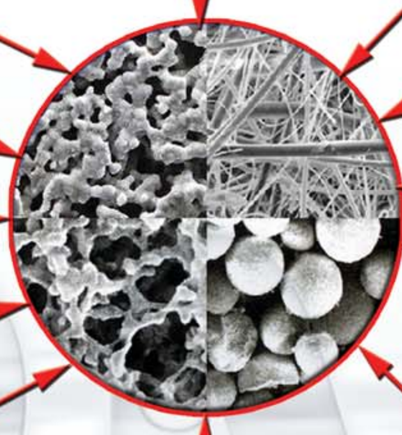
Characterization of Pore Structure



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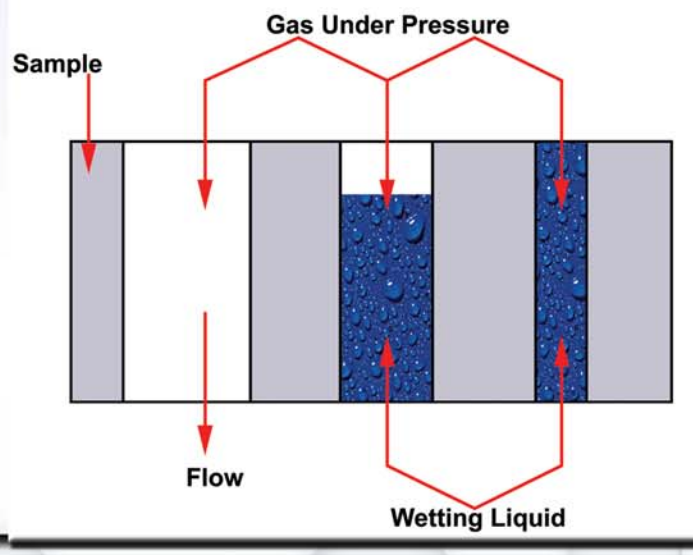
Extrusion Porometer

The pores of the sample are filled with a wetting liquid, and gas pressure is used to expel the liquid. Gas flow rates through wet and dry samples are measured. Differential pressure is used to compute throat diameters of through pores. Flow rates and differential pressures yield the largest pore diameter, mean flow pore diameter, pore distribution, envelope surface area (through pore surface area), and gas permeability.

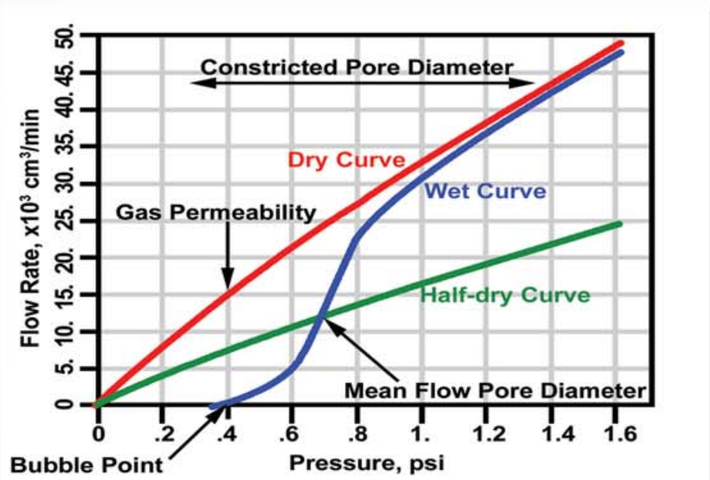


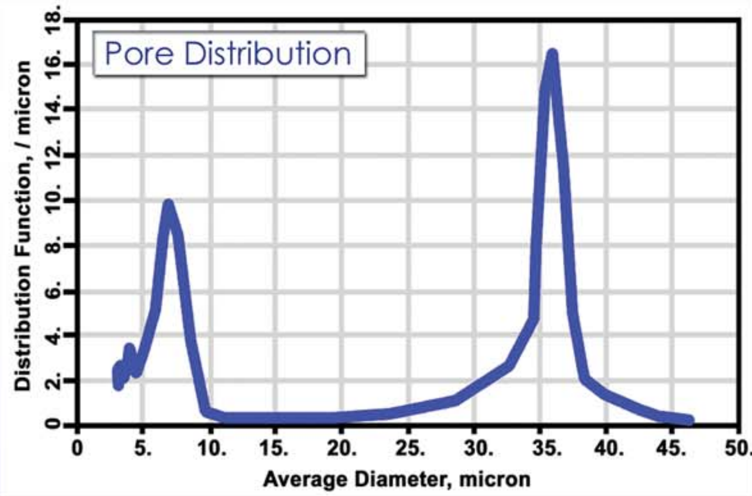
The instrument is fully automated. Test execution, data acquisition, data storage, and data reduction are automatically performed. Windows based operation is simple and user friendly. A wide variety of sample shapes and sizes can be accommodated. The pore size from 500 microns down to about 0.013 microns can be measured by different models of the porometer.

Capillary Flow Porometer

This instrument measures differential pressures and gas flow rates through dry samples and samples wetted with a wetting liquid. The most constricted through pore diameter, mean flow pore diameter, pore distribution, pore diameter range, and gas permeability are computed from such data. The instrument may have optional features to permit determination of liquid permeability, envelope surface area, and multiple sample testing. Many operator adjustable test parameters of the instrument permit acquisition of very accurate results from a variety of samples with a wide range of pore size and permeability.

Area under the distribution curve in any pore diameter range yields percentage flow in that range.



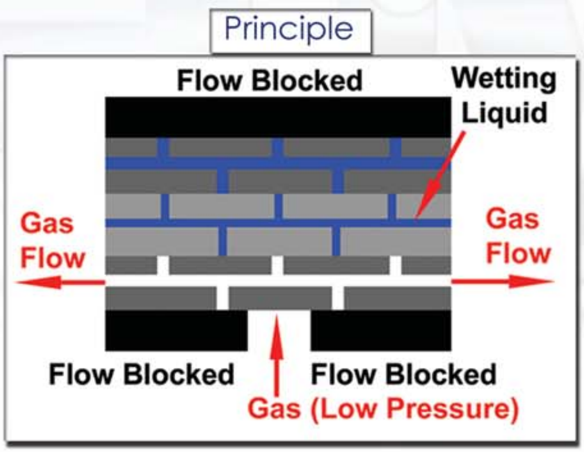


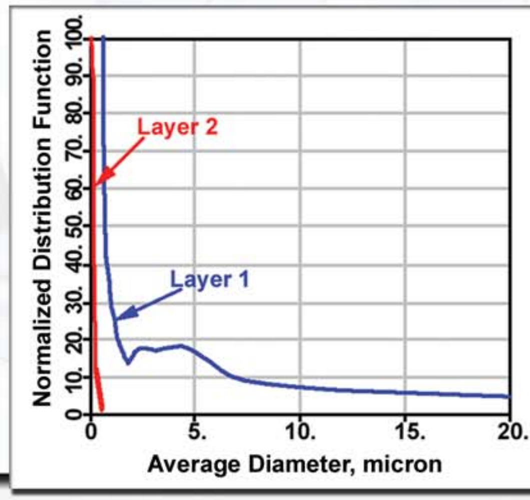
Sophisticated design and complete automation for accurate and reprocible output

In-Plane Porometer

This is a capillary flow porometer that contains specially designed sample chambers and software. In addition to measuring all the z-direction (thickness direction) pore structure characteristics measurable by the capillary flow porometer, the in-plane porometer can measure the largest through pore diameter, mean flow pore diameter, pore distribution, and permeability in the x-y plane of the sample.

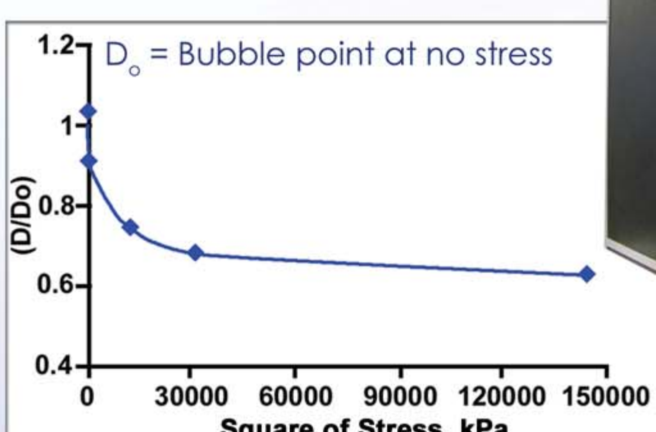
The in-plane porometer can be used to measure pore structure characteristics of individual layers of a multi-layer composite insitu without separating the layers.





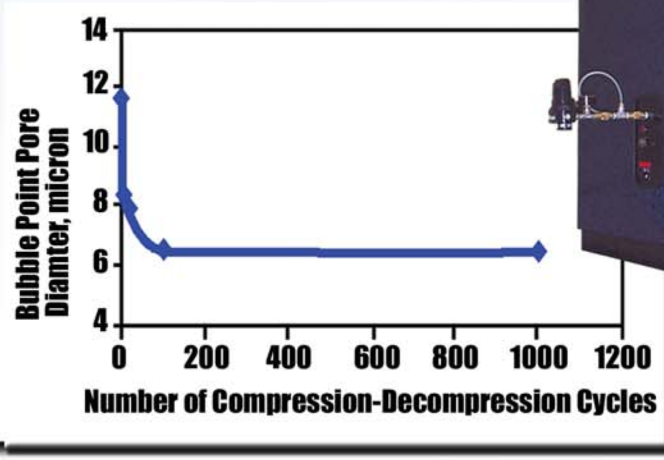
Compression Porometer

A Compression Porometer is a capillary flow porometer with an attachment for maintaining the sample under any desired compressive stress while the test is being performed. The pore structure of the material under compressive stress can be determined. The sample can be subjected to a compressive stress up to 1000 psi. The instrument permits pore structure characterization under true service conditions.



Cyclic Compression Porometer

A cyclic Compression Porometer is a specially designed porometer that subjects the sample to cyclic compression and decompression. The number of cycles and stress limits for each cycle are user definable. The instrument executes the desired number of stress cycles, performs the test, and at the end of the test continues applying the stress cycles until the next test. The instrument can be programmed to interrupt the stress cycles to perform the test any number of times.



QC Porometer

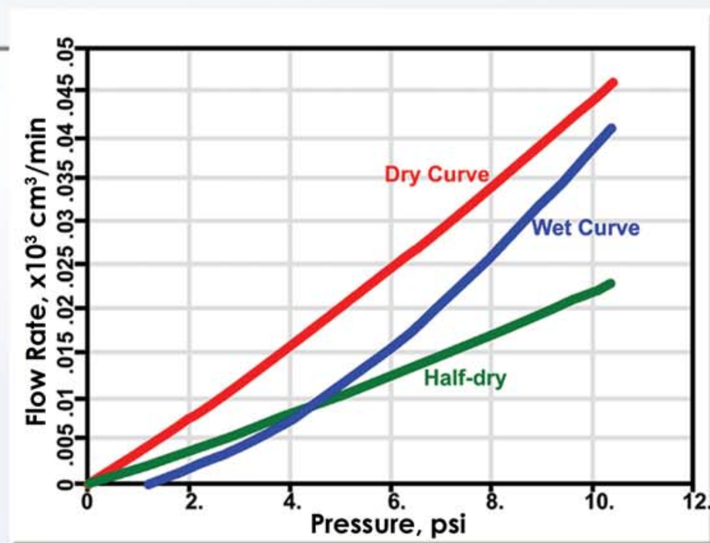
This is a capillary flow porometer that has fixed test parameters so tests can be performed without worrying about appropriate test parameters. Operator involvement is minimal and the tests are rapid. The instrument is suitable for quality control applications.

Clamp-On Porometer

This is a porometer with a sample chamber that permits the test material to be clamped between two test heads on any desired location. There is no need for a sample to be cut from the bulk material. The bulk material can slide through the test head. Many tests can be performed rapidly on many locations on the bulk material without damaging the bulk material in anyway.

Microflow Porometer

Samples with very low permeability cannot be tested in the porometers considered above, because the flow rates are two small to be accurately detectable by flow meters. In order to measure flow rate in microflow porometers, instead of flow meters, pressure transducers are used to measure time rate of pressure increase in a constant volume on the outlet side of the sample. The pore structure analysis is performed in the same way as the other porometers. The small magnitude of flow rate measured in this test is seen in the figure.

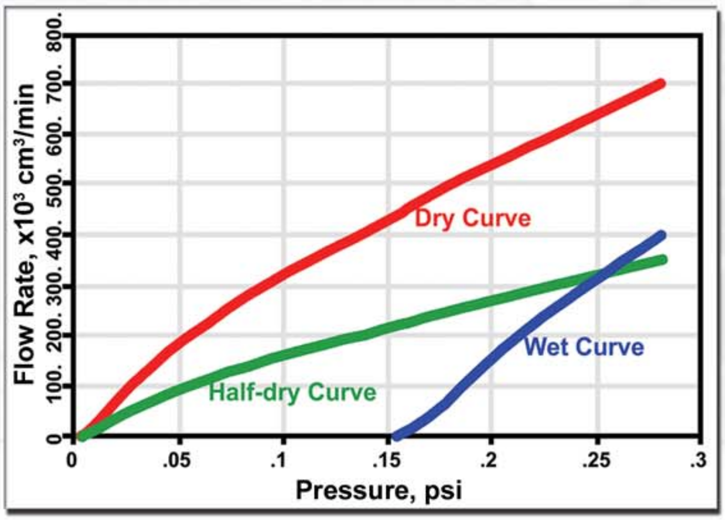


Complete Filter Cartridge Analyzer

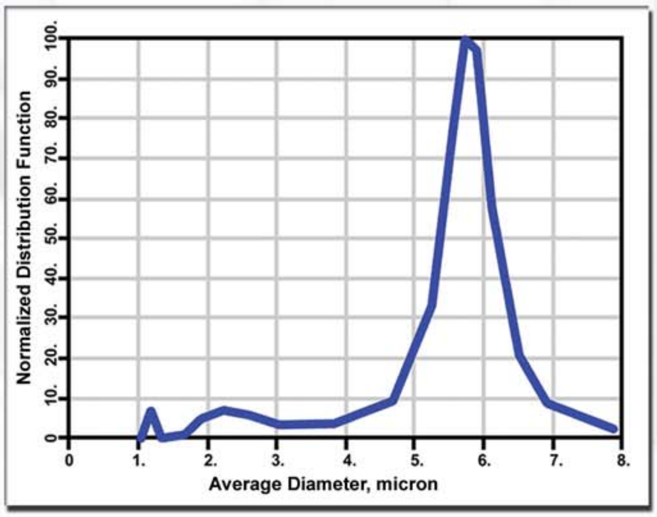
The Complete Filter Cartridge Analyzer is a porometer, which is capable of testing the complete filter cartridge. The adjustable sample holder of the sample chamber of the instrument can hold cartridges of almost any length and diameter. The instrument can accurately measure pressure drops and high gas flow rates through large filter cartridges. All kinds of cartridges including sintered metal, nonwoven, woven metal, polymeric, and ceramic cartridges can be tested with ease. The large flow rates measured in the instrument are seen in the figure. The instrument measures the characteristics of the entire cartridge rather than a small sample.

A Cartridge Holder

Complete Filter Cartridge Analyzer



High gas flow rates through a filter cartridge measured as functions of differential pressure



Pore Distribution in a Complete Cartridge

Integrity Analyzer

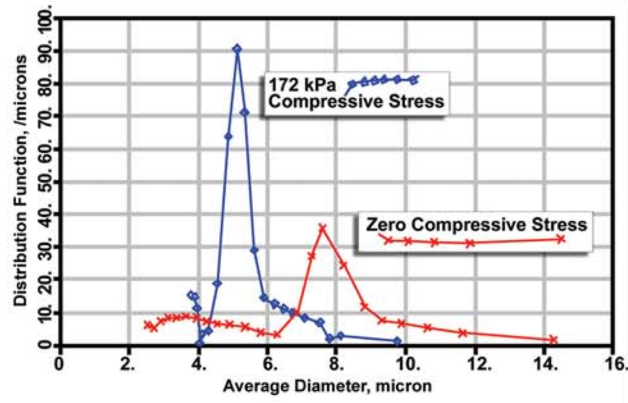
The Integrity Analyzer measures the flow rate of the gas on the outlet side of the sample. The instrument can measure gas flow by diffusion through the liquid-filled pores of the sample even before the bubble point is reached. Besides assuring that the leak rate is within the specified limits, the instrument can measure bubble point, mean flow pore diameter and pore distribution in the usual manner.

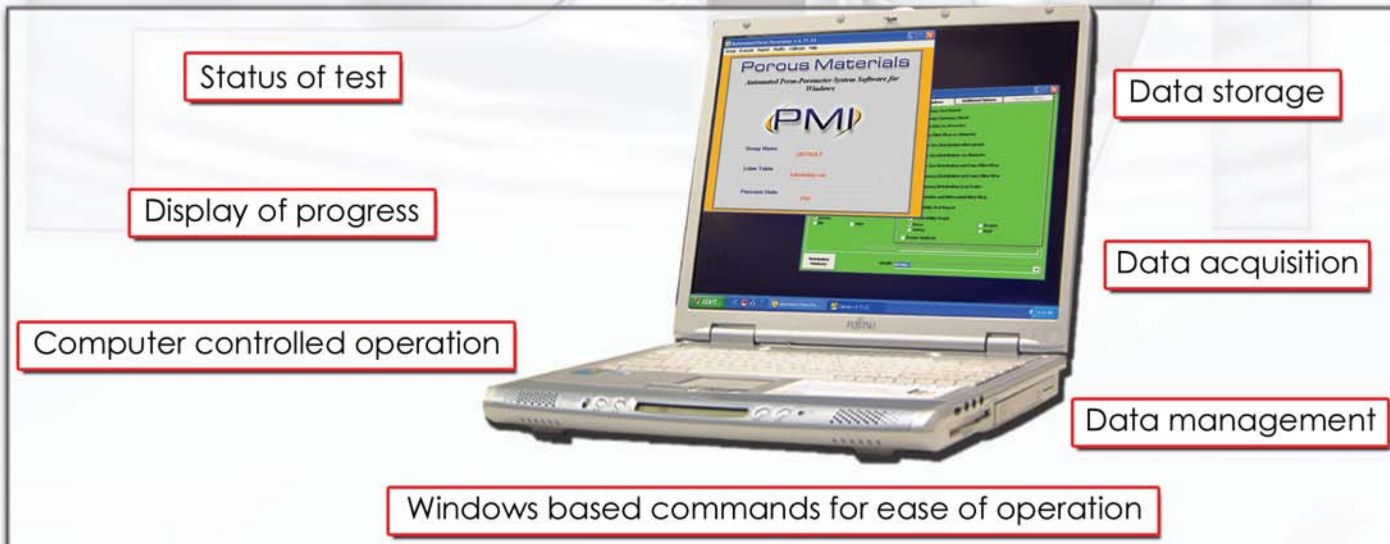
Bubble Point Tester

The bubble Point Tester measures the bubble point (the largest through pore diameter) in a material. It can use a variety of materials in many shapes and sizes. Multiple test heads can be used for high volume testing. Software can be designed for segregating products on go/no go and pass/fail basis.

Custom Porometers

These are instruments having multiple capability. Multi-Chamber and Multi-Mode Porometer is such an instrument. Multiple chambers permit high volume testing. Different kinds of sample chambers permit through-plane, in-plane and clamp-on testing using the same instrument. Various test modes like research mode and QC mode could be included. Capability for high temperature, high pressure, compressive stress, liquid permeability and chemical compatibility can be incorporated.



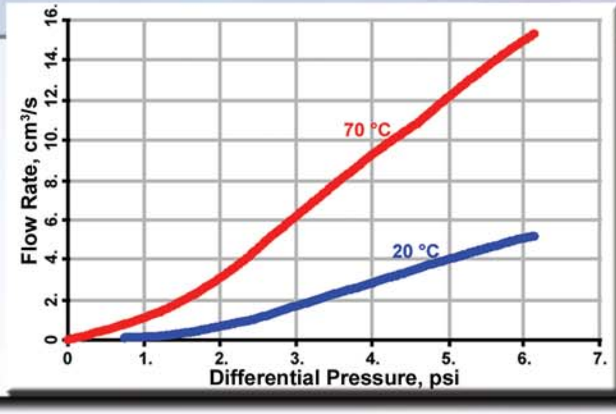


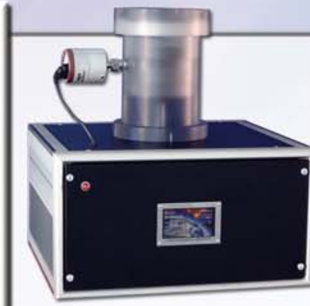
Permeameters

Liquid, gas, or vapor is allowed to flow through the sample. The pressure gradient is measured. The liquid flow rate is measured using either a penetrometer or a weighing balance. The gas flow rates are obtained either using a flow transducer or using the time rate of pressure change in a constant volume chamber on the outlet side of the sample. Test execution, data acquisition, data storage, and data reduction are fully automated. The Windows based operation is simple and user friendly.

Gas Permeameter

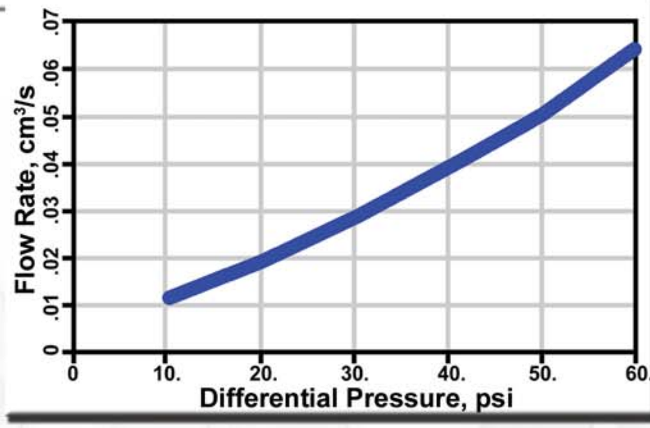
Gas Permeameters can operate at temperatures up to 200 °C. Custom porometers capable of measurements up to 800 °C can be designed. The output can be in any desired unit including fazier, gurley, rayl, and darcy.





Liquid Permeameter

Liquid Permeameters can measure permeability at pressures up to 200 psi. Permeability of strong chemicals like potassium hydroxide, saline solutions, and phosphoric acid can be measured. The result can be expressed in many convenient units.



Envelope Surface Area Analyzer

This instrument measures gas flow rates through a sample as a function of differential pressure and computes the surface area of through pores using the Kozeny-Carman relation. The robust, dependable, and inexpensive instrument is capable of speedy generation of reproducible data.

Average Particle Size Analyzer

Average Particle Size Analyzer is an envelope surface area analyzer that measures envelope surface area and calculates the average particle diameter, making used of envelope surface area and the true density of the material.

Porosity Characterization Chart

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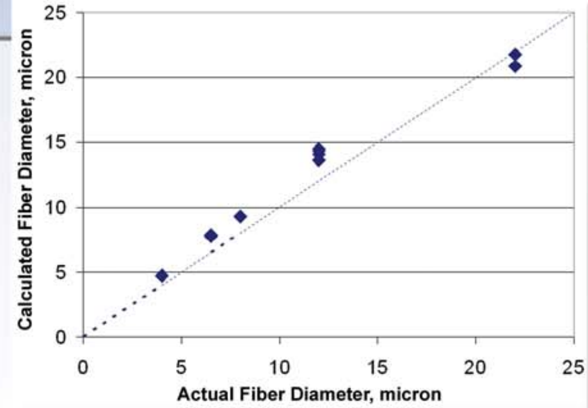
		Porometry (Extrusion)						Porosimetry (Extrusion)	Porosimetry (Intrusion)		Gas Adsorption		Permeametry					Pycnometry	
		Capillary Flow Porometer	Cyclic Compression/ Compression Porometer	Integrity Analyzer	Bubble Point Tester	Filtration Media Analyzer	Complete Filter Cartridge Analyzer	Liquid Extrusion Porosimeter	Mercury/Nonmercury Porosimeter	Aquapore	BET Sorptometer	BET Liquisorb Sorptometer	Liquid Permeameter	Gas Permeameter	Envelope Surface Area Analyzer	Diffusion Permeameter	Water Vapor Transmission Analyzer	Gas Pycnometer	Mercury Pycnometer
Pore Structure Characteristics	Mean Pore Size	X	X	X		X	X	X	X	X	X	X							
	Pore Size Distribution	X	X	X		X	X	X	X	X	X	X							
	Total Pore Volume							X	X	X	X	X							
	Bubble Point (largest pore)	X	X	X	X	X	X												
	Integrity	X		X		X	X												
	Gas Permeability	X	X	X		X	X							X			X		
	Liquid Permeability	X	X			X	X	X					X						
	Frazier Permeability	X	X			X	X												
	Diffusion Permeability															X	X		
	Hydro-Head Test	X				X	X												
	Single Point Surface Area										X	X							
	Multi-Point Surface Area										X	X							
	Envelope Surface Area	X	X												X				
	Porosimetry Surface Area							X	X	X									
	Adsorption & Desorption Isotherms										X	X							
	Chemisoroption										X	X							
	Liquid Vapor Adsorption											X							
	Bulk Density								X	X									X
	Absolute Density								X									X	
	Particle Size Distribution								X										
Operating Conditions	Compression/Cyclic Compression	X	X	X	X	X		X					X	X					
	Tension	X			X	X							X	X		X			
	Elevated Temperature	X		X	X	X	X	X	X	X	X		X	X	X	X	X		
Sample Characteristics	Pore Size Range	0.013-500 µ						2000-0.05µ	0.0035-500µ	0.001-20µ	20x10³-3 Å		N/A	N/A	N/A	N/A	N/A	Down to 2Å	N/A
	Surface Area Range (in m²/g)								1-100	1-100	> 0.01		10⁻³-50		0.1-10			N/A	N/A
	Permeability Range (in darcies)	10⁻³-50		10⁻³-50	N/A	10⁻³-50			N/A	N/A	N/A	N/A				10⁻¹²-10⁻⁶		N/A	N/A
	Permeability Range (Microflow in cc/sec/m/torr)	10⁻¹⁰-10⁻⁶		N/A	N/A	10⁻¹⁰-10⁻⁶	N/A		N/A	N/A	N/A	N/A	N/A	N/A	N/A			N/A	N/A
	Dead-end & Through-pores								X	X	X	X							
	Through-pores only	X	X	X	X	X	X	X					X	X	X	X	X		
	Special Sample Requirements						Complete Filters		N/A	Hydro-phobic	N/A	N/A	No Powders		N/A			N/A	N/A
Features	Nondestructive	X	X	X	X	X	X	X		X			X	X	X	X	X	X	
	Test Substance	Air Or Noncorrosive Gas							Mercury	Water	Any Pure Gas	Water, Hydro-carbon solvents	Air or Noncorrosive Gas					Helium or non-corrosive gas	Mercury
	Automated Control	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Applications	Automotive Industry	X	X	X	X		X	X	X	X	X		X	X				X	
	Batery/Fuel Cells Industry	X	X	X	X				X	X	X		X	X	X	X	X	X	X
	Ceramic Industry	X		X	X		X	X	X	X	X	X	X	X	X	X		X	X
	Chemical Industry	X							X	X	X	X			X	X		X	
	Filtration Industry	X	X	X	X	X	X	X	X		X		X	X		X			
	Geotextiles/Textiles Industry	X	X	X	X			X					X	X		X			
	Nonwovens Industry	X	X	X	X		X	X				X	X	X		X	X	X	
	Paper Industry	X	X	X	X				X	X	X		X	X	X	X	X		
	Pharmaceutical/Medical Industry	X		X	X	X		X	X	X	X	X			X	X	X	X	
	Powder Metallurgy Industry	X						X	X	X	X	X			X	X		X	

Average Fiber Diameter Analyzer

The Average Fiber Diameter Analyzer measures the flow rate of gas through the dry sample as a function of differential pressure and computes the average diameter using the Davis relation.



Gas Permeameter G

The PMI Gas Permeameter G is specifically designed to measure Gurley permeability. Gurley permeability is given by time needed for flow of air at a small differential pressure of 125 mm of water. The instrument computes Gurley permeability from gas flow rates measured at low differential pressures.

Gas Permeameter F

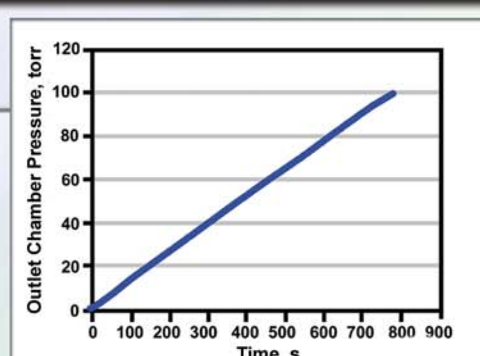
The PMI Gas Permeameter F is specifically designed to measure Frazier permeability. Frazier permeability is given by the flow rate of air at 23 °C under a differential pressure of 0.5 inches of water. The instrument computes Frazier permeability from measured gas flow rates at low differential pressures.

Gas Permeameter C-522

The PMI Gas Permeameter C-522 measures air flow resistance after ASTM C-522-87. Air flow resistance is important for sound absorption and sound-transmitting characteristics of acoustical materials. Because flow resistance is usually a constant in laminar flow region, the instrument measures flow rates in the ASTM recommended ranges of 0.1 - 250 Pa pressure difference and 0.05 - 5 cm/s flow velocity. The results are reported in terms of specific air flow resistance, rayl, at 22 °C. Air flow resistance and air flow resistivity can also be computed.

Microflow Gas Permeameter

These instruments are capable of measuring small gas flow rates through the sample not measurable by the gas permeameter. The time rate of pressure increase in a known volume in the outlet side of the sample is used to compute gas permeability.

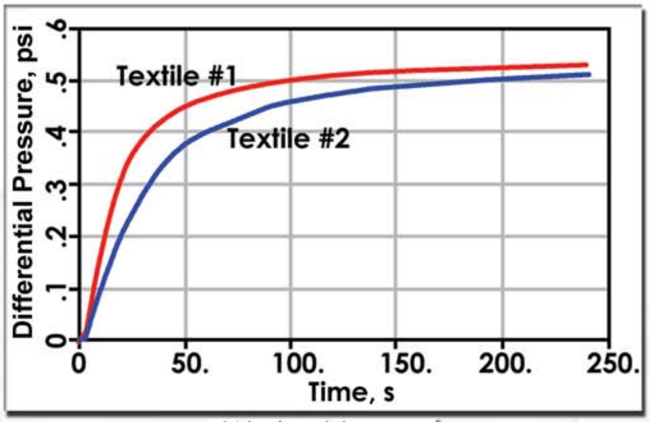


Microflow Liquid Permeameter

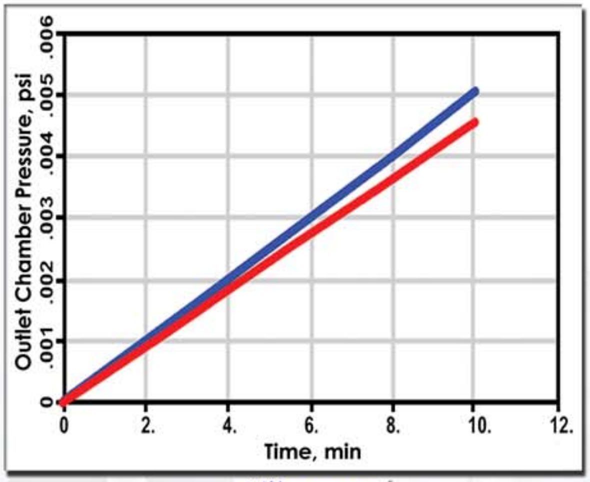
This instrument is a liquid permeameter that measures liquid flow rates by weighing the liquid in a balance. The resolution of measurement is very high so that very small flow rates of liquid through nearly impermeable samples like packaging materials, ceramics, and vegetables can be measured.

Diffusion Permeameter

Diffusion Permeameters can measure very low gas permeability not measurable even by microflow permeameters. The sample chamber is evacuated, gas at a known pressure is maintained on the inlet side of the sample, and time rate of pressure increase on the outlet side is measured. The instrument is capable of measuring flow rates as low as 10^{-4} cm^3/s.



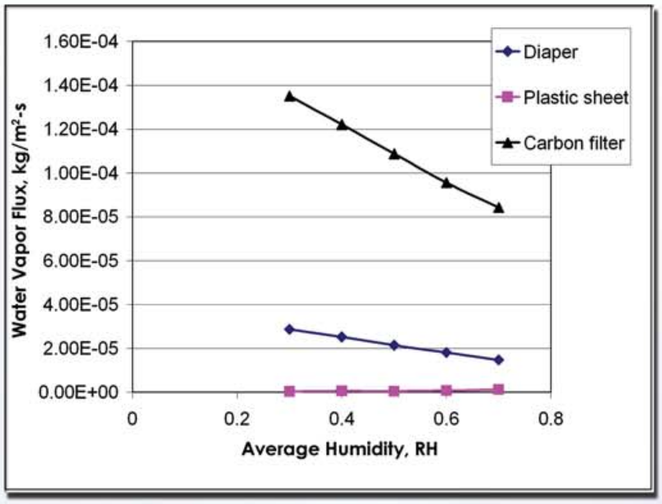
Water Vapor

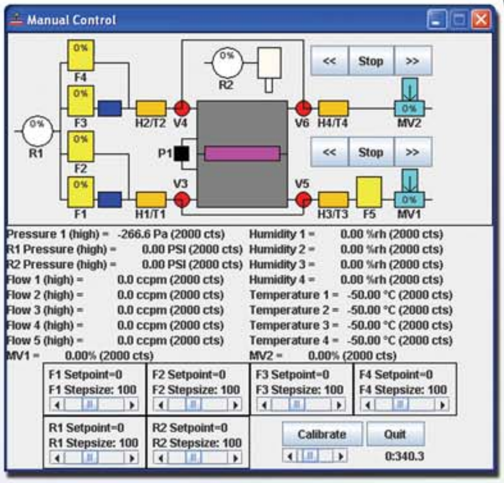


Nitrogen

Water Vapor Transmission Analyzer

This instrument uses the dynamic moisture permeation cell (ASTM F2298-03) for measurement of water vapor transmission rate. Transmission across a sample due to imposed humidity gradient, pressure gradient, or both gradients can be measured. The instrument is capable of measuring transmission rate and flow resistance as functions of humidity, pressure and temperature.

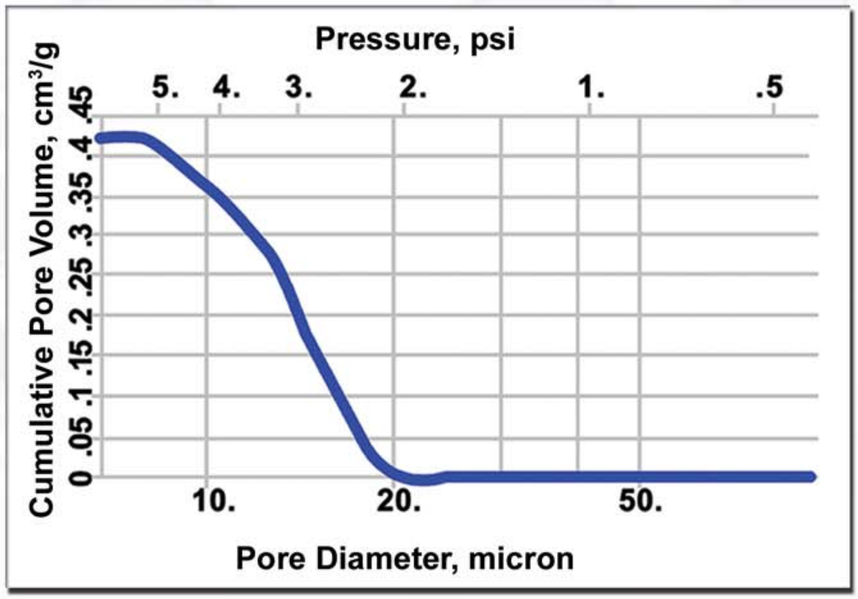




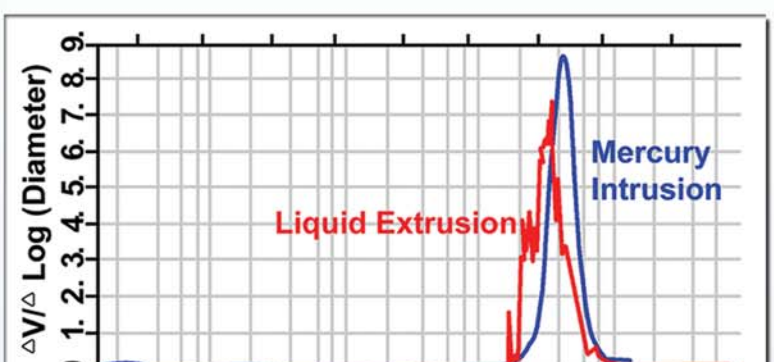
Extrusion Porosimeters

In extrusion porosimeters, the sample is placed on a membrane whose largest pore is smaller than the smallest pore of interest in the sample. A wetting liquid is allowed to fill all the pores of the membrane and the sample. Gas pressure is used to extrude liquid from pores of the sample. The membrane allows the liquid to pass through but prevents the gas from flowing through the membrane. The volume of liquid flowing out and differential pressure are measured. Differential pressure yields pore diameters of through pores. Volume of extruded liquid yields pore volume and pore distribution of through pores. Area under the distribution function in any pore diameter range yields volume of pores in that range. The envelope surface (through pore surface) area is computed from measured pore volume and pore diameter. This instrument is also capable of measuring liquid permeability.

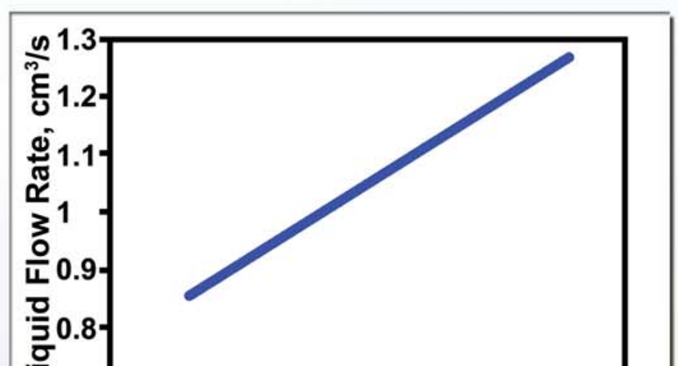
The extrusion porosimeters normally use penetrometers to measure volume of liquids extruded from pores. Models capable of measuring very small pore volumes use weighing balances to compute volume of extruded liquid. The fully automated instruments perform test execution, data acquisition, data storage, and data reduction. Windows based operation of the instrument is simple and user friendly. The pore size from 2000 microns down to about 0.05 microns are measurable by different models of the porosimeter.



Through Pore Volume



Pore Volume Distribution



Liquid Flow Rate

Intrusion Porosimeters

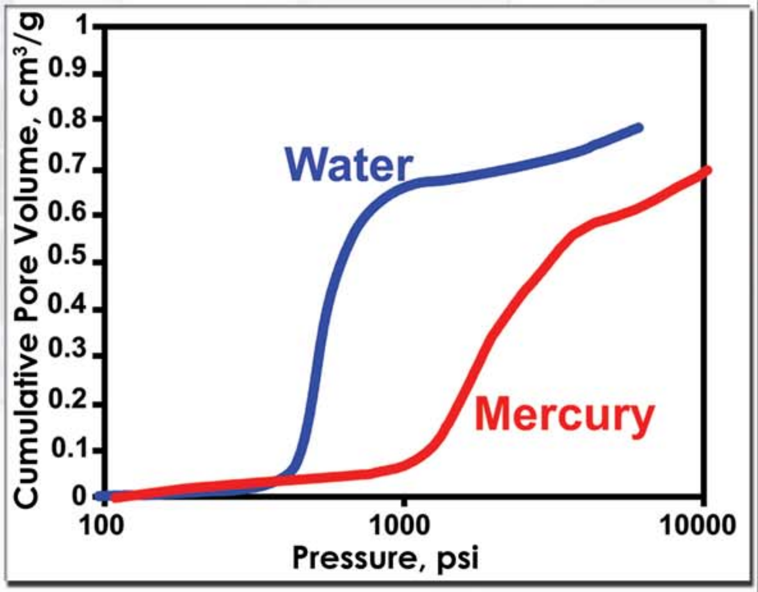
A nonwetting liquid cannot spontaneously enter pores of a sample. Pressure applied on the liquid surrounding the sample forces the liquid into pores. The pressure gives pore diameter, and the volume of intruded liquid is equal to the pore volume. The instruments are fully automated. Very little operator involvement is required. Data acquisition, data processing , and display of experiment in progress are also automatically performed.

Mercury Intrusion Porosimeters

Mercury is a widely used intrusion liquid because it does not wet many materials. Mercury intrusion porosimeters can measure pore diameters down to 0.005 µm under suitably applied pressure. Models of PMI porosimeters are available having up to 60,000 psi pressurization capability. In order to minimize exposure to mercury, PMI porosimeters have many specially designed features such as automatic refilling of mercury, use of non-breakable stainless steel rather than glass sample chambers, elimination of the need for transferring or handling sample during test and many more.

Nonmercury Porosimeters

The Nonmercury Intrusion Porosimeters use a nonwetting liquid other than mercury. Because of very high surface tension and contact angle of mercury the pressures required for intrusion in a mercury porosimeter is high. The nonmercury wetting liquids normally have much lower contact angle and surface tension than mercury. Therefore, the intrusion pressures required in a nonmercury porosimeter are much lower than those in a mercury porosimeter. The nonmercury intrusion porosimeter is particularly useful for pressure sensitive materials, for avoiding use of toxic mercury, and for using actual application liquids for intrusion.



Water Intrusion Porosimeter (Aquapore)

Water intrusion porosimeters use water as the intrusion liquid. The instrument can be used for characterization of material to which water is nonwetting (hydrophobic). This instrument has all the advantages that a nonmercury intrusion porosimeter has over mercury intrusion porosimeter. Various models of this instrument are available for different pressure ranges.

Vapor Condensation Porometers/Porosimeters

At a given temperature, the vapor of gas at a pressure less than the equilibrium vapor pressure in contact with liquid can condense in small pores of a porous material. Measurement of weight gain of the sample or flow rate of the vapor through the sample are used to compute pore size, pore volume, and flow rate. These instruments are also fully automated and require very little operator involvement.

Vapor Condensation Flow Porometer

In the vapor condensation flow porometer, the sample divides the sample chamber into two parts. A known amount of vapor at a known pressure is introduced to both the inlet and outlet sides of the sample. The final pressure and the reduction in the amount of vapor are measured at equilibrium. The pore diameter and pore volume are calculated. A small differential pressure is imposed on the sample. The pressure equalization with time is monitored and flow rate per unit pressure difference is computed. The experiment is repeated for a number of vapor pressures. Such data are used to compute pore diameter, pore volume, pore volume distribution, flow rate, and flow distribution. This is a unique technique that can measure pore volume and flow at very low pressures with out using liquid nitrogen. Also very small pores can be measured.

Vapor Condensation Gravimetric Porosimeter

In the vapor condensation gravimetric porosimeter, the weight change of samples placed on a balance inside the sample chamber is measured. The vapor pressure gives the pore diameter, and increase in weight gives the volume of liquid in pores. The increase in weight at different vapor pressures are measured for computing pore diameter, pore volume, and pore volume distribution. Liquid nitrogen temperatures are not required to be used. Application fluids can often be used.

Gas Adsorption Sorptometers

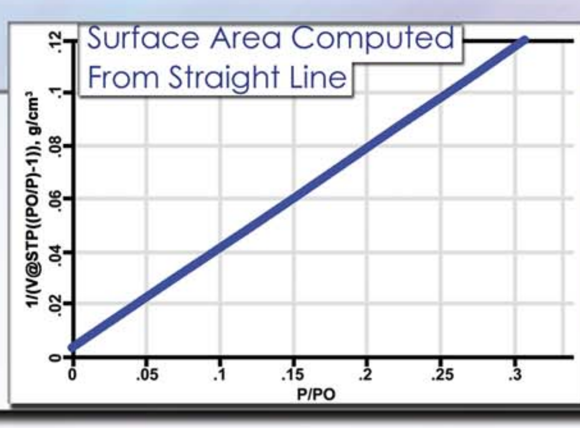
A clean surface exposed to a gas adsorbs molecules of the gas. BET theory provides the relationship between the amount of gas adsorbed at a constant temperature on the surfaces of the pores and the vapor pressures below the vapor pressure of the gas in equilibrium with its liquid. The amounts of gas adsorbed at the liquid nitrogen temperature using gases like nitrogen and krypton are usually measured. The surface are is computed using BET theory.

When relative pressure of the vapor on the sample is increased, vapor condenses in small pores. With increasing relative pressure of the vapor, it condenses in larger pores. The pore volume is equal to the volume of liquid condensed in pores, and the pore diameter in which the vapor condenses is given by the relative pressure of the vapor. The pore volume, pore size, and pore volume distribution are computed from measured vapor pressure and the amount of vapor that condenses in pores. Complete adsorption/desorption isotherms using many gases can be measured. Chemisorption of gases like CO_2, H_2O, NH_3 and many others can also be measured.

The instruments are completely automated. Provisions for degassing and baking of the sample are provided. Multiple sample chambers for high volume testing are also available. Experiment execution and data management are automatically performed. Windows based operation is simple.

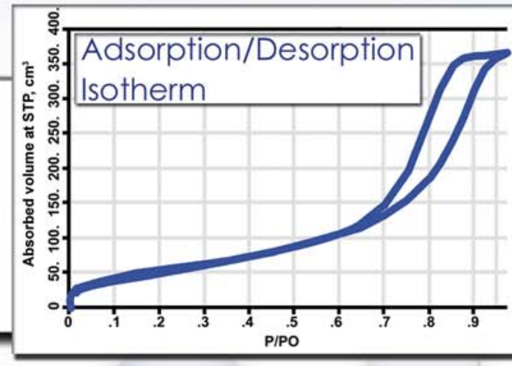
Q BET Sorptometer

Instruments in the quick BET series measure the amount of gas introduced into the sample chamber by flow controllers. The instruments can measure surface area quickly using a number of gases. These are inexpensive, physically small, and robust units for speedy determination of surface area.



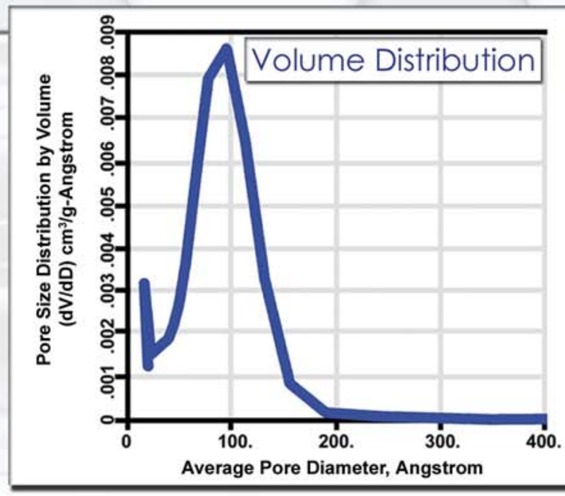
C BET Sorptometer

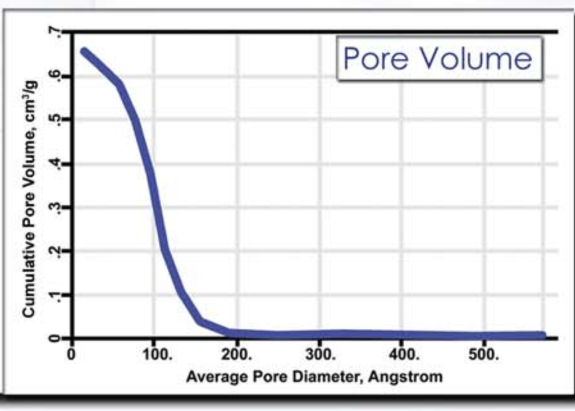
The instruments in this compact BET series have all the features to determine surface area, pore volume, pore size, pore volume distribution, and adsorption/desorption isotherms. These are tabletop models capable of using a number of gases, and having multiple sample chambers and degassing facilities.



A BET Sorptometer

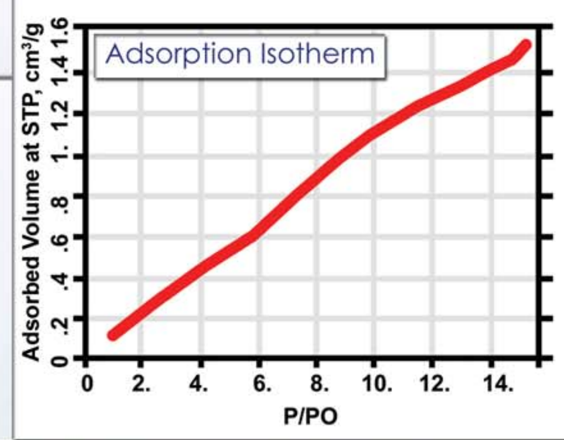
Instruments in this series are advanced sorptometers having all the advanced capabilities. In addition to measuring all the characteristics measurable by C BET, these instruments can have a number of sample chambers each having the capability to simultaneously use a different gas. These instruments are ideal for testing a large volume of samples using many gases at different temperatures. Chemisorption of gases like, NH_3, CO_2, and H_2O can be measured.





Water Vapor Adsorption Analyzer

This Instrument **(Aquasorb)** is specially designed to measure the amount of water vapor adsorbed by a porous sample at a specified temperature and pressure of water vapor. The data in the figure were acquired at room temperature.



Pycnometers

Pycnometers measure the true and bulk densities of materials from the weight and volume of their samples. Gas pycnometers measure the volume of solid in the sample and yield the true density of the material. Mercury pycnometers measure the total volume of the sample including the volume of its pores and yield the bulk density of the material. The true and bulk densities can be used to compute percentage porosity.

Gas Pycnometer

Mercury Pycnometer

Testing Services

The Testing Services Division can test samples for a fee. Our engineers talk to the customers about their test requirements and suggest tests suitable for their samples. One of our standard tests can often be used. Special tests can be designed to test unusual samples. Two day to three day or five day priority testing is possible. Reports can be e-mailed or hard copy of reports can be sent by mail.

Consulting Services

The Consulting Services Divesion provides solutions to customer problems, designs specialized instruments to suit the requirements of customers, and offers short courses to explain pore structure characterization techniques, interpretation of structural characteristics, and applications in product development.

Normal Capabilities of Instruments

Instruments	Pore Diameter Range, mm	Minimum Pore Volume, cm^3	Surface Area, m^2/g	Flow Rate, cm^3/s	
				Liquid	Gas
Porometers	0.013 - 500	—	< 10	10^{-5}-1	10^{-6}-10^{+5}
Extrusion Porosimeters	1 - 2000	0.0001	—	10^{-5}-1	—
Intrusion Porosimeters					
Mercury	0.003 - 500	0.0001	—	—	—
Nonmercury	0.001 - 50	0.0001	—	—	—
Vapor Condensation Porometers/Porosimeters	0.001 - 0.1	0.0001	—	—	10^{-6}-10^{-3}
Sorptometers	0.0005 - 0.2	0.0001	> 0.01	—	—
Permeameters					
Gas	—	—	—	—	10^{-6}-10^{+5}
Liquid	—	—	—	10^{-5}-1	—