# Comparative Methods for the Pore Size Distribution of Woven and Metal Filter Media

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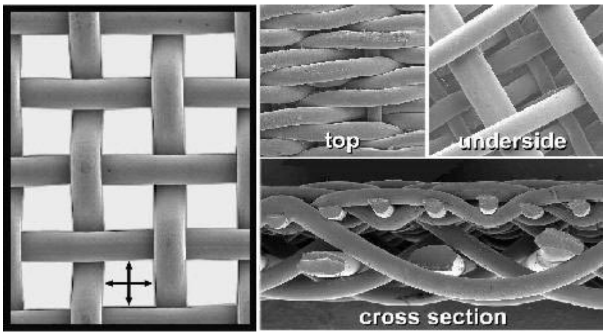
## Abstract

This paper investigates the permeability of several multi-layered, woven filter media using air, water and bubble point methods. Estimated filter efficiencies from the bubble point measurements were then compared to a new sonic challenge test method where precision microspheres are fluidised through the pores. Inconsistencies in the bubble point filter efficiencies were found to be dependent on the openness or permeability of the weave. The filter efficiency of a non woven metal filter medium was then related to the pore size distribution measured by microscopy.

Key words: Porometry, Woven filter media, Metal filter media

## 1. Introduction

In plain or semi plain filter /mesh materials the pore structure is clearly defined so when viewed under a microscope an aperture can be observed with minimal interference from the warp and weft filaments, figure 1(a). In most cases it is possible to measure across the opening (in each direction) to get an indication of the pore width/size.




a) A plain weave (b) A Double layered weave

**Figure 1.**

Microscopic aperture measurement is not possible however on composite or double-layered weave (DLW) structures similar to those in figure 1 (b). When viewed from the top surface it is difficult to see through the fabric (unless it is extremely open). In most cases the cross sectional path through a composite or DLW is a torturous one with interweaving between the layers. Furthermore increasingly tighter weaves in the more recent plain fabrics severely limit the use of microscopy as an analytical tool to measure aperture size.

In complex, 3-dimensional filter media, porometry via capillary flow from wetted media has long been used for assessing the relative pore size distribution (PSD). Theoretically it is based on the LaPlace equation for cylindrical capillary pores (ASTM F316-80 and SAE ARP901). However, most filter media have irregular pores, which makes the theoretical assumptions suspect and this is especially the case in multi-layered structures. Nevertheless, porometry has been firmly established as a key test procedure for filter media characterization, and now can even be reasonably used to assess efficiency.

Early investigators used the laborious bubble point method for PSD determinations, but with the advent of the Coulter-I porometer in 1988 this task has become relatively easy. In the ensuing years many other porometers have been introduced.

Using multi-layered woven media, as shown in figure 1, this paper compares four methods of pore size analysis based on permeability testing. In addition it will compare porometry data with that of direct so-called 'Challenge test'. In this method standard test dusts or glass beads are presented to a filter medium and the particles in the downstream filtrate analysed.

In the latest development of this method, accurately calibrated, narrow size distribution glass microspheres have been produced covering the size range 5 - 600μm in 20 grades. Knowing the size distribution by weight eliminates the need for particle sizing equipment as the pore size can be directly related to the percentage of the standard passing the filter medium through a calibration graph or formula.

Finally, the pore size distribution of an open, non woven metal filter medium is measured by microscopy and the data compared to the challenge test analysis.

# 2. Experimental

## 2.1 The challenge test method

### 2.1.1 Preparing microsphere standards

In the challenge method, particles of known size distribution are presented to a filter and any changes down stream measured by a particle size analyser. Traditionally test dusts have been used but the accuracy of the method is limited by the shape of the irregular particles, figure 2. Elongated particles can pass through smaller pores than their equivalent spherical diameter would suggest. Although the situation can be improved by using spherical particles, the accuracy of the method can be compromised by using broad particle size distributions.

The most accurate method of challenge testing is to use narrow size distribution spherical particles, figure 3.

Furthermore to simulate the way in which the particles pass through a filter medium, any particle sizing method should measure their width, for example a sieve dimension. However, sieve dimensions in wire woven sieves have an unacceptable wide distribution. For highest accuracy, precision electroformed sieves should be used for analysis, figure 4.

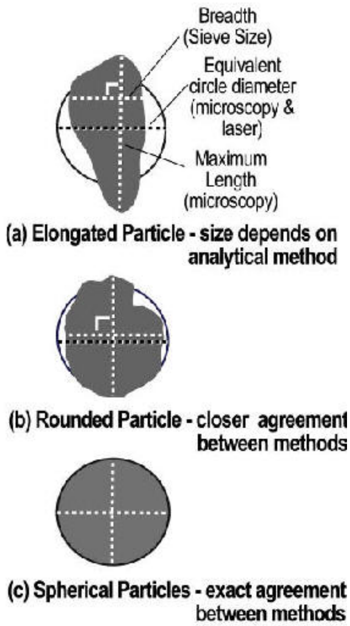



**Figure 2.** Size definitions of various particles

In this work, narrow particle size distribution glass microspheres have been produced and NIST certified using highly accurate electroformed sieves.

Over 20 filter calibration standards are now available between 15μm and 1mm. Only three electroformed sieves could be used for analysis because the narrowness of the distribution so the data was supported by microscopy to ensure a uniform distribution. Provided the results were comparable, the sieve data was then used to construct a calibration graph of the percentage passing a filter to its pore size, figure 5.

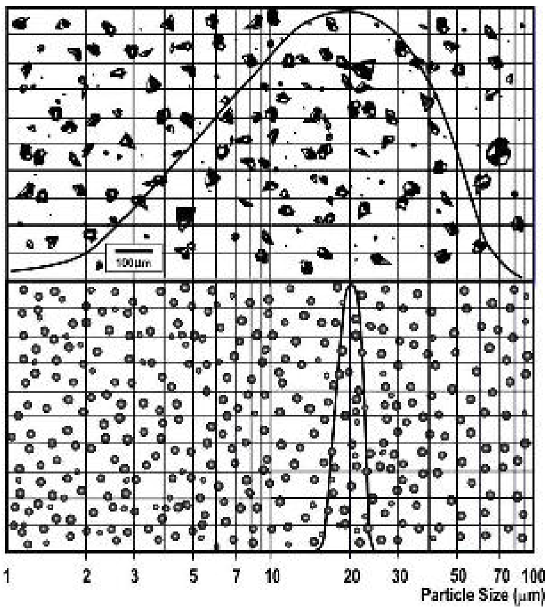



**Figure 3.** A test dust compared to narrow distribution spherical test standard

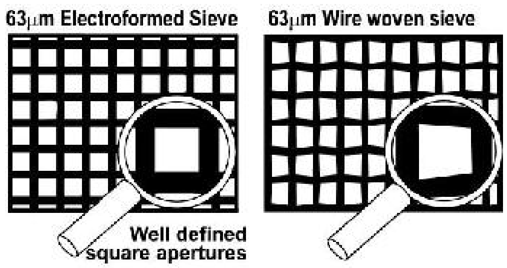



**Figure 4.** Electroformed sieve have well defined accurate apertures

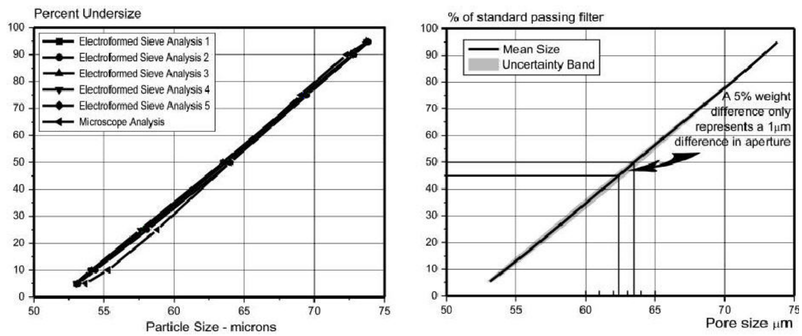



**Figure 5.** Construction of filter standard calibration graph

### 2.1.2 Measuring pore sizes using glass microspheres

Having a well calibrated calibration standard is only the first step in testing filter media. It is essential to have a means of transporting the microspheres effectively through the often tortuous path in the complex filter structure. This problem has been solved by using a Sonic sifting device that fluidises the microspheres rather than shake the filter. The enormous energy imparted to the particles ensures that there is efficient penetration through even the most complex filter media, figures 6 and 7.


**Figure 6.** A filter challenge tester based on the Gilson sonic autosifter

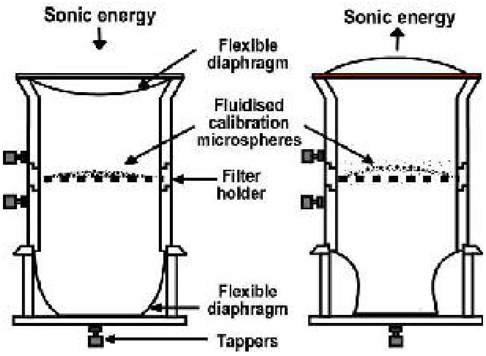



**Figure 7.** Sonic sieving action

To measure the pore size of filter, a 90mm disc was clamped into the filter holder and the appropriate calibration standard fluidised on the surface. The end point corresponded to a change in weight of less than 1% passing per minute and was usually achieved in 1 – 2 minutes. The pore size was then determined from the calibration graph. In this context the pore size measured is approximately 97% of the maximum and corresponds to approximately D97 of the particles passing the medium when measured by microscopy.

## 2.2 Bubble point testing

### 2.2.1 Coulter Porometer

A Coulter Poromerer-I was used for this work, figure 8. 25mm diameter discs were cut from a range of Dual-Tex™ filter media for analysis.

**Figure 8.** A Coulter Porometer - I

Experiments were conducted with two wetting agents, Porofil and Gatwick. Two parameters were recorded, the Bubble Point (b.pt), which corresponds to the pressure required to form a bubble and relates to the maximum pore size. The second parameter measured was Mean Flow Pore size (MFP), which is the micron size where 50% of the flow was higher and 50% of the flow was lower, (i.e., the mean (X)). The standard deviation ($\sigma$) was calculated for three determinations on each sample.

In operation the drainage plate was used in its normal mode of Wet Up/dry up configuration.

### 2.2.2 PMI Porometer

The latest version, 1100AEX Capillary Flow Porometer, see figure 9, was used in the work. The same parameters were measured as in the Coulter analysis except that the measurements were restricted to the Gatwick wetting agent. The more accurate Dry up/Wet down mode of operation was again employed.

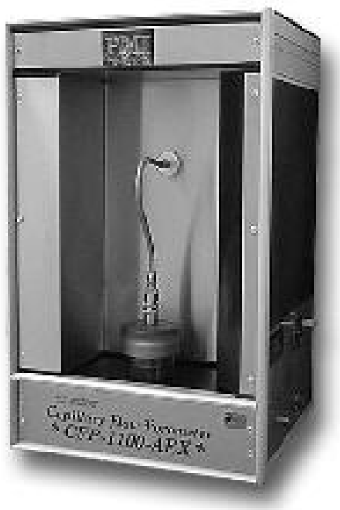


**Figure 9.** A PMI Capillary Flow Porometer model 1100 AEX

The operational principle is similar to that of the Coulter Porometer 1 instrument. A fully wetted sample is placed in the sample chamber and the chamber is sealed. Gas is then allowed to flow into the chamber behind the sample. When the pressure reaches a point that can overcome the capillary action of the fluid within the pore (largest pore), the bubble point has been found. After determination of the bubble point, the pressure is increased and the flow is measured until all pores are empty, and the sample is considered dry.

To calculate the 'Porometer efficiency', the average bubble point was divided by 1.7 (a typical screen tortuosity factor), which was equivalent to approximately a 98% filtration (or removal) efficiency. The data could then be compared with the Whitehouse micron rating as measured by the challenge test, which corresponds approximately to 97% of the largest pore size.

## 2.3 Permeability testing

### 2.3.1 Frazier air permeability

Air permeabilities were measured by the filter media manufacturer (Madison Filter) on an original Frazier machine, figure 10. They were also measured on the latest PMI Porometer, figure 9.

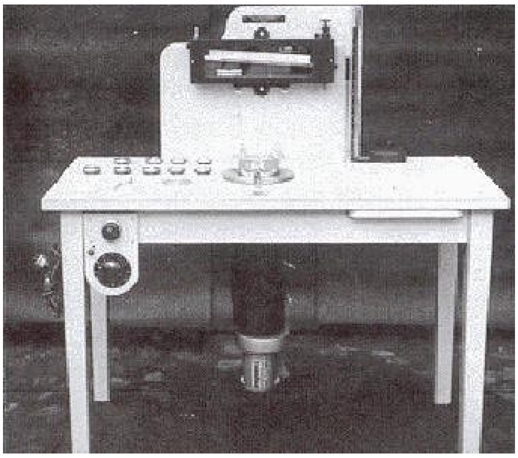


**Figure 10.** Frazier low pressure machine for measuring air permeability

### 2.3.2 Water permeability

The same samples used in the Coulter and PMI Porometers were used for water flux testing. The water was filtered at 0.2μm and applied at a pressure of 5 psig

## 3. Results and discussion

This work has endeavoured to comprehensively evaluate all the current methods of analysing filter efficiency using a wide range of double-layered weave filter media. When determining the suitability of a particular filter medium, potential users will usually examine filtration efficiency from a combination of air and/or water permeability, mean flow pore size and bubble point pore size from which a porometer efficiency can be calculated. Bubble point and flow testing methods of assessing pore sizes have therefore been compared with a new challenge method based on precision, narrow particle size distribution glass microspheres. For completion, the secondary methods of air and water permeability have been included. The results summarised in table 1 below.

**Table 1.** Comparison of pore size measurements on Madison Dual-Tex™ media

| Sample | Mfg's Rating (μm) | Pore size[1] (μm) | Coulter-I[2] (μm) | | PMI-1100[3] (μm) | | Avg[4] b.pt | Porometer efficiency[5] (μm) | Frazier Air Perm (cfm/ft$^2$) | | Water Flux[6] (gpm/ft$^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | b.pt | X | b.pt | X | | | Mfg | PMI | |
| PX-20 | 20 | 21 | 36 | 12.5 | 57 | 19.5 | 41 | 24 | 10 | 1.3 | 46 |
| PX-40 | 40 | 36 | 56 | 29.1 | 102 | 39.2 | 71 | 42 | 13 | 8 | 155 |
| PX-50 | 50 | 48 | 90 | 34.7 | 125 | 40.4 | 102 | 59 | 36[7] | 13 | 210 |
| PX-70 | 70 | 75 | 180 | 69.1 | 238 | 84.3 | 186 | 110 | 56[8] | 97 | 3370 |
| PX-100 | 100 | 95 | 160 | 46.9 | 173 | 58.8 | 164 | 97 | 56 | 29 | 670 |
| PX-140 | 140 | 140 | 230 | 75.0 | 240 | 82.3 | 234 | 138 | 98 | 65 | 1610 |
| PX-170 | 170 | 175 | 300 | 125 | 443 | 130 | 348 | 203 | 295 | 285 | 9220 |
| PX-200 | 200 | 203 | 300 | 140 | 362 | 156 | 362 | 213 | ? | 160 | 5220 |

1. Whitehouse challenge test pore size - 97% efficiency in removing stated size.
2. Coulter Porometer-I, b.pt – bubble point, X - Mean Flow Pore (MFP) size. NB. Data for Galwick wetting agent. Porofil wetting agent also used but not included in this column.
3. PMI model 1100 with Galwick wetting fluid.
4. Average of all tests using both wetting agents.
5. Tortuosity factor 1.7 equates to 98% efficiency in removing stated size( = B.pt/1.7).
6. Based on 5 psid and 0.2μm DI water.
7. Values for PX-60
8. Values for PX-80

In most cases, the final Porometer efficiency (an average of the Coulter and PMI data for all the wetting agents) matches both the manufacturers rating and the Whitehouse pore size and confirms the validity of using the screen tortuosity factor of 1.7 in converting the bubble point (the maximum pore size) into the more relevant 98% efficiency used to assess the retention properties of filter media (for further details, see bibliography).

It is interesting to note that the PMI data is consistently higher than the Coulter data, especially in two samples (PX-70 and PX-170), which had unusually high air and water permeabilities. The Whitehouse results for the same samples, however did not reflect the higher pore sizes observed from the Porometers and produced results more consistent with the manufacturers nominal sizes.

The comparison of all the test methods can clearly be seen in figure 11, where the air and water permeabilities are expressed as percentages of their maximum values.

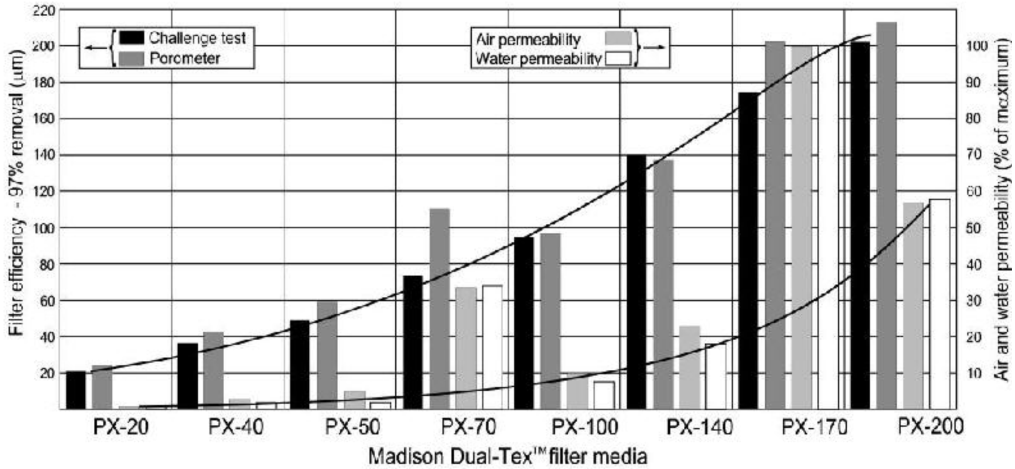



**Figure 11.** Comparison of test methods on a range of Dual-TexTM filter media

The results show firstly, a very close agreement between the Frazier air permeability and the Water Flux data for all the filter media and secondly, when the permeabilities are unexpectedly high, as in PX-70 and PX-170, they have the effect of inflating the values from the Porometers.

A consequence of relying on the permeability and Porometer results alone is that a processor may reject a high through flow medium such as PX-70 when in fact the challenge test data show that the actual retention properties were much better than expected. The filter mesh would then be over specified and so significantly increase processing costs.

## 3.1 Sand screen applications

The importance of specifying the cut point of a filter rather than the mean pore size is well illustrated in sand screens applications in the oil extraction industry. Sand screens are used at the extraction point to prevent abrasive sand damaging the pipeline to the surface.

The filter media are usually made of stainless steel wire either as complex 3-dimensional weaves or as non-woven fabrics. The main difference between the two is that woven filter media have a much narrower range of pore sizes compared to non-wovens.

As the performance of filter media is determined by the larger pore sizes, mean pore size is an inappropriate parameter for non-wovens with a wide range of pore sizes. Figure 12 shows a microscope image of a typical stainless steel, non-woven sand screen having a nominal pore size of 125μm.

The mean size and size at 95% of the maximum pore size measured by microscopy were approximately 150μm and 350μm respectively. The 95% value measured by microscopy was very close to the cut point by the sonic challenge test measured at 336μm.

In the case of the equivalent woven sand screen of nominal pore size 115μm, the measured cut point was much closer at 135μm. Note, a microscope comparison is not possible because complex 3-dimensional weaves are opaque.

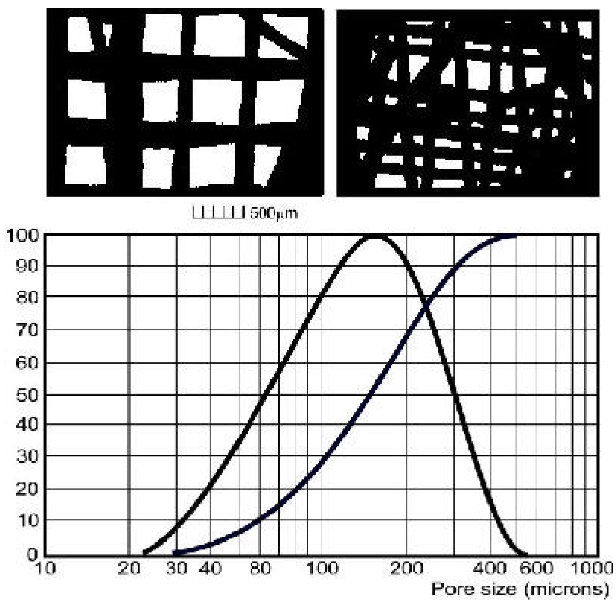



**Figure 11.** Comparison of test methods on a range of Dual-TexTM filter media

## 3.2 Mining applications

Some pilot scale trials involving the filtration and dewatering of a synthetic rutile (mineral sand) from the Southern Hemisphere was a good example of the application of accurate test data from the Whitehouse challenge test. The precision in determining the filter efficiency by the method allowed the manufacturer a greater degree of confidence in selecting the optimum filter medium for the application. The objective was to de-water a product having a median size between 130 - 150μm. From the challenge test data, a PX 100 was chosen and excellent filter efficiency was observed both during start up and subsequent operation.

The DualTex media outperformed the customer's expectations not just in efficiency but also in improved filter cleaning as no particle ingress occurred into the material structure. In addition to operational enhancements, prolonged life to the filter media was observed.

## 4. Conclusions

This study on comparative methods for measuring pore sizes between 20 - 200μm has shown good agreement between theoretical porometer measurements and a new challenge test involving the permeation of precision microspheres through the media. Furthermore, when the data is normalised, both Frazier air permeabilities and water flux tests are remarkably consistent over a wide range of samples.

One significant observation was that, when unusually high permeabilities were observed, there were higher than expected results from the theoretical pore size measurements compared to the challenge test results. For high through flow media therefore, some modifications to the tortuosity factor may be required for converting bubble points to filter efficiencies to bring them more in line with the challenge tests.

In applications involving the clarification of particle suspensions, mean pore size is not a meaningful parameter especially when the filter medium has a wide range of pore sizes. The Sonic challenge test is an unambiguous and high speed method of measuring the performance of filter media.

Having more accurate methods of measuring filter cut point is already leading to benefits, both from the manufacturer who has a greater confidence in specifying filter media and from the process operators who are reaping the rewards from improved performance.

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