CHARACTERIZATION OF THE PORE STRUCTURE OF COMPLETE FILTER CARTRIDGES USING HIGH FLOW POROMETRY

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ABSTRACT

Measurement of pore structure characteristics of complete filter cartridges is a real challenge because of the high gas flow rates through large cartridges, large size of the sample holder, and other related problems. A high flow porometer designed and built for testing high gas flow samples has been described. The equipment yields highly reproducible and accurate data. Sintered metal, woven metal and ceramic cartridges have been tested. Pore structures of these cartridges have been successfully measured. These data are presented and discussed.

Keywords: Filter Cartridge. Pore Structure. Porometry. Pore Diameter. Pore Distribution.

INTRODUCTION

Product development ideally requires measurement of pore structure characteristics of complete filtration cartridges for design and performance evaluation. Important pore structure characteristics required for filtration are through-pore throat diameters, the bubble point pore diameter, mean flow pore diameter, and pore distribution. All these characteristics can be measured by capillary flow porometry. However, testing of a complete filter cartridge by capillary flow porometry is a real challenge because of the high gas flow rates through large

cartridges, large size of the sample holder, need for accurate measurement of pressure drop, and requirement of sufficient supply of gas for a reasonable time. In this presentation, a High Flow Porometer designed to test complete filter cartridges has been described and results obtained using ceramic, sintered metal, and woven metal cartridges have been presented and discussed.

EXPERIMENTTAL

Basic Principle

The pores of the sample to be tested in a flow porometer are spontaneously filled with a wetting liquid and differential pressure of an inert gas is slowly increased on the sample to remove liquid from pores and to permit gas flow. The differential pressure and flow rates through dry and wet samples are measured. All the required pore structure characteristics are computed from the measured differential pressures and gas flow rates [1].

It can be shown that the differential pressure required to remove liquid from a pore is related to the pore diameter [1]

$$D = 4 \gamma \cos \theta / p \quad (1)$$

where D is the pore diameter, γ is the surface tension of wetting liquid, θ is the contact angle of the wetting liquid with the sample, and p is the differential pressure. Because pores cross-sections are normally irregular, pore diameter is defined as the diameter of a cylindrical opening such that perimeter to area ratio of the pore is the same as that of the cylindrical opening. This is equivalent to the fact that (dS/dV) of the pore is equal to the (dS/dV) of the cylindrical opening,

where dS is an infinitesimal change in surface area because of infinitesimal increase in volume dV [1,2].

Pore diameter normally varies along pore path and each pore exhibits many pore diameters. Flow porometry detects the presence of a pore by sensing increase in flow when gas pressure is sufficient to empty the pore. Because pressure needed to displace liquid from a pore is the highest at its throat, at this highest pressure liquid is completely removed from the pore and increase in flow rate is sensed. Thus, the measured differential pressure corresponding to increase in flow rate gives throat diameter of the pore [1]. Thus, only one diameter of each pore is detected. The measured pore diameter is the most constricted pore size. Pore throat diameters determine size of particles that can be retained by the filter.

Instrument

The instrument has provision for gas supply from a storage tank capable of supplying sufficient gas to maintain adequate flow rate over the test duration. The gas supply from storage tank can be used for very high flow samples. The technique requires measurement of pressure drop across the sample. However, pressure drops occur because of many factors including tube diameter, cross-sectional shape, tube length, sudden change of cross-section, sharp-edge entrances, fittings and valves in the piping network, flow rate, nature of flow (laminar, turbulent, etc), and sample support. Large pipes were used and the bends and constrictions were eliminated in the construction of the equipment. All other factors were considered in the design and pressure drop in the system was minimized.

The sample chamber is shown in Figure 1. The cylindrical chamber has two test heads, which enter the chamber from both ends and form gasket seals on the two ends of cartridge. One of the heads is fixed and it allows test gas to enter the cartridge. The other head is mounted on a rod of adjustable length so that cartridges of any length could be mounted. The rod passes through a cylinder and is connected to a pneumatically operated piston. Thus, pressure on the gasket seal and leak through it are controlled by controlling air pressure on the piston.

Figure 1. Sample chamber for testing filter cartridges.

The instrument is fully automated. After the sample is loaded, sealing of the ends, performance of the test, data acquisition, storage, data reduction and graphical display are automatically carried out. Results are presentable in many convenient and customer friendly forms. The instrument is shown in Figure 2.

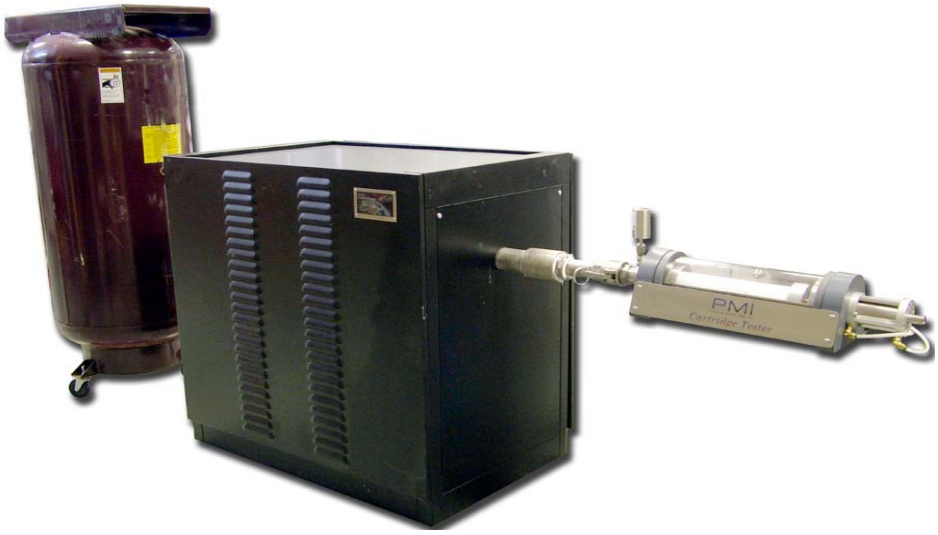

Figure 2. The High Flow Porometer

RESULTS AND DISCUSSION

Reproducibility

In order to test the reproducibility of data generated by the high flow porometer, gas flow rate through a ceramic cartridge was measured in the high flow porometer. The test was repeated three times. Because pore structure of ceramic materials are insensitive to pressure and flow, flow rate is expected to be the same in each repeated experiment in an instrument capable of producing reproducible results. The data presented in Figure 3 shows excellent reproducibility of data generated by the High Flow Porometer.

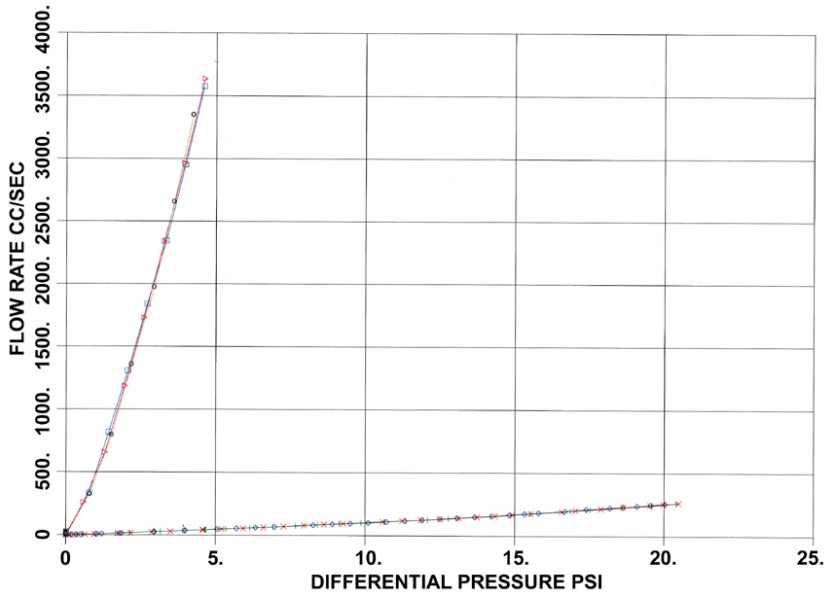

Figure 3 Gas flow rates through a ceramic cartridge measured in repeated experiments in the High Flow Porometer and data obtained using the Capillary Flow Porometer on a small sample taken from the cartridge

Accuracy

In order to test the accuracy of results obtained from the high flow instrument, differential pressures and gas flow rates through a small piece of the dry ceramic cartridge were measured in the PMI Capillary Flow Porometer. The Capillary Flow Porometer uses a small sample, tests the sample at low flow rates and gives accurate results [1,2]. Figure 3 shows results obtained from repeated experiments using the Capillary flow Porometer. As expected the reproducibility of data generated by Capillary Flow Porometer is excellent. The reproducibility of both machines is,

thus, very good. The values of gas permeability computed for the same material based on data from the two instruments were compared.

The permeability was computed from the flow rates measured in both machines. The results shown in Table I are in excellent agreement with each other. The accuracy of results obtained using the high flow machine is considered to be very good.

Table I Permeability of a ceramic cartridge obtained using the Capillary Flow Porometer and the High Flow Porometer.

Instrument	Permeability
Capillary Flow Porometer	0.0447 ± 0.0021 darcies
High Flow Porometer	0.0424 ± 0.0020 darcies

Pore Structure of Sintered Metal Cartridge

Gas flow rate through wet and dry sample: The sintered metal cartridge was 23 cm long and 6.5 cm diameter. The cartridge was easily loaded in the chamber. No leak was observed. The air flow rate through the dry sample was determined. The cartridge was then soaked in the wetting liquid, Silwick, in a large trough so as to completely fill the pores with the wetting liquid. The cartridge was reloaded and the wet curve was determined. A typical flow rate versus differential pressure plot is shown in Figure 4.

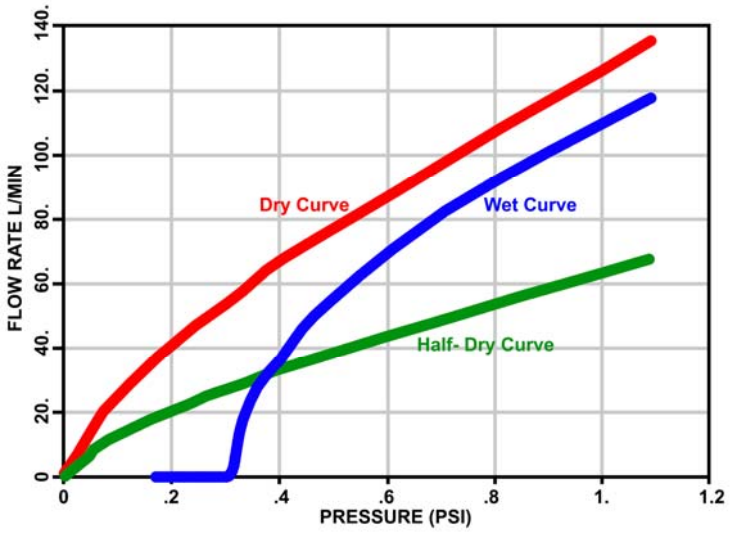

Figure 4. Variation of air flow rate with differential pressure for a 23 cm long and 6.5 cm diameter sintered metal cartridge measured in the High Flow Porometer.

Pore throat diameter: The bubble point pore diameter is the largest throat diameter. It is computed from the bubble point pressure, which is the pressure needed for initiation of flow through the wet sample (Figure 4). The bubble point pore diameter is 67.0 µm. For determination of the mean flow pore diameter, the half-dry curve that gives half of the flow rate through dry sample at a given differential pressure is computed. The mean flow pressure is determined as the differential pressure corresponding to the intersection of the half-dry curve with wet curve. The mean flow pore diameter is computed from mean flow pressure. The mean flow pore diameter is 30.4 µm. The mean flow pore diameter is such that 50 % of flow is through pores larger than the

mean flow pore diameter and 50 % of flow is through pores smaller than the mean flow pore diameter.

Pore distribution: Pore distribution is given in terms of the distribution function, f.

$$f = - d [(F_w/F_d)\times 100] / dD \quad (2)$$

where F_w and F_d are flow rates through wet and dry cartridge respectively. The area under the distribution function in any pore diameter range is the percentage flow in that range. The pore size distribution is shown in Figure 5. Since most of the flow is in the pore diameter range of about 15 to 27 µm, most of the pores are expected to be in that range.

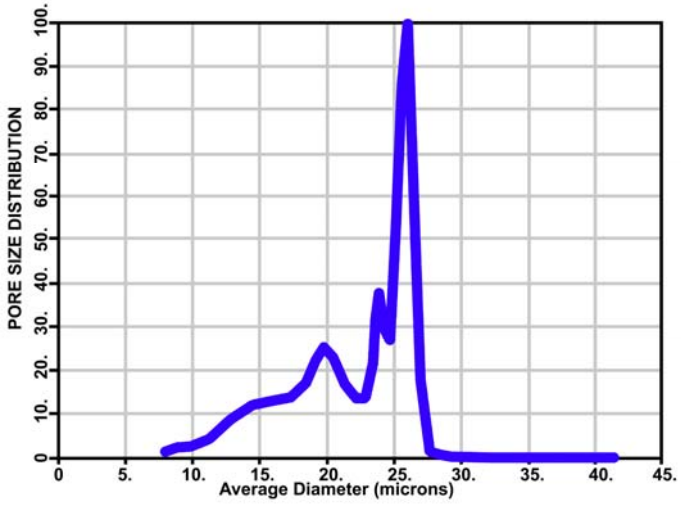

Figure 5. Pore distribution in the sintered metal cartridge

Pore Structure of Ceramic Cartridge

The 29 cm long and 2.5 cm diameter ceramic cartridge was tested in the High Flow Porometer in the same way as the sintered metal cartridge. Silwick was used as the wetting liquid in order to

prevent any possible evaporation of liquid due to high flow rate of gas through the sample. The measured variation of flow rate with differential pressure is shown in Figure 6. The bubble point computed from these data is 7.52 µm and the mean flow pore diameter is 3.57 µm. The histogram in Figure 7 gives pore distribution. All the characteristics of this cartridge were measurable by the High Flow Porometer.

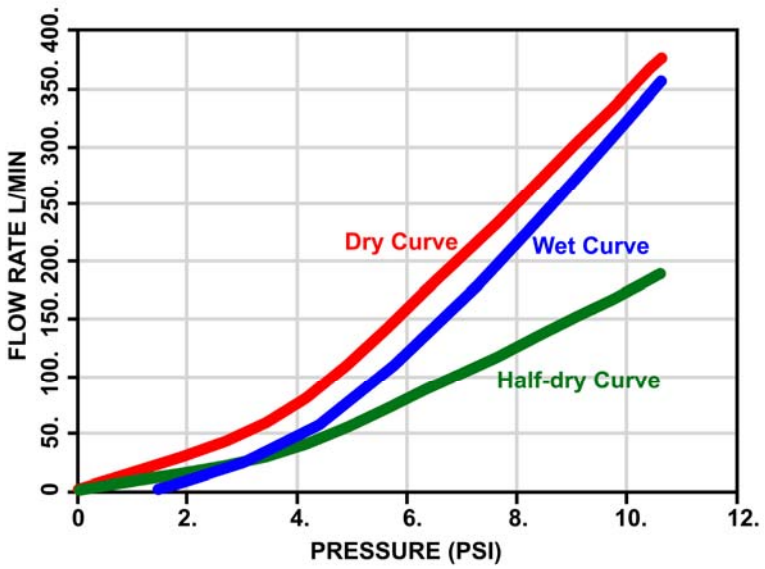

Figure 6. Variation of air flow rate with differential pressure for a 29 cm long and 2.5 cm diameter ceramic cartridge measured in the High Flow Porometer.

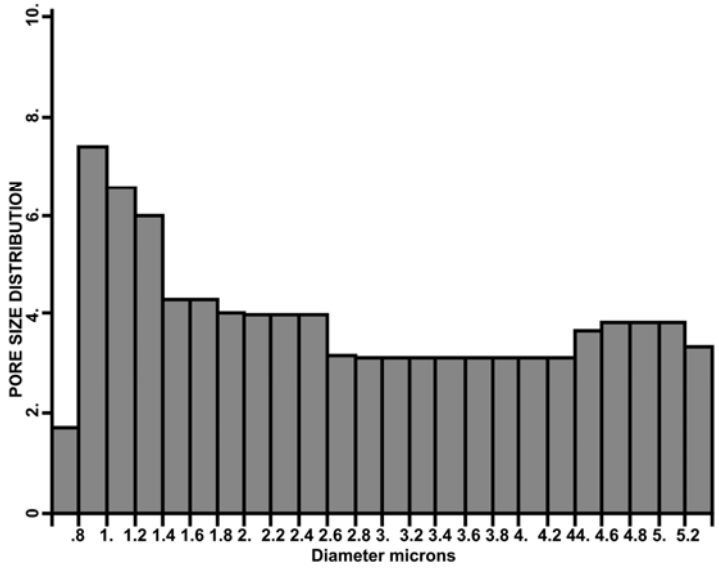

Figure 7. Pore distribution in the ceramic cartridge presented as a histogram

Pore Structure of Woven Metal Cartridge

The 25 cm long and 6 cm diameter woven metal cartridge was tested in the High Flow Porometer in the same way as the sintered metal cartridge. Silwick was used as the wetting liquid in order to prevent any possible loss of wetting liquid from pores due to evaporation because of high flow rate of gas through the sample. The measured variation of flow rate with differential pressure is shown in Figure 8. The bubble point computed from these data is 58.5 μm and the mean flow pore diameter is 35.7 μm. The histogram in Figure 9 gives pore distribution. All the characteristics of this cartridge were measurable by the High Flow Porometer.

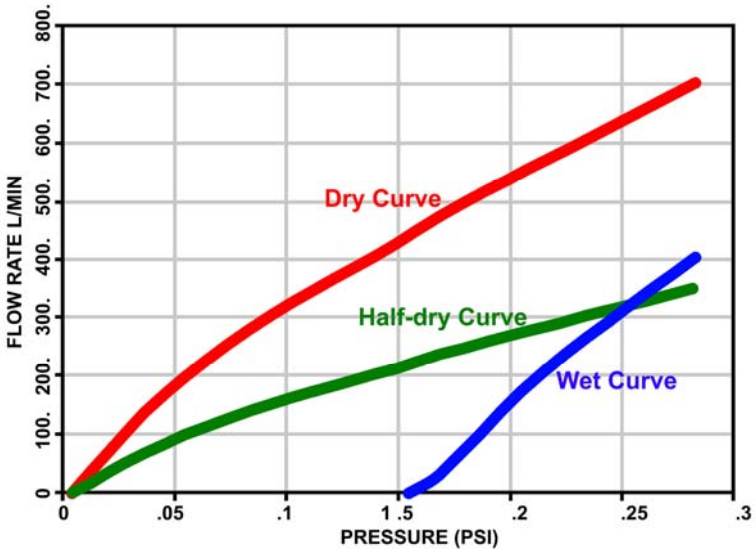

Figure 8. Variation of air flow rate with differential pressure for a 25 cm long and 6 cm diameter woven metal cartridge measured in the High Flow Porometer.

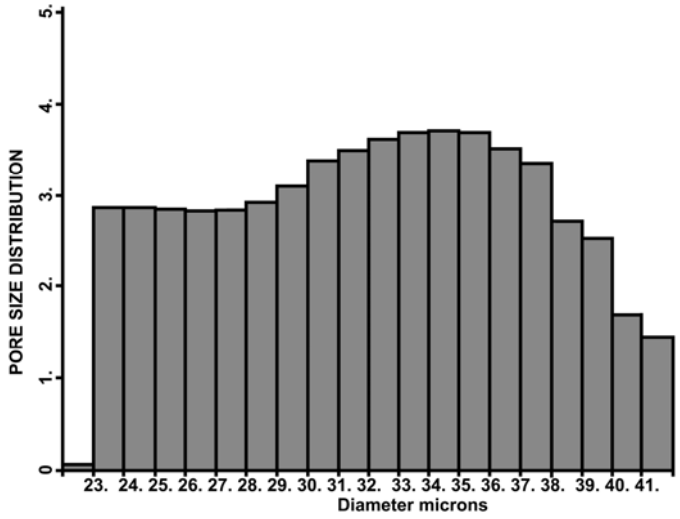

Figure 9. Pore distribution in the woven metal cartridge given by histogram

Testing Capability

The current set of tests have been performed over a wide range (Table III). The bubble point pore diameters are between 65 and 7.5 μm. The measured flow rate is as high as 700 L/min. The cartridges investigated had lengths between 23 and 29 cm. The cartridge diameters were between 6 to 2.5 cm. A variety of cartridge materials, sintered metal, woven metal, and ceramic, were also investigated. In all cases repeatable and accurate results were obtained using the high flow porometer.

Table III. Measured characteristics of investigated cartridges

Cartridge	Size, cm		Largest pore diameter, μm	Mean flow pore diameter, μm	Maximum measured flow rate, L/min
	Length	Diameter			
Sintered metal	23	6.5	67.0	30.4	135
Ceramic	29	2.5	7.52	3.57	377
Woven metal	25	6	58.5	35.7	700

SUMMARY AND CONCLUSION

1. A high flow porometer capable of testing large filter cartridges has been described.
2. The high flow porometer is capable of yielding accurate and repeatable data.
3. Sintered metal, ceramic, and woven metal cartridges, of length around 30 cm and diameter up to 6.5 cm were tested.
4. The bubble point pore diameter, the mean flow pore diameter, permeability, and pore distribution of complete cartridges were measured. The bubble point pore diameter was between 7.5 and 67 μm. Gas flow rate during the test reached up to 700 L/min.

REFERENCES

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