/m^2.

[c] PP, polypropylene; PAN, polyacrylonitryl; PES, polyethersulphone.

[d] Maximum penetration (%) at 8 cm/s.

[e] Maximum flow resistance (Pa) at 8 cm/s.

ASHRAE is working on a new standard (161) to cover air quality in commercial aircraft.

5.3.4 Vacuum cleaner filters

The domestic or commercial vacuum cleaner is a significant user of filter media, mainly in the dust collecting bag, but for other purposes as well. Even the newer cyclonic designs still need final exit filters to stop the emission of fine particles back into living or working spaces. There are three stages of filtration in the standard vacuum cleaner:

- the main dust collecting bag;
- the motor protection filter; and
- the final exhaust filter.

The bag, in a sense, acts as a prefilter, collecting only coarse dust. It is normally made from cellulose paper, although non-woven media are used where wet cleaning is undertaken. The medium needs to be mechanically strong, and have a good dust retention capability for coarse dusts.

There is then a filter to protect the cleaner's electric motor, both from the fine dust that gets through the bag, and from a coarse dust invasion should the bag fail or be incorrectly installed. The medium needs to be able to collect fine particles, and will often be a two-layer material, made from non-wovens, and often including electret media.

The final exhaust filter has to retain very fine dusts, especially including pollen grains, bacteria and other micro-organisms. It must supply this high collection efficiency without affecting the cleaner's suction performance. This medium is now made from microfibre non-wovens, very probably with an electret component. For this function, Freudenberg supplies a three-layer medium, the central one being an electret, made from polycarbonate fibres, sandwiched between two supporting layers of polypropylene. Some typical examples of this medium are given in Table 5.18.

Table 5.18 Viledon exhaust filter media for vacuum cleaners[a]

Property	LRS 302	LRS 304	LRS 305	LRS 306	LRS 310	LRS 311
Basis weight (g/m^2)	170	177	180	174	170	120
M/f weight[b] (g/m^2)	40	14	20	14	7	20
M/f diameter[c] (μm)	4–6	7–10	7–10	7–10	7–10	7–10
NaCl penetration[d] (%)	0.5	10	6	10	28	6
Pressure drop[d] (Pa)	100	23	30	23	11	30

[a] Freudenberg Vliesstoffe KG.

[b] Basis weight of central microfibre layer.

[c] Microfibre diameter range.

[d] Maximum level at 8 cm/s.

5.4 Industrial Dust Removal Filters

Whilst the air and gas cleaning filters described so far have some quite severe constraints in terms of fine particle removal, the filters used in industrial processes have a rather different problem to face – that of relatively high quantities of dust in the inlet gas, often so much as to need arrangements to remove the collected dust at regular intervals. There are two main types to consider, those mainly concerned with exhaust streams from large processes, and those installed around the workshop for local gas cleaning duties.

5.4.1 Process exhaust filters

The filters installed on process exhaust streams – boiler, furnace and incinerator exhausts, and the outlet flows from metallurgical and chemical processes – are normally expected to handle dust loadings an order of magnitude greater than filters used in ventilation applications. (Very large dust loadings would normally be passed through a cyclone first, before the exhaust filters.)

Such flows, as well as being quite heavily dust laden will usually be large in volumetric terms, and quite often very hot. The particular situation of excessively hot gases is covered in the next section, while the present one covers temperatures at or not far above ambient.

The filters used here are usually built to accommodate a large number of filter elements – bags, pockets or cartridges – and much of the discussion relates to the nature of these elements, which is further expanded in Chapter 9.

5.4.1.1 Fabric filters

The term 'fabric filters' conventionally embraces the various forms of bag house and bag filters that are formed by a housing containing a multiplicity of vertical tubular (bag) or rectangular (pocket) cloth-covered elements, as shown in Figures 5.18 and 5.19. Filtration may deposit dust either on the inside or outside surface of each bag, depending on the direction of flow. Operation is cyclical, with filtration intermittently interrupted to permit cleaning by a variety of techniques, including mechanical shaking and reverse flow of the gas.

The type of filter, and especially the mode of cleaning, broadly determines the type of fabric that is appropriate to it. Bergman(14) comments that American practice is generally to use needlefelts for pulse jet filters requiring cake removal from the outside, but woven fabrics for the inside cleaning of shaker and reverse air filters.

With the increasing application of cartridge filters for dust collection, it is logical to classify some of these as fabric filters. Generally these are of conventional tubular pleated form, mostly based on spunbonded nonwoven media, but some (e.g. Figure 5.20) utilize membrane laminates. By contrast, a novel form of pocket filter introduced by Donaldson DCE is made from disposable pleated flat cartridges or modules of spunbonded polyester (Figure 5.21), each providing a filtration area of 4 m^2.

5.4.1.2 Rigidized media

The term 'rigidized media' was devised by Smith(15) to identify a category of dust filters that has evolved from the conventional pocket fabric filter illustrated in Figure 5.19. The name is apposite since it highlights their key distinguishing feature, namely that the traditional flexible fabric has either been made rigid or has been replaced by rigid material. This rigidity makes possible two major constructional modifications, as illustrated in Figure 5.22: the filtration surface is ribbed, thereby increasing the filtration area per unit volume; and the resultant filter medium is self-supporting, without need of internal separators between the two faces of an element. The resultant filter element is, in effect, a flat disposable cartridge.

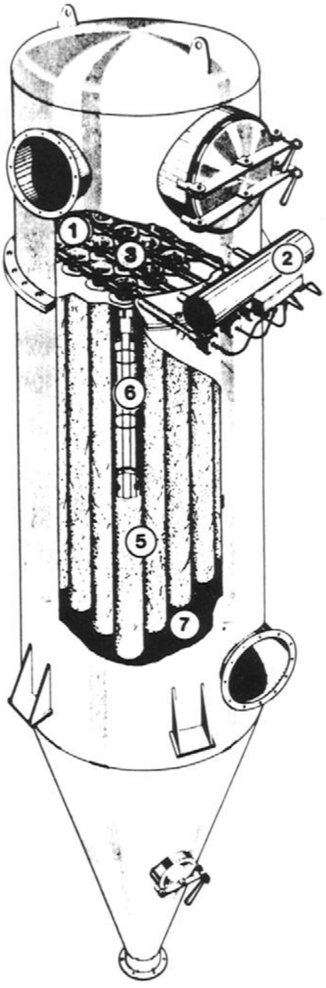


Figure 5.18. A tubular bag fabric filter with pulse jet cleaning: 1. clean gas duct; 2. compressed air; 3. nozzle; 4. baffle plate; 5. filter bag; 6. support cage; 7. dirty gas chamber. (Illustration: Intensiv Filter GmbH)

The pioneers in this technique were the German company Herding GmbH Filtertechnik, whose technology under licence is the basis of Donaldson DCE's range of Sintermatic filters. The filter medium is made from polyethylene granules that are firmly fused or sintered in a ribbed aluminium mould, the active surface then being subjected to a PTFE-epoxy treatment to form a microporous coating, which both improves filtration efficiency and aids cake discharge.

The commercial success of these filter elements stimulated efforts to develop alternative versions that would avoid the relative complexity and high capital cost associated with the sintering process. One option is to rigidize filter cloth by impregnating it with epoxy resin and heat-curing it: despite difficulty in achieving even distribution and concentration of the resin, this has been shown to work reasonably well with both woven and needlefelt fabrics.

As described by Smith, a more elegant method to rigidize filter cloth is to construct it from a fibre, the properties of which enable it to be heat set without the use of a resin. Whilst the theoretical possibility of this had long been recognized, there are practical difficulties in controlling both shrinkage and the embrittlement that occur with many synthetic polymers when they are heated

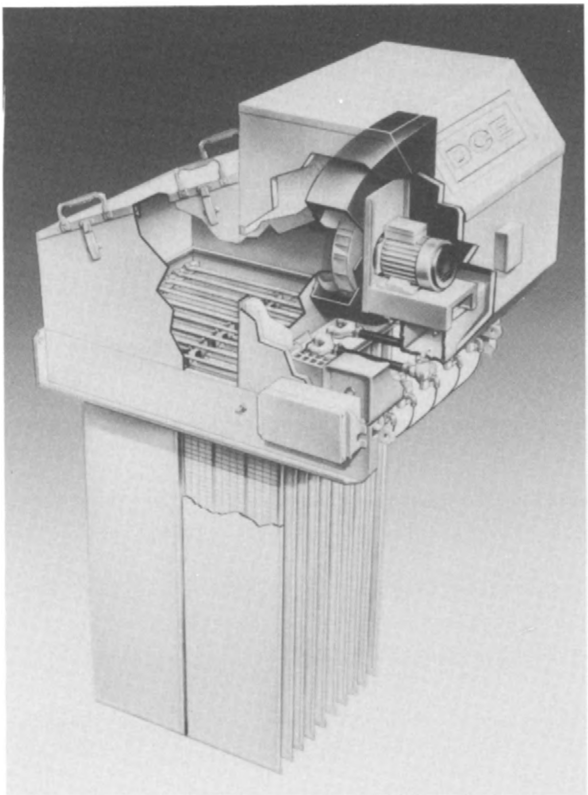


Figure 5.19. A pocket bag filter. (Illustration: DCE Ltd)

above their transition temperature. These problems have been overcome by a patented process that employs special tooling, with the advantage that the shrinkage tends to reduce the pore size of the fabric and so to improve the smoothness of its surface.

By comparison with conventional needlefelt fabric filter bags, those of rigidized media elements potentially offer advantages, but also have some limitations. The key points identified by Smith are summarized in Table 5.19, while Table 5.20 provides typical comparative data; both the resin- and heat-rigidized elements are based on needlefelts.

5.4.2 Workshop filters

Many industrial processes, especially in the mechanical engineering and metal products processing sectors, produce dusts in very localized zones, such that efficient system operation requires local filtration activity, to prevent dusts from spreading too far from their point of origin, or to pick up any dusts that settle in

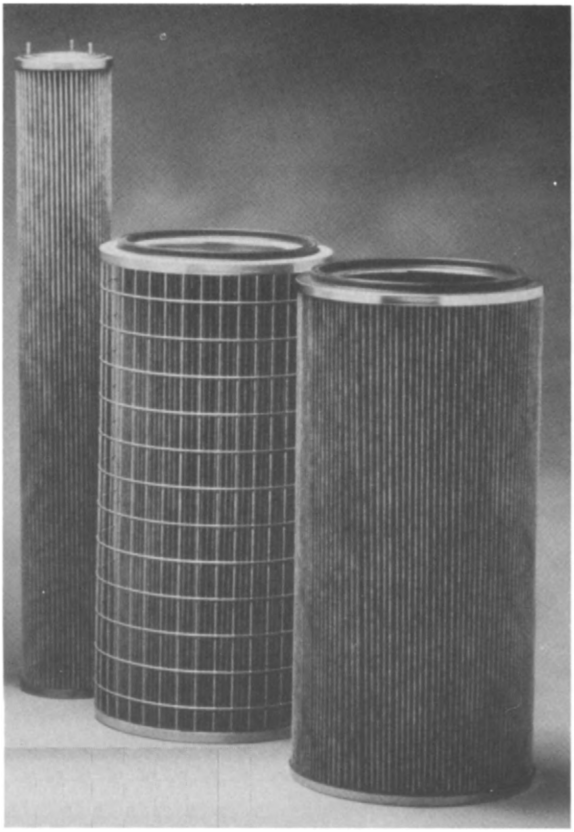


Figure 5.20. Antistatic grade membrane cartridges. (Photograph: W L Gore Associates Ltd)

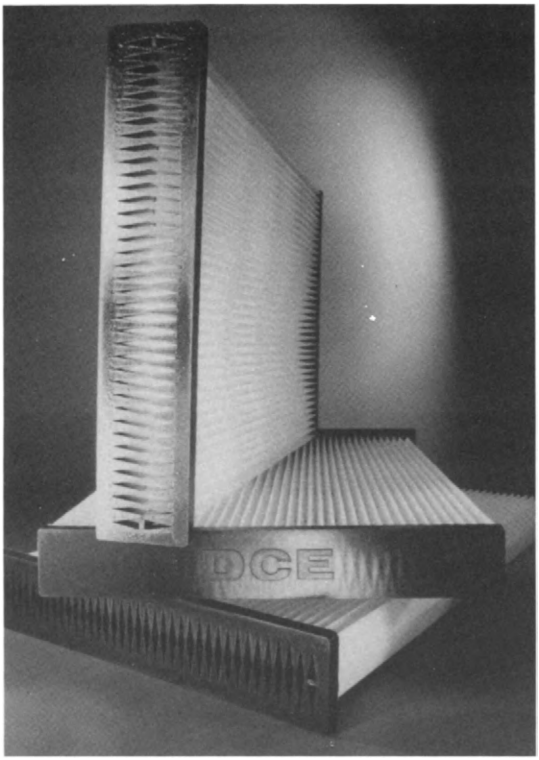


Figure 5.21. Replaceable pleated elements for a DCE 'Unicell' filter.

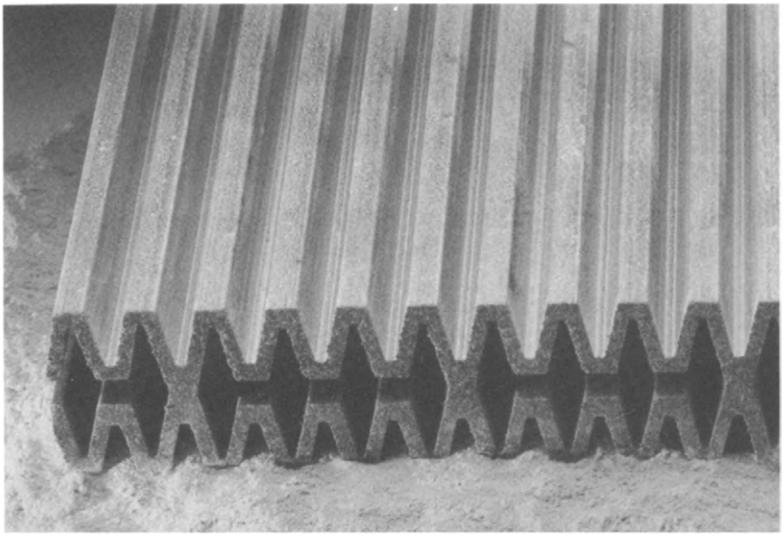


Figure 5.22. A section through a 'Sintermatic' rigidized media filter element. (Photograph: DCE Ltd)

the immediate vicinity of the dust producing unit. Quite often, the dusts are worth recovering, so that the filters involved will be required to release their collected solids efficiently.

Local collection of spilled dust is the province of the industrial suction cleaner, with filtration needs very similar to those discussed in Section 5.3.4. Hoods may be placed over machinery and an air flow sucked from around it, through a filter system, probably similar to the ventilation filters discussed earlier. This is especially true for systems such as a paint booth, where an air flow is necessary to carry fumes away from any workers, and needing to be filtered before it can be released (or further processed).

There are some localized processes, such as an air circulation through a dryer, where the operating temperature is significantly above ambient, but not as high as to be the subject of the next section. For these duties, manufacturers can supply glass fibre filters, such as Freudenberg's Viledon LH series of filterpacks, which are able to accept gases at up to 300°C.

Table 5.19 Rigidized media filters versus fabric filters

Advantages of rigidized media elements	
Very compact:	filtration area in a given volume is 50–200% greater
High efficiency:	concentration of outlet emission is greatly reduced, especially for sintered media
Self-supporting:	no inserts needed to prevent collapse of bags under suction
Long bag life:	3 year warranty is standard for some rigidized filters
Limitations of rigidized media elements	
Pressure loss:	higher resistance to flow, especially for sintered media
Cleaning:	shaker/vibration mechanisms not suitable; pulse-jet cleaning is good for free flowing dusts but incomplete with tenacious dust
Blinding:	may occur with very fine dusts
Quality control:	must be higher than for conventional bags
Replacement cost:	the higher cost may be offset by longer life

Table 5.20 Comparative data for fabric rigidized media filter elements

	Standard bags	Sintered elements	Resin rigidized elements	Heat rigidized elements
Effective area per bag (m^2)	1.5	3.3	2.3	2.3
Typical clean air pressure drop at 1.5 m/min (mm WG)	10	70	20	15
Typical dust pressure drop at 10 g/Nm^3 and 1.5 m/min (mm WG)	100	170	120	100
Typical outlet emission (mg/Nm^2)	10	<1	2	2
Comparative cost per m^2 (media only)	1	4	3	2.5
Comparative cost including housing (typical only)	1	1.2	1	0.9

5.5 Hot Gas Filtration

The processing of hot exhaust gases from a wide variety of industrial processes, including power stations, imposes a difficult problem upon the system designer. If the process is to be efficiently run, then as much heat energy as possible should be recovered from the exhaust gas. Heat recovery usually means passage of the exhaust gas through some kind of heat exchanger – and most heat exchanger designs are easily plugged with solids if the exhaust is dusty – which most are. Hence, it is necessary to filter the exhaust gases free of such solids – and most filter media are unsuitable for temperatures much in excess of 100°C, let alone the 500°C or more of most process exhausts(16).

This quandary has led to one of the fastest growing parts of the filter media business – the provision of media capable of withstanding hot exhaust gas temperatures. These temperatures are such that no organic material is likely to be suitable, and recourse has to be made to inorganic media. Ceramic materials have become the obvious choice for this role, and much skill is now expended by the makers of such media in making them of adequate strength and filtration efficiency. Two major developments for future benefit – solid waste incineration and coal-fired energy generation – will rely on efficient hot gas filtration.

5.5.1 High-density, 'hard' ceramic media

This category, which is considered at length in Chapter 7, embraces the porous ceramic tubes and sheets that have long been used for a variety of industrial applications, including filtration, where they are particularly useful for hot gas clean-up operations. Typically made from granules of refractory materials such as aluminosilicates, silicon carbide and silicon nitrate, their void fraction is of the order of 40%, with pore sizes ranging from several hundred micrometres down to about 10 μm. A significant step in recent years is the development of laminated forms that incorporate ceramic membranes.

5.5.2 Low-density, 'soft' ceramic media

In contrast to the high-density ceramics, the modern low-density media are made from chopped ceramic fibres and have void fractions of about 90%. They are the basis of the filter candles that have been developed specifically for the rigorous needs of high-temperature dust filtration associated with processes such as coal combustion and gasification, incineration, and catalyst recovery. However, their use is by no means restricted to such arduous conditions: at the beginnings of the 1990s a report stated that around 30% of Cerafil plants were operating below 200°C, with another 30% in the 200–300°C range, and only 5% above 500°C.

Numerous advantages are claimed for these filter candles, as compared with traditional hard ceramics, including greater resistance to thermal and physical shock, lower pressure drop, less weight and lower cost.

5.5.3 Other rigid porous media

Sintered metal and porous plastic materials are suitable for use in dust filtration. Both, but especially sintered metal, permit fabrication to form self-supporting elements of diverse shapes. Sintered metals are suitable for hot gas treatment, while there are some plastic media capable of operating at 150°C and higher – but not at most exhaust gas temperatures. These media are discussed in more detail in Chapter 7.

5.6 Filtration of Compressed Air and Other Gases

The compressed air or other gas leaving a compressor will contain all of the impurities that were present in the inlet gas, plus oil picked up from the lubricant in the compressor (assuming that it is oil lubricated). A range of filters and other process units will usually be required as ancillaries to a standard compressor system. The number of filtration stages and the types of filter media appropriate to these stages depend both on the source of the gas (and hence the nature and amounts of contaminant) and on the degree of purity necessary for a specific application. To illustrate this, the following overview considers first a basic general-purpose compressed air system, and then the additional series of purification stages appropriate to achieve the very high purity essential for the most critical of the medical gas systems used by hospitals. (This treatment is an edited version of that included in the first edition of this Handbook, which was prepared with the assistance of domnick hunter ltd.)

5.6.1 Basic general-purpose compressed air system

The source of compressed air is the ambient air around the compressor, which could be quite dirty. Contamination may arise from the atmosphere or from the compressor itself (or, of course, from the compressed air distribution system). Typical levels of contaminants to be expected are summarized in Table 5.21. Minimizing their presence in the compressed air is achieved by the combined

Table 5.21 Level of contaminants to be expected in compressed air

Contaminant	Source	Typical concentration
Dirt particles	Atmosphere	Up to $140 \times 10^6/m^3$
Carbon	Burnt oil	Up to 10 mg/m^3
Water	Atmosphere	Up to 11 g/m^3
Rust	Pipework	Up to 4 mg/m^3
Oil	Compressor lubricant	5–50 mg/m^3
Oil/water emulsion	Mixture of oil and water	Up to 11 g/m^3
Vapour	Gaseous oil	0.05–0.5 mg/m^3
Micro-organisms	Atmosphere	Up to $3850/m^3$
Unburnt hydrocarbons	Atmosphere	Up to 0.5 mg/m^3

effects of an air intake filter that also protects the compressor from the ingress of damaging solid particles and an outlet air/oil separator. (Contamination that is picked up in the distribution pipework has to be dealt with by an additional point-of-use filter.)

5.6.1.1 *Air intake filter*

The air intake filter on a compressor normally consists of a mechanical separation stage combined with a pleated cylindrical fibrous paper filter with a high surface area. The filter medium is usually unsupported resin-impregnated cellulose paper of industrial grade (similar to that often used in automotive applications); polyurethane resin forms an integral end seal preventing bypassing of the medium, while the side seam can be mechanical, thermally formed or resin sealed. Typically the medium has a basis weight of 145 g/m^2, a thickness of 0.6–0.8 mm, and a minimum particle retention size of 5–10 μm.

5.6.1.2 *Air/oil separator*

The air/oil separator is basically a coalescing filter. It follows the compression, and comprises primary and secondary stages, with the objective of reclaiming the lubricating oil prior to the air being discharged at the required pressure. The primary stage utilizes gravity settling assisted by a reduction in gas velocity; downstream from it, the typical oil loading is 5–50 g/m^3 of polydispersed aerosols.

The second stage is normally a multi-layer cartridge, the media used depending on whether the flow through it is out-to-in or in-to-out. With the latter, the first, prefiltration layer can be a choice of several high particulate loading fibrous fabrics, such as a 0.3–0.7 mm thick, 100 g/m^2 viscose rayon bonded with regenerated cellulose. There is then an overlapping support layer, typically a 1 mm thick, 120 g/m^2 50% mixture of polyester/nylon bonded with synthetic rubber; the function of this is to contain the multiple layers of high-efficiency media wherein the fine oil mist droplets coalesce into much larger droplets.

These high-efficiency layers are of borosilicate glass fibres of various characteristics. They include a thin felt of coarser fibres bonded with phenolic resin and also microfibres bonded with an acrylic binder; integral support layers of spunbonded nylon provide intimate support for the fragile glass media to help the separator survive the rigours of frequent changes in pressure and the resultant cyclic loading of the media. Following the coalescing action of the glass fibre media, the large oil droplets are prevented from re-entrainment by a barrier comprising a 3–5 mm thick, 250 g/m^2 nylon or polyester non-woven acrylic bonded fabric; this ensures rapid drainage of the coalesced liquid to the base of the separator, for subsequent pressurized expulsion back to the air intake.

The whole coalescer assembly is resin bonded and mechanically locked into end caps of suitable location design, thus forming a highly efficient separator capable of removing particles down to 0.3 μm at over 99.995% efficiency. Oil carryover from a compressor is usually less than 5 mg/m^3 of air; this allows for long service periods for the compressor.

5.6.2 Purification stages for medically pure air

Each of the sequence of purification stages summarized in Figure 5.23 is discussed in sequence in the following discussion.

5.6.2.1 First stage: coalescing prefilter

This may be a combination of a cyclonic device with coarse coalescing media, and/or a pre-coalescer designed for high liquid and particulate loading. Non-woven synthetic fabrics coalesce relatively large droplets of oil and water: polypropylene, glazed on both sides for integral strength, is typically used, followed by anti-re-entrainment barriers similar to those used in the air/oil separator described above, which together give a high particulate loading device of long life.

5.6.2.2 Second stage: high-efficiency coalescing filters

Various grades of borosilicate glass microfibre media form the main component of this multi-layer filter. In order, the layers are: first a perforated stainless steel supporting cylinder, then graded nylon and polypropylene spunbonded sheets and then 0.5–1.5 mm thick, 100 g/m^2 microfibre media;

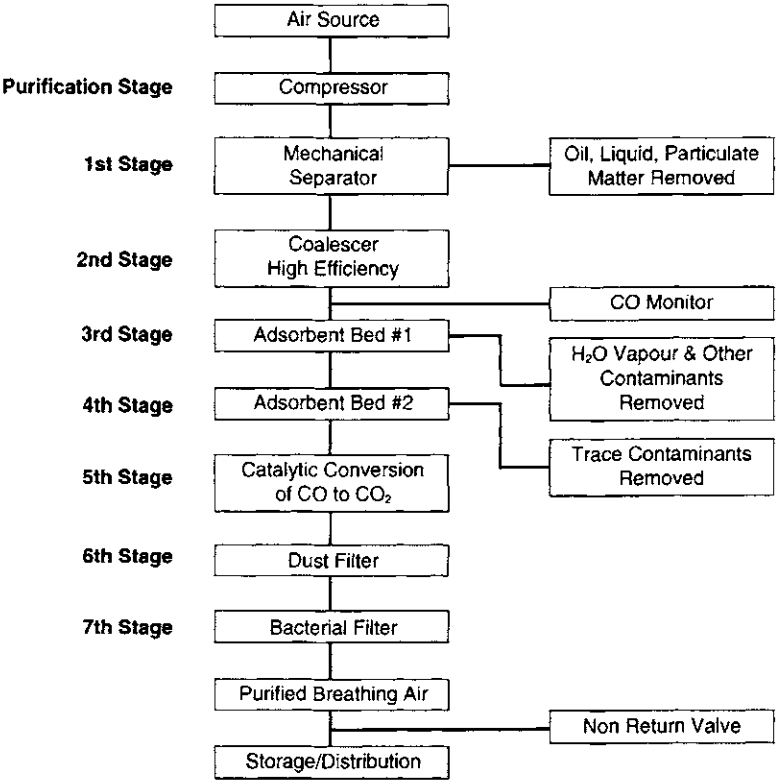


Figure 5.23. The sequence of separation stages to purify compressed air or gas for use in critical medical applications. (Illustration: domnick hunter ltd)

occasionally, a prefilter layer of phenolic bonded glass fibre is also included to collect particulates. The final layer is an anti-re-entrainment barrier to prevent coalesced liquid from being dispersed again into the air stream; this is generally reticulated polymeric foam with high drainage capacity, but for higher temperatures 2–4 mm thick, 400 g/m^2 spunbonded polyester media may be used. The oil carryover achieved is down to 0.01 mg/m^3 of air, with particulate retention of 0.01 µm.

5.6.2.3 *Third stage: adsorbent bed air dryer*

A desiccant dryer must be used if a low dewpoint (down to −70°C) is required. This is a bed of granular adsorbent material such as activated alumina or synthetic zeolites; when loaded with moisture, the bed may be regenerated by various means, including the use of heat or pressure swing desorption. Stainless steel screens are typically used to support and retain the granules; integral polyester spunbonded pads prevent most particles generated by attrition from migrating downstream.

5.6.2.4 *Fourth stage: adsorbent bed for removing hydrocarbon vapours*

This closely resembles a desiccant dryer but utilizes activated carbon as the adsorbent bed. Activated carbons may be manufactured from a wide range of materials, including wood, coal, and nut shell. For the removal of hydrocarbon vapours from compressed air streams, carbons based on coconut shell are often preferred. This bed is not regenerated *in situ* but is periodically replaced.

5.6.2.5 *Fifth stage: catalytic bed for conversion of toxic gases*

Normally this comprises a bed of granular oxides of copper and manganese that, by catalytic action and chemisorption, oxidize inorganic gases such as carbon monoxide to carbon dioxide and water. Because the levels of carbon monoxide present in compressed air are generally relatively low (15 ppm), the oxidation products do not usually form a problem. Dust retention pads need to be of high temperature resistance; bonded glass fibres are suitable for this use.

5.6.2.6 *Sixth stage: dust filter*

Despite their individual retaining filters, some dust fines will escape from the three preceding beds. Such fines are typically below 5 µm in size, so a high-efficiency dust removal medium is required at this point. Generally this will comprise 1.5 mm thick, 150 g/m^2 pads of an intermediate grade of borosilicate glass fibres. As in other filters using this type of media, a bonded synthetic support is necessary to prevent flexing and possible fracture of the glass fibres due to cyclic differential pressure loading. With flow out-to-in, a perforated steel core supports a thermally sealed polyester scrim; this inner scrim acts as a prefilter and also supports the glass fibres, outside of which there is a retaining screen.

5.6.2.7 *Seventh stage: bacterial filter*

The function of this final filter is to cold-sterilize the clean compressed air by the removal of any remaining viable organisms that are trapped and held within the filter matrix. In the presence of a carrier such as water, bacteria and viruses could eventually compromise the integrity of the filter; it is therefore essential that these filters remain dry, although they will also be subjected to a steam or chemical sterilization process to clean them. The filter media must consequently withstand sterilization, and must not add to the potential to support the growth of organisms. Favoured materials for this filter are highly efficient borosilicate glass microfibres or PTFE absolute membranes, supported by 100% glass fibre woven fabric or polysulphone/polypropylene spunbonded textiles; the media must not shed and must remain integral throughout repeated sterilization cycles. Stainless steel support cylinders and end caps are essential, whereas the membrane products tend to favour heat-treated moulded polypropylene support cages. The achievement of logarithmic reduction values greater than 9 (i.e. 9 orders of magnitude) for virus levels down to 0.04 μm (T4 Phage) must be demonstrated and verified.

5.7 Demisters

A demister comprises a thick pad of filaments that provide a high surface area, so that the liquid droplets of the mist may be captured by the individual filaments. The mechanisms of capture include direct interception (where the space between adjacent fibres is less than the diameter of a larger droplet), inertial impaction (due to the momentum of a larger droplet), and Brownian movement (bringing fine droplets sufficiently close to fine fibres). Since, especially with very small droplets, the minimum size of droplet captured is closely related to the fineness of the filaments, two basic forms of demister have evolved, one for coarse mists (droplets greater than 5 μm) and the other for fine mists (droplets less than 2 μm).

5.7.1 Coarse mists

Coarse mists comprise droplets ranging upwards from about 5 μm in diameter. Such droplets can readily be caught by comparatively heavy gauge (e.g. 100–300 μm) filaments of either metal or plastic, in the form of flat or (less often) tubular knitted mesh pads; these are illustrated in Figure 5.24 and are described in more detail in Chapter 6. The liquid thus collected within the pad drains from it continuously under gravity.

Table 5.22 summarizes the specifications of some of the most commonly used demister pads of one leading manufacturer.

Another manufacturer, KnitMesh, reports that normally a 10–15 cm thick demister pad will remove 99% of all droplets of 5 μm or greater, and over 99.5% of those above 10 μm, whilst still being very effective down to 2 μm.

For maximum efficiency, the superficial face velocity should be between certain limits; if it is too low, insufficient impingement will occur, whereas too high a velocity will result in re-entrainment. Accordingly, it is recommended that the working velocity should be between 75 and 30% of the maximum allowable velocity as given by the relationship:

$$V_m = K[(D-d)/d]^{0.5}$$

where V_m = maximum allowable velocity (m/s),

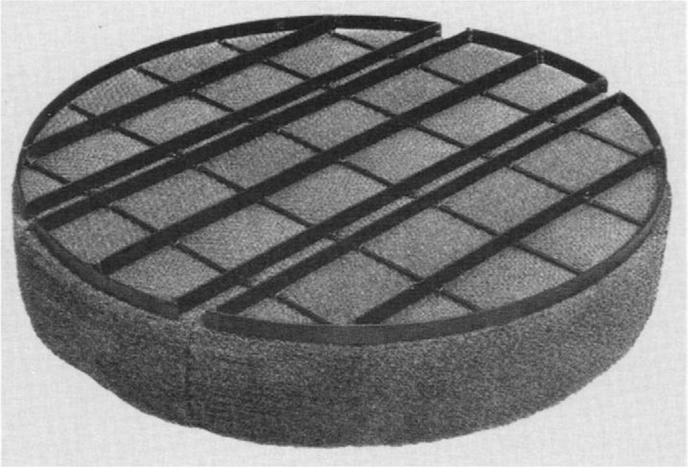


Figure 5.24. Knitted wire mesh demister pad. (Photograph: Begg Cousland Ltd)

Table 5.22 Specifications of most commonly used 'Becoil' demister pads*

Material	Mesh style	Wire diameter (mm)	Density (kg/m^3)	% Free volume	Surface area (m^2/m^3)
Stainless steel	H	0.28	192	97.5	360
	H	0.265	168	97.9	320
	SH	0.28	136	98.0	256
	SH	0.265	120	98.5	228
	L	0.28	112	98.5	210
	L	0.265	101	98.7	192
	UL	0.28	80	99.0	151
	UL	0.265	70	99.1	133
	H237	0.1524	135	98.3	430
	UL238	0.1524	54	99.3	194
	H1241	0.112	430	94.6	1936
Polypropylene	L	0.25	21	97.7	369
	UL	0.25	15	98.3	264
	H	0.50	69	92.4	606
	SH	0.50	50	94.5	439
Halar	H	0.50	127	92.4	606
	SH	0.27/0.5	59	96.5	390

*Begg Cousland Ltd.

d = density of gas/air,
D = density of liquid,
K = a constant, usually 0.107, but see Table 5.23.

Typical relationships between superficial gas velocity, droplet size and separating efficiency, and between superficial face velocity, water loading and pressure drop, are given in Figures 5.25 and 5.26. These are based on extensive tests with air and entrained water (at atmospheric pressure and 20°C) with standard general purpose KnitMesh.

Table 5.23 *K* values recommended by Knitmesh Ltd

Duty	K value
Clean conditions	0.107
Vacuum operation	0.061–0.085
High efficiency: clean conditions	0.107
Plastic demisters: highly corrosive conditions	0.064
High pressure: >20 bar	0.085

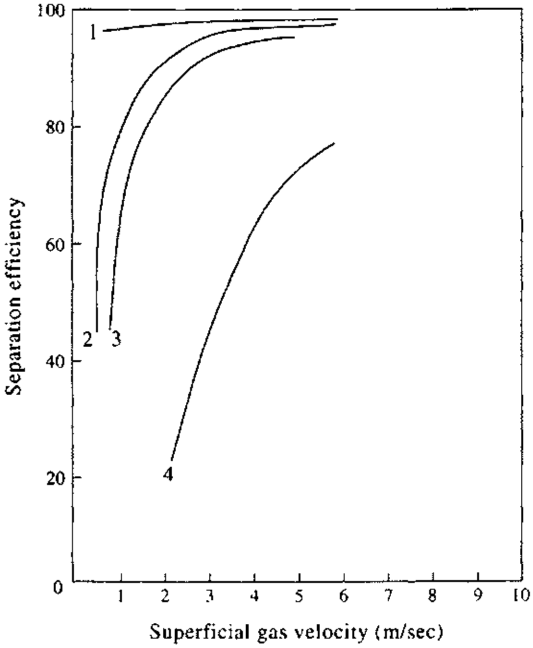


Figure 5.25. Effect of face velocity and droplet size on the efficiency of KnitMesh Type 9030 SL/SS demister. Air/water @ 20°C. Droplet sizes: curve 1–10 μm; curve 2–5 μm; curve 3–4 μm; curve 4–2 μm.

5.7.2 Hybrid mists

Hybrid droplets in the size range 2–5 μm can be agglomerated into greater than 5 μm droplets by prefiltration through a coalescer pad, the resultant larger droplets then being trapped by a conventional coarse demister. For example, Begg Cousland Ltd use this two-stage technique by combining their Becoil demister and Becone coalescer in series, to achieve an overall 100% removal of droplets greater than 5 μm and 98% removal of those greater than 2 μm, the corresponding overall pressure drop being approximately 120 mm WG.

The Becone coalescer pad is itself a modified form of the demister pad illustrated in Figure 5.23, being fabricated from a composite fabric that consists partly of monofilaments and partly of a staple fibre yarn. The very fine staple fibres, having a correspondingly higher filtration efficiency, serve as sites for collection of fine droplets; these coalesce into larger droplets that are then re-entrained into the discharging gas. The pressure drop across a coalescer pad is typically some three times that across a demister.

5.7.3 Fine mists

Candle-type demisters comprising annular pads of very fine fibres were developed simultaneously by Fairs(17) of ICI in the UK and by Brink(18) of Monsanto in the USA in the late 1950s. Separate accounts of both are included in the 1964 book edited by Nonhebel(19,20).

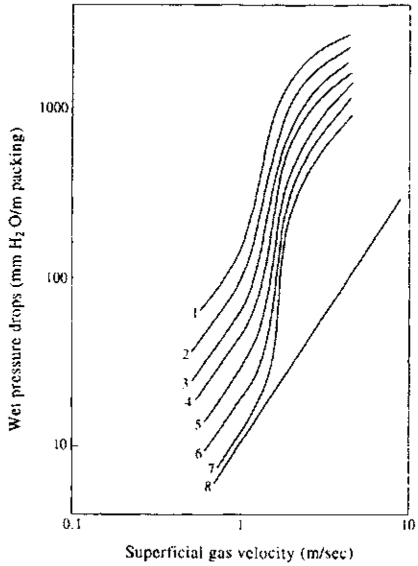


Figure 5.26. Effect of face velocity and water loading on the pressure drop of KnitMesh Type 9030 SL/SS demister. Air/water @ 20°C. Water loading curves: 1. 40 m^3/m^2 h; 2. 35 m^3/m^3 h; 3. 30 m^3/m^2 h; 4. 25 m^3/m^2 h; 5. 20 m^3/m^2 h; 6. 15 m^3/m^2 h; 7. 10 m^3/m^2 h; 8. dry pad.

While the general forms of these demisters are understandably very similar, comprising a multiplicity of long vertical candles (Figure 5.27) suspended in a suitable housing, there was a point of crucial difference in respect of the fibres: Fairs insisted on the importance of the fibres being hydrophobic, whereas Brink regarded this as an unnecessary limitation.

The Fairs thesis was based on the observations that hitherto the filtration efficiency of candle demisters was significantly less than that theoretically predicted, and that they tended to become waterlogged with collected liquid. By contrast, demisters of hydrophobic fibres were found to achieve the high efficiencies theoretically predicted, and to be free from water logging. This was explained by differences in the mode of collection of droplets on fibres, which could be ascribed to the one being hydrophilic and the other hydrophobic, as revealed in the photographs reproduced as Figure 5.28. The wetting of the surface of the hydrophilic untreated glass fibre (Figure 5.28(a)) causes its diameter to increase and therefore its filtration efficiency to decrease, a deterioration not suffered by the unwetted hydrophobic silicone-treated glass fibre (Figure 5.28(b)).

This erstwhile ICI technology is the basis of the Becofil range of candle demisters summarized in Table 5.24 and produced by Begg Cousland, utilizing fibres of different sizes, materials and packing densities. The fibres need to be as fine as possible, and typically are less than 15 μm. In practice, however, it is customary to incorporate a proportion of coarser fibres of about 30–40 μm, so as to provide stability and strength: experience showed that, with aqueous mists,

Figure 5.27. Candle type demister filter cartridges. (Photograph: Begg Cousland Ltd)

fine fibres alone tended to become saturated and not to drain due to partial collapse of part of the bed.

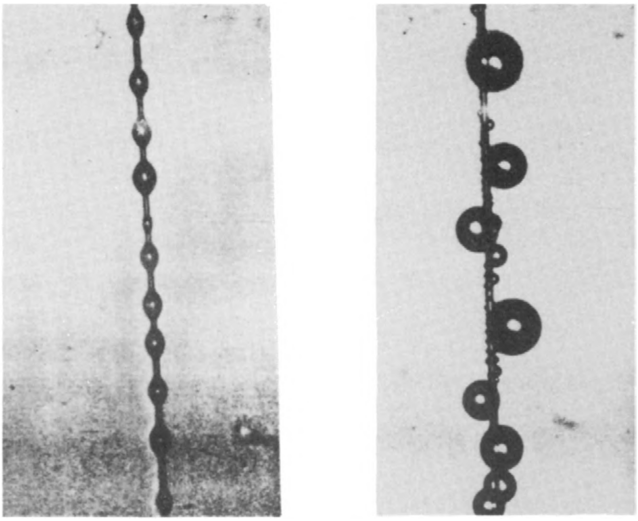
The carded mixture of fibres is compressed into a mould at about 110–160 kg/m^2, to form sections up to 0.6 m long, 5 cm thick and with an outside diameter up to 60 cm. These are thermally stress relieved and made up into candles up to about 5 m long, with internal and external mesh screens; the preformed media can be replaced in the field. Flow may be either out-to-in or in-to-out, the relationship between velocity through the exit phase (at equilibrium, with continuous drainage) and pressure drop being shown for two styles of cartridge in Figure 5.29.

5.8 Selection of Gas Cleaning Equipment

Four very different kinds of filtration equipment have been described in this chapter:

- ventilation and other atmospheric air filters;
- industrial dust collectors;
- compressed air systems; and
- demisters.

Of these four, the choices in compressed air treatment and demisters are relatively simple: standard or special quality for the delivered air, and size of liquid droplet in demisting.



(a) (b)

Figure 5.28. The mechanisms of mist collection depends on the wettability of fibres: (a) film-wise collection on hydrophilic glass fibres, (b) drop-wise collection on silicone-treated hydrophobic glass fibres.

The choices in industrial dust collection have a major divider, the level of operating temperature: a high temperature (certainly above 150°C) needs inorganic media – ceramics or possibly glass fibre. For ambient temperature conditions, then the choice lies basically between achieving solids recovery (using fabric filters) or an adequately clean air stream (the two together are not

Table 5.24 Examples of "Becofil" non-wettable fibre demisters[a]

Style	Removal efficiency	Pressure loss (mm WG)	Typical service
FFG 25 FF	High throughput 100% above 3 μ 90% above 1 μ 70% above 0.5 μ	100–300	Acid plants
TGW 15	High efficiency 100% above 1 μ 98% above 0.5 μ	150–450	Acid plants High pressure systems Plasticizer mists
B.12	High efficiency 100% above 3 μ 95% above 1 μ 80% above 0.5 μ	100–250	Acid plants Soluble fume
P.P.12	High efficiency 100% above 3 μ 98% above 0.5 μ	100–350	Corrosive service Soluble fume
P.T.12	High efficiency 100% above 3 μ 95% below 3 μ	100–300	Wet chlorine systems
H.T.P.	High throughput 85%+ on 1–3 μ 70%+ on 0.5–1 μ	100–300	Restricted space Lower efficiency below 3 μ

[a] Begg Cousland Ltd.

[b] Types of fibre used: glass wools, polypropylene, polyester.

[c] Support cage materials: mild steel, stainless steels, titanium, high nickel alloys, etc., polypropylene, pvc, pvdf, grp.

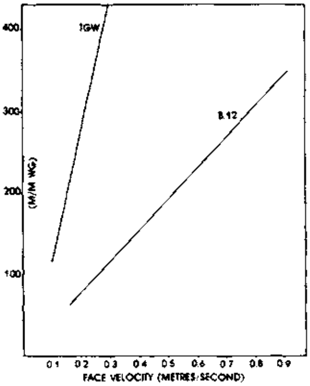


Figure 5.29. Pressure drop versus exit face velocity through 'Becofil' candle type demisters.

an impossible requirement). The choice among bag, pocket or cartridge is largely a matter of getting the correct medium – in addition to operating temperature, the parameters of abrasion, corrosiveness of the gas/solid system and flexibility govern the final choice. There may also be a problem in moisture content in the gas stream – too high a relative humidity may cause some media to weaken (especially polyester).

There is a bewildering choice available in the selection of ventilating filters, and here the decision will be influenced by the incoming dirt load and air flow required, but mostly on the degree of cleanliness in the delivered air.

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