A Study of the Mechanism of Wet & Dry Filtration using NIST Traceable Glass Microspheres

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ABSTRACT

The objective of this work was to investigate the performance differences in filter media depending on whether the challenge test is conducted in the dry state or using a liquid suspension of microspheres. Comparisons of filter cut points between a pulsed airflow and a single pass liquid suspension method were used to investigate the mechanisms of filtration. Depth filtration effects were examined by comparing 2-dimensional filters (precision electroformed filters) to moderate depth filters (pillow fabric and needle felts) and a 3-dimensional depth filter (water cartridge filters). No differences were found for 2-dimensional filters but significant differences in performance were found between wet and dry analysis of 3-dimensional filters. There was little evidence of secondary filtration in the suspension method for concentrations from 0.2% down to 0.025%.

1. Introduction

It is a well-known phenomenon that bag house filters are least efficient when virgin bags are used. However, particle build-up on the media rapidly occurs resulting in a secondary, enhanced filter efficiency. The measurement of filter performance should be undertaken in the application environment of the filter. For example, the results of a wet challenge test must be questionable in needle-felt applications where electrostatic and Van der Waal forces are the primary source of particle capture and not the physical size of the pores.

Nevertheless, Porometry is often employed, where the expulsion of a wetting agent from the pores is used to measure aperture size. The wet challenge test should therefore simulate the Pomometry method while the Sonic dry test is more analogous to the operating conditions of a bag filter. The wet challenge test on water filters, on the other hand, is an ideal test because it parallels the running conditions. The main area of concern here is the effectiveness of the filter in relation to the concentration of particles presented to it.

In this work, a new range of narrow and ultra-narrow particle size distribution glass microspheres have been produced for challenge testing. They cover the size range 1000μm down to 1μm and are certified according to NIST and NPL standards using advanced microscopic techniques. Liquid or air was then used as carrier fluids to transport the microspheres through the filter media. The percentage and maximum size passing can then be used to measure the filter efficiency and maximum pore size respectively.

Fig.1 Sonic filter tester and holders for 2-Dimension filters

2. Challenge test equipment and filter media

(a) Sonic challenge test apparatus

The Sonic Filter Tester was used for the dry testing of filter media, figure 1. Intense oscillating air currents fluidise the reference glass microspheres through the filter. From the weight of microspheres passing, the cut point of the filter can be determined. The minimum cut point depends on the geometry of the filter medium. 2-Dimensional electroformed sieves can be measured down to 5μm but as filter depth increases and porosity decreases, the lower limit increases to approximately 20μm. The Sonic method was used to test electroformed filters and needle felt bag filters of nominal ratings from 200μm to 5μm.

(b) Aqueous suspension test apparatus

For measuring filter performance below 20μm, where air permeability can be low, a liquid carrier is required to transport the calibrating microspheres through the filter. A simple split filter holder over a vacuum source is all that is required for 2-Dimensional filters, figure 2. This apparatus was used to test some anti allergic bedding fabric and needle felt bag filters of nominal ratings from 200μm down to 5μm. The filter disc diameter was 47μm while the suspension concentration ranged

Fig.2 Suspension filter tester for 2-Dimension filters

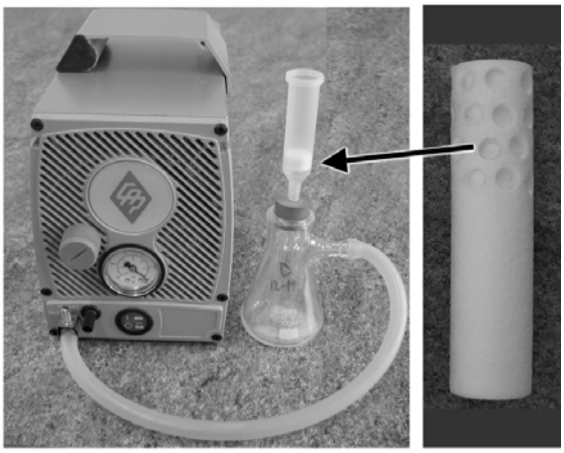


Fig.3 Suspension filter tester for 3D filters showing holder for core plugs

from 0.2% down to 0.025%. Porometer and test dust data was also obtained for the needle felt filters.

In 3-Dimensional cases, a core plug must be taken and mounted in a suitable holder. Figure 3 shows 15mm diameter plugs extracted from a water cartridge. A higher sensitivity vacuum pump was used to enhance vacuum control.

The primary data is the filter efficiency, or the percentage of the challenging particles retained by the filter.

The filter cut point can be determined, either by analysing the particles passing the filter to see if there is a cut off in the size distribution of the calibrating microspheres or by gradually increasing the size of the challenging particles until they no longer pass.

3. Results and discussion

(a) Comparison of dry and wet challenge testing of needle felt filters

To test the accuracy of the Sonic Filter Tester, electroformed filters of the same nominal sizes of the felts were tested. The filter cut points obtained were very close to the microscopic analysis of the pores, table 1.

Table 1. Calibration of the Sonic Filter Tester using Electroformed filters

Nominal Electroform filter size (μm)	5	10	25	106	210
Pore size by Microscopy (μm)	-	11.8	25.2	104.5	212.9
Sonic cut point* (μm)	-	11.1	25.8	105	208

*** Microscope analysis of the microspheres passing (D97%)**

The experiment was then repeated with the bag filters, table 2. An interesting observation on the nominal 25μm filter was that, although the 16–25μm beads failed to pass, about 45% of the 45–62μm filter standard passed. The phenomenon was also seen with the larger filters, eg. 16–25μm would not pass the 200μm filter, but about 50% of a 180–248μm standard passed. The mechanism of the dry filtration does not therefore depend on the physical size of the pores for these non-wovens.

Table 2. Comparison of dry and wet filter testing of needle felts

Needle felt reference	PO 5	PO 10	PO 25	PO 100	PO 200
Nominal filter size (μm)	5	10	25	100	200
Sonic cut point (μm)	<20	<20	53[1]	164	202[1]
Wet challenge test cut point[2]	31	36	59	127	180
Porometer efficiency (μm)	61	74	98	219	292
Manufacturer's Test Dust rating (μm)	65	80	116	218	290

[1] Average of 2 tests [2] Using a 0.1% solids concentration

When the experiment was repeated wet, using the equivalent calibrating beads, there was good agreement with the Sonic dry test, table 2. However, nearly all the 16–25μm always passed the filters, especially the largest. Unlike dry filtration therefore, wet filtration does not depend on the physical size of the pores. To ensure that there was no secondary filtration through particle build-up on or within the filter, a concentration titration from 0.2% to 0.025% was performed. There was no significant effect, table 3.

Table 3. Effect of particle concentration on the wet challenge test efficiencies

Needle felt reference	**PO 5**	**PO 10**	**PO 25**	**PO 100**	**PO 200**
Filter standard used - μm	15-31	25-39	36-59	75-103	80-123
Efficiency @ 0.2% solids[1]	**59[2]**	74	65	57	68
Efficiency @ 0.1% solids	83	66	64	64	63
Efficiency @ 0.025% solids	75	63	**43[2]**	56	63

*** Percentage of the standard retained by the filter [2] Outlier probably from sample inhomogeneity**

The somewhat higher pore sizes from Porometry measurements in table 2 could be due to irregular pore shape, but the Test Dust rating supplied by the manufacturer was also unusually high considering the test was analogous to the glass bead test at the lowest concentration.

(b) Analysis of water filter cartridges using the wet challenge test method

Clean water always has been, and will continue to be, one of the most important resources to the human race. The performance of cartridge filters is therefore of paramount importance. Nominal 10µm and 20µm cartridges were selected for analysis using the equipment illustrated in figure 3. Because of potential sealing problems with the 15mm diameter core plugs in the holder, a repeatability test was conducted to quantify the uncertainty of the method, table 4.

Table 4. Repeatability testing of a 20µm water cartridge using a 0.025% concentration of a 14–30µm filter standard

						Av.
% retained	63	47	40	52	53	51

20µm water cartridge

A concentration titration eliminated a secondary filtration mechanism, table 5, while systematically increasing the sizes of the filter standards used showed the cut point to be approximately 31µm.

Table 5. Effect of the concentration of a 14–30µm filter standard on the filter efficiency of a 20µm water cartridge

Conc. (%)	**0.025**	**0.05**	**0.1**
% retained*	51	49	45

***> 3 tests**

10µm water cartridge

The 10µm cartridge also showed no evidence of secondary filtration, table 6. The effective cut point of the cartridge was again significantly higher than the nominal rating at approximately 21µm. Microscope analysis of the microspheres passing both cartridges showed that no cut off in the particle size distribution of the standards.

Table 6. Effect of the concentration of a 12-19µm filter standard on the filter efficiency of a 10µm water cartridge

Conc. (%)	**0.025**	**0.05**	**0.1**
% retained*	51	45	40

***> 3 tests**

(c) Analysis of anti-allergic pillow fabric using the wet challenge test method

Challenge testing is crucial in anti-allergic filter applications because, unlike Porometry, it simulates the resistance of fabrics to the physical objects that often cause the allergic responses. The filter efficiency of a pillow fabric was tested using a range of filter standards. As the size of the filter standard increased, the percentage retained also increased. Table 7. The higher resolving power of the 22.8µm Monosphere^{TM} was used to accurately locate the cut point at between 19 and 22µm.

Table 7. Filtration Efficiency of a pillow (wet)

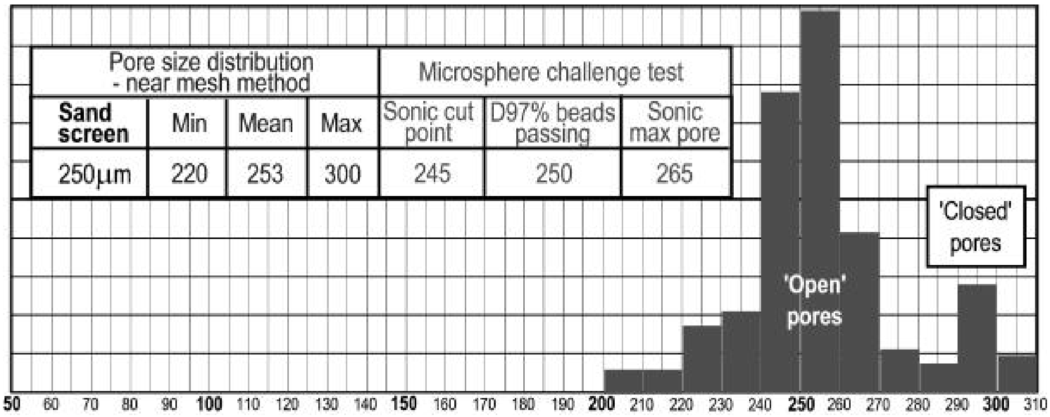
Filter std.	**5-9**	**8-11**	**12-19**	**14-30**	**22.8***
% retained	70	77	96	>99	>99

*** A single size MonosphereTM**

Unlike the filter standards in the electroformed filter tests above, whose size distributions were dissected during testing, microscope analysis of the standards passing the pillow fabrics showed no change in the particle size distribution. The interesting observation from this experiment was that even with the smallest standard, a significant portion of the microspheres were held back, indicating that the effective minimum pore size was below 5µm.

(d) A study of 'open' and 'closed' pores

It was apparent from the wet analysis of the anti-allergic pillow fabrics that some filters contain a number of 'closed' pores into which the microspheres can become embedded and are not easily released. This explains the fact that, although a cut point of approximately 20µm was measured, the fabric still removed 70% of the 5–9µm filter standard. In larger pore size filters it is possible to recover and analyse the beads trapped in a mesh after Sonic Challenge testing (the 'near mesh' beads) and compare their size distribution to those passing the mesh, figure 4.



Pore size distribution - near mesh method				Microsphere challenge test		
Sand screen	Min	Mean	Max	Sonic cut point	D97% beads passing	Sonic max pore
250µm	220	253	300	245	250	265

Fig.4. Analysis of beads trapped in a 3-Dimensional sand screen reveal the presence of 'open' and 'closed' pores

The results from the Sonic Challenge test and the microscopic analysis of the beads passing agree well, 245μm and 250μm respectively, as was previously seen for precisely defined apertures, table 1, but the narrow peak at 300μm indicated the presence of ‘closed’ pores where the trapped particles were unable to penetrate the structure of the filter.

4. Conclusion

The selection of an appropriate filter testing method depends critically on the final application of the filter. If a filter is to be used wet, then a liquid carrier must be used for the challenge test. In such cases the performance of the filter is usually related to the physical size of the pores.

In dry filtration, however the effectiveness may not be directly related to pore size and other mechanisms of particle capture may come into play. For example, in depth filtration, attractive forces between the particles being filtered and the filter fibres increase as the particles decrease in size, so although there may be pores over 200μm present, particles of 20μm are captured in the dry test but pass straight through when presented as an aqueous suspension.

Unlike fixed pore size filters, such as electroformed filters that filter at a specific cut point, depth filters can remove a wide range of particle sizes below the cut point or maximum pore size. Both wet and dry challenge tests methods have been shown to be capable of measuring pore size distribution.