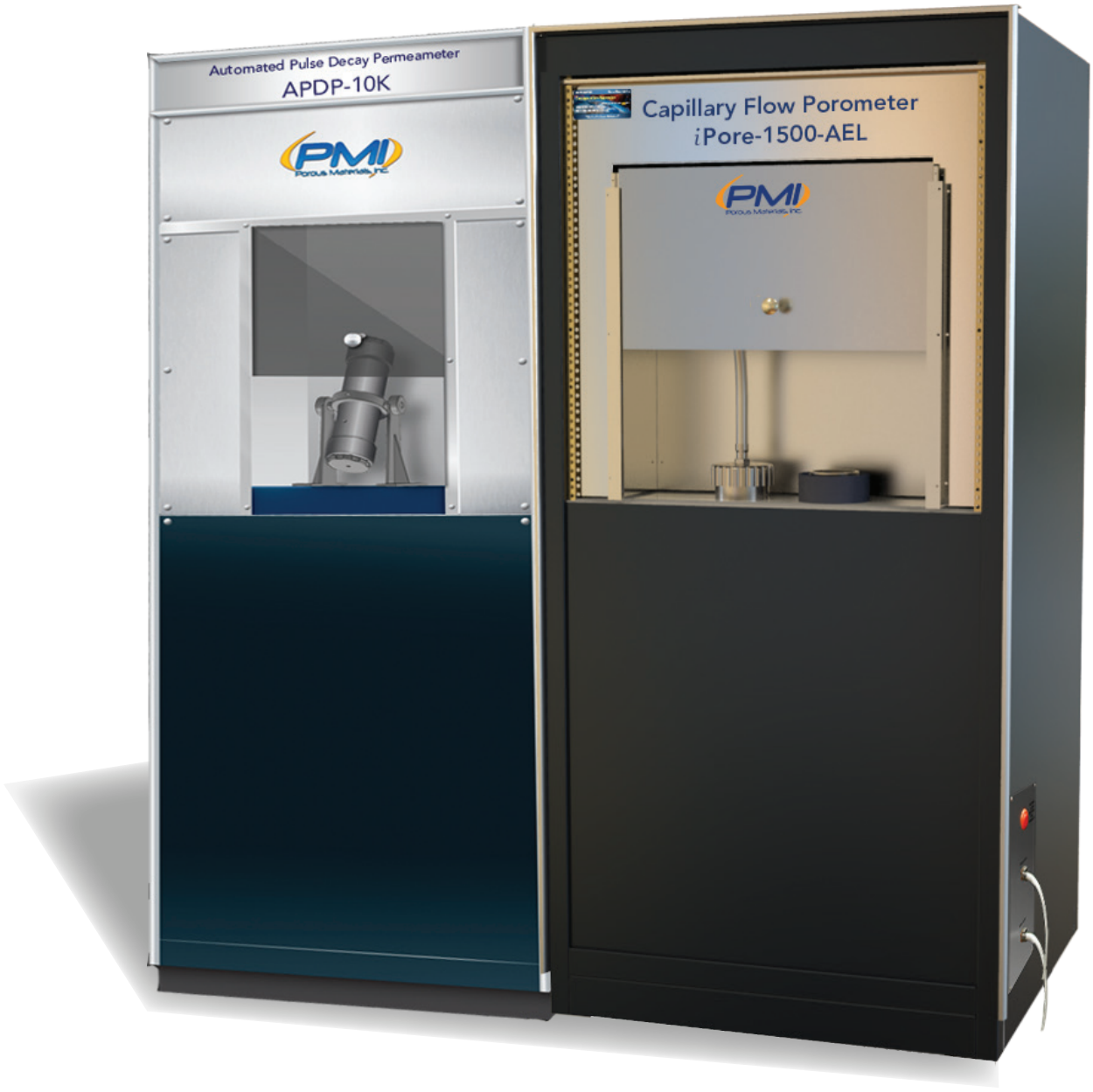
Porous Materials, Inc.




Not just products... Solutions !

# Combined Automated Pulse Decay Permeameter & Automated Capillary Flow Porometer (with confining pressure)

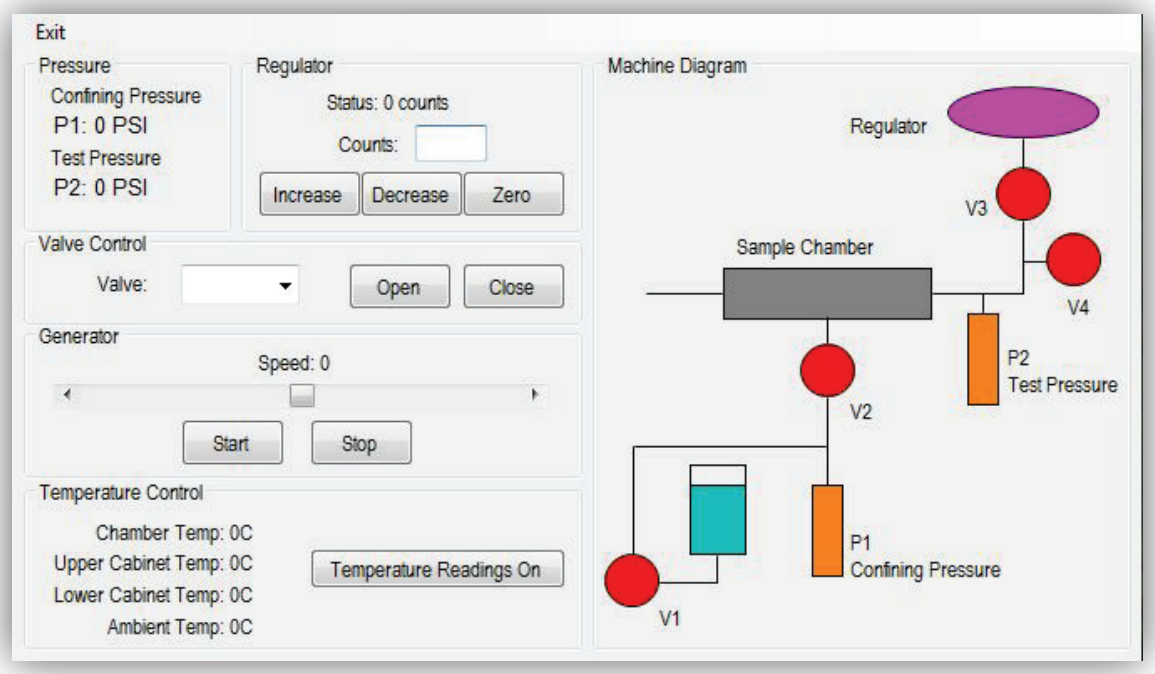
# APDP-10K & CFP-1500AEL

# Automated Pulse Decay Permeameter

The PMI's Advanced automated pulse decay Permeameter is used to measure gas permeability of samples such as oil well cores, tight gas sandstones, shale and other very low permeability rocks. The system creates a differential pressure across the core and monitors the resulting pressure decay over time. PMI software utilizes this data along with known system volumes to calculate permeability. Use of the pulse decay method allows for the measurement of very low permeability samples that would be impractical to analyze using traditional steady-state techniques.

# Principle

A rock sample is held in the sample chamber and compressive stress is applied. While the sample is under compressive stress, the desired properties are measured. The Pressure Decay Permeameter is used to determine the properties of cut samples at a controlled confining pressure. The PMI Automated Pressure Decay Permeability System has been specially designed for testing core samples. Core samples are held in a sleeve which hydraulically compresses the sample to the desired pressure. While at this controlled confining pressure, the instrument measures the rate of a known amount of gas to compute permeability. The equipment is fully automated. Execution of the test, data acquisition, data storage, & data management are all carried out by PMI Software.



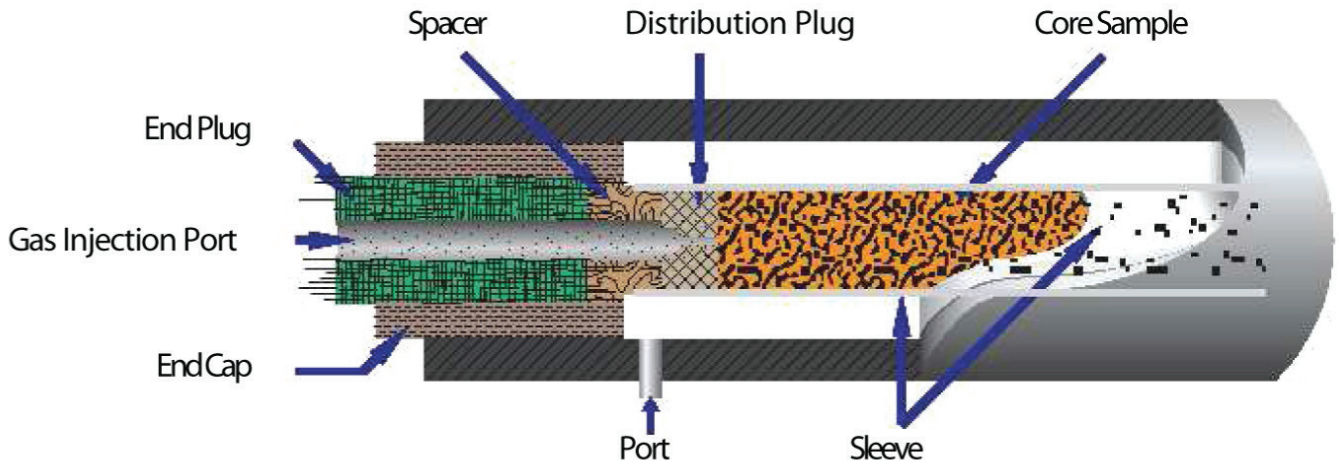

Software Manual Screen

# Instrument

The system is consisting of Core Holder, Pressure Sensors, Pressure reducer, Pulse decay system and an automatic pump for confining pressure. The system consists of advanced computer controlled automation package that allows precise data acquisition and handles all control measurement, data collection and report generation. Operator involvement is minimal, and the instrument is robust and requires a minimal amount of care.

# Core Holder

A Hassler type core holder with up to 10,000 PSI confining pressure. Features quick release aluminium core holder to accommodate core holders custom manufactured to meet your testing needs.




Core Holder Cross Section

# Types of Samples

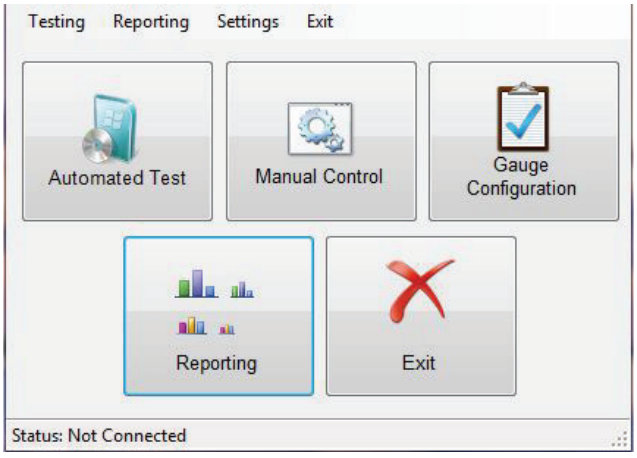
- Rock Core
- Well Core
- Tight Gas Sandstones
- Low Permeability Rock Cores

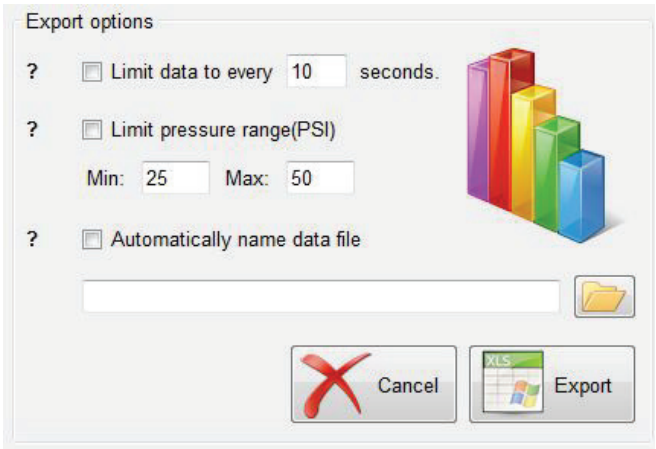
# Applications

Industries worldwide utilize PMI Permeameters like the PMI Automated Pulse Decay Permeameter for research and development and quality control. Uses Boyles Law and software calculation of Klinkenberg. Applicable industries include: Oil refineries, Oil and gas exploration, Geotechnical, Geophysics, Automotive and Battery development.

# Features

- Fully automated Permeameter System.
- Gas permeability determination based on the unsteady State pressure falloff method.
- Includes data acquisition, calculation and reporting software includes calculation of Klinkenberg corrected permeability.
- User-friendly Windows based software handles all control, measurement, data collection and report generation
- Complete manual control from software
- Non-destructive testing
- Length of test varies with sample, test to 7 days or more continuously
- The machine has many advanced hardware and software features not available from other manufacturers.



# Unique Features

- Integrated detailed help system
- For off-line data processing
- Graphic presentation of the data to be evaluated and analysis results
- Exporting graphic files to window based word / excel processing files for report generation
- Capable to be programmed for automatic repeat measurements or for data acquisition under user selected tolerances

# Specifications

- **Pore Pressure:** 150 psi - 250 psi
- **Confining Pressure:** 1,000 PSI - 10,000 psi
- **Core Sample Diameter:** 1" & 1.5"
- **Core Sample Length:** 1" to 3"
- **Permeability Range:** 0.01mD to 10D
- **Porosity Range:** 0.1% > 60%
- **Resolution:** 0.1% of full scale
- **Accuracy:** 0.25% or Better
- **Temperature Accuracy:** ±0.1°C
- **Pressure Transducer Range:** 0.25% F.S
- **Power Requirements:** 110 VAC, 50/60 Hz (Others Available)

# *i*Pore Porometers

The ***i*Pore** is an advanced capillary flow porometer series, which yield accurate and reproducible data. The ***i*Pore** series porometers require minimal operator involvement with considerably small test durations. The ***i*Pore** porometers are designed for linear turbulence free flow of test gas, the pressure is measured closed to the sample thereby minimizing the correction in differential pressure measurement. ***i*Pore** series has six different models to suit varying pore size ranges and flow rates. Each model has appropriate measuring system with pressure control, sensing, acquisition and data analysis software, sample holders, various unique upgrade options, accessory and consumable kit.

# *i*Pore Principle

***i*Pore** is based on capillary flow porometry, where a non toxic wetting liquid is allowed to spontaneously fill the pores in the sample and a non reacting gas is allowed to displace liquid from pores. First the largest pores will get emptied, as they require lower pressure than smaller pores. As the pressure is increased, more and more smaller pores are progressively emptied. The pressure and flow rate of gas through the emptied pores provides the through pore distribution. The pressure at which through pores empty is inversely proportional to the pore size. Through pores (fig.1) are the pores connected from one side of material to the other side. ***i*Pore** capillary flow Porometer measures the pore throat diameter, which is the most constricted part of the entire pore path.

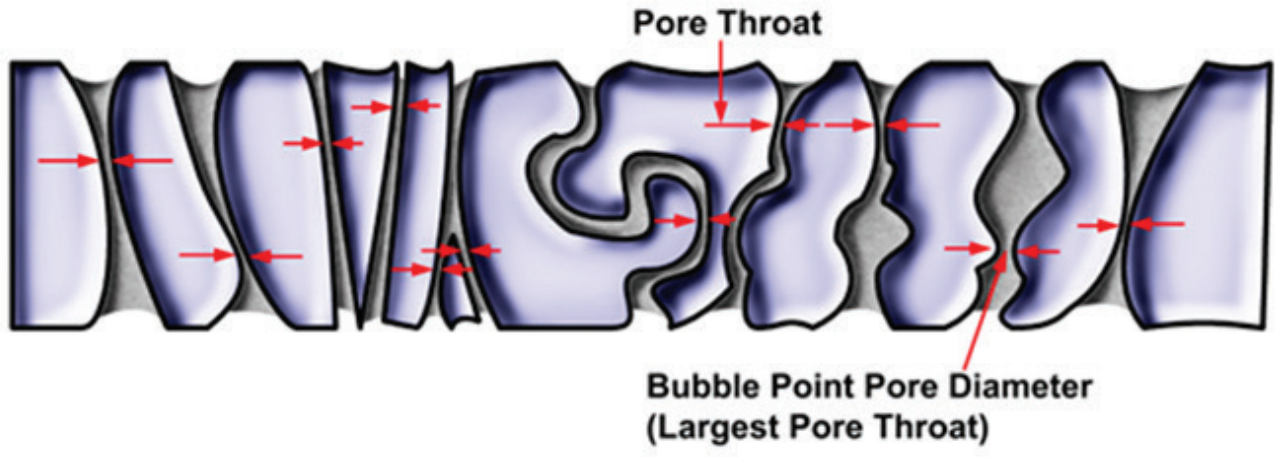



Fig.1 shows the through pores

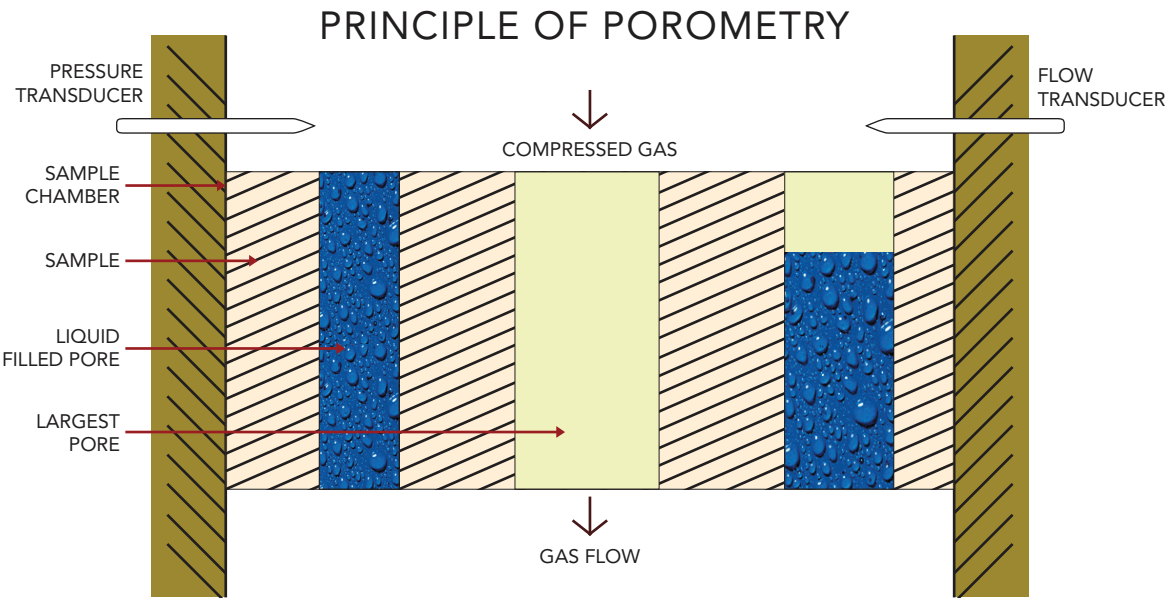



Fig. 2 Principle of Capillary Flow Porometry

# Measurement Technique

The *i***Pore** series capillary flow porometry allows the user to obtain several parameters and information in single measurement. Generally, a measurement with the wet sample (impregnated with wetting liquid) is carried out first. It is normally known as the "wet run" and the representation of the gas flow vs. the applied pressure i.e. "wet curve" is obtained. After the wet run the measurement of the same sample in dry state is carried out in order to register and analogous "dry curve". The half-dry curve is calculated and represented by dividing the flow values with respect to the applied pressure by 2 and it is also represented in the same graphic. From the representation of the three curves it is possible to identify relevant information about the sample: the maximum pore size (or first bubble point) is recorded when gas flow through the sample is detected, the mean flow pore size corresponds to the pore size calculated at the pressure where the wet curve and the half dry curve meet (it corresponds at the pore size at which 50% of the total gas flow can be accounted), and the minimum pore size results from the pressure at which the wet and the dry curve meet (from this point onwards the flow will be the same because all the pores have been emptied).

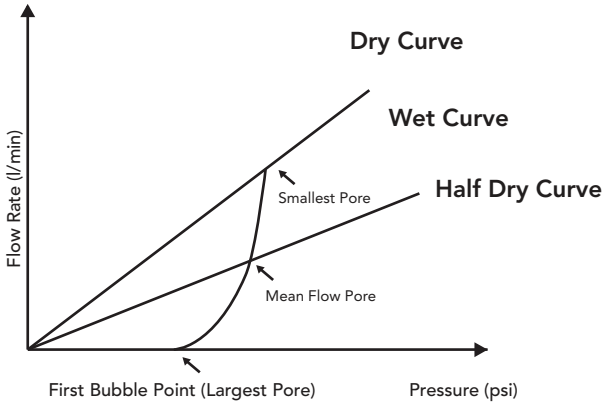



Fig.3 Parameters measured in porometry

Apart from these individual pore sizes, the same measurement permits the representation of the cumulative filter flow distribution vs the pore size, which provides information about the percentage of the cumulative total flow through the sample that goes through pores of a larger size than a certain value. Another information that can be obtained from the measurements is the corrected differential filter flow, which shows the flow distribution per unit of change in size, i.e. the increase in flow rate per unit increase in pore diameter. It is also defined as pore size distribution.

# Pore Characteristics

## Bubble Point

The Bubble point is one of the preliminary but important attributes measured by *i***Pore**. The Bubble Point is defined by the **ASTM F-316-03** standard as the pressure at which the first continuous gas bubbles are detected, this measurement corresponds to the largest (or maximum) pore size. Besides Bubble Point, *i***Pore** provides a comprehensive set of pore size and flow measurement to study the pore characteristics.

## Pore Size

The pore size is calcultated using Washburn equation:

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

Where:

D = pore diameter
γ = surface tension of liquid
θ = contact angle of liquid
p = differential gas pressure
From measured pressure and flow rates, the pore throat diameters, pore size distribution, and gas permeability are calculated.

Here the pore diameter is assumed to be that of a cylindrical pore, for membranes and other materials the appropriate pore shape factor is provided in the Capwin software , which is a multiplier to the Washburn equation.

## Pore Distribution

Pore distribution is calculated by

$$f = -d[(fw/fd)x100]/dD$$

Where:
fw = flow rate through wet sample
fd = flow rate through dry sample

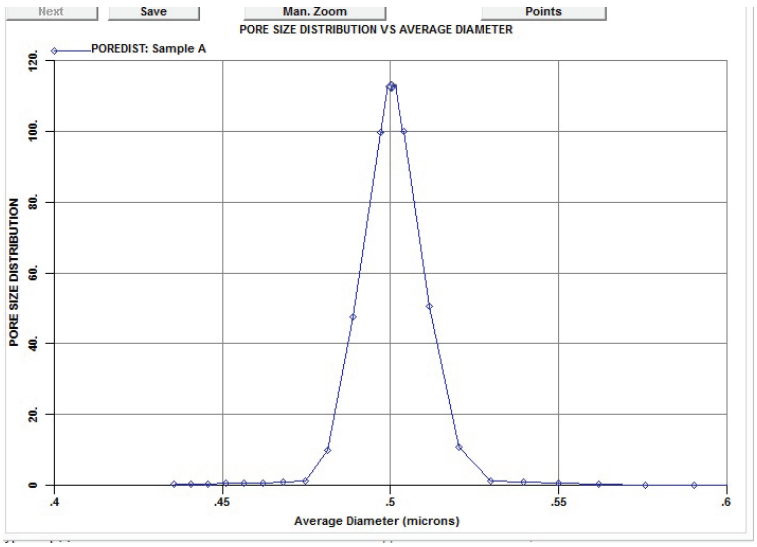



Fig.4 Pore size distribution

# Pore Flow % Distribution

Pore Flow % Distribution also known as Pore size frequency is defined by ASTM Designation F 316-86 is the percentage flow through pores in a given size range.

% Flow through wet sample at pressure $p_j = (F_{w,j} / F_{d,j} \times 100)$

% Flow through wet sample at pressure $p_{j+1} = (F_{w,j+1} / F_{d,j+1} \times 100)$

% of flow through pores of diameter between $D_j$ and $D_{j+1} = [(F_{w,j+1}/F_{d,j+1} \times 100)] - [(F_{w,j}/F_{d,j} \times 100)]$

Percentage flow through pores calculated in this manner from data in Fig.5(a) is presented as pore size frequency in Fig.5(b).

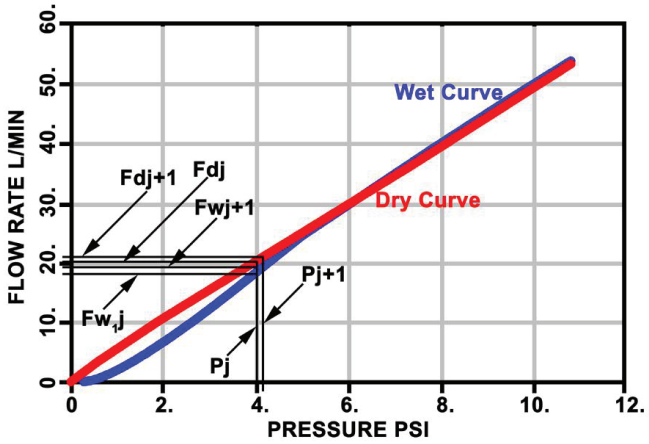



Fig.5 (a) Wet and dry curves showing flow rates at two consecutive readings.

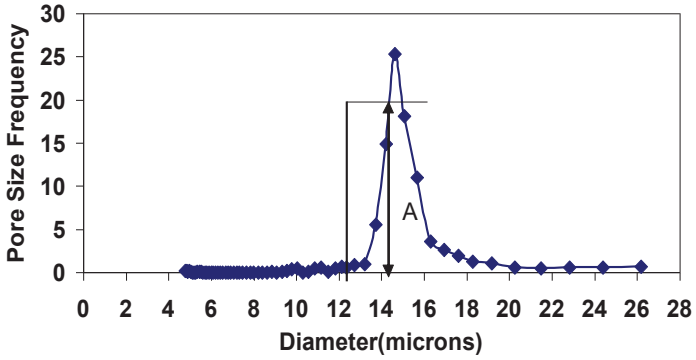



Fig.5 (b) Pore size frequency

# Pore Density

Pore Density can be expressed in terms of fractional pore number distribution, $f_N$

$f_N = d[(N_j / \Sigma^{\infty}_{j} N_j)]/dD$

$= [(f_{j+1}/\Sigma^{\infty}_{j} f_j) \times 100 - (f_j/\Sigma^{\infty}_{j} f_j) \times 100]/[-(D_{j+1} - D_j)]$

The area under the fractional pore number distribution function in a pore diameter range gives the percentage of pores in that diameter range.

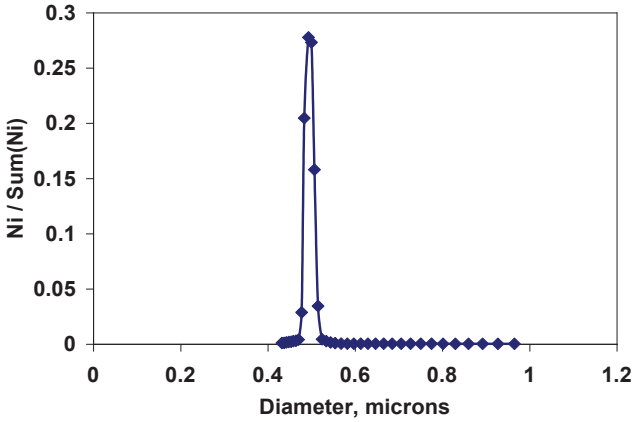



Fig.6 Pore fraction distribution

# Liquid Permeability

The flow of liquid through a sample is measured by the distance, a column of liquid drops in relation to time and pressure. This method gives reproducible results, even for hydrophobic materials, as pressure is applied to the liquid column to force the liquid through the sample. Very low permeability samples are tested using an accurate weighing balance to measure liquid flow rate.

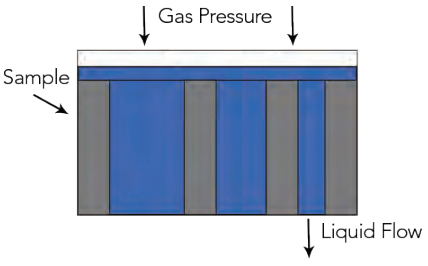
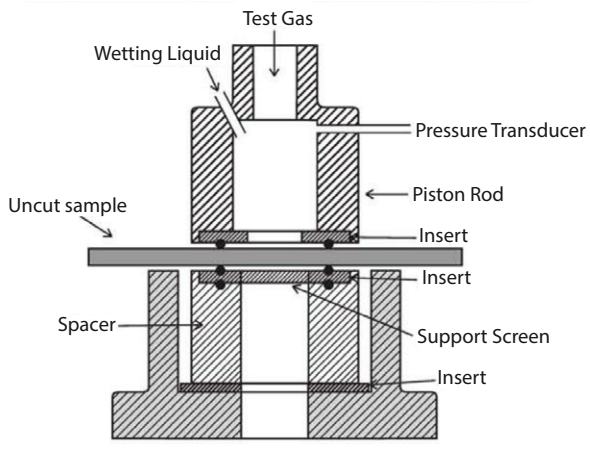


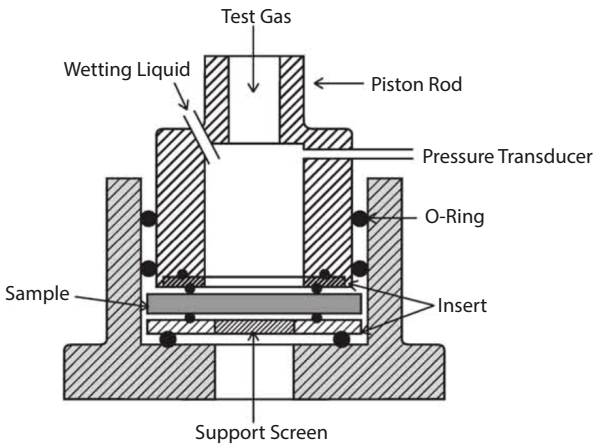

Fig.7 Principle for how the Liquid Permeameter functions

# FEATURES

- Testing of small samples as well as complete parts
- Any sample geometry (Example: sheets, rods, tubes, hollow fibers, cartridges & powders) can be used with selection of appropriate sample holders (options available)
- Any nonwetting liquid
- Tests in QC, research or any number of user defined modes
- Real time graphic display
- Window based software for all control, measurements, data collection, data reduction and report preparation
- Automatic piston movement to close the chamber while starting the test
- Region of interest doesn't change due to automatic piston movement
- Measurement of pressure close to the sample to minimize pressure drop correction
- Straight flow path avoiding turbulence
- Versatile sample chamber for a variety of samples and test modes
- Pore Structure ctharacteristics:
    - Mean Pore Size
    - Pore Size Distribution
    - Pore Flow % Distribution
    - Pore Number Distribution
    - Bubble Point (the largest through pore throat diameter)
    - Bubble Point Mean flow pore diameter (50% of flow is through pores smaller than the mean flow pore)
    - Pore Surface Area
    - Gas Permeability in many desired units including Frazier, Gurley, Rayl & Darcy
    - Liquid Permeability
    - Diameter of the most constricted part of a through pore (Pore throat)
    - Unlimited Data Points




*Sample Chamber*



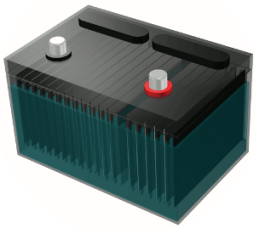

*Sample Chamber with Spacer*

Fig.8 Sample Chamber

# APPLICATIONS

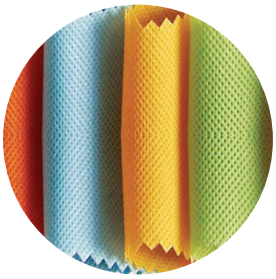
- Rock Cores
- Membranes
- Battery/Fuel Cells Industry
- Automotive Industry
- Ceramic Industry
- Chemical Industry
- Filtration Industry
- Geo-textiles/Textiles Industry
- Nonwovens Industry
- Paper Industry
- Pharmaceutical/Medical Industry
- Powder Metallurgy Industry
  & many more...












# SPECIFICATIONS

- **Liquid Permeability** Function is by Penetrometer (higher sensitivity and accuracy compared to weighing balance system. Also liquid filling and draining is automatic)
- **Pore Size Range:** 0.013 to 80 µm
- **Permeability Range:** $10^{-3}$ to 50 darcies
- **Confining Pressure:** 1,000 psi to 10,000 psi
- **Pressure & Flow Resolution:** 1/60,000 of full scale ( 1 part in 60,000)
- **Pressure sensing accuracy:** 0.1 of FS
- **Through Pores only**
- **Power Supply:** 110 VAC, 60 Hz

**Pore Structure Characteristics:**

- Mean Pore Size
- Pore Size Distribution
- Bubble Point (Largest Pore)
- Pressure hold Test
- Gas Permeability
- Liquid Permeability

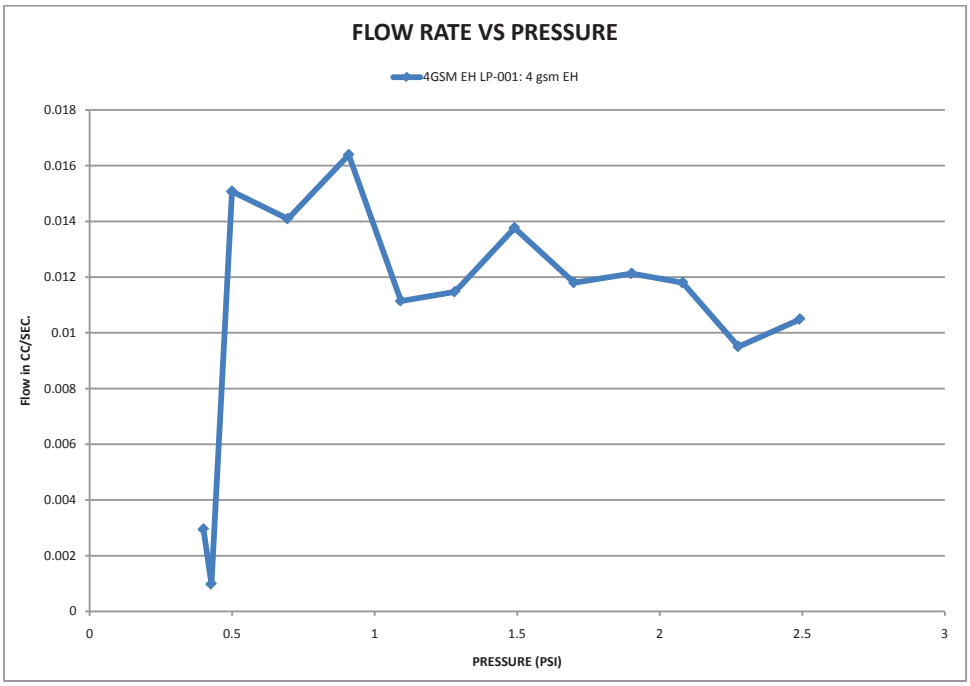



Fig.9 Liquid Permeability Graph: Flow rate Vs Pressure

# Additional function:

| | |
|---|---|
| **-X** | Extended Range (Extra Pressure Gauge): up to 4 set pressure gauge |
| **-P** | Pneumatic clamp-on device |
| **-E** | Extended Accuracy (Extra Flow Meter): up to 4 set Flow meter |
| **-I** | Integrity Test |
| **-S** | Surface Area/ Fiber Diameter |
| **-CR** | Chemical Resistance Option (KOH) |
| **-L** | Liquid Permeability (Penetrometer Type) |
| **-ALD** | Automated Wetting Liquid Dispenser |
| **-TL** | High Temperature for Liquid Permeability |
| **-TG** | High Temperature for Gas Permeability |
| **-F** | Frazier Permeability |
| **-G** | Gurley Permeability |
| **-R** | Rayles Permeability |
| **-M** | Sheffield Smoothness Test |
| **-N** | In-Plane |
| **-CC** | Cyclic Compression Test |
| **-C** | Compression Test |
| **-HC** | Bubblers with Humidity Control |
| **-B** | Burst Pressure Test |
| **-H** | Hydrohead Test |
| **-D** | Microflow (Low Flow) |
| **-HF** | High Flow (up to 2,000 L/min) |

# SOFTWARE

We work closely with our customers to provide the most user friendly software for porometery. PMI Capwin software is updated to meet customer needs & requirements. The comprehensive software can be used for all PMI porometers. The software is customized to offer convenient operation with default settings for beginners and full access to all relevant measuring parameters for advanced researchers.

- Capwin manages manual instrument control, automated measuring routines and report print out or graph
- Capwin Data manager for interactive evaluation of measured data as well as providing sophisticated tools for creating reports & generating templates for graphs, tables and screen views
- Capwin user manager for comprehensive user management regarding user access control
- Remote diagnostic from anywhere in the world
- Links to databases, outputs to: MS Excel, Text files, and other formats upon request
- User defined paths and sub directories for data filling

# SALES & SERVICE

We at Porous Materials Inc., have dedicated sales team helping thousand's of our customers identify the right solution for their scientific problems. We are also proud to offer customized instruments for your unique needs. Our service and applications team is committed to effective support with short response times, we offer comprehensive range of solutions from new and customized systems, calibration and maintenance to testing services.
Explore more about us at www.pmiapp.com

*Customize your machine today !*

*Disclaimer: *We are continously improving our products,*
*Design is subject to change without prior notice.*

The most advanced, accurate, reproducible and easy to use Porometers/Permeameters in the world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