CHAPTER 7

Coarse Porous Sheets and Tubes

Considerable attention has been given to natural and synthetic organic fibres as the main materials for dry- and wet-laid filter media in the earlier chapters of this Handbook. A quite different group of media is based on inorganic materials, with the use of granules or fibres bonded together, usually by the process of sintering. They are covered here, together with similar materials made from plastics, where the granules are also sintered.

7.1 Introduction

A group of porous media that provide filtration of coarser particles, from suspension in gases or liquids, is made by the aggregation of small particles (granules or fibres) of the basic material into useful shapes, either between rolls or in a mould. The aggregate is then heated to a temperature close to the melting point of the material, under pressure, so that there is localized melting at the points of contact among the particles (and any binder used in the aggregation is driven off or incinerated).

This sintering process confers an element of rigidity upon the resulting materials, so that they are used, for filtration purposes, either as sheets (including sheets cut into appropriately shaped pieces), or as tubes (open ended or closed at one end). This is a very useful group of media, with the inorganic nature of some of the materials enabling their use at quite high temperatures.

Included here are media made from the same basic materials (plastics, metals and ceramics), but now from the molten bulk material as foams – still rigid and strong in their solid form. For the sake of completion, tubes made from sintered glass fibres are also included in this chapter, even though the bulk of glass fibre media is covered in detail in Chapters 4 and 5 (as wet-laid glass paper and pads). There is also an overlap, in application terms, between the sintered metal fibre media discussed here, and the sintered metal meshes covered in Chapter 6.

As already mentioned, a major feature of the inorganic materials included here is their ability to operate at high temperatures. The importance of this particular set of applications is continually growing, although Bergmann's review of high-temperature gas cleaning requirements[11] still has a great deal of relevance. The topic is reviewed at a series of symposia, arranged at approximately three-yearly intervals.

7.2 Porous Plastic Media

By virtue of their organic nature, the media made from plastics stand apart from the other media discussed in this chapter, which are all inorganic. Nevertheless, their filtration characteristics merge seamlessly into those of the inorganic materials, the only significant difference being the reduced applicability in temperature terms.

The plastic media covered here are those made by the sintering of polymeric powders or granules, and those made from the molten state as foams. Not covered are sintered plastic fibre materials – because most of the non-woven media of Chapter 3 could be classified as sintered plastic fibre, since most synthetic fibre needlefelts and spun media have an element of sintering in their manufacture.

7.2.1 Sintered granular plastics

Thermoplastic powders may be moulded and sintered to produce flat porous sheets or a wide variety of three-dimensional shapes, as indicated in Figure 7.1. The most commonly used materials are high-density polyethylene and polypropylene, others being PTFE and PVDF. Table 7.1 summarizes the properties of the 1 m^2 sheets of one supplier. Examples of moulded discs and cylinders are given in Table 7.2, while a good view of the structure of such materials is shown in Figure 7.2.

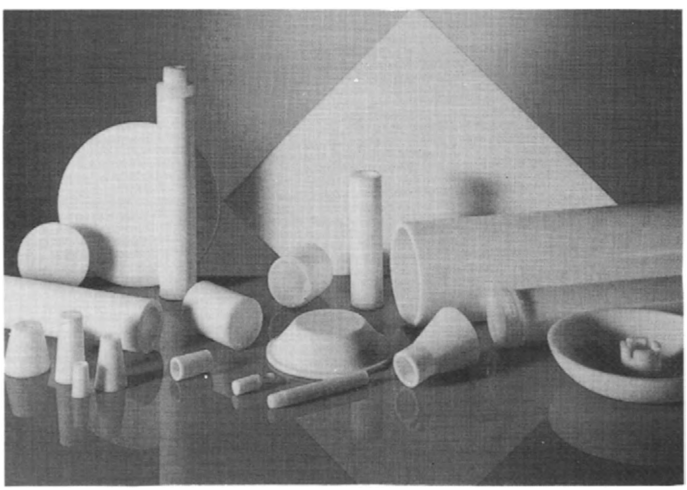

Figure 7.1. Examples of sintered porous plastic mouldings.

Table 7.1 Porvair's 'Vyon' porous sintered plastic flat sheets

Trade name	Material type: HDPE	PP	UHMWPE	Thickness (mm)	Pore size (μm): Max	Mean flow	Min	Typical air flow ($m^3/min/m^2$ at various pressures) (mbar): 1.27	2.45	5.00	10	20	Removal efficiencies (μm): Air nominal	Water nominal
Vyon D	*			3.20±0.18	30	16	8	–	–	2	3	8	6	10
	*			4.75±0.25	27	16	8	–	–	2	3	8	6	10
	*			6.00±0.40	–	35#	–	–	–	2	3	8	6	10
	*			8.00±0.40	–	30#	–	–	–	1	3	6	6	10
	*			10.00±0.40	–	27#	–	–	–	1	2	5	6	10
Vyon PPD		*		3.20±0.25	30	8	2	–	–	1	2	5	1	5
		*		4.75±0.25	30	8	2	–	–	1	2	5	1	5
		*		6.00±0.40	–	35#	–	–	–	1	2	5	1	5
Vyon F	*			0.75±0.12	127	40	12	–	28	–	66	106	25	40
	*			1.00±0.12	120	38	10	–	22	–	56	92	20	35
	*			1.50±0.15	105	36	10	–	14	–	43	75	20	30
	*			1.68±0.15	95	35	9	–	–	23	38	62	–	–
	*			2.00±0.20	78	30	9	–	–	16	30	53	20	30
	*			2.50±0.25	65	25	8	–	–	13	24	44	15	25
	*			3.20±0.25	55	23	8	–	–	10	20	36	15	25
	*			4.75±0.25	50	20	7	–	–	7	13	24	10	20
	*			6.00±0.40	56	22	10	–	–	4	8	16	10	20
	*			8.00±0.40	–	57#	–	–	–	3	6	11	–	–
	*			10.0±0.40	–	57#	–	–	–	3	5	11	–	–
Vyon PPF		*		1.50±0.15	145	40	8	–	–	20	38	58	10	20
		*		2.00±0.20	140	35	8	–	–	15	28	44	10	20
		*		2.50±0.25	105	30	5	–	–	14	27	43	5	15
		*		3.20±0.25	75	23	5	–	–	6	13	24	5	15
		*		4.75±0.25	75	23	4	–	–	6	12	24	5	15
		*		6.00±0.40	–	88#	–	–	–	4	8	18	5	15
Vyon Porvent	*			2.00±0.20	55	20	6	–	–	7	14	26	5	15
	*			2.50±0.25	55	20	6	–	–	7	14	26	5	15
	*			3.20±0.18	55	20	6	–	–	7	14	26	7	17
Vyon Porvent PP		*		2.00±0.20	72	28	6	–	–	7	14	26	5	15
		*		3.20±0.18	60	19	5	–	–	7	14	24	5	15
		*		4.00±0.25	65	20	4	–	–	7	14	26	5	15
Vyon HP	*			2.00±0.20	> 300	91	27	29	46	–	–	–	50	70
	*			2.50±0.25	> 300	98	21	34	62	–	–	–	80	100
	*			3.20±0.25	> 200	100	30	29	58	–	–	–	50	70
	*			5.30±0.30	–	125#	–	12	19	32	–	–	50	70
	*			6.00±0.40	–	180#	–	9	17	29	–	–	50	70
	*			10.0±0.40	–	125#	–	6	22	41	–	–	50	70
Vyon PPHJP		*		2.00±0.20	> 300	90	15	28	43	–	–	–	50	70
		*		2.50±0.25	> 300	87	14	24	38	–	–	–	50	70
		*		3.20±0.25	> 300	80	22	18	32	–	–	–	40	60
		*		4.75±0.25	170	60	10	11	20	34	–	–	40	60

Table 7.1 (*continued*)

Trade name	Material type			Thickness (mm)	Pore size (µm)			Typical air flow ($m^3/min/m^2$ at various pressures) (mbar)					Removal efficiencies (µm)	
	HDPE	PP	UHMWPE		Max	Mean flow	Min	1.27	2.45	5.00	10	20	Air nominal	Water nominal
		*		6.00±0.40	–	135#	–	11	19	34	–	–	40	60
Vyton T			*	1.00±0.07	40	18	10	–	–	4	8	20	2	10
			*	1.50±0.07	30	12	8	–	–	3	4	13	2	8
			*	2.00±0.10	15	10	6	–	–	2	4	8	1	5
			*	2.50±0.12	15	9	6	–	–	1	3	6	1	5
			*	3.20±0.16	15	9	6	–	–	1	3	6	1	5
			*	5.00±0.16	20	9	4	–	–	1	3	6	1	5
Vyton RT			*	3.20±0.25	28	11	3	–	–	1	6	9	6	10
			*	6.35±0.40	–	25#	–	–	–	1	3	5	6	10
			*	10.0±0.40	–	21#	–	–	–	–	1	3	6	10

Table 7.2 Properties of moulded HDPE discs and cylinders[a]

Grade	Pore size distribution			Permeability (darcies $\times 10^{-8}$)	Density (g/cm^3)	Minimum thickness (mm)	Porosity (%)	Removal rating from liquid[b] (µm)
	Min (µm)	Mean (µm)	Max (µm)					
P05	4	15	35	30	0.4–0.6	3.0	45	15
P10	7	30	75	40	0.4–0.6	3.0	45	30
P20	10	60	100	70	0.4–0.6	3.0	45	60
P30	15	75	175	70	0.4–0.6	4.0	45	75
P40	20	90	275	280	0.4–0.6	5.0	45	90
P50	30	125	350	440	0.4–0.6	6.0	45	125

[a] Porvair Technology Ltd.
[b] @ 99.9% efficiency.

7.2.2 Plastic foams

Polyurethanes are a conglomerate family of polymers in which the formation of the urethane group, –NH–CO–O–, by reaction between hydroxyl and isocyanate groups, is an important step in polymerization. This provides a linkage mechanism that may involve a variety of aromatic or aliphatic groups; aliphatic isocyanates tend to form the more flexible polyurethanes, such as the polyether and polyester types, which are used as filter media. Polyester foams are stiffer and less resilient than the polyether type.

Urethane foam formulations consist of low viscosity liquids, which, when mixed in appropriate proportions, react to form a foam and then cure into a cellular mass. Typically formulations contain isocyanates and polyols, together with catalysts, surfactants for stabilizing the foam structure, and blowing agents to generate gas and expand the mass. Most urethane foams are produced by one-shot processes in which all the raw materials are combined in a single step. Foam is produced in blocks that can be sliced to give thicknesses from 3 to 200 mm, and form sheets 2 m × 1 m.

An important feature of these foams is that the cells are reticulated, which means that they are open and interconnected, with a porosity of some 97%. This results from thermal chemical treatment, which causes shrinkage of material enclosing cells to leave the very open skeletal structure illustrated in Figure 7.3; in so doing, the thickness of the residual contracted walls is increased, with a corresponding increase in tensile strength and in resistance to heat, abrasion and chemical attack.

Appropriate regulation of the manufacturing process enables foams to be produced with pores of predetermined sizes. It is usual practice to characterize the pores in terms of the number per linear inch (e.g. 30 ppi); the average pore diameter corresponding to foams graded on this basis is indicated in Figure 7.4.

An alternative basis for classifying reticulated foams for use as filter media is in terms of the resistance of a 25 mm thick pad to the flow of air at 175 m/min, foam grades being expressed in nominal forms such as PPI-60. The relationship between these two grading scales is given in Figure 7.5.

Both polyester and polyether urethanes have good chemical resistance excepting against strong acids, alkalis and solvents; soaps, detergents, mineral

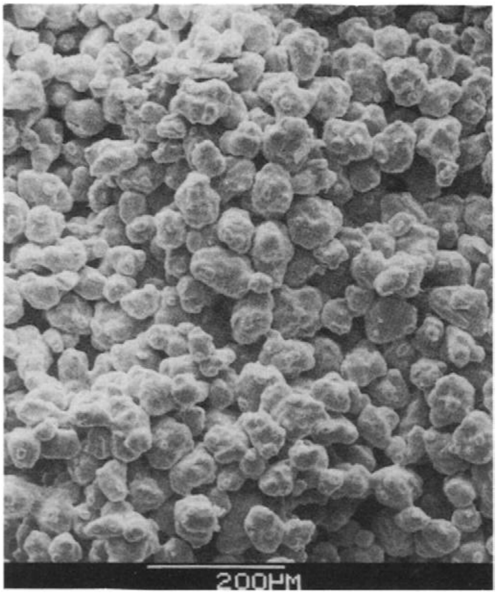

Figure 7.2. Micrograph of the fracture surface of 'Filtroplast' porous sintered plastic media.

oils and grease have no noticeable effect, allowing the foams to be easily cleaned and reused. Sterilization with boiling water or steam up to 105°C is not harmful for short periods.

Data for the Poret polyester type products of one manufacturer are given in Table 7.3; special foams based on silicon are completely nonflammable for operation at temperatures up to 220°C. Typical efficiencies available in air filtration are reported to be in the range 70–90% (ASHRAE 52-68).

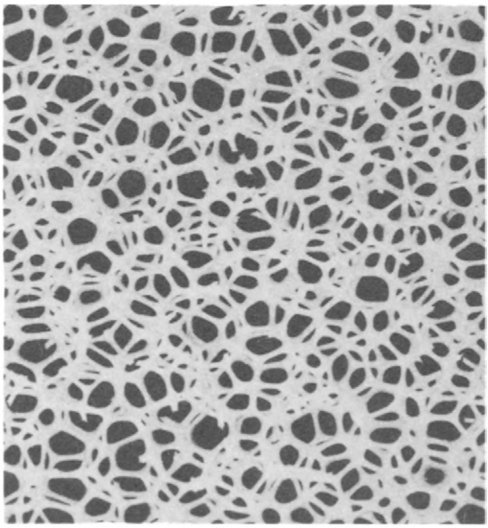

Figure 7.3. ×4 magnified view of Scott reticulated foam.

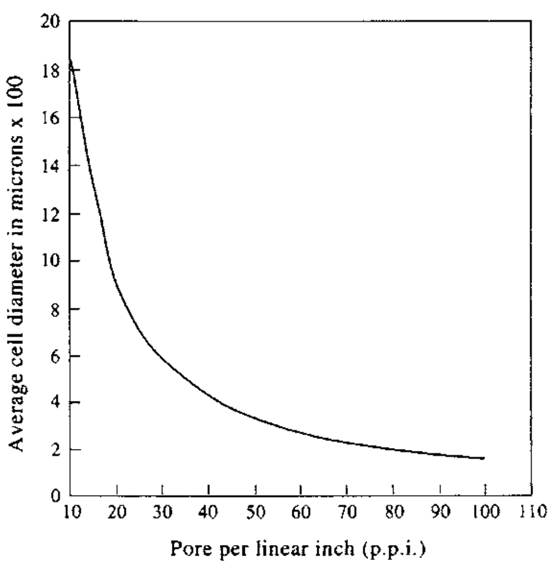

Figure 7.4. Average pore diameter versus pores per linear inch in polyurethane foam.

7.2.3 Microporous polyurethane

Figure 7.6 shows an electron microscope scan of a cross-section through Porvair's microporous Permair F medium developed for the filtration of liquids and gases. This is made from high molecular weight polyurethane using a process that involves leaching of soluble salts to form pores with an average size of 27 μm and a porosity of 80%. Available in continuous rolls approximately 1 m wide, and in thicknesses from 0.5 to 1.5 mm, its properties are summarized in Table 7.4.

7.3 Metallic Media

A wide variety of filter media is available based upon metals as the fundamental material. Such media carry the advantages of the characteristics of the metals, namely corrosion resistance, abrasion resistance and ability to operate at elevated temperatures. Metallic material is also quite easily workable, and this enables metallic media to be made from granules, fibres and filaments (wires), as required for the filtration needs of the media.

7.3.1 Metal fibre webs

Under the trade name Bekipor WB, the Belgian company NV Bekaert SA produces a range of webs of very fine 316L stainless steel fibres of diameters 22 μm down to 1 μm. The standard grades, extending down to 2 μm, are listed in Table 7.5; 1.5 and 1.0 μm grades are under active development. Some grades (8, 12 and 22 μm) are also available in Inconel 601 or Hastelloy; in addition, the 22 μm grade can be supplied in Fecralloy.

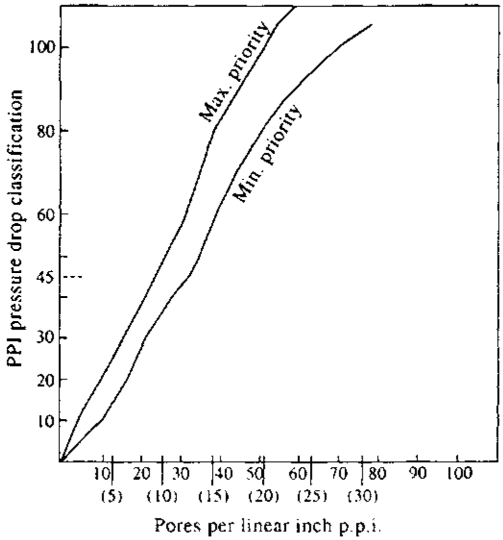

Figure 7.5. Relationship between the two pore grading scales for polyurethane foam.

Table 7.3 'Poret' reticulated polyurethane foams[a]

Nominal pore rating (ppi)	10	20	30	45	60	66	80
Nominal pore tolerance	8–15	15–20	25–35	40–50	55–56	60–70	70–90
True cell count tolerance (pores per linear inch)	5–11	11–20	20–28	33–43	43–58	58–62	62–76
Pressure drop[b] range @ air velocity of 100 m/min (mm WG)	0.7–1.1	1.1–2.2	2.2–3.4	4.5–6.4	6.4–12.2	7.6–12.7	12.7–14.7
Tensile strength (kg/cm^2)							
Average	1.34	1.55	1.83	2.04	2.20	2.20	2.25
Minimum	1.05	1.13	1.48	1.55	1.69	1.69	1.76
Elongation @ break%							
Average	300	325	350	400	400	400	400
Minimum	200	250	250	300	300	300	300
Tear strength (kg)							
Average	2.27	2.27	2.27	2.27	2.27	2.27	2.27
Minimum	1.36	1.36	1.36	1.36	1.36	1.36	1.36
Hardness to BS3367 (kg)							
Minimum	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Minimum sheet thickness recommended for air filtration (mm)	10	8	6	6	4	3	2.5

[a] Automet Filtration Ltd.

[b] Pressure drop through minimum recommended thickness.

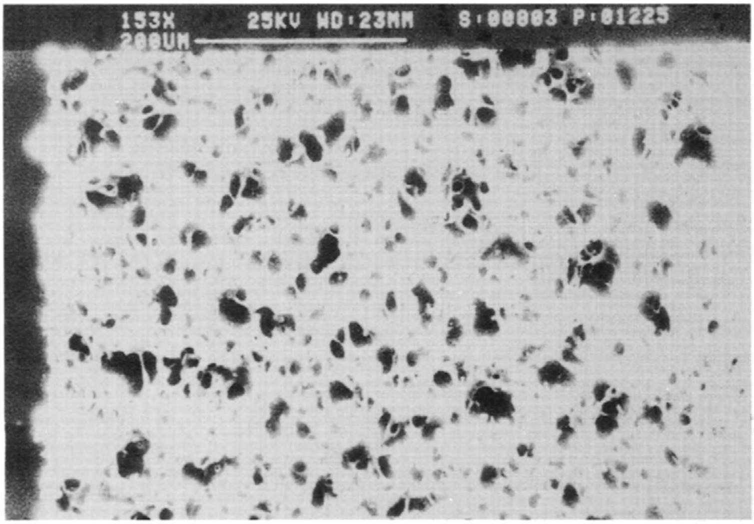

Figure 7.6. A cross section (magnification ×208) of 'Permair F'.

Table 7.4 Properties of 'Permair F' microporous polyurethane[a]

Average pore size (μm)	27
Porosity (%)	80
Operating temperature (°C)	
Maximum	150
Minimum	−20
Ultimate tensile strength (kg/cm^2)	1.9
Elongation (%)	300
Air permeability, m^3/m^2/min @ 25 mm WG	
0.5 mm thick sheet	9.2
0.7 mm thick sheet	3.9

Table 7.5 Standard grades of 'Bekipor WB' stainless steel fibre web[a]

Bekipor grade	Fibre diameter (μm)	Weight (g/m^2)
WB 02/150	2	150
WB 04/150	4	150
WB 08/300	8	300
WB 12/300	12	300
WB 22/300	22	300

[a] N.V. Bekaert S.A.

These very fine fibres are produced from metal rods by sophisticated adaptations of conventional wire drawing techniques. The final stages involve drawing bundles of wires, in some cases comprising several thousands in a bundle. The bundle-drawn fibres can be produced in the form of continuous bundles, broken bundles (slivers), cut fibres, spun yarns, threads, strands, web, sintered web, needlefelt, etc.

Web is supplied in standard panels of 1.2 m × 1.5 m. It is described as being composed of loose metal fibres in a non-woven labyrinth structure, and is used in coalescing, in air filtration (including HEPA filters) and demisting. It is also the basic material used by Bekaert to manufacture its range of sintered media.

7.3.2 Sintered metal media

Four main types of sintered metal media are available, depending upon the form of the metal prior to sintering: powders, fibres, woven meshes and composites that utilize combinations of media, such as powder and a mesh, or two or more layers of mesh.

This inevitably leads to major structural differences, which are reflected in properties such as porosity, pore size distribution, permeability and filtration efficiency. Both powder and fibre media function primarily by depth filtration: they are therefore generally less easily cleaned than surface-filtering sintered meshes.

Whilst bronze and stainless steel are the most commonly used metals, others available include nickel, Monel, Hastelloy, Inconel, titanium, aluminium and tantalum. Their mechanical properties are similar or identical to those of the virgin metal, the tensile strength decreasing as the porosity increases, but generally remaining high. One of the advantages of porous metals is that they can be rolled, cut, welded and generally fabricated by standard metalworking techniques (although localized blinding of pores may occur).

Many factors need to be taken into account in selecting the appropriate type of sintered metal for any specific duty. Some of these are listed in Table 7.6, in which the media types are crudely rated in respect of factors such as dirt-holding capacity or permeability, using a simple numerical scale; a high number (such as 4) is a poor rating. This preliminary selection matrix is based on experience of Pall Corporation who manufacture in-house all four basic types of media, the absolute micrometre removal ratings of which are included in the table. It is emphasized, however, that the relative performance of different media can vary widely with the nature of the suspension being filtered and operating conditions including filtration rate.

7.3.2.1 Sintered metal powder

Whereas earlier forms of sintered metals were made from particles of irregular shape, modern practice is based on powders comprising carefully graded spherical particles, typically in the range 0.5–100 μm. The free-flowing nature of these metal powders facilitates the use of moulding techniques to manufacture a wide diversity of shapes, such as shown in Figure 7.7. The manufacturing process may either involve a compression stage prior to sintering of moulded shapes, or it may effectively rely on sintering alone. Bronze and stainless steel are the most commonly used metals; examples of the standard products of one manufacturer are summarized in Table 7.7.

Although cylinders and tubes may be formed by conventional moulding methods, other techniques are also available. Isotropic moulding involves an inflatable insert that creates an annular space within which powder can be compressed radially. A proprietary process developed by Pall uses centrifugal force to form tubes with high-performance characteristics, as indicated for the four standard grades of Pall's S-Series PSS stainless steel medium in Table 7.8;

Table 7.6 Preliminary selection matrix for sintered metal media[a]

Basic type of medium Pall medium	Powder PSS	Fibre PMF	Mesh Rigimesh	Composite PMM
Absolute micron rating of finest grade (μm)				
Liquid duty	5	2.5	18	2
Gas duty	0.4		13	0.4
Dirt-holding capacity	2	1	4	3
Permeability	3	1	2	4
Gel removal	1	1	4	3
Durability	1	4	1	1
Cleanability	4	1	3	1
Area/1001[b]	4	1	3	1
Cost/1001[b]	1	4	3	2

[a] Pall Corporation.
[b] For a Pall 1001 cartridge, 254 mm long × 60 mm diameter.

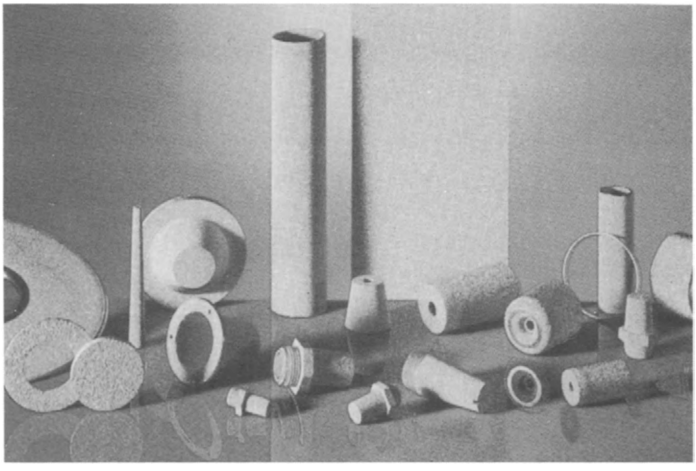

Figure 7.7. Examples of sintered bronze powder porous filter elements.

Table 7.7 Moulded bronze and stainless steel powder media[a]

Grade[b]	Pore size distribution			Permeability (darcies $\times 10^{-8}$)	Density (g/cm^3)	Minimum thickness (mm)	Porosity (%)	Micron removal rating	
	Min (μm)	Mean (μm)	Max (μm)					Liquid (μm)	Gas (μm)
B05	0.75	2	9	1.0	6.0–7.5	1.5	25	2	–
B10	2.5	6	25	2.5	6.0–7.0	2.0	30	6	–
B20	7.5	20	85	7.0	5.0–6.0	2.5	40	20	–
B30	10	35	150	30	5.0–6.0	3.0	40	35	–
B40	15	50	250	90	5.0–6.0	3.5	40	50	–
B50	20	75	320	150	4.5–5.5	4.0	45	75	–
S10	1.5	6	20	1.0	3.5–5.5	1.5	55	6	3
S20	2	10	30	2.0	3.5–5.5	2.0	55	10	3.7
S30	3	15	70	7.5	3.5–5.5	2.5	55	15	4.1
S40	5	30	160	25	3.5–5.5	3.0	55	30	5.5
S50	10	60	250	70	3.5–5.5	4.0	55	60	6.5

[a] Porvair Technology Limited.

[b] B=bronze 89/11; S=stainless steel 316L.

Table 7.8 Pall's PSS sintered metal powder media

Media grade	Form as produced	Micron removal rating: Liquid service[a] $\beta=2$ (50%)	$\beta=10$ (90%)	$\beta=100$ (99%)	absolute[c] (100%)	Gas service[b] absolute[c] (100%)	Nominal standard thickness (mm)	Permeability[e] to air	to water
P05	Sheets	0.5	2	3	5	0.3	1.3	5.3	0.07
P09	Sheets	2	4	7	9	0.5	1.3	7.0	0.22
H	Sheets	5	7	9	13	1	1.6[d]	17.7	0.26
F	Sheets	8	12	15	20	3	1.6[d]	53	1.13
E	Sheets	15	22	25	35	11	1.6[d]	98	3.7
D	Sheets	20	28	40	55	20	1.6[d]	340	8.7
H150	Discs	–	6.5	9	15	–	2	77	–
H250	Discs	–	10.5	18	25	–	2	218	–
H550	Discs	–	33	54	55	–	2	285	–
S050	Cylinders	0.5	2	3	5	0.4	1.6[d]	9	0.11
S100	Cylinders	4	7	8	10	0.8	1.6[d]	28	0.28
S200	Cylinders	7	10	14	20	2.8	1.6[d]	147	1.48
S350	Cylinders	13	17	24	35	11	1.6[d]	442	5.90

[a] Using AC dusts in water, efficiency measured by particle count.
[b] At air flow velocities of 3–5 m/min.
[c] Absolute ratings based on particle count.
[d] 3.1 mm thick also available as standard.
[e] $l/dm^2/min$ @ 10 mbar pressure drop.

these are available in lengths up to 50.8 cm and in four standard diameters: 12.7, 38.1, 50.8 and 60.3 mm.

Cylinders, as well as other shapes, can also be fabricated from flat sheet, by conventional metalworking techniques such as cutting, rolling and welding. Besides being versatile, this method has the added advantage of permitting close control of the thickness of the sintered metal, and facilitates the use of a wide range of different metals. For example, whilst 316L stainless steel is the standard material for sheets of Pall's PSS media, most of the six grades in Table 7.8 can also be supplied in the other metals listed in Table 7.9; these sheets are relatively large in size (585 × 1500 mm), with nominal thicknesses of 1.5 or 3.0 mm. Another variant of Paul's PSS media is the H-Series, which is produced only in the form of discs intended for the manufacture of the stacks of capsules widely used for polymer filtration. These items are similar to those shown in Figure 7.8.

Sintered metal powder media are generally of isotropic structure, with the same pore size distribution throughout their depth. They function by depth filtration, with small particles that pass through large pores in or near the inlet surface been subsequently trapped in smaller pores. Whilst this mechanism has the advantage of providing a high dirt-holding capacity, cleaning a filter element

Table 7.9 Alloys in which Pall PSS sintered powder media are produced

Stainless steel	316L, 304L, 310S, 347
Inconel	600, 671
Nickel	200
Hastelloy X	B2, C276
Carpenter	20

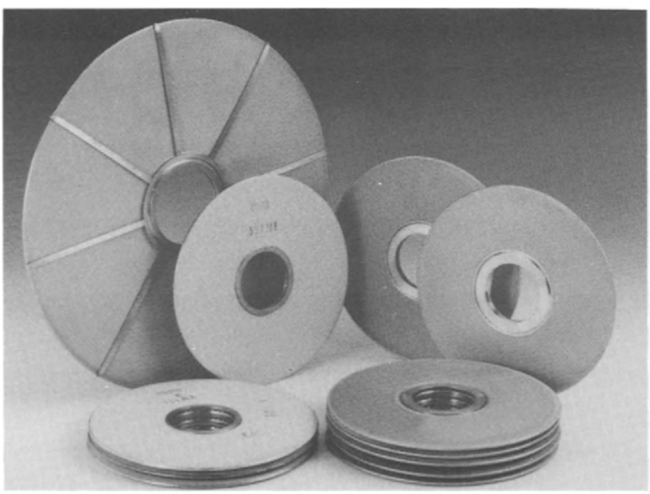

Figure 7.8. Examples of disc capsules used for polymer filtration. (Photograph: Fairey Microfiltration)

so that it can be repeatedly reused may require more vigorous methods than simple back-washing; the usual alternatives are ultrasonics and/or chemical cleaning, perhaps involving the use of an off-site service station. On the other hand, where bronze is chemically compatible with an application, its relative cheapness may justify discarding dirty elements with little or even no attempt to clean them.

GKN Sintermetal has developed an anisotropic sintered powder element, its Sika-R AS, which has a 200 μm coating of fine powder bonded on to the face of a coarse substrate. As compared with an isotropic medium of the same particle retention performance, the flow rate achieved is 3–4 times higher, while also backwash cleaning is improved[2]. As this material is effectively a membrane, it is further discussed in Chapter 8.

7.3.2.2 Sintered metal fibres

Sintered metal fibre media are made from long fibres of controlled diameters ranging upwards from 2 μm, and an outstanding characteristic of such media is their very high porosity. This is some twice that of typical powder-based media, with the consequential benefits of much lower resistance to flow and higher dirt-holding capacity. The pore size distribution is equally distinctive, as illustrated in Figure 7.9, which compares four different types of metal media for all of which the maximum pore size is approximately 30 μm; curve 1 for sintered fibres shows that the greatest flow goes through the smallest pores, thereby increasing the

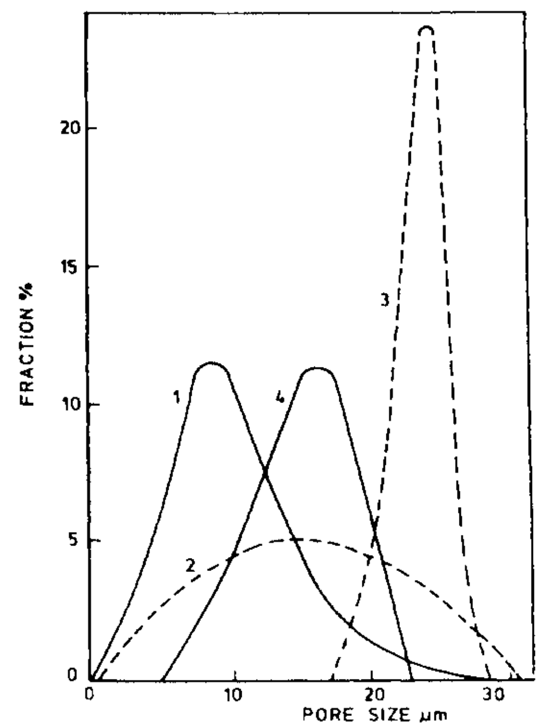

Figure 7.9. Pore size distribution curves for different types of media, as identified in Table 7.10.

probability of trapping the smallest particles, and resulting in achieving the smallest absolute filter rating, as shown in Table 7.10.

Figure 7.10 illustrates the close relationships between fibre diameter, porosity, the maximum pore size (d_m) and the absolute filter rating (a), as determined by challenging with glass beads. Note that, for these fibrous media, De Bruyne reported(3) $d_m = 2.4a$; moreover, as predicted theoretically(4), the absolute filter rating equals the mean flow pore size (i.e. the size at which 50% of the flow passes through the larger pores):

$$a = a_{MFP}$$

The high dirt-holding capacity of sintered fibre media is demonstrated by Figure 7.11, which shows the increase in pressure drop as different types of media, all of the same 20 μm absolute filter rating, become loaded with deposited solids.

Bekaert produces a variety of sintered media, based on the Bekipor web (see Section 7.3.1), as standard 1.1 m × 1.50 m panels; these may be fabricated by normal techniques (cutting, welding, pleating) to form filter elements in the shape of discs, cylinders, etc. Collectively identified as Bekipor ST, there are three standard series, identified by the suffixes AL, BL and CL, with a final numerical digit indicating the product generation (3 or 4); the characteristics of the standard grades are summarized in Table 7.11. The standard metal is 316L stainless steel but Inconel 601, Hastelloy X and Fecralloy are also available in some grades.

Table 7.10 Pore size comparisons for four different metal media

Curve	Type of medium	Maximum pore size[a] (μm)	Absolute filter rating[b] (μm)
1	Sintered fibre	30.9	13
2	Sintered powder	30.8	20
3	Wire mesh	28.4	23
4	Sintered wire mesh	22.8	17

[a] Maximum pore size from initial bubble point pressure.
[b] Absolute filter rating from challenge with glass beads.

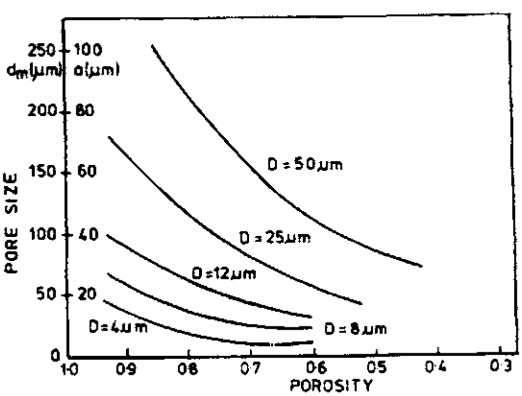

Figure 7.10. Porosity versus pore diameter for sintered metals made from fibres of various diameters.

Of the media listed in Table 7.11, both ST-AL3 and ST-CL3 are of graded multi-layered construction. Flow in the direction coarse-to-fine gives a high dirt-holding capacity and gel retention capability; the reverse direction of flow permits cake filtration and facilitates backwash cleaning. Sheets of these media are relatively soft and flexible, requiring adequate support in use. They may be supplied with supporting mesh sintered to both sides (indicated by the suffix SS) or to one side only (S), this being the flow-out side; this support is a 48 mesh of 0.125 mm wire with 400 μm openings, 0.17 mm thick and weighing 380 g/m^2. A distinguishing feature of the fourth generation media (ST-AL4 and ST-CL4) is their non-compressibility even at the high hydraulic pressures in polymer filtration.

Bekipor ST-BL is a non-graded sintered metal fibre medium that functions in the same way with flow from either side. One of the most common uses for this economical and lightweight material is for the filtration of low-viscosity fluids such as fuels and hydraulic fluids.

Pall's PMF fibre media are available in three distinct types, all in 316L stainless steel. The FH-Series, which can be corrugated or pleated (as in Figure 7.12), is suitable for pressures up to 69 bar and has been optimized for polymer melt filtration. The FL-Series, which can also be pleated into high area packs, is intended for low-pressure applications up to 17 bar. FS-Series media are composites, comprising a profiled pore structure of fibres sandwiched between supporting and protective layers of mesh; with high dirt-holding capacities, their application is for polymer filter segments. Removal efficiencies and flow characteristics of these media are summarized in Table 7.12.

7.3.2.3 Sintered woven metal

Unsintered woven meshes suffer from instability, with relative movement or deformation of the wires possible, resulting from stresses imposed by vibration, pulsating flow or high differential pressure. This can result in deterioration of the

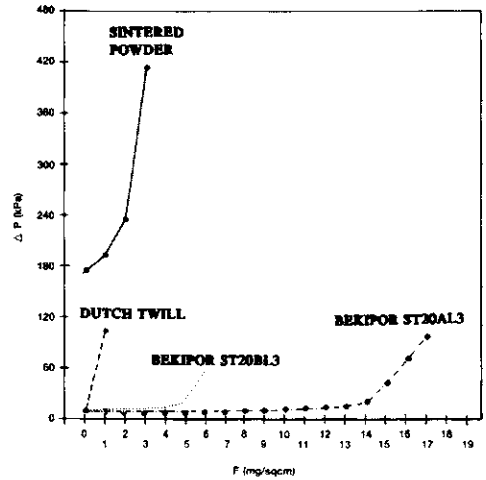

Figure 7.11. The rate of increase in pressure drop as dirt collects on a filter depends on the type of the medium.

Table 7.11 Characteristics of Bekipor ST sintered metal fibre media[a]

	Absolute filter-rating (μm)	Bubble point pressure[b] (Pa)	Average air permeability at 200 Pa[c] (l/dm^{-1}/min)	Permeability factor, k (m^2)	H/k (l/m)	Thickness, H (mm)	Weight (g/m^2)	Porosity (%)	Dirt holding capacity[d] (mg/cm^2)
3AL3	3	12 300	9	4.80E-13	7.29E+08	0.35	975	65	6.40
5AL3	5	7600	34	1.76E-12	1.93E+08	0.34	600	78	5.47
7AL3	7	5045	57	2.35E-12	1.15E+08	0.27	600	72	6.47
10AL3	10	3700	100	4.88E-12	6.56E+07	0.32	600	77	7.56
15AL3	15	2470	175	9.87E-12	3.75E+07	0.37	600	80	7.92
20AL3	20	1850	255	1.91E-11	2.57E+07	0.49	750	81	12.44
25AL3	25	1480	320	2.98E-11	2.05E+07	0.61	1050	79	19.38
30AL3	30	1235	455	4.37E-11	1.44E+07	0.63	1050	79	23.07
40AL3	40	925	580	5.84E-11	1.13E+07	0.66	1200	77	25.96
60AL3	59	630	1000	1.07E-10	6.56E+06	0.70	750	87	33.97
5BL3	5	7000	45	1.17E-12	1.46E+08	0.17	300	78	4.00
10BL3	10	3700	100	2.59E-12	6.56E+07	0.17	300	78	4.63
15BL3	15	2470	175	4.54E-12	3.75E+07	0.17	300	78	4.70
20BL3	20	1850	255	6.61E-12	2.57E+07	0.17	300	78	6.10
40BL3	40	925	580	1.50E-11	1.13E+07	0.17	300	78	14.60
60BL3	59	650	1100	2.43E-11	5.96E+06	0.15	300	74	21.50
5CL3	6	6100	35	4.38E-12	1.87E+08	0.82	975	85	11.67
10CL3	11	3500	95	1.07E-11	6.90E+07	0.74	900	85	17.13
15CL3	15	2400	200	2.29E-11	3.28E+07	0.75	900	85	18.95
20CL3	22	1700	325	3.67E-11	2.02E+07	0.74	900	85	29.10
5CL4	5	7400	27	1.65E-12	2.43E+08	0.40	900	72	6.80
10CL4	10	3700	71	4.33E-12	9.23E+07	0.40	900	72	9.50
15AL4	15	2450	140	7.26E-12	4.68E+07	0.34	750	73	8.20
15CL4	16	2400	150	9.15E-12	4.37E+07	0.40	900	72	11.90
20CL4	20	1850	200	1.22E-11	3.28E+07	0.40	900	72	12.00

[a] N.V. Beckaert S.A.

[b] Determined according to ASTM E128-61 equivalent ISO 4003.

[c] Determined according to NFA 95-352 equivalent ISO 4022.

[d] Determined according to Multipars method ISO 4572. Differential pressure = 8 × initial differential pressure.

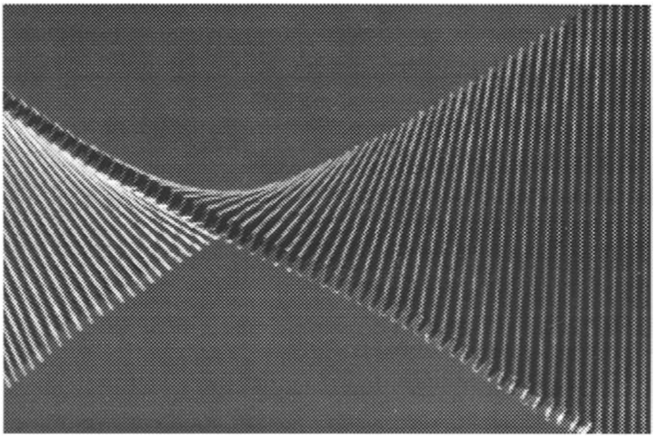

Figure 7.12. Pleated 'PMF' filter medium.

Table 7.12 Pall's PMF sintered metal fibre media[d]

Media grade	Micron removal rating in liquid service[a]				Thickness[b] (mm)	Permeability[c]	
	90%	98%	99%	100%		to air	to water
FH025	< 1.0	< 1.0	1.4	2.5	0.35	21.5	4.76
FH050	0.5	1.0	2	5	0.51	94	1.18
FH080	2	3	4	8	0.38	130	1.69
FH100	5	7	8	10	0.33	233	2.95
FH150	6	9	11	15	0.38	442	5.9
FH200	8	12	14	20	0.38	737	9.83
FH250	10	14	17	25	0.38	884	11.8
FH300	12	18	20	30	0.38	1105	14.75
FH400	14	20	24	40	0.38	1474	19.67
FL050	2	2.5	3	5	0.28	138	1.97
FL080	3.5	4	5	7	0.41	340	4.54
FL100	6	8	9	10	0.36	491	6.56
FL150	7	9	1	15	0.23	737	9.83
FL200	11	14	15	20	0.30	1474	19.67
FL250	13	18	19	25	0.30	2210	29.5
FS025	0.5	0.8	0.9	2.5	1.40	36	–
FS050	1.7	2.5	3	7.5	1.17	68	–
FS075	2.5	4	5	7.5	1.12	92	–
FS100	4.5	6	7	10	1.09	158	–
FS150	6.5	8.5	10	15	1.07	201	–
FS200	9	12	13	20	1.07	233	–
FS300	14	18	19	30	0.94	737	–

[a] Removal efficiency ratings are based on a modified F2 test method and actual particle count data.
[b] Thickness includes upstream mesh and downstream support.
[c] /dm^2/min @ 10 mbar.
[d] Pall Inc.

rated filtration efficiency, abrasion of the wires, the generation of metal particles that contaminate the filtrate, the unloading of previously collected particles into the filtrate, and structural failure.

These problems can be avoided by sintering the mesh so as to bond together the wires at all their points of contact. This greatly increases the rigidity of the mesh to produce an extremely strong structure that is resistant to deformation; it also permits the use of finer wires, resulting in more voids per unit area with a consequential decrease in resistance to flow and an increase in dirt-holding capacity. In addition, these media have the great advantage that they may be cut and shaped without risk of disintegration, in a way not possible with unsintered mesh.

Because of the similarity of application between sintered and unsintered meshes, these media are discussed in more detail in Chapter 6.

7.3.3 Metal foams

Retimet is a metal foam, developed by Dunlop, produced by replicating the skeletal or reticulated structure of the polyurethane foam described earlier in this chapter. The process involves electroplating the plastic foam with a metal such as copper, nickel, nickel-chrome or iron, and then removing the plastic by pyrolysis, to leave a structure of hollow metal struts as shown in Figure 7.13.

By controlling the thickness of metal deposited by electroplating, the density of Retimet can be controlled within the wide range of 1.55–15% of the density of the pure metal. The standard nickel foam has a nominal density of 0.45 g/cm^3, as compared with 0.65 g/cm^3 for nickel-chrome foam. Although certain prefabricated shapes can be produced, Retimet is most conventionally produced as sheets up to 20 mm thick, in grades determined by the number of pores per inch (see Table 7.13); the maximum sheet size is 700 mm × 375 mm in nickel, and 600 mm × 350 mm in nickel-chrome.

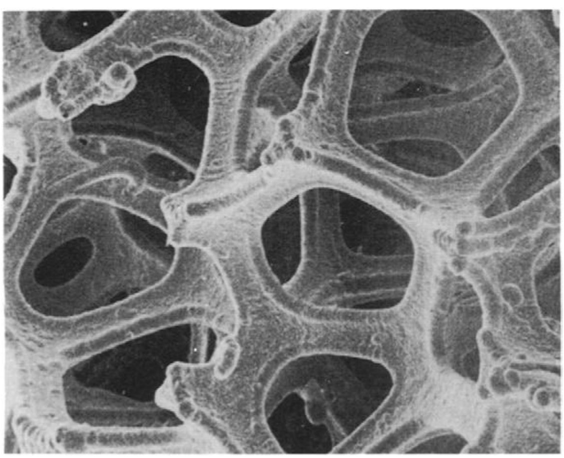

Figure 7.13. The pore structure of 'Retimet' metal foam.

The pore size and structure of Retimet are very similar to those of the precursor polyurethane foam. Its filtration characteristics are therefore generally also similar, but with some exceptions that are attributable to differences in electrostatic properties. For example, inorganic dusts are reported to blind polymer foam significantly faster than similar metal foam, probably because the polymer arrests much smaller particles; on the other hand, metal foam can be more readily and completely cleaned[5].

Retimet is a highly permeable material with a low pressure drop proportional to thickness and flow velocity. Figure 7.14 shows the pressure drop for air at 1.78 m/s through various grades of 10 mm thick Retimet, while Figure 7.15

Table 7.13 Thickness versus grades of Retimet metal foam[a]

Thickness (mm)	Grade (pores per inch)			
	10	20	45	80
2	No	No	Yes	Yes
4	No	Yes	Yes	Yes
7	Yes	Yes	Yes	Yes
13	Yes	Yes	Yes	Yes
20	Yes	Yes	No	No

[a] Dunlop Ltd.

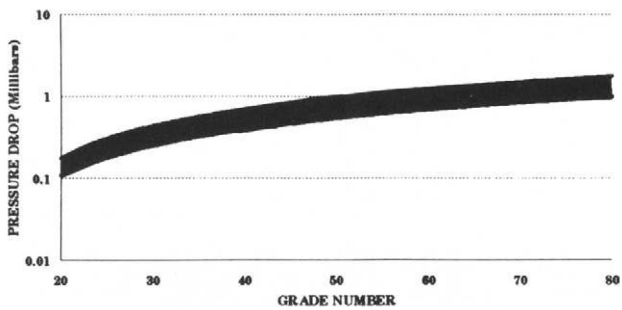

Figure 7.14. Pressure drop with air flowing at 1.78 m/s through 10 mm thick 'Retimet' metal foam.

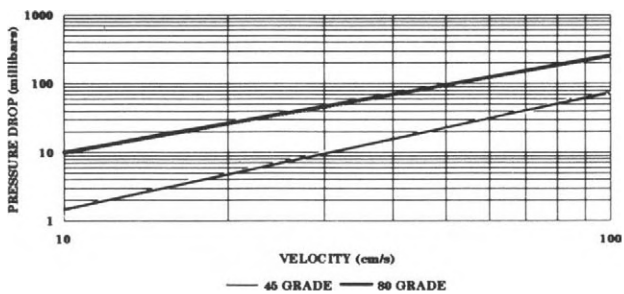

Figure 7.15. Pressure drop versus velocity of water flowing through 10 mm of 45 grade and 80 grade 'Retimet' metal foam.

correlates the pressure drop versus velocity for water through a 10 mm thickness of either 45 or 80 grade material.

The strength of Retimet is approximately proportional to its nominal density, nickel-chrome material being some 10 times stronger than nickel. A current application for the material is in the air/oil separation duty in jet engines.

7.4 Ceramic Media

It is appropriate to distinguish among four broad categories of ceramic filter media:

- conventional ceramics, including stoneware, which have long been used for industrial filtration, and are characterized as being hard and of high density;
- 'soft' low-density ceramic media, which are a recent development in response to the increasingly rigorous demands of the rapidly evolving field of hot gas filtration;
- ceramic membranes, important in cross-flow filtration, which are available with either ceramic or metal substrates; and
- ceramic foams, which have a unique role in the filtration of molten metals.

The key application for ceramic media is in the filtration of fluids, especially gases, at moderate to high temperatures. Whereas conventional ceramics are used for this application, Table 7.14 shows that low-density media offer both technical and economic advantages[6].

The media discussed in separate sections below: sintered particles and fibres, and foams, do not include all the types of ceramic media under development. Although formally classifiable as woven media, 3M's Nextel media[7] are based on extruded chemical sols of ceramic materials. The resultant filaments, after firing, can be combined into yarns and then woven, to give a ceramic medium that works well as a bag for use in fabric filters.

A quite different type of filter[8] for hot gases employs the ceramic material in the form of a honeycomb, with a series of 'dirty' gas channels arranged in parallel, in the direction of the gas flow, with a matching set of clean channels, into which the gas flows through the dividing walls. The collected dust is removed by a pulse jet.

Table 7.14 Properties of ceramic materials used for hot gas filter elements

Characteristic	Mullite	Bonded SiC	Vacuum-formed ceramic fibre	Post-treated vacuum-formed ceramic fibre
Relative hardness	'Hard'	'Hard'	'Soft'	'Soft'
Temperature limit (°C)	1000	> 1000	> 1250	> 1250
Weight (10 mm wall)	1.25	2.2	0.3	0.3
Resistance to thermal and physical shock	1.0	1.25	1.75	1.85
Cost	1.0	1.6	0.5	0.7

A major problem with ceramic filters is the achievement of adequate dust cake discharge, and this remains the current topic of greatest research effort[9]. By comparison with fabric elements, there is no movement of the medium during back flushing, and so the cleaning air pressures need to be significantly higher.

7.4.1 High-density ('hard') ceramics

This category of media embraces the porous ceramic tubes and sheets that have long been used for a variety of industrial filtration duties, especially for hot gases, and the now old-fashioned moulded stoneware filters for industrial liquids. Typically made from granules of refractory materials such as aluminosilicates, silicon carbide and silicon nitride, the void fraction of hard porous ceramic media is of the order of 40% with pore sizes ranging from several hundred micrometres down to about 10 μm, as illustrated by the data in Table 7.15.

Whilst this Table 7.15 includes pore size data, the microphotograph of Pyrolith in Figure 7.16 provides a useful reminder that pores are rarely circular. Eight grades of these media and the corresponding range of Coralith media are made by the techniques of powder metallurgy, rather than by traditional ceramic methods. Carefully graded particles are mixed with solid additives, which form high-temperature bonds, and with liquid additives, which give unfired strength. Semi-dry techniques are used to form the required shapes, which are fired, ground to the final dimensions if necessary, and checked for pore size. Examples of standard tubes and plates are summarized in Table 7.16; typical flow/pressure characteristics are illustrated in Figures 7.17 and 7.18.

The extensive Schumacher range of ceramic media is summarized in Tables 7.17 and 7.18. The three Dia materials (Dia-Brandol, Dia-Kermodur and Dia-Schumalith) are the result of the development of asymmetric structures that favour surface instead of depth filtration; they combine a thin fibrous fine pore layer with a coarse substrate, as shown in the example of Figure 7.19. They are thus membranes within the definition of Chapter 8, but reference to them and their characteristics are included here to show the differences between the two categories, with more data in Section 7.4.3.

Pall Vitropore ceramic candles were developed specifically to meet the demanding needs of CHP (combined heat and power) systems, but have proved successful in other aggressive gas-phase environments, such as petrochemical processing. Made entirely of silicon carbide (with sodium aluminosilicate as binder), with a fine outer coating on a coarse substrate, they are available in only one high-performance grade and one diameter, but of four different lengths; their dimensions, physical properties and performance characteristics are summarized in Table 7.19.

7.4.2 Low-density ('soft') ceramics

In contrast to the high-density ceramics, the modern low-density ceramic media are made from chopped ceramic fibres and have void fractions of about 90%. They are the basis of the novel filter candles developed for use in multiple

Table 7.15 Fairey Industrial Ceramics range of high density ceramic media[a]

Composition	Chemical resistance	Trade name	Grade	Pore diameter (μm)		Porosity (%)	Cross breaking strength (kg/cm^2)	Average specific weight (g/cm^3)	Nominal micron retention	
				Average	Maximum				Air/gas	Liquid
Alumino-silicate particles bonded by glass based flux	Hot and cold acids (not hydrofluoric acid or acid fluorides) and alkaline solutions up to pH 9 and hot gases up to 900°C	Pyrolith	P0	11	15	35	175	1.5	0.3	1
			P9	20	25	35	161		1	2
			P8	30	35	35	140		2	6
			P6	50	70	45	105		10	20
			P5	90	110	45	88		20	40
			P4	155	200	45	70		30	60
			P3	300	400	45	53		50	150
			P2	525	650	45	35		100	230
Alumina particles bonded by a glass based flux	Hot and cold acids (not hydrofluoric acid or acid fluorides) and alkaline solutions up to pH 9 and hot gases up to 1000°C	Coralith	C0	11	15	35	263	1.5	0.3	1
			C9	20	25	35	242		1	2
			C8	30	35	35	210		3	6
			C6	50	70	45	158		10	20
			C5	90	110	45	133		20	40
			C4	155	200	45	105		30	60
			C3	300	400	45	79		50	150
			C2	525	650	45	53		100	230
Alumino-silicate particles bonded by refractory agents	Poor resistance to chemical and physical abrasion (not usually critical as main use is hot gases up to 1400°C)	TR Media	TR6	90	110	45	35	1.5	20	–
			TR5	155	200	45	35		30	–
			TR4	300	400	45	35		50	–

Composition	Chemical resistance	Trade name	Grade	Pore diameter (µm)		Porosity (%)	Cross breaking strength (kg/cm²)	Average specific weight (g/cm³)	Nominal micron retention	
				Average	Maximum				Air/gas	Liquid
Siliceous material	Good resistance to acids although liable to attack by physical abrasion (main use is on domestic water systems)	KN Media	KN	–	4.5	65	42	0.8	–	–
Porcelain mullite	High resistance to acids and alkalis up to 1400°C	Celloton	VI	–	1	50	350	1.5	–	–

[a] Fairey Industrial Ceramics Ltd.

assemblies with pulse jet or reverse flow cleaning, as shown in Figure 7.20, used 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, many installations having operating temperatures well below 500°C.

The candles are formed by vacuum filtration of a water suspension of chopped fibres and a ceramic or clay binder, using a suitably shaped porous forming tool on which a filter cake is deposited. This cake is then removed from the former and thermally treated to evaporate water and solidify the binder; the candle may also be subjected to post-treatment with a variety of ceramic coatings, such as colloidal alumina to increase corrosion resistance. Clift[10] stated that appropriate techniques ensure that the orientation of the fibres is generally normal to the direction of flow through the candle, which is important in ensuring good filtration properties.

Their typical form and dimensions are as indicated in Figure 7.21 and Table 7.20, although the details vary from one manufacturer to another; for example, Tenmat utilizes multiple tubular sections to achieve lengths up to 4 m or more.

Table 7.16 Standard sizes of ceramic filter tubes and plates[a]

Dimensions, inches (mm)			Grades	
			Pyrolith	Coralith
Max. length	*i.d.*	*o.d.*		
4 1/2 (114)	1 1/8 (29)	1/2 (13)	P3–P0	C3–C0
10 (254)	1 1/8 (39)	1 (25)	P4–P9	C4–C9
10 (254)	2 (50)	1 1/4 (32)	P2–P0	C3–C0
15 (381)	2 3/4 (70)	2 (50)	P3–P0	C3–C0
20 (508)	2.9 (74)	2.4 (61)	P5 only	–
18 (458)	3 (77)	2 (50)	P3–P0	C3–C0
12 (305)	4 (102)	3 (77)	P3–P0	C3–C0
39 3/8 (1000)	2 3/8 (60)	1 1/2 (40)	P5–P9	C5–C9
39 3/8 (1000)	2 3/4 (70)	2 (50)	P5–P9	C5–C9
Flanged elements				
1000 mm Flanged 70 mm dia.	60	40	P5–P9	C5–C9
Tiles/filter plates *Sizes, inches (mm)*			*Grades*	
12 (305)×2 (50)×1 (25)			Pyrolith P2–P8	
12 (305)×4 (100)×1 (25)				
12 (305)×6 (153)×1 (25)				
12 (305)×12 (305)×1 (25)			Coralith C2–C8	
20 (508)×16 (406)×1 (25)				
20 (610)×12 (305)×1 (25)				
20 (610)×16 (406)×1 (25)			TR4–TR6	

[a] Fairey Industrial Ceramics Ltd.

Table 7.17 Properties of Schumacher high density ceramic filter media[d]

Filter media		Filtration fineness (nominal) (μm)[a]	Pressure drop (mbar)[b]	Specific permeability, (nPm)[c]	Porosity (%)	Density (g/cm³)	Linear expansion coefficient (10^{-6}·1/K)	Temperature resistance (°C)	Bending strength (Pa)	Bursting pressure (bar 10^5 Pa)	Test piece dimensions (mm) i.d./o.d.
AEROLITH	5	1.0	75	2.52×10^1	45	1.40	16	400	17	50	Ø70/40
	10	1.5	30	4.20×10^1	45	1.25	16	400	15	30	Ø60/40
	20	2.0	10	1.89×10^2	45	1.25	15	400	7	15	Ø70/40
	30	3.0	4	3.15×10^2	45	1.25	15	400	6	10	Ø60/40
	40	5.0	3	4.19×10^2	45	1.20	15	400	5	10	Ø60/40
	60	ca 15.0	1	6.29×10^3	45	1.20	15	400	4	–	tile h=50
BRANDOL	20	–	12.5	2.01×10^2	35	1.60	–	180	13	–	tile h=20
	60	–	2	9.44×10^2	30	1.60	–	180	10	40	070/40
	80	–	1.5	1.25×10^3	30	1.70	–	180	10	40	070/40
	120	–	0.5	3.77×10^3	30	1.70	–	180	9	30	070/40
DIA-BRANDOL	60	0.5	5.5	2.28×10^2	30	1.6	–	180	10	40	060/40
DIA-KERMODUR	30	1.0	12	1.57×10^2	40	2.1	8	1000	15	25	Ø60/30
DIA-SCHUMALITH	30	1.0	12	1.57×10^2	35	2.0	5.5	1000	15	50	060/30
	40	1.0	9.5	1.98×10^2	35	2.0	5.5	1000	10	40	060/30
DIAPOR	G30	<0.05	1500	4.17×10^1	55	1.5	6.8	1000	13	–	tile h=5
	G40	<0.03	2000	3.15×10^1	55	1.5	6.8	1000	13	–	tile h=5
DUROCEL	5	<0.03	70	2.68×10^1	65	0.6	–	150	–	6	Ø70/40
	20	0.5	35	5.36×10^1	60	0.6	–	150	–	15	Ø70/40
KERMODUR EK	10	1.5	20	6.29×10^1	40	2.1	8	1000	25	90	Ø60/40
	20	2.0	10	1.25×10^2	40	2.1	8	1000	20	50	060/40
	30	3.0	5	2.52×10^2	40	2.1	8	1000	15	30	060/40
	50	ca 15.0	2	9.38×10^2	45	1.8	8	1000	10	–	tile h=15
	100	ca 25.0	0.3	1.05×10^4	45	1.8	8	1000	8	–	tile h=25

Table 7.17 (*continued*)

Filter media		Filtration fineness (nominal) (μm)[a]	Pressure drop (mbar)[b]	Specific permeability, (nPm)[c]	Porosity (%)	Density (g/cm^3)	Linear expansion coefficient (10^{-6}·1/K)	Temperature resistance (°C)	Bending strength (Pa)	Bursting pressure (bar 10^5 Pa)	Test piece dimensions (mm) i.d./o.d.
KERMODUR KK	20	2.0	10	1.26×10^2	55	1.5	7.5	1000	9	25	Ø60/40
	30	3.0	5	2.52×10^2	55	1.4	7.5	1000	8	25	Ø60/40
SCHUMACEL HTHP		1.0	26	4.81×10^1	50	1.6	5	1000	–	20	Ø60/40
SCHUMALITH	3	0.5	700	2.70	25	2.1	5.5	1000	35	100	Ø70/40
	5	1.0	300	6.29	30	2.0	5.5	1000	35	80	Ø70/40
	10	2.0	30	6.29×10^1	35	2.0	5.5	1000	25	60	Ø70/40
	20	3.0	15	1.25×10^2	35	2.0	5.5	1000	20	60	Ø70/40
	30	5.0	7	2.70×10^2	35	2.0	5.5	1000	15	50	Ø70/40
	40	ca 10.0	5	3.77×10^2	35	2.0	5.5	1000	10	45	Ø70/40
	50	ca 15.0	2	9.38×10^2	45	1.8	5.5	1000	10	–	tile h=15
	100	ca 25.0	0.3	1.05×10^4	45	1.8	5.5	1000	8	–	tile h=25
SCHUMATHERM	10	1.5	100	1.89×10^1	35	1.6	5	600	9	40	Ø70/40
	20	2.0	40	4.71×10^1	40	1.5	5	600	8	30	Ø70/40
	30	4.0	25	7.55×10^1	40	1.5	5	600	7	20	Ø70/40
	40	8.0	10	3.15×10^2	40	1.5	5	600	6	20	Ø120/40
	60	ca 10.0	5	3.75×10^2	35	1.4	5	600	5	20	Ø70/40
THERMOLITH	20	2.0	40	4.71×10^1	40	1.5	5	1000	8	30	Ø70/40

[a] Ambient air, particle counter.
[b] Air @ 250 m/min.
[c] 1 Nanoperm (nPm)=0.1013 darcy.
[d] Pall Inc/Schumacher.

Table 7.18 Schumacher range of high density ceramic filter media[a]

Trade name	Description
Aerolith	A pure white mixture of crystalline and amorphous silicates. Thermally resistant to 400°C. Chemically resistant to hot and cold neutral and acidic liquids and gases. Suitable for wide range of applications.
Brandol	Quartz sand bonded with phenolic resin for use in fine bubble aeration or fluidization. Resistant to cold and warm neutral and acidic fluids.
Diapor	A mixture of alumina silicates with extremely fine porosity and highly resistant to acid. Ideal for diaphragms in electro-chemical processes.
Dia-Brandol Dia-Kermodur Dia-Schumalith	Schumacher's newest developments. Asymmetric open-pored support body with ceramic membrane surface. Used mainly for dust filtration up to 1000°C.
Durocel	Glass microfibres bonded with resin for use at up to 150°C to separate aerosols and fine particles from compressed air and vacuum pump exhausts. Chemically resistant to nearly all mineral and synthetic lubricating oils and to carbon tetrachloride.
Kermodur	Aluminium oxide assures high strength and high resistance to temperature changes. Resistant to acidic and alkaline environments. For high temperature processes (filtration of metals) up to 1000°C.
Schumacel HTHP	Silicon carbide and fibres of aluminium oxide bonded with silicon. For hot gas filtration, resistant to aggressively oxidizing or reducing atmospheres at temperatures above 1000°C.
Schumalith	Ceramic-bonded silicon carbide. Very good resistance to solutions of acids and acidic salts, saturated and superheated steam and to hot gases up to 1000°C. In grain size 3 can be used for sterile filtration of gases.
Schumatherm	A mixture of alumino silicates, stable to 600°C. Mainly used for filtration of liquids, as linings for nutsches and as support bodies for precoat filtration.
Thermolith	A mixture of ceramic-bonded fire-clay, stable at temperatures of 900°C. For filtration of liquids and process gases.

[a] See also Schumacher's carbon media in Table 7.27.

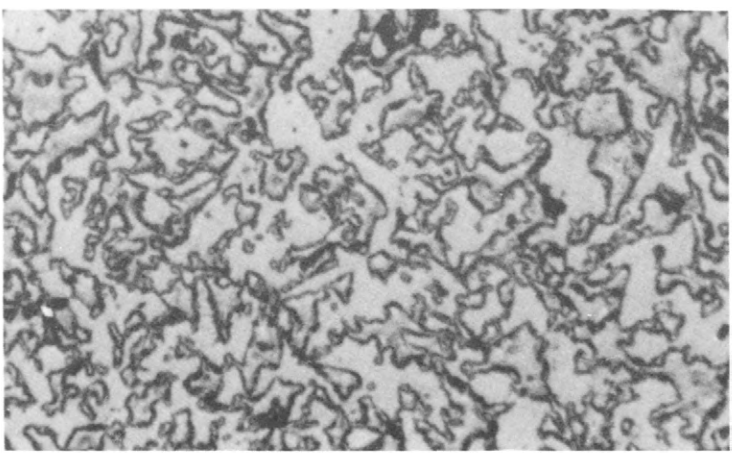

Figure 7.16. Photomicrograph (×32 magnification) of polished 'Pyrolith P8' with pores visible as darker areas.

The ceramic materials also vary as therefore do both the densities and maximum operating temperatures; some examples are given in Table 7.21.

Numerous advantages are claimed for these filter elements, as compared with traditional hard ceramics, including greater resistance to thermal and physical shock, lower pressure drop, less weight and lower cost. Care must, of course, be taken to ensure the absence of liquids in the use of ceramic filters[11], either as condensed vapours through operation below the dew point, or as molten droplets in the dirty gas, that might block the filter.

They achieve high levels of filtration efficiency with dust emissions less than 1 mg/m^3; as the data in Table 7.22 illustrate, the high efficiency of a virgin filter (which is dependent on the face velocity) increases after 'conditioning' by operation through

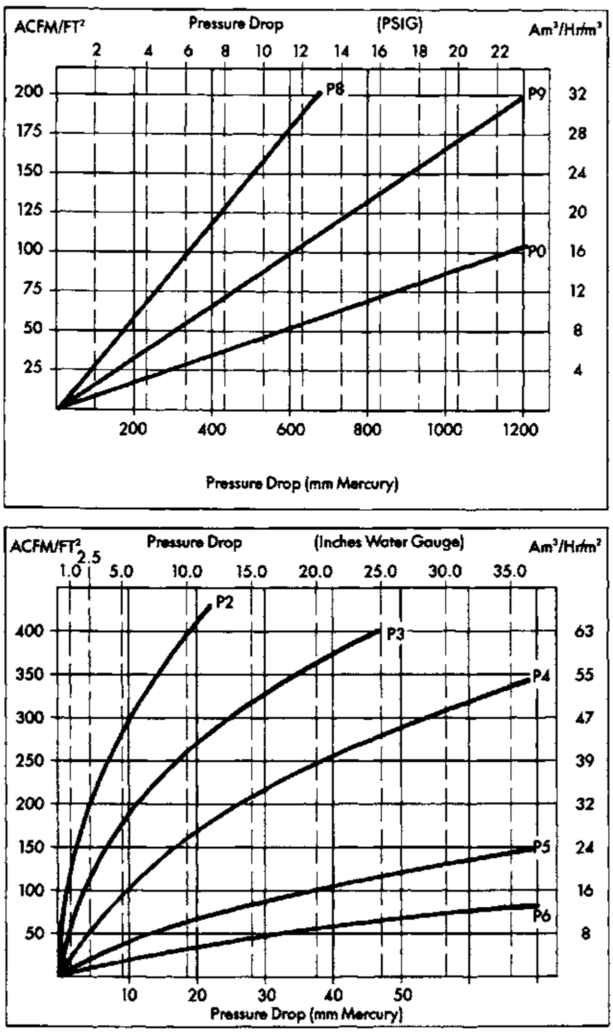

Figure 7.17. Typical clean air flow/pressure curves for 'Pyrolith' and 'Coralith' ceramic media.

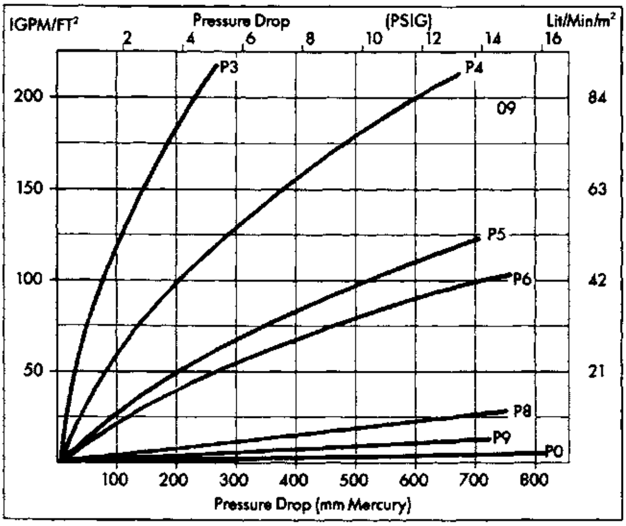

Figure 7.18. Typical clean water flow/pressure curves for 'Pyrolith' and 'Coralith' ceramic media.

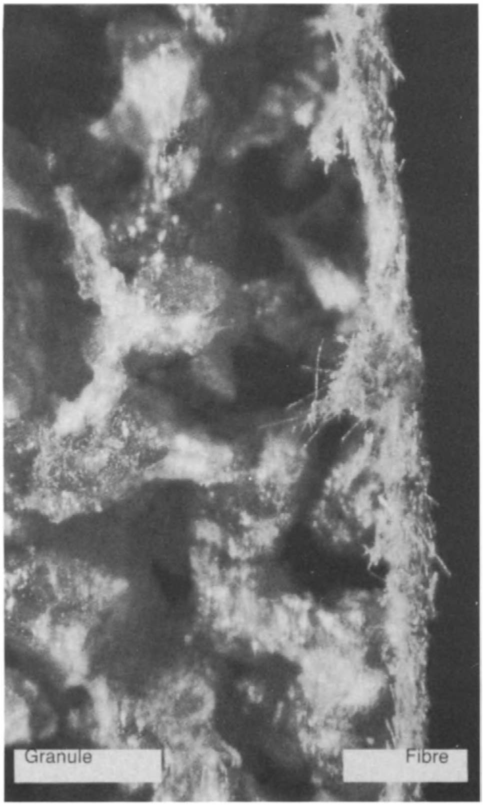

Figure 7.19. Microphotograph of a section through 'Dia-Brandol' showing the thin fibrous layer on a coarse granular substrate.

15–20 cleaning cycles, and becomes even higher during extended operation, because of the retention of a thin cake of dust particles on the surface[12].

A secondary effect of this residual cake of dust is that, under equilibrium operating conditions, the pressure drop is dependent on the nature of the dust as well as on the face velocity, as is illustrated in Figure 7.22.

Table 7.19 Properties and dimensions of 'Vitropore' ceramic candles[a]

Gas removal rating[b] (μm)	2
Removal efficiency[c] (%)	99.9
Mean pore size (μm)	7–10
Average 1st bubble point pressure (mbar)	10.96
Average open bubble point pressure (mbar)	16.44
Permeability to clean air (bar/m^3/s/m^2)	0.0869
Dimensions	
Length (m)	0.5, 1.0, 1.5, 2.0
Inside diameter (mm)	40
Outside diameter (mm)	60
Bulk density (g/cm^3)	1.7
Weight, 1.5 m long (kg)	4
Porosity (%)	46
Maximum temperature (°C)	1000
Thermal expansion coefficient per °C	4.7×10^{-6}
Modulus of rupture[d] (bar)	110 minimum

[a] Pall Corporation.
[b] Particle count.
[c] Weight % based on AC FineTest dust in air, particles 1 μm and greater.
[d] Burst test subjects 2.54 cm long ring sample 60 mm o.d.×40 cm i.d. to slowly increasing uniform internal pressure.

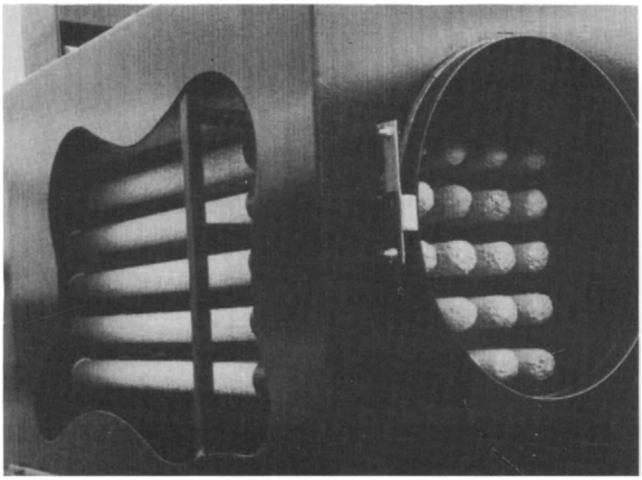

Figure 7.20. A multi-element ceramic candle filter. Dust collects on the outside surfaces.

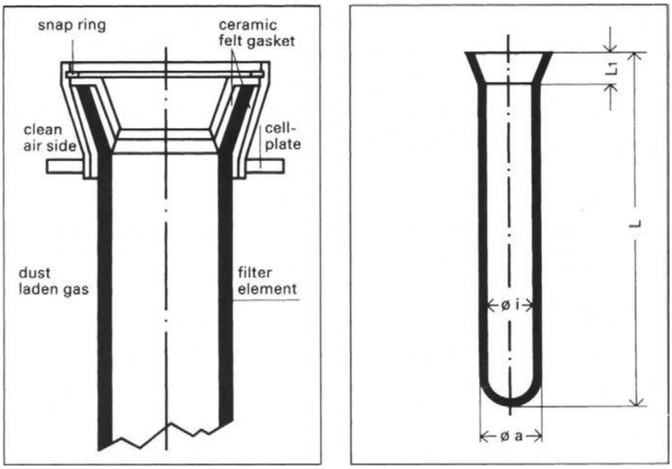

Figure 7.21. Typical form of candle filter element. See Table 7.20 for dimensions.

Table 7.20 Characteristics of 'Pyrotex' low density filter candles[a]

	KE 85/60		KE 85/150	KE 85/200
Outside diameter Ø a (mm)	60	60	150	200
Inside diameter Ø i (mm)	42	42	110	160
Length of element L (mm)	985	1500	1530	1000
Length of collar L_1 (mm)	10	10	130	100
Weight (g/m^2)	1600	1600	35 000	3500
Weight/element (g)	300	450	2600	2400
Thickness, mm	9	9	20	20
Density (g/cm^3)	0.18	0.18	0.18	1.18
AP, l/dm^2.min at 200 Pa	120	120	60	60
Pore volume (%)	93	93	93	93
Surface area/element (m^2)	0.19	0.28	0.66	0.60

[a] BWF Textil GmbH & Co. KG.

Table 7.21 Temperature limits of low density ceramic candle filter

Manufacturer	Trade names	Material limit	Temperature (°C)	Density (gm/cm^3)	Porosity (%)
Madison	Cerafil S	Aluminosilicate	900	0.37	86
	Cerafil XS	Aluminosilicate	900	0.39	86
	Cerafil HS	Alumina	1200	0.61	–
Tenmat	Firefly	Various	1600	0.25–0.40	85–95
BWF Textil	Pyrotex KE85	Ceramic fibres	850	0.18	93

The low-density ceramic candles supplied by Brightcross[12] are available either in cylindrical form, or with a slight taper, which is claimed to reduce bridging between candles, and to increase ease of dust removal. Their temperature limits are dependent upon their material of construction:

Mineral fibre	Continuous: 700°C	Intermittent: 1000°C
Calcium silicate	1000°C	1500°C
Refractory ceramic	1200°C	1700°C

7.4.3 Ceramic membranes

Ceramic membranes are generally composites, with the membrane supported on a coarser ceramic substrate, which may be in the form of a flat plate or a tube. An important and growing variety utilizes metal as the substrate. Both types are discussed in Chapter 8.

Table 7.22 Filtration efficiencies of Cerafil S ceramic candles[a]

State of filter	Face velocity (cm/s)	Efficiency[b] (%)	Eurovent class (EU)
Virgin	1	99.6	12
	3	98.8	11
	4	97.6	11
Preconditioned	4	99.3	12
Used	4	99.9	12

[a] Madison Filter.

[b] Tested to BS 3928 using 0.6 μm NaCl particles.

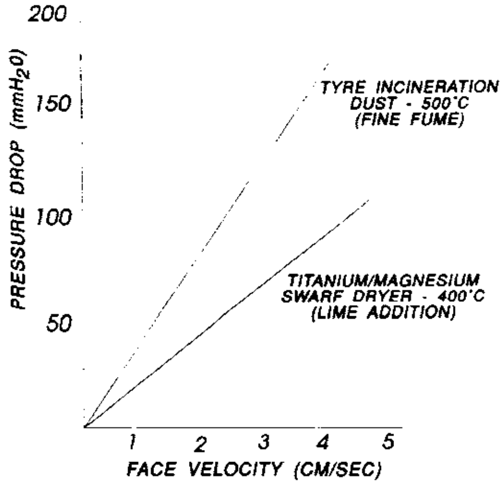

Figure 7.22. The pressure drop across a conditioned filter candle depends on both the face velocity and the nature of the dust being filtered.

These composites are primarily used for hot gas filtration of fine dusts in the form of tubular and star-shaped elements. for which typical data are given in Table 7.23. Because they function by surface filtration, composites are cleaned more thoroughly by an intermittent back pulse: this is demonstrated by Figure 7.23, which shows the typical relationship between pressure drop and the number of filtration cycles for several different media. Very much better performance is shown for the four grades of 'membrane' element, as compared to the standard elements.

7.4.4 Ceramic foams

This distinctive form of porous ceramic, used for many years in the foundry industry for gravity filtration of molten metal, is known as ceramic foam because of its very open structure, with porosities typically from 70 to 90% or more. One manufacturing process[13] involves impregnating polyurethane foam with an aqueous ceramic slurry and compressing it to expel excess slurry; the coated foam is then subjected to several stages of heat treatment, resulting in combustion of the organic polymer and sintering of the ceramic particles. The latter are typically mixtures of alumina and chromia, but may also be zirconia, magnesia, silica, etc.

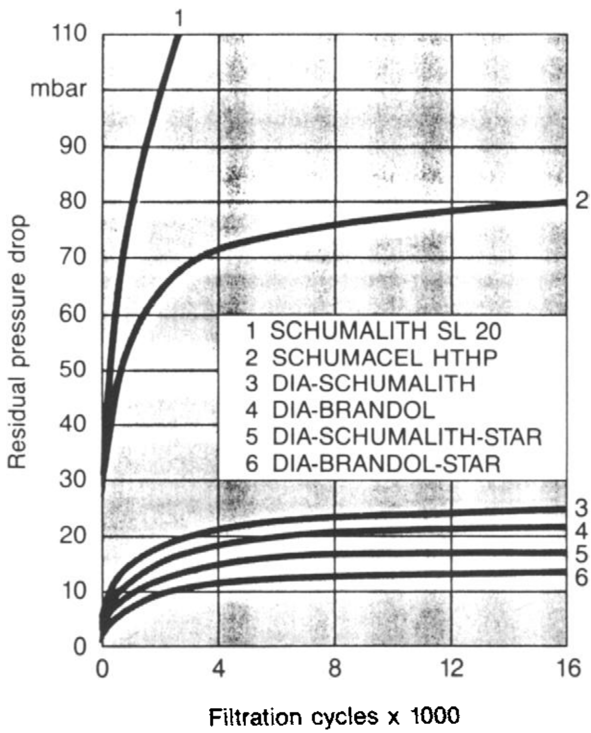

Figure 7.23. Example of the residual pressure drop of ceramic filter elements as a function of the number of filtration/cleaning cycles. Temperature 20°C; gas velocity 200 m/h; cycle time 6 min.

Table 7.23 Schumacher ceramic candle filter elements

	Schumalith 20 homogeneous granular	Schumacel HTHP heterogeneous granular/fibre	Dia-Schumalith asymmetric granular/fibre	Dia-Schumalith Star asymmetric, fluted granular/fibre	Dia-Brandol asymmetric granular/fibre	Dia-Brandol-Star asymmetric fluted granular/fibre
Maximum temperature (°C)	1000	1000	1000	1000	180	180
Granule/fibre diameter (μm)	120	120/3	300/3	300/3	500/1	500/1
Pore size (μm)	40	30/10	100/30	100/30	200/5	200/5
Outer element diameter (mm)	60	60	60	60	60	60
Inner element diameter (mm)	40	40	30	30	40	30
Wall thickness (mm)	10	10	15	15	10	15
Flange diameter (mm)	75	75	75	75	75	75
Flange thickness (mm)	15	15	15	15	15	15
Element length (mm)	1000/1500	1000/1500	1000/1500	1000/1500	1000/1500	1000/1500
Filtration area (m^2)	0.16/0.26	0.16/0.26	0.16/0.26	0.29/0.47	0.16/0.26	0.26/0.45
Weight (kg)	4.2/6.2	4.1/6.2	4.1/6.2	3.3/4.7	2.7/4.0	2.2/3.2

The structure of the ceramic foam thus effectively replicates the skeletal or reticulated form of the polyurethane foam discussed in Section 7.2.2. By selecting grades of polyurethane foam with pores of appropriate sizes (or combinations of sizes), and by forming it into the desired shape, a correspondingly wide variety of ceramic foam products may be produced, such as is shown in Figure 7.24.

Pore sizes are generally characterized in terms of the number per inch or centimetre, and can be controlled within the range 3–100 ppi. For example, there are three standard grades of Foseco's Sedex filters for cast iron alloys; the 10 ppi grade is for ductile and austenitic irons, the 20 ppi for grey iron and the 30 ppi for malleable iron. As indicated in Table 7.24, the capacity of these rectangular blocks depends both on their dimensions and on the alloy being filtered.

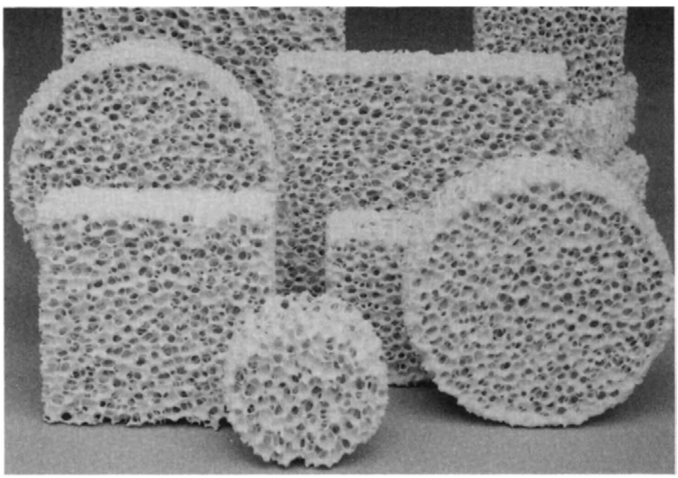

Figure 7.24. Examples of 'Stelex' ceramic foam filters for molten metals.

Table 7.24 Capacity of 'Sedex' ceramic foam blocks for filtering molten metal[a]

Block size (mm)	Surface area (cm^2)	Maximum capacity (kg)		
		Cast iron		Ni Resist/Inmold
		Grey iron	Spheroidal graphite	
35×35×22	12.5	50	25	12
35×50×22	17.5	70	–	–
50×50×22	25	100	50	25
50×75×22	37.5	150	75	37
50×100×22	50	200	100	50
75×75×22	56	200	100	50
100×100×22	100	400	200	–

[a] Foseco Ltd.

An approximate relationship between pore diameter and the number of pores is provided by Figure 7.25. An indication of air permeability as a function of the number of pores is given by the pressure drop curves at various face velocities in Figure 7.26. These figures relate to the ceramic foams produced by the Selee Corporation (now part of Porvair) from the variety of ceramic materials summarized in Table 7.25; comments on the applications of these foams are summarized in Table 7.26.

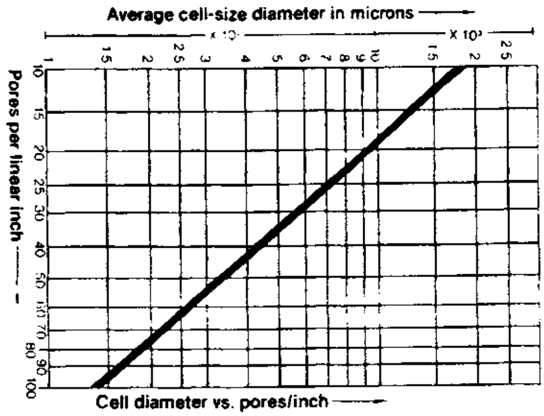

Figure 7.25. Relationship between pore diameter and pores per inch in ceramic foam.

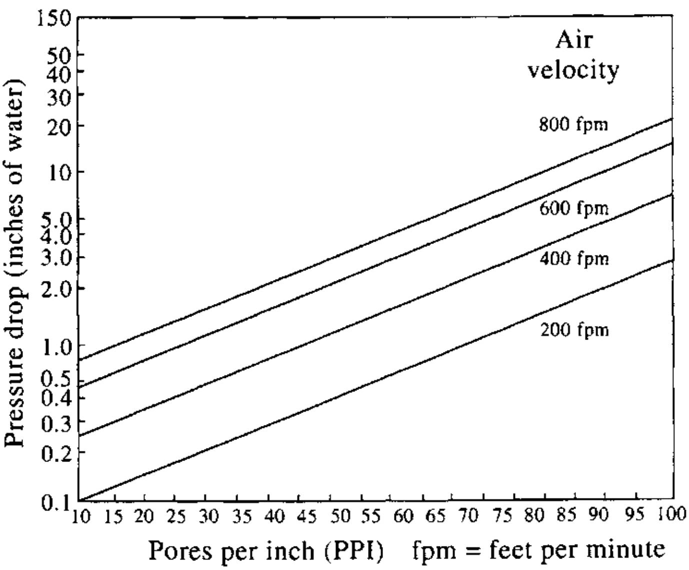

Figure 7.26. Relationship between pores per inch in ceramic foam and pressure with water flowing at various velocities.

Table 7.25 Typical properties of ceramic foams[a]

	Phosphate bonded alumina	Sintered alumina	Cordierite	Mullite	Partially stabilized zirconia	Zirconia alumina	Magnesia	Spinel	Silicon carbide
Chemical composition	Al_2O_3+ aluminium phosphate	99+%Al_2O_3	2 MgO 2 Al_2O_3 5 SiO_2	3 Al_2O_3 2 SiO_2	ZrO_2+CaO or MgO or Y_2O	65% partially stabilized ZrO_2 +35% Al_2O_3	MgO	MgO Al_2O_3	SiC
True density (g/cm^3)	3.9	4	2.5	3.2	5.4	5	3.6	3.6	3.2
Chemical resistance	Poor	Very good acids and bases	Fair	Good	Very good	Very good	Very good in bases	Good to very good	Very good
Max. use temperature °C (°F)	1430 (2600)	1650 (3000)	1100 (2000)	1540 (2800)	1760 (3200)	1700 (3100)	1650 (3000)	1650 (3000)	1540 (2800)
Thermal shock resistance	Fair	Fair to good	Excellent	Very good	Very good	Very good	Fair to poor	N/A	Very good to excellent
Compressive strength N/cm^2 (psi)	86 (125)	349 (506)	144 (209)	207 (300)	N/A	207 (300)	317 (460)	N/A	N/A
Bending strength N/cm^2 (psi)	35 (50)	86 (125)	64 (93)	69 (100)	N/A	69 (100)	86 (125)	N/A	N/A
Possible applications	1 Aluminium filtration	1 Ferrous, especially iron, filtration	1 Automotive catalyst substrates – catalytic converter and diesel particulate traps	1 Automotive substrates	1 Superalloy filtration	1 Ferrous filtration	1 Chemical industry	1 Magnesium filtration	1 High surface area heaters

Table 7.25 (*continued*)

	Phosphate bonded alumina	Sintered alumina	Cordierite	Mullite	Partially stabilized zirconia	Zirconia alumina	Magnesia	Spinel	Silicon carbide
	2 Non-ferrous filtration	2 High-melting non-ferrous filtration incl. reactive metals 3 Chemical industry filtration	2 High thermal shock applications	2 Chemical industry	2 Ferrous filtration 3 Chemical industry applications	2 Automotive substrates	2 Ferrous filtration 3 Magnesium filtration		2 Abrasives 3 High wear applications

[a] Selee Corporation.

7.5 Porous Carbon

Another range of coarse porous media may be formed either from elemental carbon, with its high chemical resistance and excellent thermal properties, or from activated carbon, the microporous structure of which provides

Table 7.26 Comments on applications of various ceramic foams[a]

Ceramic composition	Comments
Phosphate-bonded alumina and chromia/alumina	Used principally for the filtration of molten aluminium and its alloys. Usable to about 1400°C.
Sintered alumina	Direct bonding of high purity aluminium oxide grains by sintering results in a lower surface area than in phosphate-bonded material and low porosity. Very strong and resistant to high temperatures and chemical attack.
Cordierite	Especially well suited to severe thermal shock at temperatures below 1093°C, thanks to near-zero thermal expansion coefficient.
Mullite	Thermal expansion coefficient half way between low level of cordierite and higher expansion of aluminas. Therefore reasonably good to thermal shock and can be used to much higher temperatures than cordierite.
Partially stabilized zirconia	An excellent combination of stability and resistance to both high temperature and thermal shock.
Zirconia-alumina	Far more thermally shock-resistant than alumina alone.
Magnesia	Advantages in non-acidic environments requiring a refractory body.
Spinal (magnesium aluminate)	Compatible with aggressive liquids, e.g. molten magnesium.
Silicon carbide	Relatively high thermal conductivity and electrical conductivity making them suitable for heating elements. Hard, highly abrasive and resistant to most acids and bases.

[a] Selee Corporation.

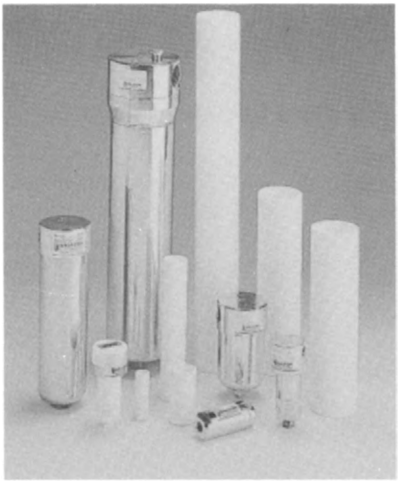

Figure 7.27. Balston filter tubes of glass microfibres.

Table 7.27 Properties of Schumacher carbon filter media[f]

Filter media		Filtration fineness (nominal) (μm)[a]	Pressure drop (mbar)[b]	Specific permeability (nPm)[c]	Porosity (%)	Density (%)	Linear expansion coefficient (10^{-6}·1/K)	Temperature resistance (°C)	Bending strength (Pa)	Bursting pressure (bar 10^5 Pa)	Test piece dimensions (mm) i.d./o.d.
Carbo	3	0.3	300	6.29	25	1.4	–	200[d], 1000[e]	7	60	Ø70/40
	5	0.5	200	9.43	30	1.35	–	200, 1000	7	60	Ø70/40
	10	1.5	80	2.34×10^1	40	1.2	–	200, 1000	6	17	Ø70/40
	20	2.5	40	4.69×10^1	40	1.15	–	200, 1000	4	12	Ø70/40
	30	3.5	20	9.44×10^1	40	1.1	–	200, 1000	3.5	10	Ø70/40
	40	ca 10.0	13	2.42×10^2	40	1.1	–	200, 1000	3	8	Ø120/70
Schumakat		–	40	6.29×10^1	60	0.7	–	180	–	–	Ø70/30
Schumasorb, AB, AC	5	0.5	2000	0.94×10^1	60	0.75	–	180	5.5	15	Ø70/40
	10	1.0	330	7.63	65	0.75	–	180	3.5	12	Ø70/30
	20	2.0	150	1.68×10^1	60	0.7	–	180	2.5	6	Ø70/30
Schumasorb AB	60	–	8	3.15×10^2	60	0.5	–	150	–	–	Ø70/30
Schumazin	20	2.0	150	1.68×10^1	60	0.7	–	180	2.5	6	Ø70/30

[a] Ambient air, particle counter.
[b] Air @ 250 m/min.
[c] 1 Nanoperm (nPm)=0.1013 darcy.
[d] Oxidizing atmosphere.
[e] Reducing atmosphere.
[f] Pall Inc/Schumacher.

exceptionally high surface areas. These two different types of media have very distinctive properties, as can be seen from examples summarized in Tables 7.27 and 7.28.

7.6 Glass Fibre Tubes

The final group of media involving inorganic materials is that employing glass. A distinctive use of the properties of glass microfibres is the range of Balston filter tubes (now supplied by Parker Hannifin). In essence, as shown in Figure 7.27,

Table 7.28 Schumacher range of carbon filter media

Trade name	Description
Carbo	Technically pure carbon and therefore very resistant to chemical reaction. Not attacked by hydrofluoric acid. Can be utilized over whole pH range 0–14. Stable in oxidizing atmospheres up to around 200°C and in reducing atmospheres to about 1000°C.
Schumakat	An open-pored sintered carbon element with low pressure loss, the support body is impregnated in catalytical substances. Used especially for catalytic reduction of hydrogen peroxide, e.g. in exhaust from packaging machines.
Schumasorb	Consists of highly porous activated carbon, stable over whole pH range 0–14.
Schumazin	Manufactured from chemically impregnated activated carbon. Its special value is for the removal of hydrazine from steam and water, together with the attend ant neutralization of ammonia.

Table 7.29 Approximate dimensions of glass microfibre tubes[a]

Code	Outside diameter (mm)	Length (mm)
050-05	19	32
050-11	19	57
100-12	38	63
100-25	38	178
150-14	52	152
200-35	65	230
288-80	65	476
250-150	78	752

[a] Parker Hannifin Inc.

Table 7.30 Retention efficiencies of glass microfibre tubes[a]

Grade	Gas (retention of 0.1 μm) (%)	Water (98% retention of particle size) (μm)
D	93	25
C	98	8
B	99.99	2
A	99.9999+	0.9
AA	99.9999+	0.3

[a] Parker Hannifin Inc.

these are a simple form of cartridge, made from borosilicate glass microfibres, similar to those supplied by Whatman (the former owner of Balston) in its range of glass filter papers (see Chapter 4). Similar tubes are also produced from fibres of pure quartz, free of binders.

The borosilicate microfibres are bonded with either organic or inorganic binders to form tubes in five standard outside diameters (from 19 to 78 mm), with walls approximately 6 mm thick; lengths, as indicated in Table 7.29, range from 32 to 752 mm. Each is available in five standard grades, the filtration efficiencies of which are summarized in Table 7.30.

7.7 Selecting Coarse Porous Media

As the chapter's title implies, the media discussed here are not intended for the finest degrees of filtration, although some of them do achieve quite high filtration efficiencies. They find their main applications in preliminary filtration steps, or in the treatment of hot gases or of corrosive liquids.

In fact, temperature and corrosion are the guiding factors in choosing among these media: if the temperature of gas (or liquid) is above 120°C or so, or if the liquid (or gas) is at all corrosive, then the likelihood is that metal or ceramic will be used, rather than plastic, although PTFE materials are capable of resisting most corrosive liquids, and quite high temperatures.

A particular feature of some of these media is their use in the processing of molten materials, especially metals (for which ceramic foams are used) and polymers ahead of their being extruded or blown into film (for which sintered metal media are often used).

For the increasingly important process of cleaning hot dusty gases, the porous ceramic candle is really the only option available to the plant designer, and the fibre-based, low-density ceramic materials are developing fast to provide satisfactory process solutions.

7.8 References

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