Differentiating Filters/Membranes by Capillary Flow Porometry

Relevant for: Ventilation systems, vacuum cleaners, clean rooms, aerospace industries, automotive industries, and personal protective equipment.

Mechanical filters/membranes are devices that use porous media, such as paper, foams, synthetic fibers, cotton, or spun fiberglass, to remove solid particles and other contaminants in applications requiring clean streams of gases or liquids. The Porometer 3G series of instruments can measure and analyze the pore characteristics of materials used in different filtering applications from contaminant removal to medical devices and electronic fabrication. This application report compares and contrasts the results for two similar looking filters used to remove contaminants from an in-house air source.

1 Introduction

Filters and membranes are devices which remove unwanted particulates such as dust, pollen, mold, bacteria and more from a continuous stream of either a gas or liquid. An important application for everyday use in air purification is notably built into building ventilation systems, engine air intakes, air compressors, gas turbines and vacuum cleaners. Importantly, cleanrooms that manufacture the latest electronics also require a high degree of clean air for material fabrication. The four main materials used in mechanical air filter media include paper, foam, synthetic polymers, and cotton. Some buildings, as well as aircraft and other man-made environments (e.g., satellites and space shuttles) use foam, pleated paper, or spun fiberglass filter elements to keep people or individual components protected from unwanted contaminants. In addition, some filters employ a static electric charge to attract dust particles to the filter.

Polyester and/or glass fibers are also commonly used to make air filters. Both materials have high temperature ratings near 120 °C, and are widely used in commercial, industrial and residential applications. In some cases polypropylene is used to enhance chemical resistance, but has a lower temperature tolerance. These materials can also be blended with cotton or other synthetic fibers to produce a wider range of performance characteristics. Tiny synthetic fibers known as micro fibers are also used in many types of HEPA (High Efficiency Particulate Air) filters.

Filter efficiency is normally reported as Minimum Efficiency Reporting Value (MERV) - a measure of the efficiency with which particulate filters remove particles of a specified size from an air stream (refer to Table 1). The higher the MERV number, the better the removal efficiency, particularly of smaller particles. MERV levels 1 through 16 are determined using the American National Standards Institute/American Society of Heating, Refrigerating and Air Conditioning Engineers (ANSI/ASHRAE) Standard 52.2-2017 test method. However, this does not address HEPA filters or Ultra Low Penetration Air (ULPA) filters (MERV 17 – 20). Instead, HEPA/ULPA filters are assigned MERVs based on their performance in accordance with standards published by the Institute of Environmental Sciences and Technology (IEST).[1, 2] Both types of test are known as “challenge” tests which require standard dust particles. These tests do not truly measure pore size but their abilities to remove certain particulates. To truly know a material’s ability to filter particles over a given size range, its through pore size distribution must be determined, and this can be quickly and automatically done by capillary flow porometry experiments.

1.1 Pore Size Distribution

In capillary flow porometry, the pore size distribution is obtained by applying the Washburn equation to a pressure vs. flow curve obtained on a wetting fluid that completely fills the pores of the filter or membrane. This fluid is expelled as increasing gas pressure is applied to the upstream side of the sample (Figure 1). This increasing force eventually overcomes the capillary forces holding the fluid in the pores. The Washburn equation [3]

$$\mathrm{Pr} = -2\gamma cos\theta$$

relates the pressure (P) to the pore radius (r) as a function of the surface tension (γ) and the contact angle (θ) of the wetting fluid. The largest pore(s) will empty first, defining the Maximum Pore Size and the Bubble Point. The Minimum Pore Size is defined at the point where the wet curve meets the dry curve. Both curves are the measured flow versus pressure, but during the wet curve analysis the sample is first steeped with a wetting fluid. The wetting fluid is expelled during this run which can then be followed by the dry curve run. The Mean Pore Size is defined as the point at which the amount of flow through the sample on the wet curve is exactly 50% of the amount of flow at the same pressure when the sample is dry (Figure 2).

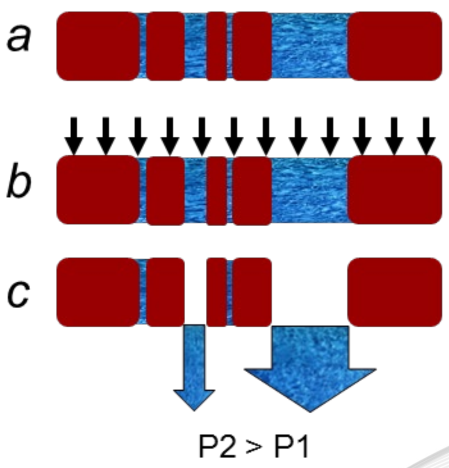

Figure 1: (*a*) A completely wetted sample (*b*) experiences a gas pressure from the upstream to the downstream which (*c*) forces the wetting fluid from the larger pores (P1) then to the smaller pores (P2) as the pressure increases.

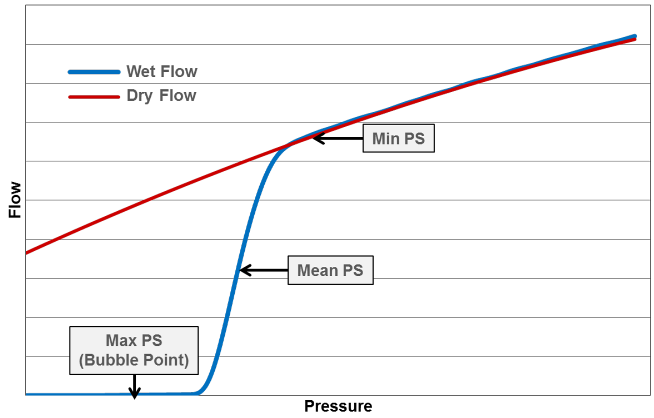

Figure 2: Characteristic wet and dry curves showing the locations of the maximum, mean, and minimum pore size.

2 Sample Preparation and Experimental Run

Two filter samples prepared for the 25 mm diameter sample holder, denoted F1 and F2 were analyzed on a Porometer 3Gz, using Porofil wetting fluid. These filters are used in a parallel system and their properties are explored here. The measured pressure range for these materials was from 0.004 bar to a little over 0.13 bar, which corresponds to pore sizes from 150 to 5 μm, using Porofil as the wetting fluid. The measured data are presented graphically in Figure 3 after the parameters were optimized to collect data whereby it was observed that these two filters, however similar in appearance, were different in their through pore makeup.

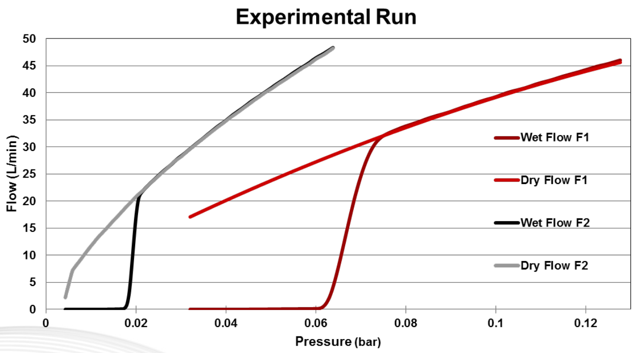

Figure 3: Measured flow rate versus pressure for the two filters F1 and F2.

3 Results

The two filters differ significantly as observed from their wet and dry runs on the graphical plot. The F2 sample required a lower initial pressure (around 0.02 bar) before a rise or emptying of the larger through pores begins. Therefore F2's bubble point pressure was at 0.0169 bar, giving the material a maximum pore size around 38 μm, a mean flow pore size of ~33 μm and a minimum pore size of ~26 μm. The F1 sample bubble point pressure was observed at 0.0601 bar showing that the material has a mean flow pore size of 9.5 μm with a maximum and minimum pore size of 10.6 and 8.2 μm respectively (Figure 4).

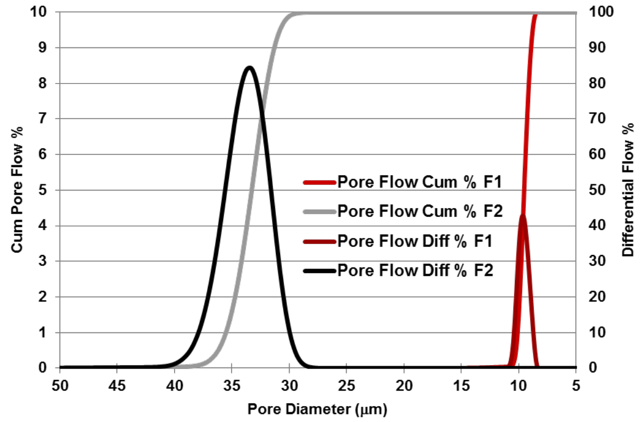

Figure 4: Cumulative flow % versus pore size and differential flow % versus pore size.

These differences are also evident when calculating the pore number per area (Figure 5) and differential pore number per area (Figure 6). It is inferred that a greater number of pores for F1 show dimensions less than ~10 μm and material F2 has more pores in the range from 30 to 40 μm.

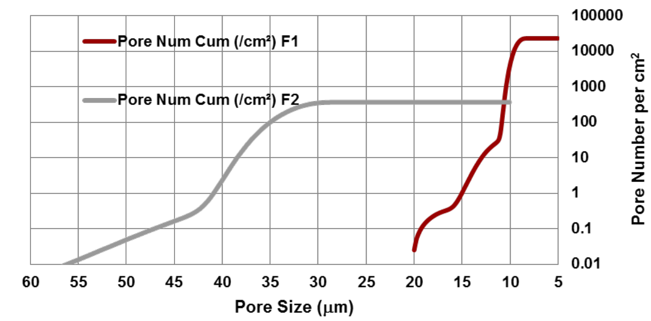

Figure 5: Cumulative pore number per unit area versus pore size.

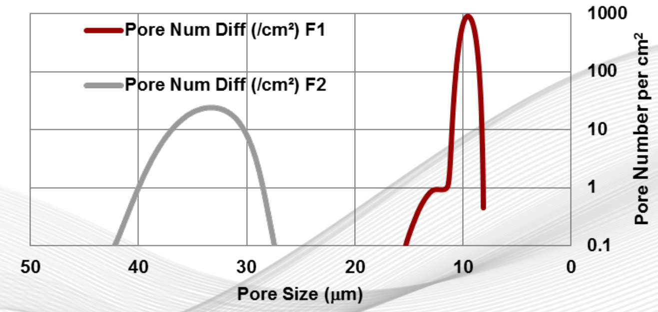

Figure 6: Differential pore number per unit area versus pore size.

These two filters when used in tandem show that filter F2 would be initially used to capture larger particles or contaminants greater than 30 μm before the stream of air passes through to filter F1. Filter F1 reduces the likelihood that particulate matter larger than 10 microns will reach the output of air moving into the system of interest.

4 Standards and Parameters

Particle-based contaminant removal standards have been established by ANSI/ASHRAE. [1] Filters are labeled with a MERV which, along with the measured air velocity, is used for standardizing the filter manufacturing industry in applications to remove specific sized particles. In addition, the Institute of Environmental Sciences and Technology addresses HEPA and ULPA filters with MERV values from 17 to 20. And ISO 14644 covers cleanroom and clean zone standards. [2]

Table 1: MERV Parameter Table

Composite Average Particle Size Removal Efficiency (%) in Size Range (µm) – ANSIA/ASHRA Standard 52.2-2017

MERV	0.3-1.0µm	1.0-3.0µm	3.0-10.0µm	Typically Control	Typical Applications
1	N/A	N/A	<20	>10.0µm pollens, dust mites, textile/ carpet fibers	Minimum filtration; residential building
2	N/A	N/A	<20		
3	N/A	N/A	<20		
4	N/A	N/A	<20		
5	N/A	N/A	30-35	3-10.0µm mold, spores, cement dust	Most commercial and better residential buildings
6	N/A	N/A	35-50		
7	N/A	N/A	>70>85		
8	N/A	N/A	>85		
9	N/A	<50	>85	1-3 µm Legionella, lead dust, coal dust, auto emissions	Superior residential and better commercial building
10	N/A	50-65	>85		
11	N/A	65-80	>85		
12	N/A	>80	>90		
13	<75	>90	>90	0.3-1.0 µm All bacterial, most tobacco smoke, droplet nuclei, most smoke	Hospital inpatient and general surgery; superior commercial building
14	75-85	>90	>90		
15	85-95	>90	>90		
16	>95	>95	>95		
IEST STANDARDS					
17	>99.97% on 0.30µm particles, IEST Type A			Particles <0.3 µm (viruses, radar progeny, carbon dust)	Cleanrooms and pharmaceutical manufacturing
18	>99.99% on 0.30µm particles, IEST Type C				
19	>99.999% on 0.30µm particles, IEST Type D				
20	>99.9999% on 0.30µm particles, IEST Type A				

5 Conclusion

In summary, even though filters or membranes may look similar in appearance, physical properties may differ significantly. The example given here shows two materials that were designed to function in sequence to remove contaminants. It was discovered that material F2 showed larger and fewer pores per area than material F1. The two materials would still function for removing larger particle contaminants. However, many smaller particle contaminants would be able to pass easily through F2 before being stopped by F1.

6 References

1. ASHRAE 52.2-2017 Standard 52.2-2017 -- Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size
2. ISO 14644:2015 Cleanrooms and associated controlled environments - Part 1: Classification of air cleanliness by particle concentration
3. Edward W. Washburn (1921). "The Dynamics of Capillary Flow". Physical Review. 17 (3): 273

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