PMI
POROSITY & PERMEABILITY TESTING

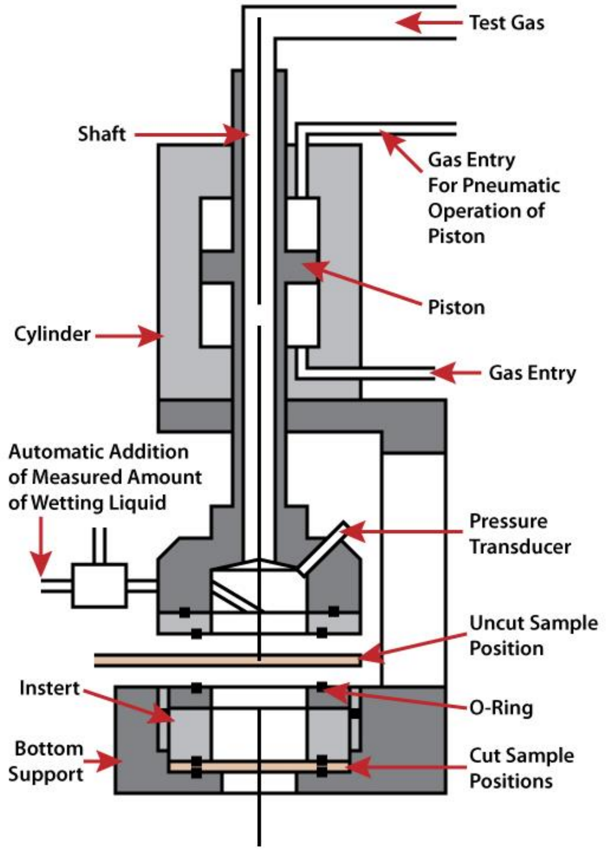
Capillary Flow Porometry with Extended Capability

Dr. Krishna Gupta

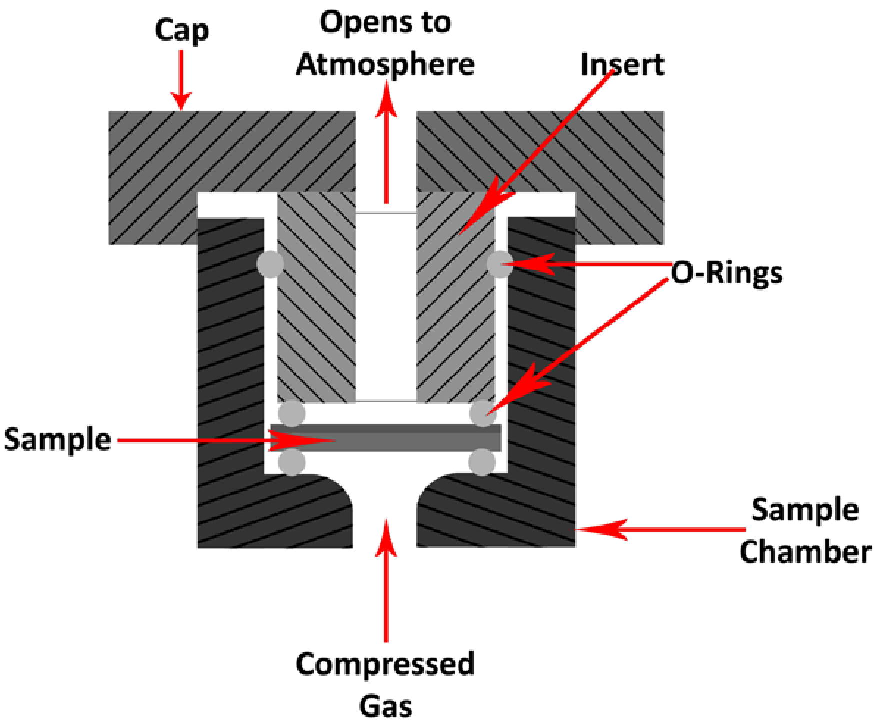
Overview

- Advanced Flow Porometry
- Microflow Porometry
- In-Plane Porometry (Directional Porometry)
- Compression Porometry
- Cyclic Compression Porometry
- Clamp-On Porometry
- Quality Control (QC) Porometry
- Nanopore Porometry
- Complete Filter Cartridge Analyzer
- Integrity Analyzer
- Bubble Point Tester
- Custom Porometers
- Liquid-Liquid Porometry
- Capability to Test Samples with a Wide Variety of Shapes and Sizes

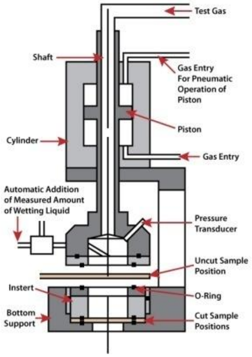
THE ADVANCED POROMETER



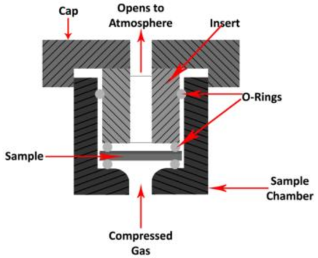
Advanced Porometer



Porometer



Improvements



Advanced Porometer

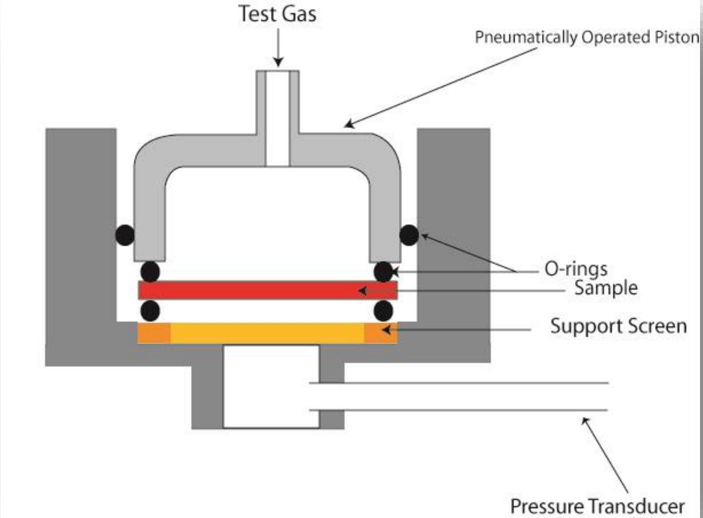
1. Automated uniform compression of O-rings with desired pressure
2. Automatic sample wetting Reduced test duration
3. Minimal pressure drop correction
4. May use differential pressure transducer close to sample
5. Sample cutting not essential
6. Minimal customer involvement
7. Considerably reduced test duration

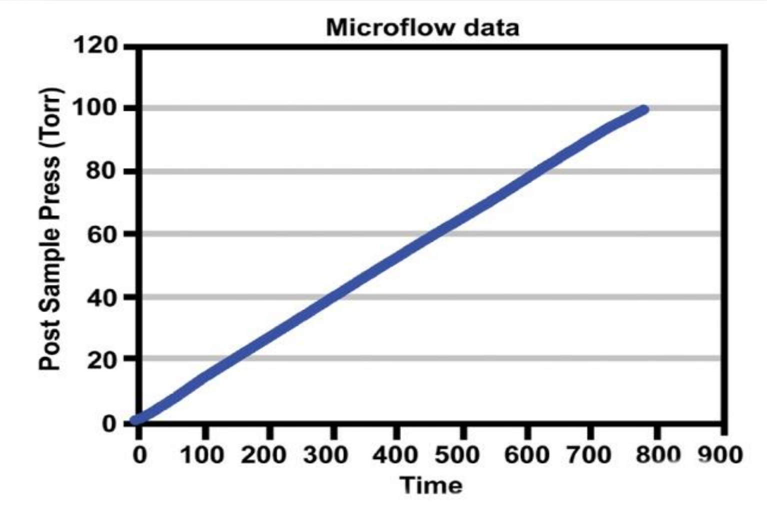
Basic Porometer

1. Manual screw on cap
2. Manual after dismantling sample chamber
3. Pressure drop in the system can be appreciable
4. Uses gauge pressure transducers
5. Sample cutting normally required
6. Very little customer involvement

Microflow Porometry

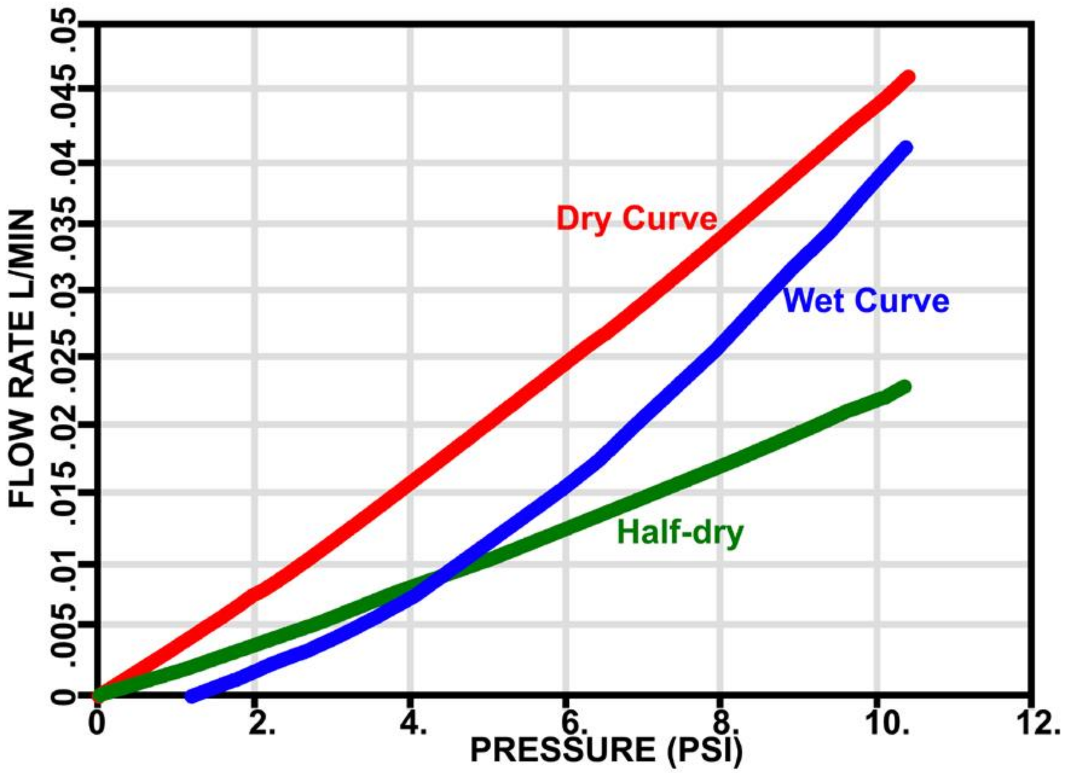
- A pressure transducer is added downstream
- Rate of change of downstream pressure yields effective flow rate





Microflow Porometry

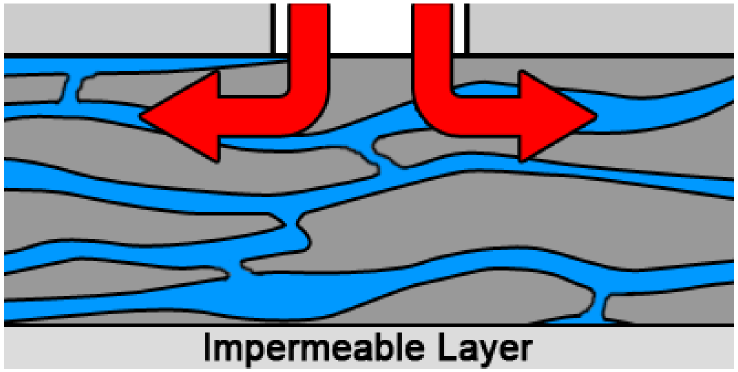
Wet & Dry Curves: Showing very small measurable flow rates

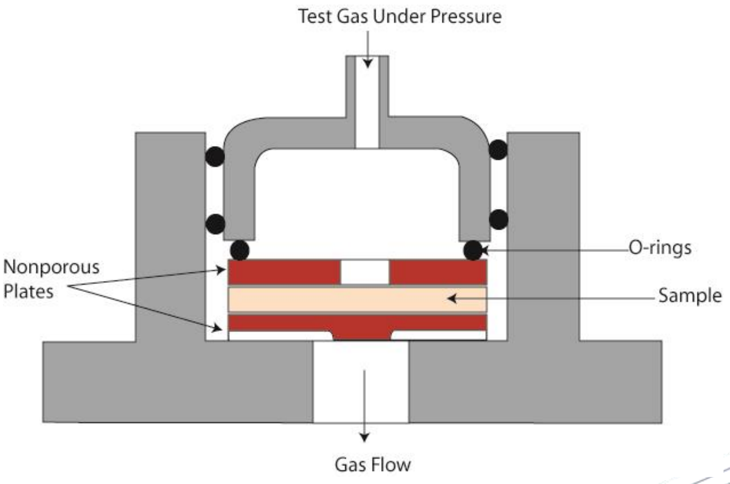


In-Plane & Directional Porometry

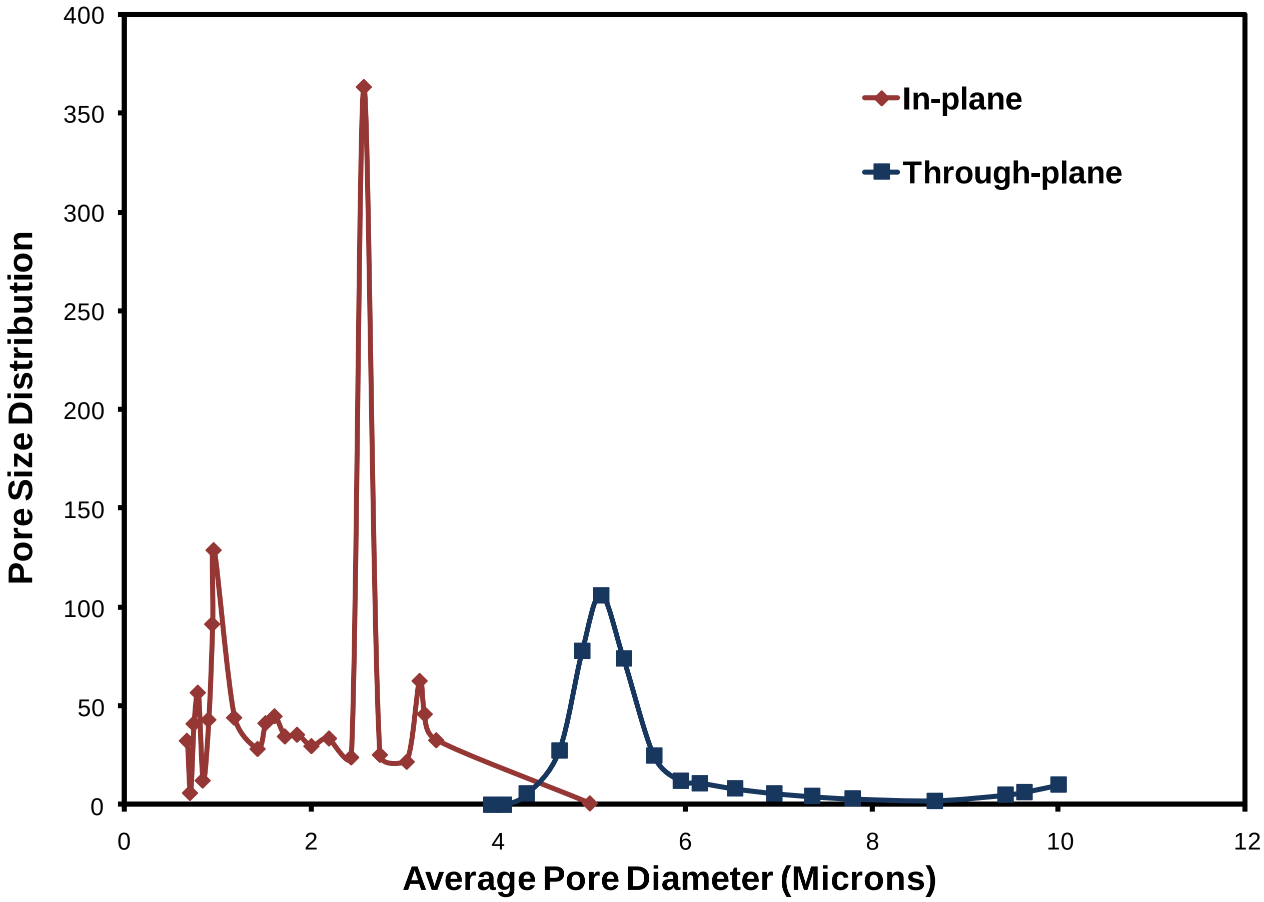
-Top and bottom of the sample blocked to force gas to flow out through the perimeter

-Flow rate measured with increasing differential pressure





In-Plane & Directional Porometry



Through Plane and In-Plane Pore Structure Characteristics

Material Tested	Material Thickness mm (approx.)	Bubble Point Pore Diameter (microns) Through-plane	 In-plane	Ratio of Pore Diameters
Wrapping Paper	0.06	26.3	0.96	27.4
Printer Paper	0.08	12.4	1.10	11.3
Notepad Backing – Cardboard	0.92	6.7	3.53	1.90
Transmission Fluid Filter Felt (thick, dense)	1.90	80.4	43.3	1.86
Meltblown Sheet (dense)	1.80	114.3	68.8	1.66
Poly Felt Blanket (soft)	2.00	51.8	19.8	2.62
Poly Filter (hard, thin)	0.49	51.1	24.1	2.12
Liquid Filter (thick, hard)	1.50	34.5	15.3	2.25

In-Plane & Directional Porometry

Direction	Bubble point (µm)	Mean flow (µm)	Permeability (darcy)
X	27.1	3.86	5.3
Y	39.1	3.39	6.9
Z	63.0	15.2	22.5

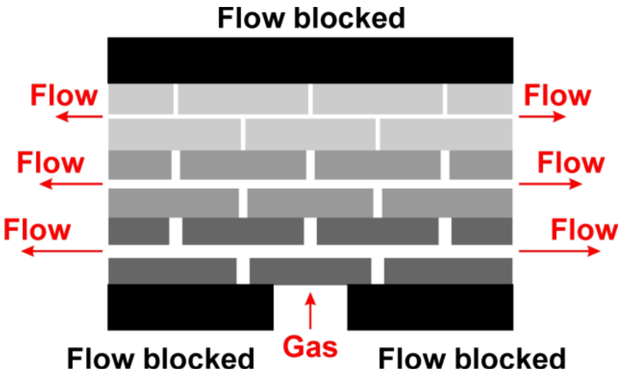
Porometry of Layered Structures by In-Plane & Directional Porometry

In-Plane Porometry:

Through plane flow blocked

Test characterizes layers with larger pores

Pore size: Layer 1 > Layer 2 > Layer 3

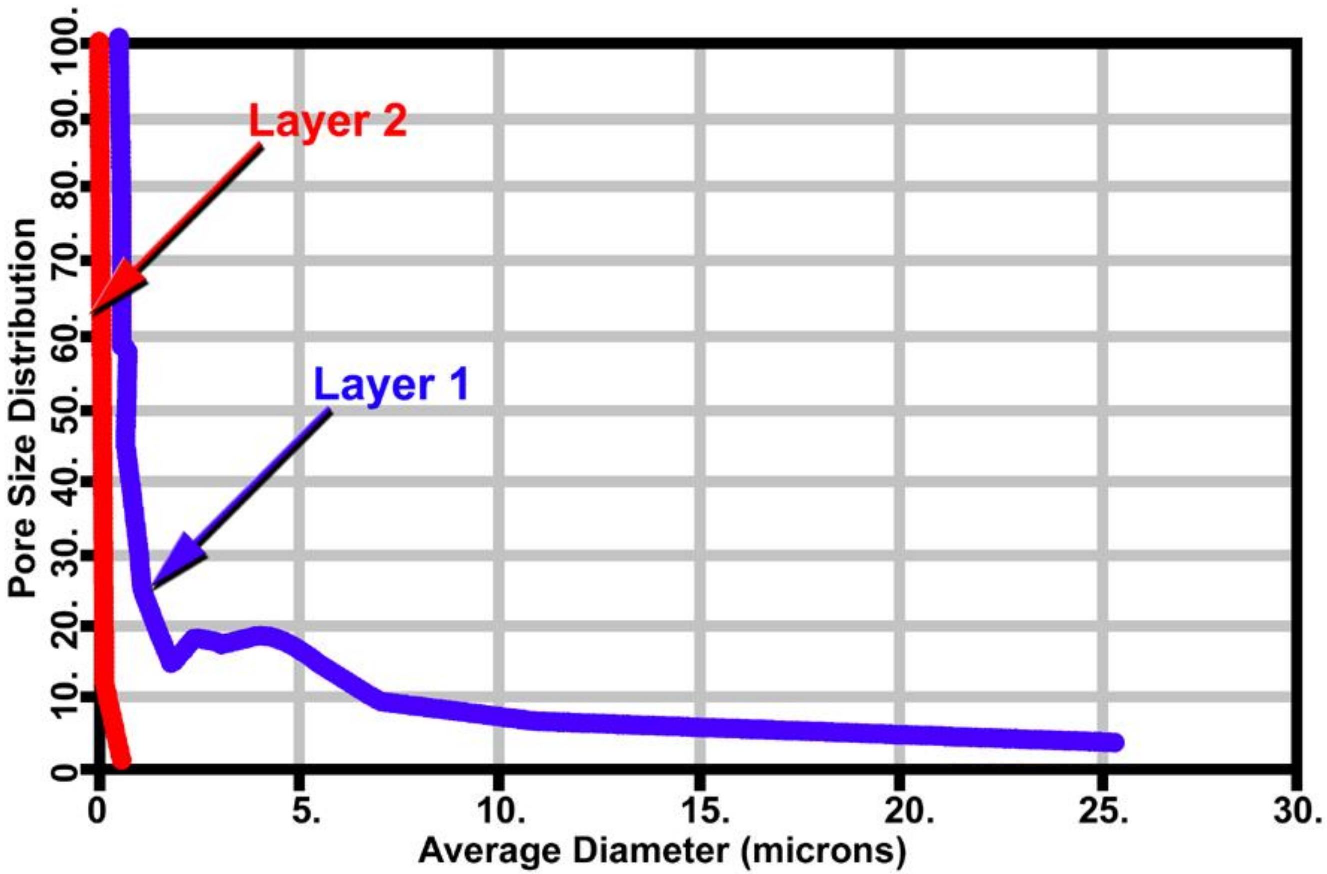


Gas pressure for flow through layers

Pressure: $(p_1 - p_1') < (p_2 - p_2') < (p_3 - p_3')$

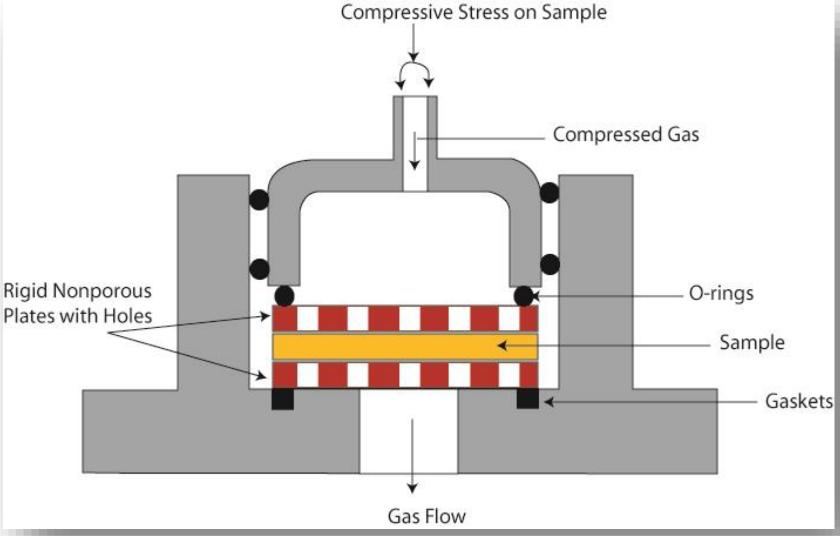
Flow Layers: 1 1+2 1+2+3

Porometry of Layered Structures
Hot Gas Filter

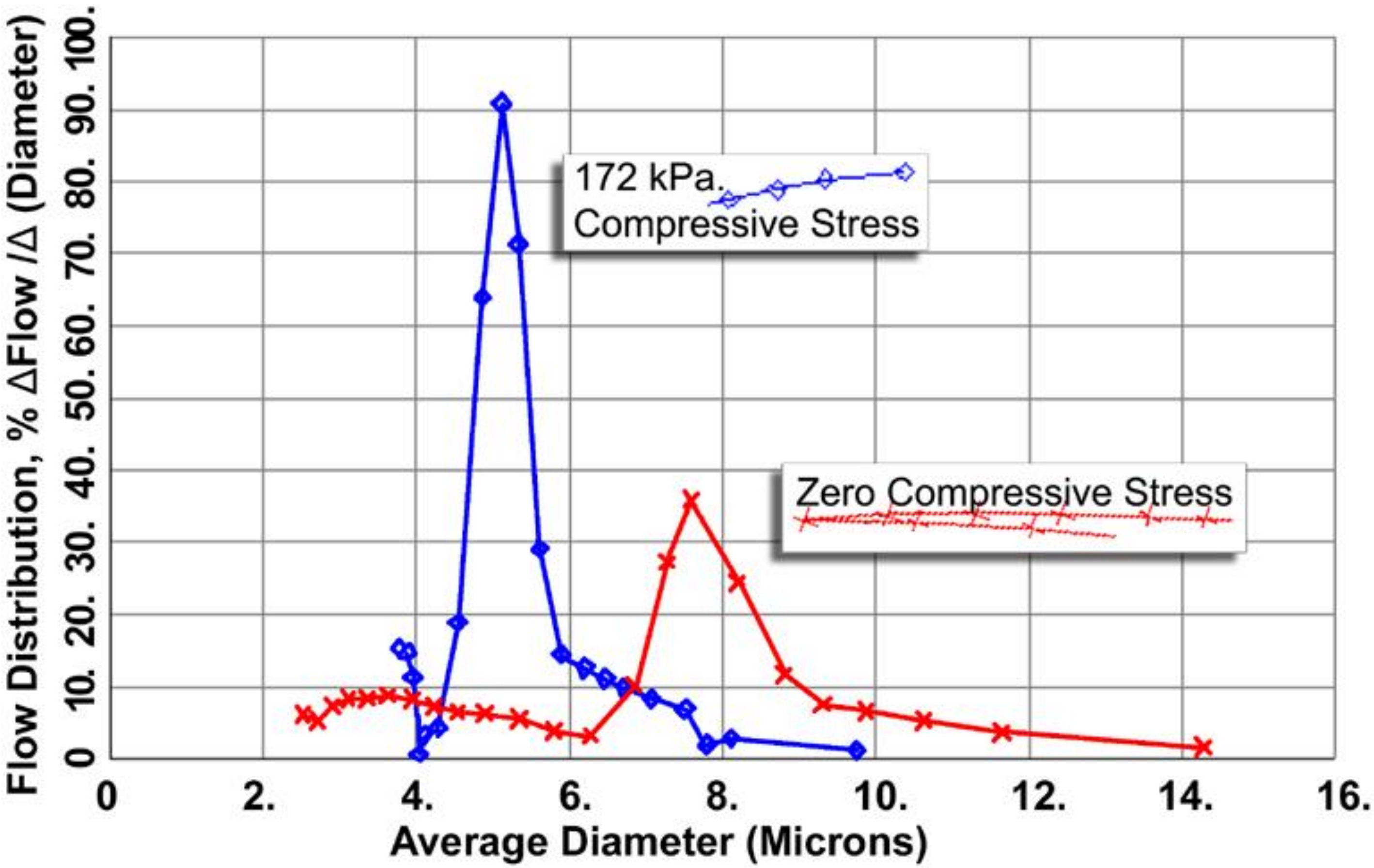


Compression Porometry

- Compressive stresses can appreciably modify the pore structure
- Compression porometer keeps the sample under compressive stress during the test



Compression Porometry



Compression Porometry

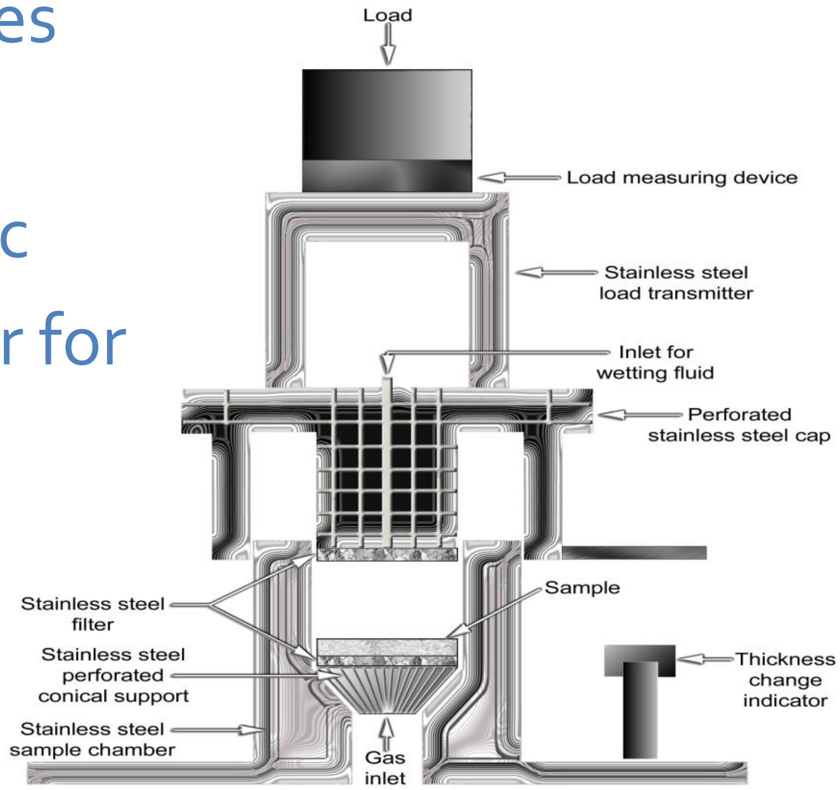
Differential Pressure			Pore Diameter, μm	
Stress, kPa	Bubble point, psi	Mean flow, psi	Bubble point, μm	Mean flow, μm
0	2.801	5.916	16.347	7.738
34.5	3.143	6.004	14.567	7.625
103	3.712	8.750	12.333	5.232
172	4.114	8.774	11.129	5.218
379	4.482	8.886	10.216	5.152

Cyclic Compression Porometry

-Pore sizes may change appreciably after repeated stressing cycles

Example: Felts

-Sample chamber of Cyclic Compression Porometer for stressing the sample

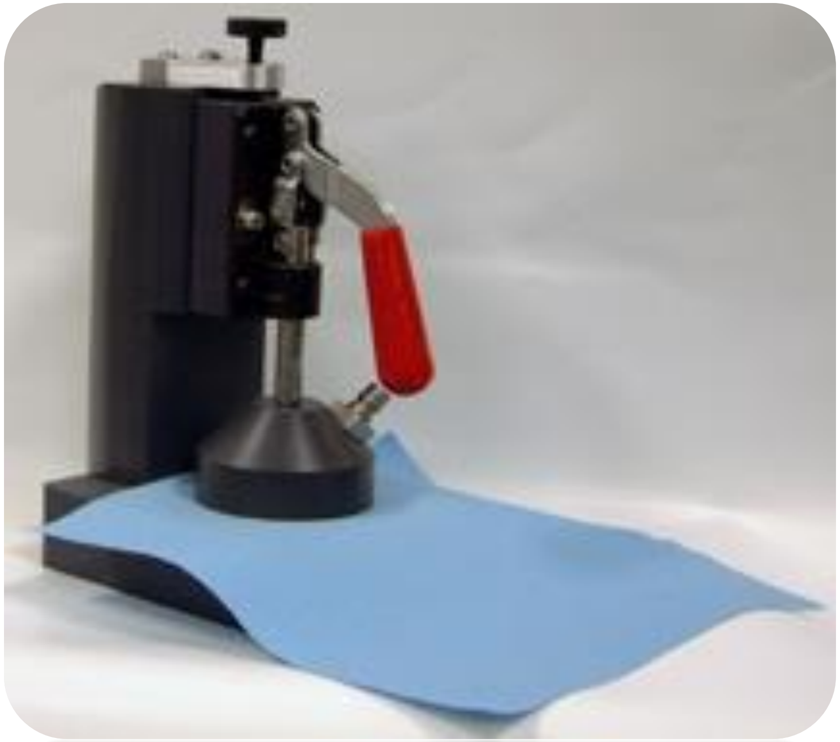


Cyclic Compression: Effects

Material	Felt 1	Felt 2
Max Comp. Stress (psi)	500	750
Cycles	15	2000
% change in BP diameter	-71.1	-68.4
% change in mean flow pore diameter	-30.3	-15.8

Clamp-On Porometry

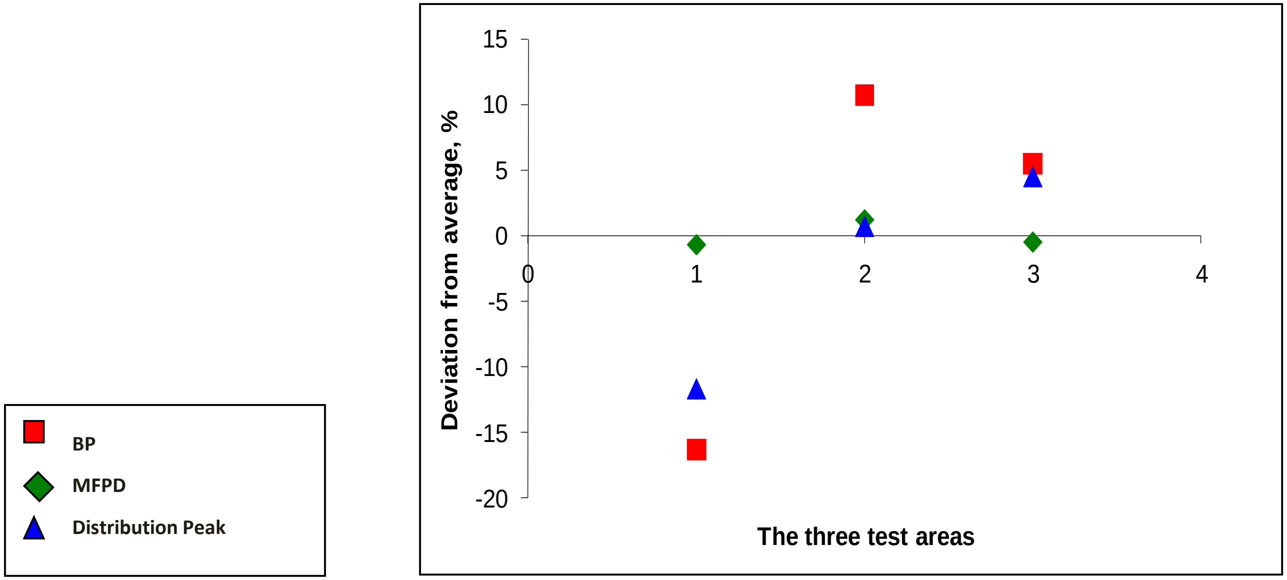
Testing without cutting



Sample Chamber for Clamp-On Porometer

CLAMP-ON POROMETRY

Minimal Time: Tests can be performed quickly, *in situ*.
Material Preparation: No cutting ▶ No waste
Sampling: Several tests can be run on areas of a sheet of materials without cutting to check homogeneity



BP, MFPD, distribution peak at three locations on a filter material

QC Porometer

Simplified Capillary Flow Porometer

- Less to configure
- Easy and quick operation
- User-friendly
- Pass/Fail indicators

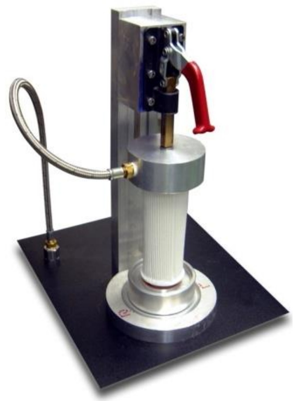
Nanopore Porometry

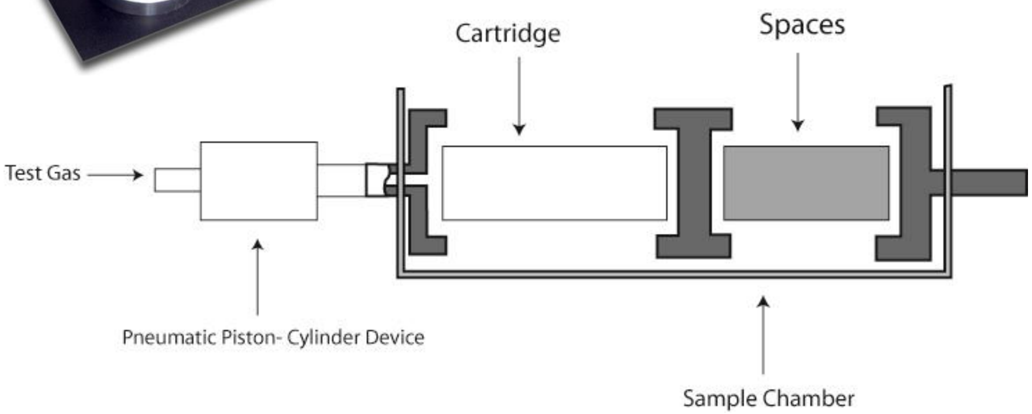
Measurement of Nanometer

- Differential pressure used up to 2000 psi
- Measurable pore size down to 0.005 μm
- Membranes need to withstand 2000 psi

Complete Filter Cartridge Analyzer

- Tests fully assembled complete filter cartridges
- Cartridge of almost any length & diameter accommodated
- End seals by automated pneumatic pressure

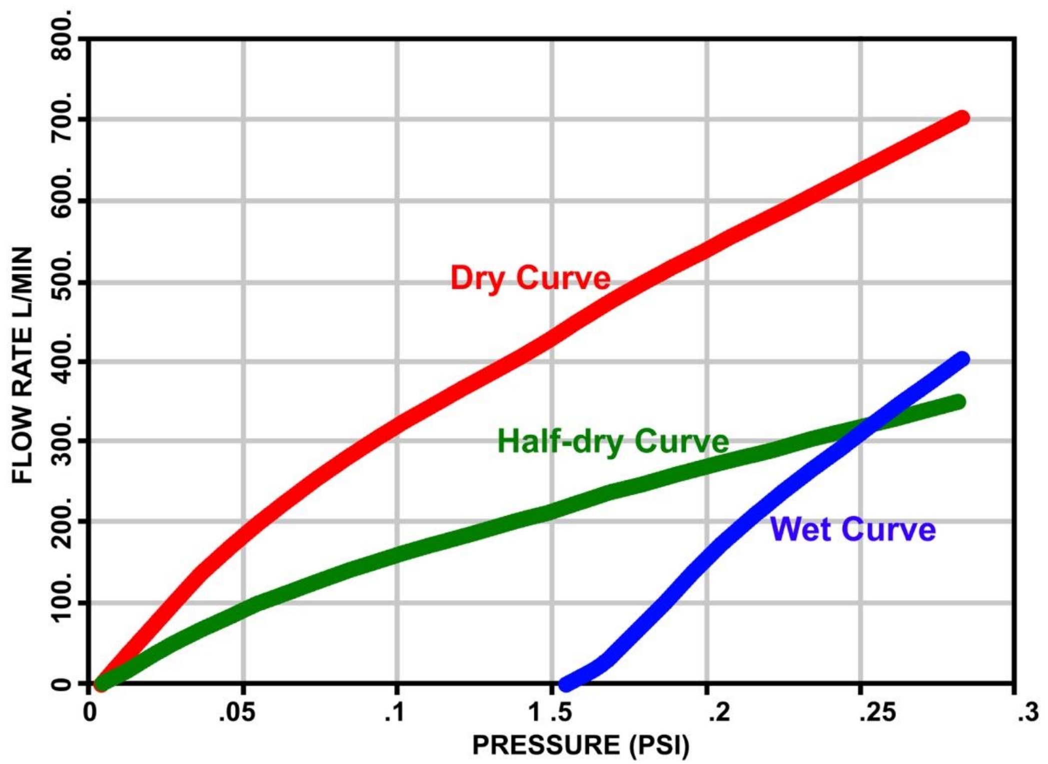




Complete Filter Cartridge Analyzer

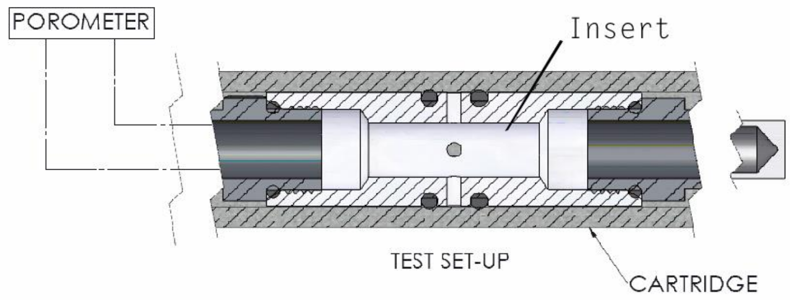
Typical Results

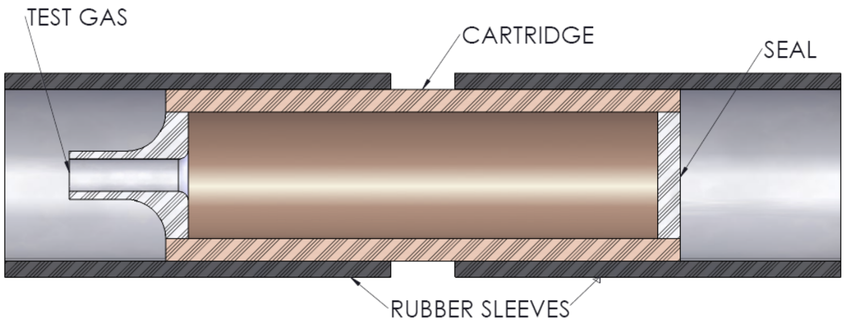
Large flow rates can be detected

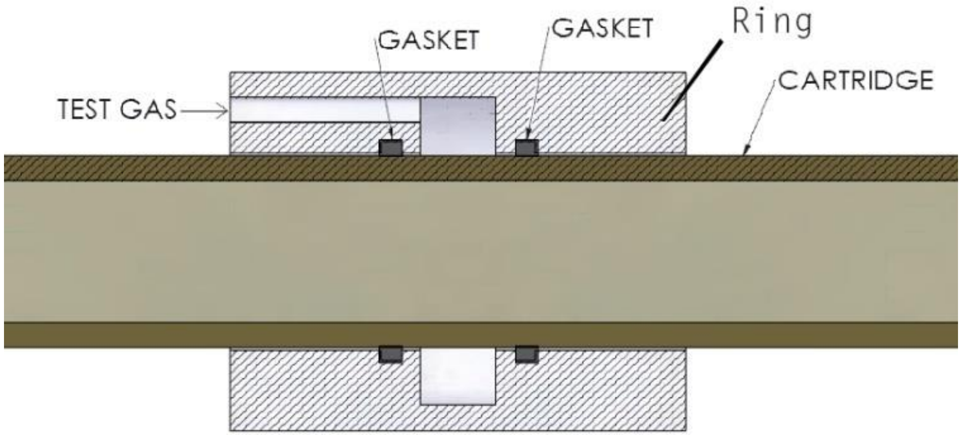


Complete Filter Cartridge Analyzer

Pore Structure as a Function of Cartridge Length







Pore Structure as a Function of Cartridge Length

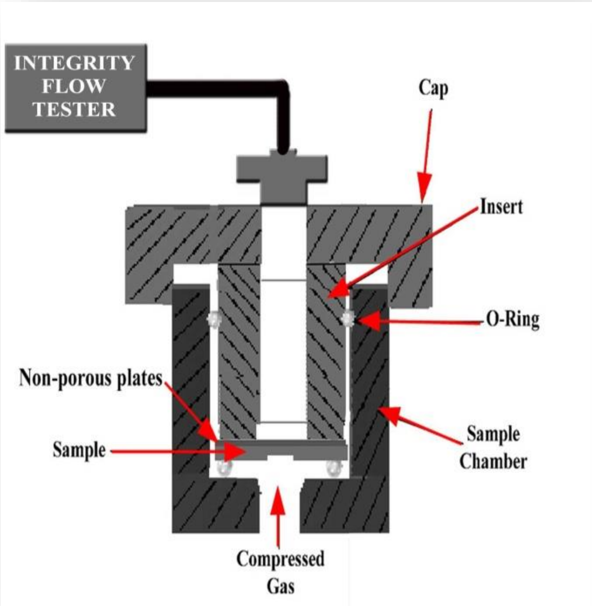
Table 6: Difference between the bubble point pore diameters (BPPD) and mean flow pore diameters (MFPD) at the left and right locations in two cartridges

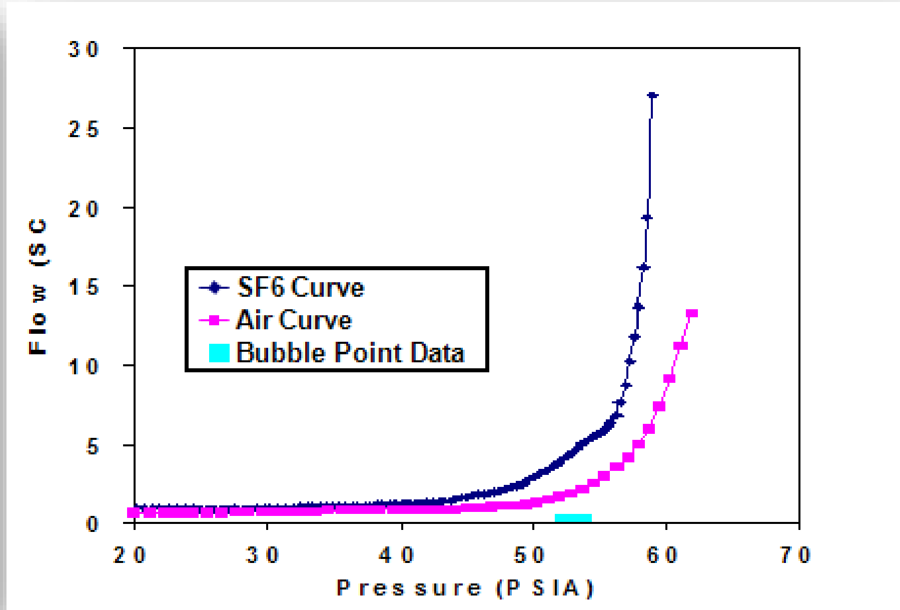
	Cartridge #1		Cartridge #2	
Difference Between Left & Right	BBPD	MFPD	BBPD	MFPD
	24%	20%	65%	56%

The pore structure along cartridge length may be unacceptable

Filter Integrity Analyzer

-Flow measured down stream to detect flow before bubble point
-Sensitivity can be improved by using different liquids





Multi-Head Bubble Point Test System

Single-chamber test systems can be impractical for high volume testing

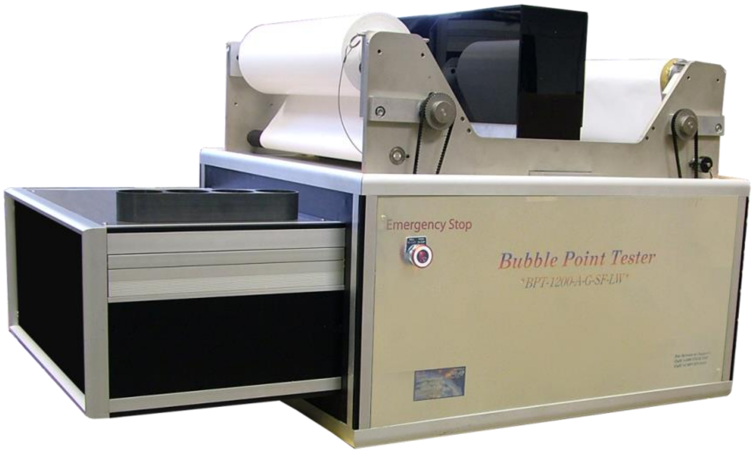
Bubble point testers can accommodate:

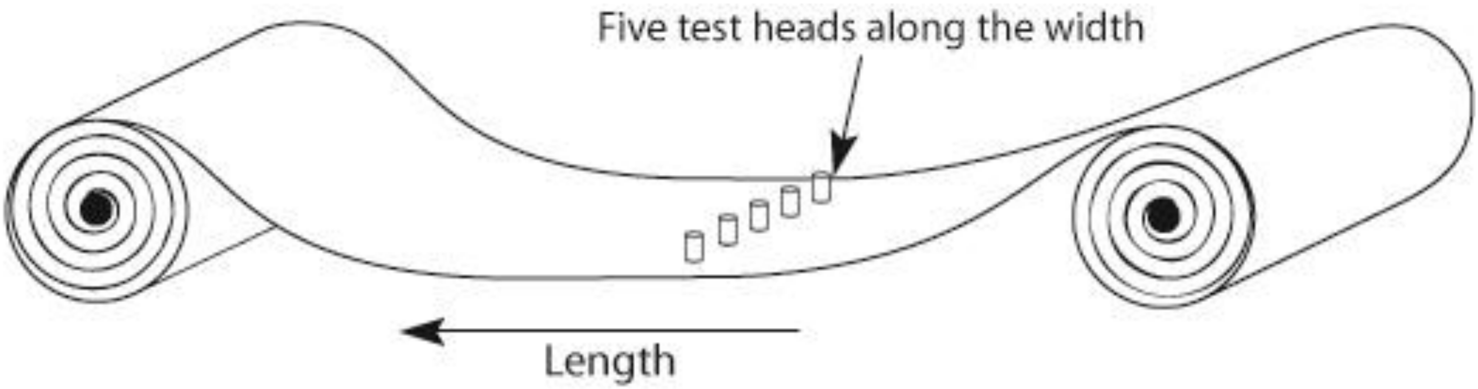
- Any number of test heads
- Any type of sample & cartridge
- Automated testing with pass/fail option

Examples of Custom Porometers

The custom porometers capable of testing cartridges and filtration media and performing liquid permeability test

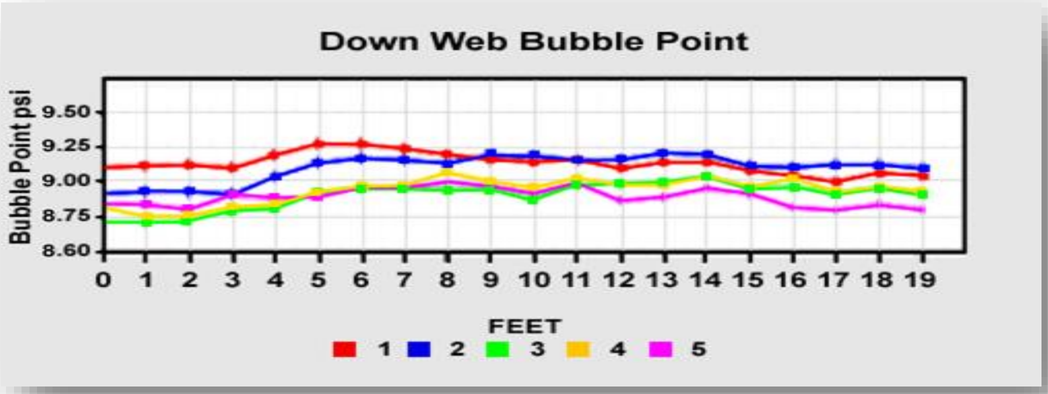
Multipoint Simultaneous Pore Structure Analyzers



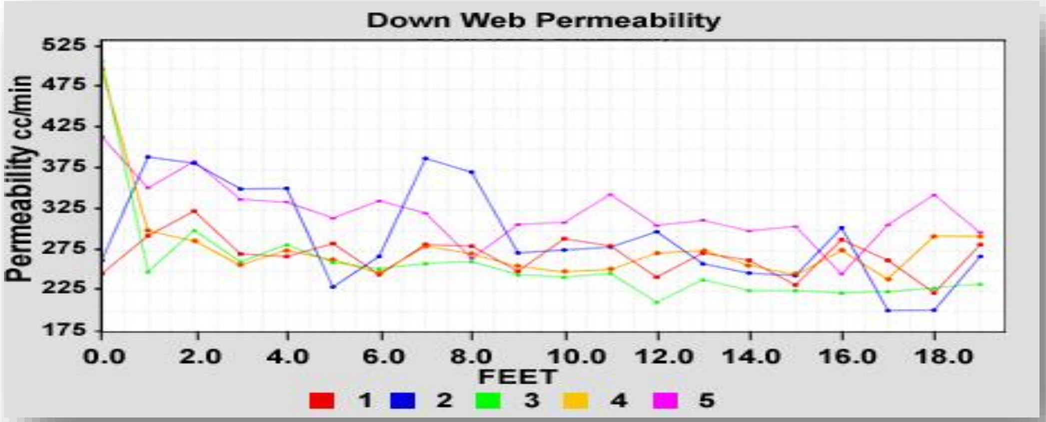


Test Sequence

Custom Porometers



Bubble point as a function of length (Down Web) at the five different locations along the width



Permeability as a function of length (Down Web) at the five different locations along the width

Controlled chemical environment Porometers

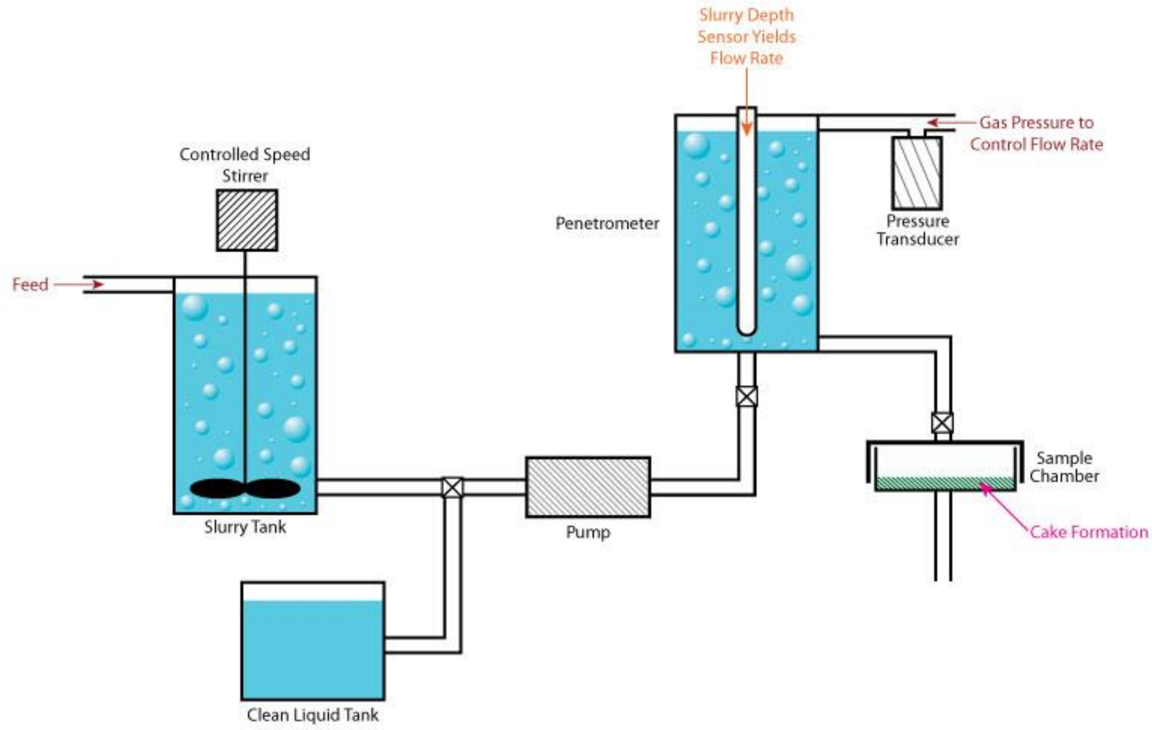
Two unique models of custom porometer capable of testing under controlled humidity & temperature

Unique Cake Forming Porometer

Porometer capable of forming cake from slurry and testing the cake in-situ

Unique Cake Forming Porometer

Porometer capable of forming cake from slurry under controlled pressure and flow



Unique Cake Forming Porometer

Effect of deposition of a slurry on pore structure of media before and after cake formation

Pore Diameter	Media µm	1^{st} Deposit µm	Change	2^{nd} Deposit µm	Change
Bubble Point	6.32	2.98	53%	1.09	83%
Mean Flow Pore Diameter	2.83	0.715	75%	0.237	92%

Liquid-Liquid Porometer

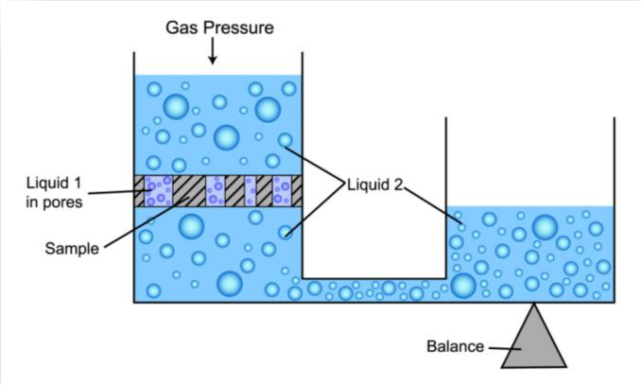
- Wetting liquid-1 is used to fill the pores of the sample
- **Wetting liquid-2 having higher surface tension is used to displace liquid-1 from pores and flow through pores**
- Flow rate of higher surface tension liquid-2 measured with differential pressure through dry and wet sample
- **Pore size, D, computed from differential pressure, p, and interfacial tension & contact angle**

$$D = 4\,\gamma \cos\theta / p$$

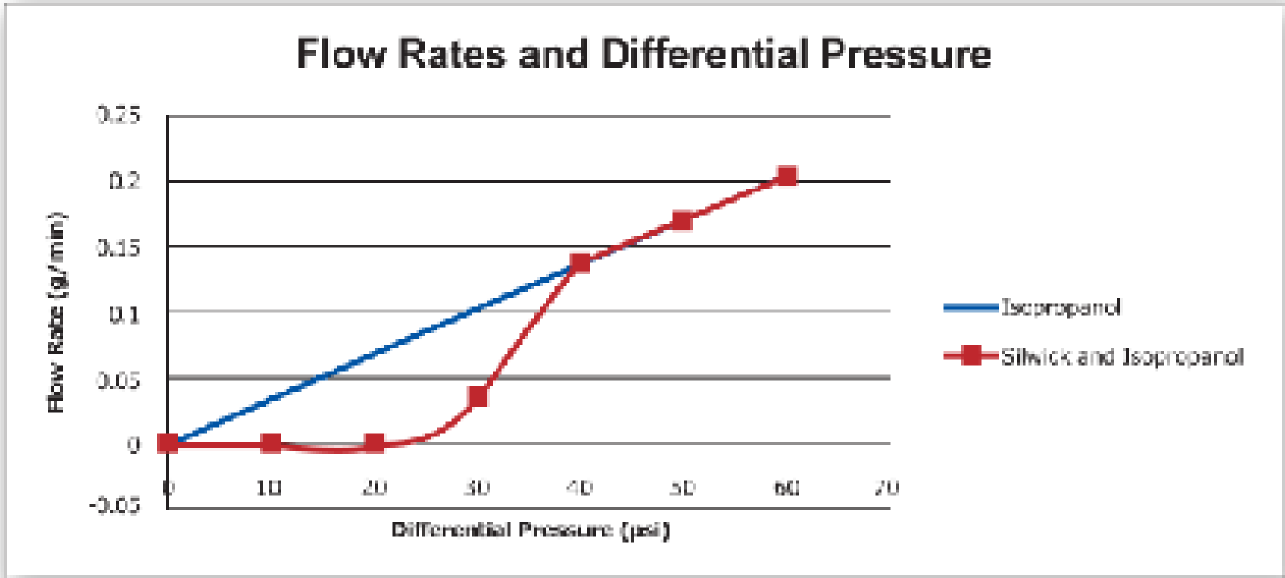
Θ= contact angle

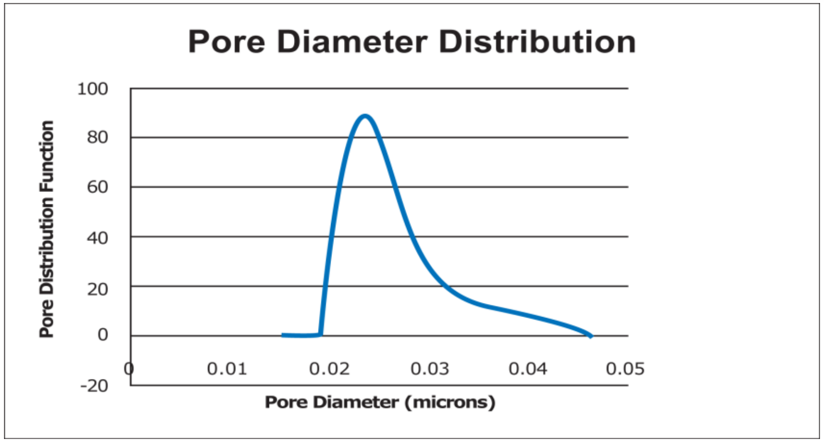
γ = interfacial tension

- Pore distribution and liquid permeability computed

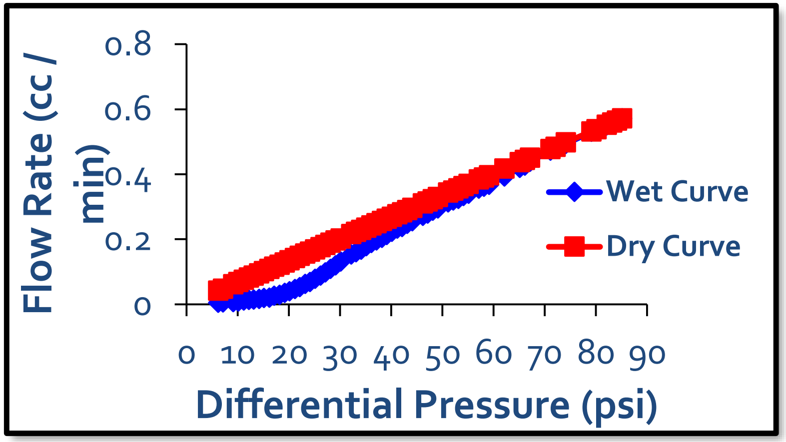


Liquid-Liquid Porometer

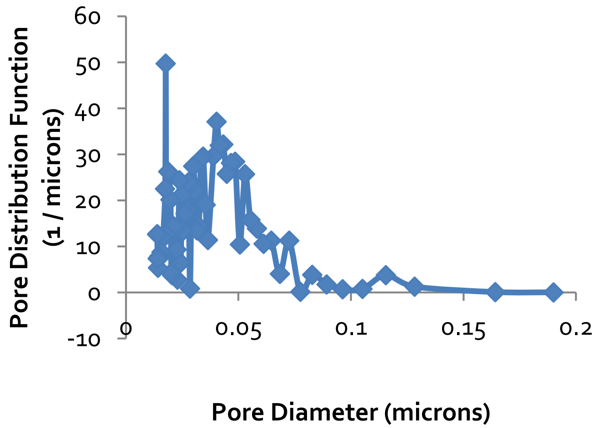




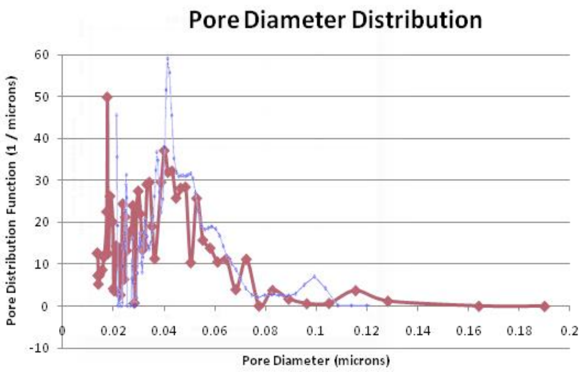
Liquid-Liquid Porometer



Wet and Dry flow by LLP



Pore Distribution by LLP



Pore Distribution by LLP & CFP

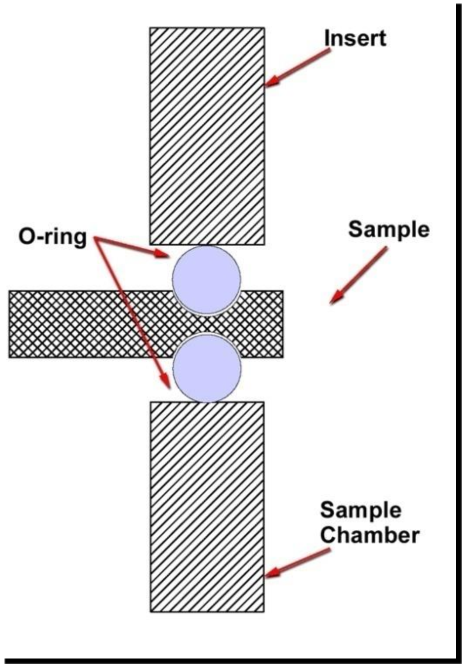
LL Porometers & CF Porometers

Characteristics	LLP	CFP
Test pressure	About an order of magnitude lower	About an order of magnitude higher
Effect of pressure On pore structure	Negligible	Can be appreciable
Through pore throat diameters	Measurable	Measurable
Smallest measurable pore diameter	2 nm	13 nm
Bubble point	Not accurately measurable	Accurately measurable
Mean Flow Pore Diameter	Measurable	Measurable
Pore distribution	Measurable	Measurable
Liquid permeability	Measurable	Not measurable
Gas Permeability	Not Measurable	Measurable

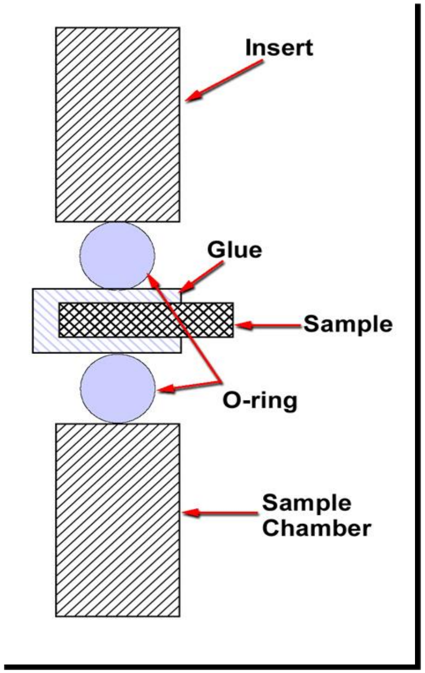
Examples of

Testing of a Wide Variety of Sample Shapes and Sizes

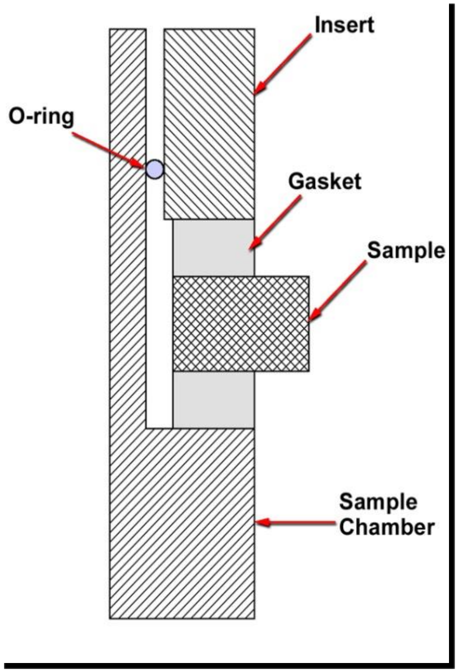
Testing of Sheet or Disc Samples



Compressible Material



Not Compressible Material



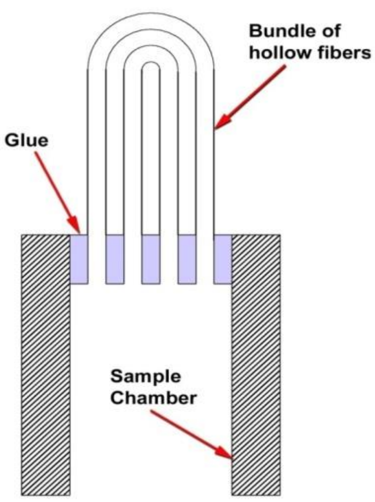
Thick & Hard

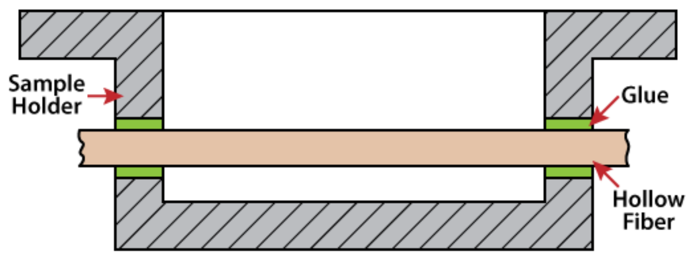
Testing of Hollow Fibers

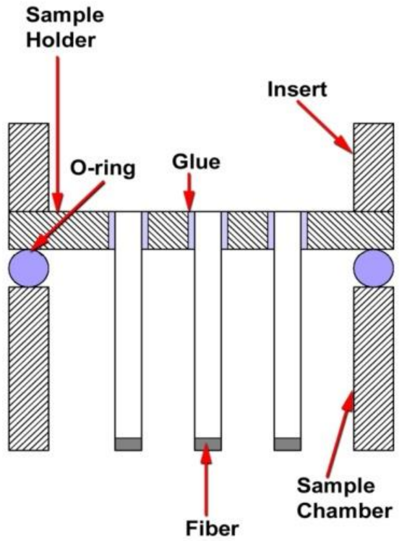
Long thin wall flexible tubular products (2 mm)

(Testing of a bundle of hollow fibers)

Gas flow: Inside to Outside   Outside to Inside



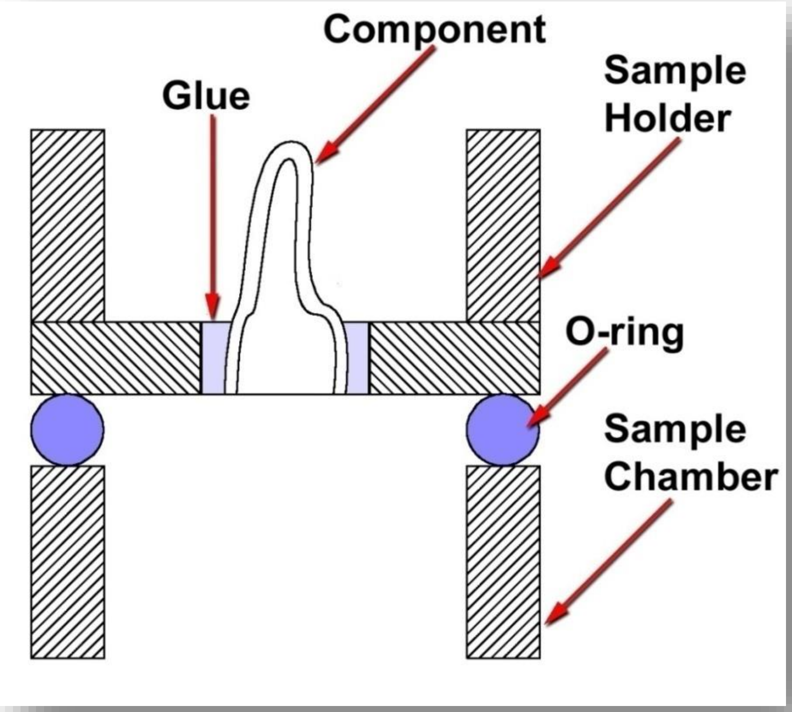




TESTING OF SMALL ODD SHAPED COMPONENTS

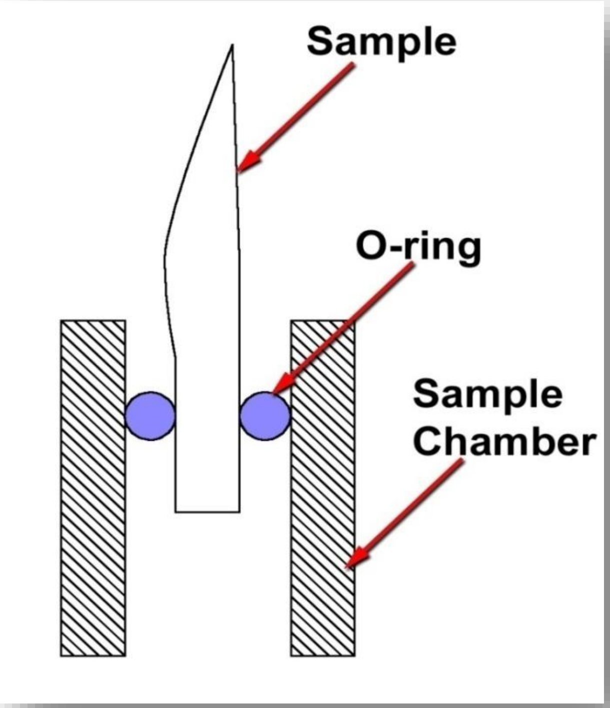
Mounted on a plate

(Absorbents in healthcare use, Pen tips)



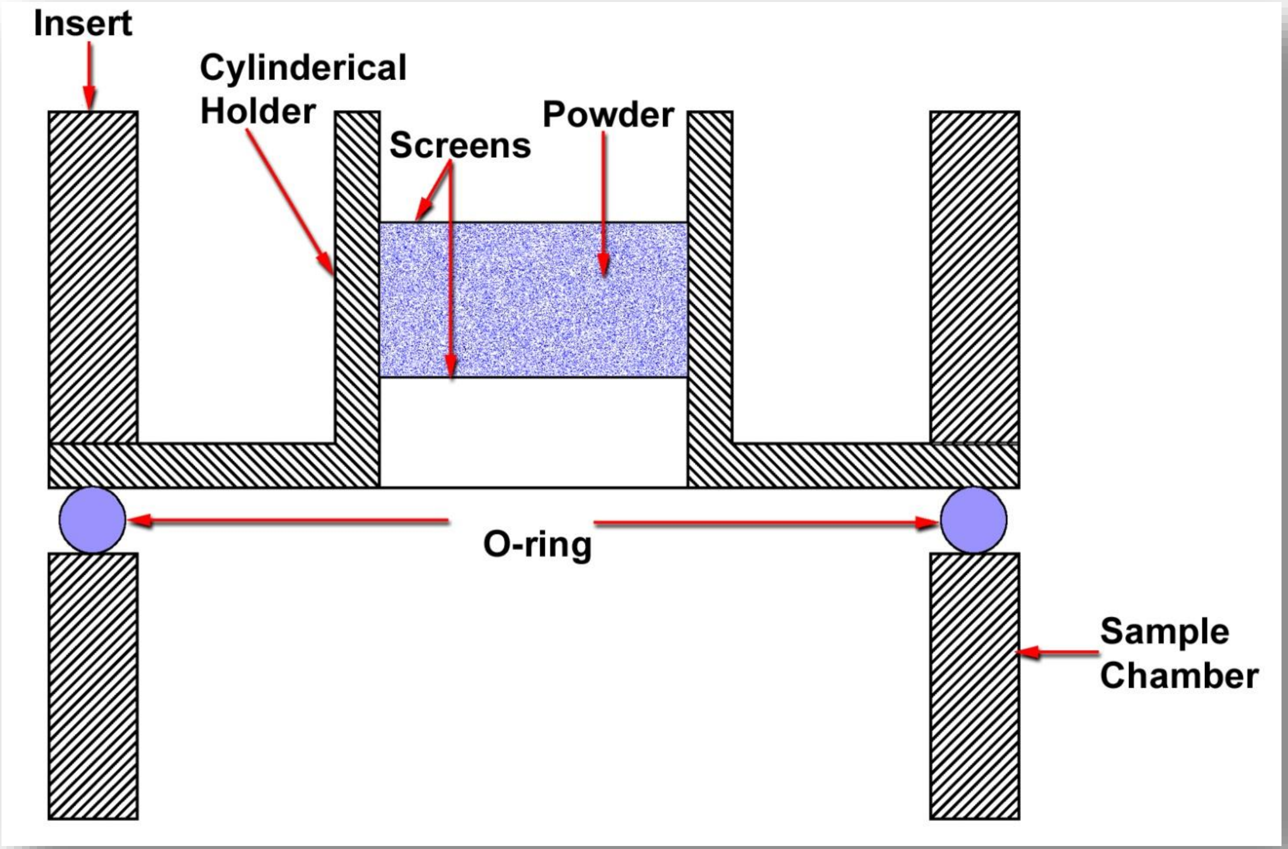
Inserted in small tubular opening

(Ceramic spikes)

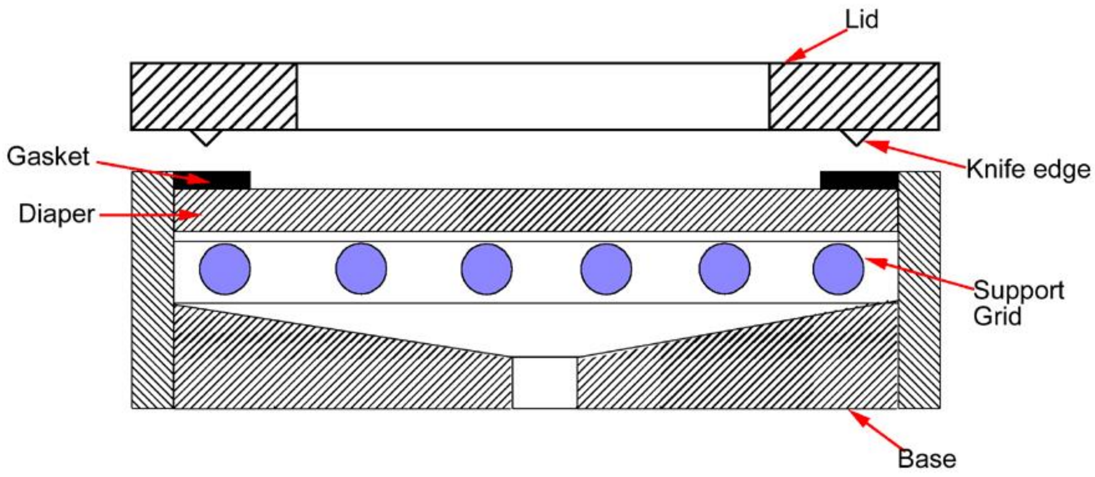


Powders

Mounting of Powder samples



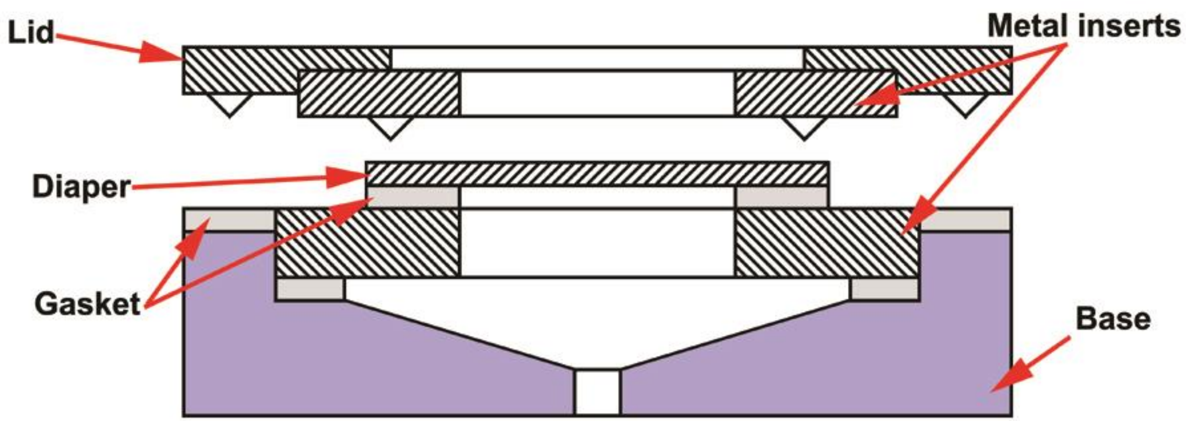
TESTING OF DIAPERS



Rectangular holder for large diapers

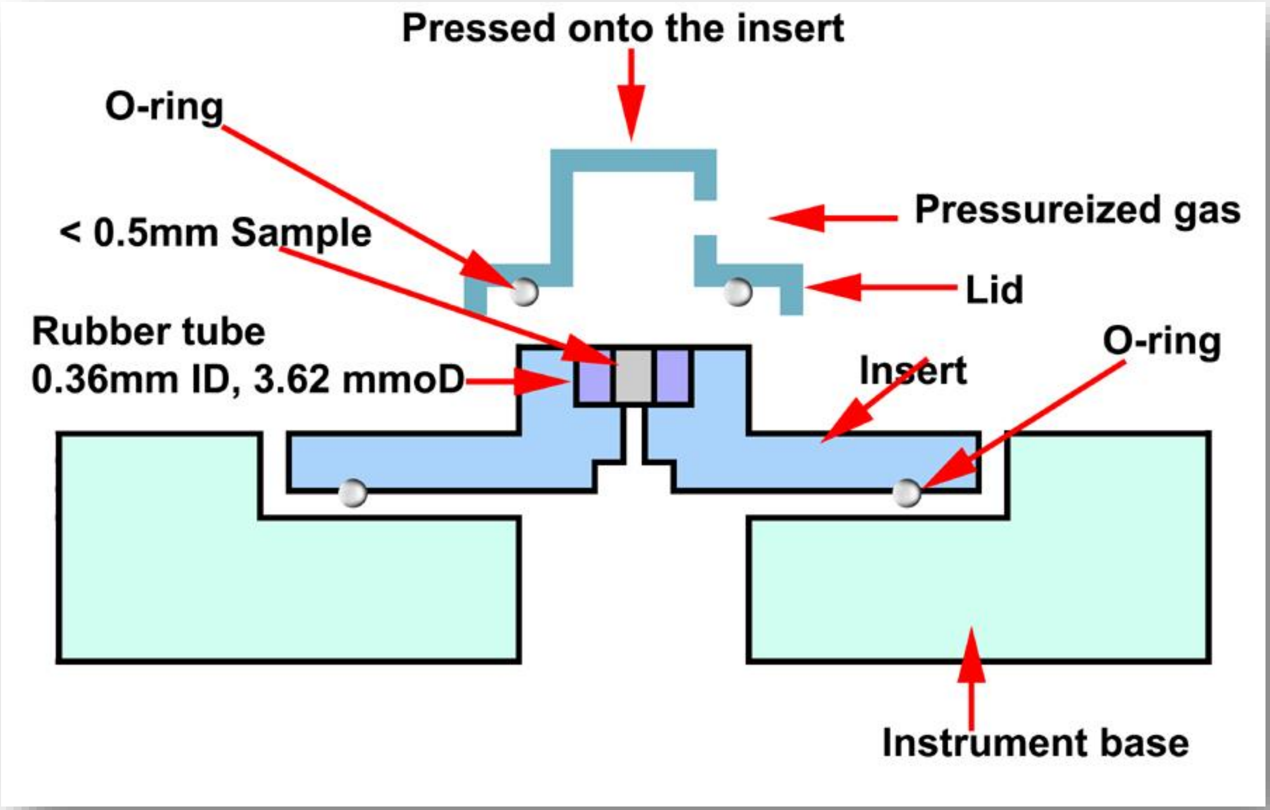
Flow rate ≈ 5000 L / min

Sample chamber for testing small diapers

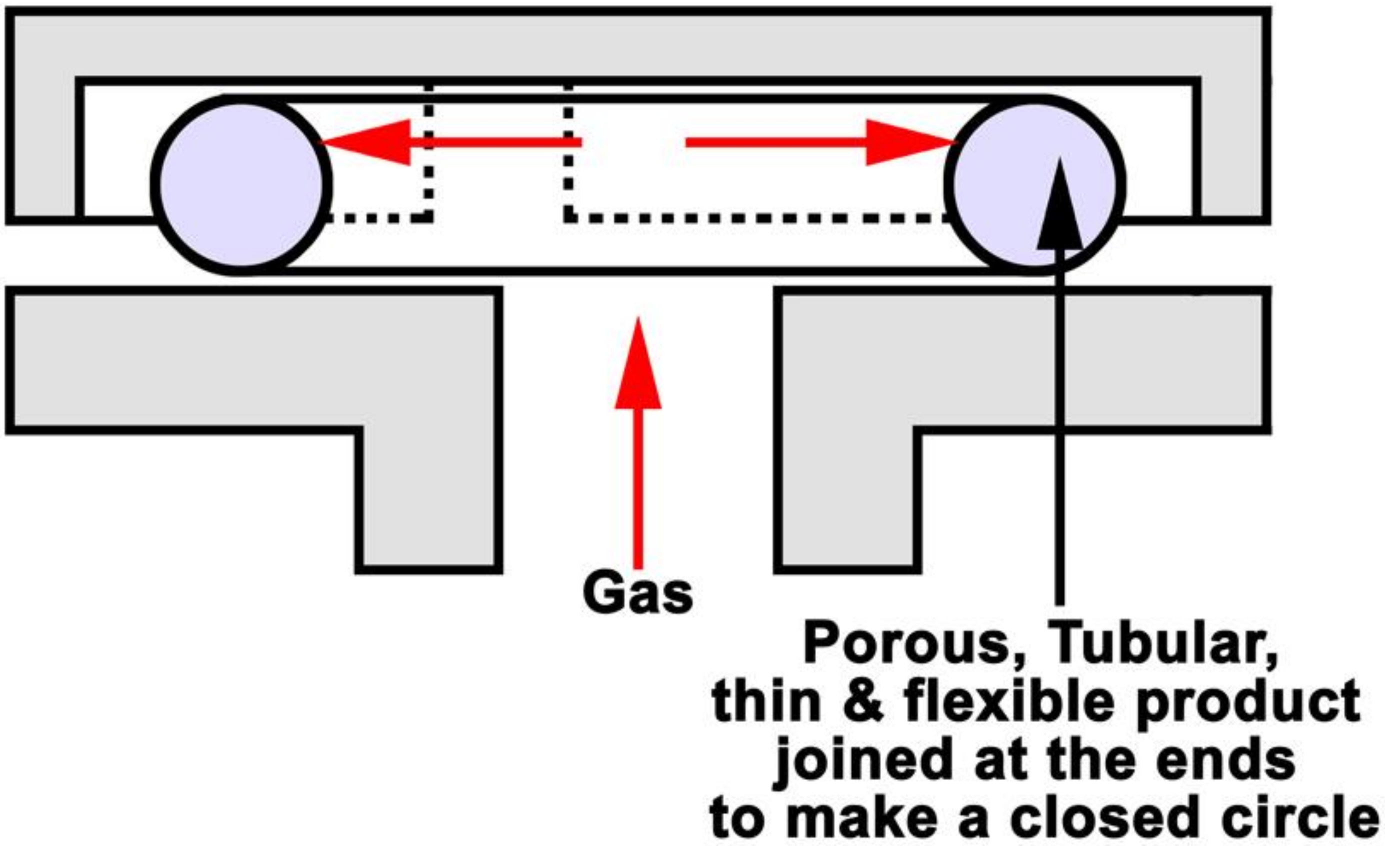


Tiny (0.5 mm diameter) Sample

Sample holder for Tiny < ½ mm diameter samples



Thin Tubular Flexible Porous Product



Sample holder for testing

Conclusion

- The basic theory of porometry is the same, but because of physical realities & complex test requirements the technology is involved.
- Product applications determine the appropriate technology for characterization.
- Many ways of dealing with varying sample shapes, material properties and configurations have been developed.
- Advanced, microflow, in-plane, clamp-on, compression, and QC porometers are finding many applications a wide range of industries.

THANK YOU!

PMI

POROSITY & PERMEABILITY TESTING