HOMOGENEITY OF PORE STRUCTURE CHARACTERISTICS OF FILTRATION CARTRIDGES

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ABSTRACT

A cylindrical insert containing two circumferential o-rings was moved inside the cylindrical filter cartridge along its length to the test location on the cartridge so that gas introduced to the center of the insert was capable of passing through the radial openings in the insert and the porous cartridge wall between the o-rings. The PMI Capillary Flow Porometer was used to measure bubble point, pore throat diameters, pore distribution, and gas flow rate as a function of the length of the cartridge.

KEYWORDS

Filter Cartridge. Flow Porometry. Pore Size. Pore Structure Characterization.
Pore Size Distribution.

INTRODUCTION

Filter cartridges are widely used in a wide variety of industries. The pore structure characteristics of a complete cartridge rather than those of small samples of the filtration media determine the filtration efficiency. Therefore, measurement of the pore structure characteristics of complete cartridges is important for evaluation of the filtration process and for product development. Pore structure characteristics relevant for filtration such as through pore throat diameter, bubble point pore diameter, mean flow pore diameter, pore distribution, and permeability are measurable by Flow Porometry [1]. However, flow porometry of a complete filter cartridge presents many challenges. The flow rate of the test gas through the cartridge is often very high and the pressure drop in the test gas during its passage through the instrument is appreciable. Cartridges come in a wide range of sizes and need to be accommodated in the sample chamber. Sufficient supply of the test gas is required for the duration of the test. Advanced equipment has been designed and used for testing large cartridges showing high permeability [2]. However, the pore structure of a large cartridge can be very inhomogeneous. The lack of homogeneity can considerably influence performance. Homogeneity of the pore structure of a cartridge can be determined by measurement of the pore structure characteristics of the cartridge as a function of its length using a unique technique that has been developed for this purpose. In this paper, the technique and the use of the technique for successful determine the homogeneity of the pore structure of a cartridge has been discussed. Data obtained with a completely assembled filter cartridge has been presented and critically examined.

EXPERIMENTAL TECHNIQUE

Principle

The surface free energy of filtration media with wetting liquids is less than the surface free energy of the filtration media with air. Therefore, filling of pores by the wetting liquid is accompanied by a decrease in free energy and the filling process is spontaneous. The wetting liquid cannot spontaneously come out of the pores. It can be removed from the pores by increasing differential pressure of a nonreacting gas on the sample. The test involves measurement of gas flow rates through a dry sample as a function of differential pressure. The differential pressure is reduced to zero, the sample is wetted with a wetting liquid, and gas flow rates through the wet sample are measured as a function of differential pressure. Figure 1 shows a schematic plot of gas flow rates through a sample in dry (dry curve) and wet (wet curve) conditions. The computed half-dry curve in Figure 1 shows half of the flow rate through dry sample at a given differential pressure.

The gas pressure needed to displace a wetting liquid from a pore is related to the pore diameter [1].

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

where, p is differential inert gas pressure on the wetting liquid in the pore, γ is the surface tension of the wetting liquid, θ is the contact angle of the wetting liquid with the pore surface of the filtration media, and D is pore diameter. The diameter of a pore can change along pore path and a pore can have many diameters. The presence of a pore is detected by this technique only when the differential gas pressure is able to completely empty the pore to permit gas flow through the pore. The differential pressure capable of completely emptying a pore is the differential pressure needed to displace the wetting liquid from the pore throat. Therefore, the pore diameter computed from the measured differential pressure yields only the through pore throat diameter (Figure 2). No other diameter of a pore is measured.

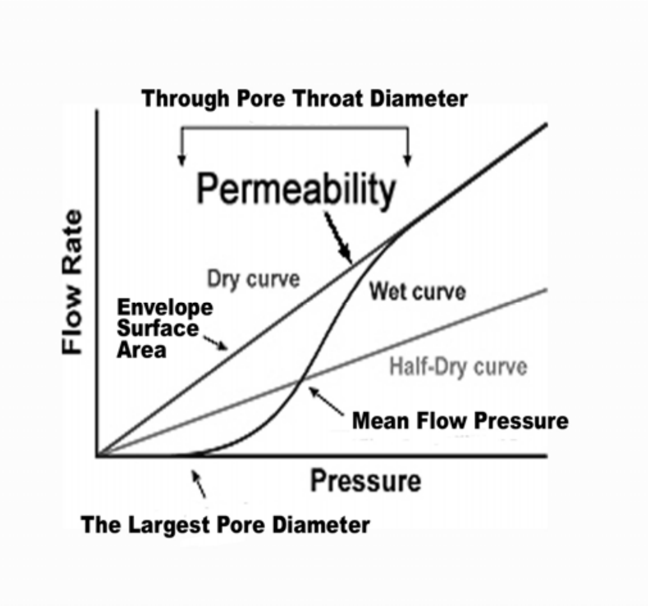

Figure 1 Pore structure characteristics measurable by flow porometry

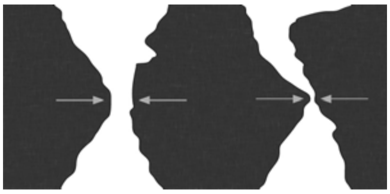

Figure 2 Through pore throat diameter

The wet curve shows no gas flow with increase in differential pressure at the beginning because all the pores are filled with the wetting liquid. The first pore to be emptied at the lowest pressure is the pore with the largest throat diameter (Equation 1). The differential pressure that initiates gas flow through a wet sample yields the largest through pore throat diameter (Figure 1). The differential pressure at which the wet curve and the half-dry curve have the same flow rates yields the mean flow through pore throat diameter. The mean flow through pore throat diameter is such that half of the flow is through pores smaller than the mean flow pore and the rest of the flow is through pores larger than the mean flow pore. Gas flow rates through the dry sample is utilized to compute gas permeability using Darcy's law [3].The ratio of flow rates through the wet sample and the dry sample (Figure 1) yields flow distribution over pore diameter. The flow distribution has been shown to be close to pore fraction distribution [4].

Available Technology and Its Limitations

The pore structure characteristics of the entire filtration cartridge are measurable by a porometer provided it is capable of accommodating the complete cartridge in the sample chamber, producing very high flow rates of gas for large cartridges, accurately measuring flow rates and pressure drops in such a system, and supplying adequate amount of gas for the test duration. The PMI Complete Filter Cartridge Analyzer has all these features and is capable of measuring the characteristics of an entire cartridge [2].

High output filter cartridges are, however, generally long. The pore structure of a long cartridge is normally not uniform. Large pores or pore clusters, increased or decreased concentration of pores, and defects produced during manufacturing due to factors such as non-uniform distribution of powders or fibers, inhomogeneous compaction, and improper sintering or hot pressing may be present at a number of locations along the length of a long cartridge. Presence of such structural abnormality is not normally revealed when the entire cartridge is tested as a whole. Thus, the performance of a cartridge may be poor, even though the overall pore structure of the entire cartridge containing defects along its length is satisfactory. It is, therefore, imperative to be able to measure the pore structure characteristics of a complete filtration cartridge at various locations along its length, eliminate cartridges with unacceptable defects, and make changes in processing techniques used for the manufacture of the cartridges so as to avoid or minimize defects.

Unique Technology to Measure Pore Structure of a Cartridge as a Function of Its Length

The filtration cartridges are long hollow objects with porous walls and a cross-section, which is normally circular. In order to test a selected location on such a cartridge, a special method is used to allow test gas to flow only through the selected location. An insert is specially designed to slide inside the cylindrical bore of the long cartridge (Figure 3). In the middle of the length of the insert (Figure 3), several radial holes extend from the outside to the central bore of the insert. Two o-rings are placed in the two circumferential o-ring grooves on the two sides of the radial holes. Two tubes, threaded to the two ends of the insert make airtight o-ring seals with the insert and connect to the central bore. Compressed test gas is introduced to the central bore through one of the tubes. The free end of the other tube is sealed to prevent escape of the test gas.

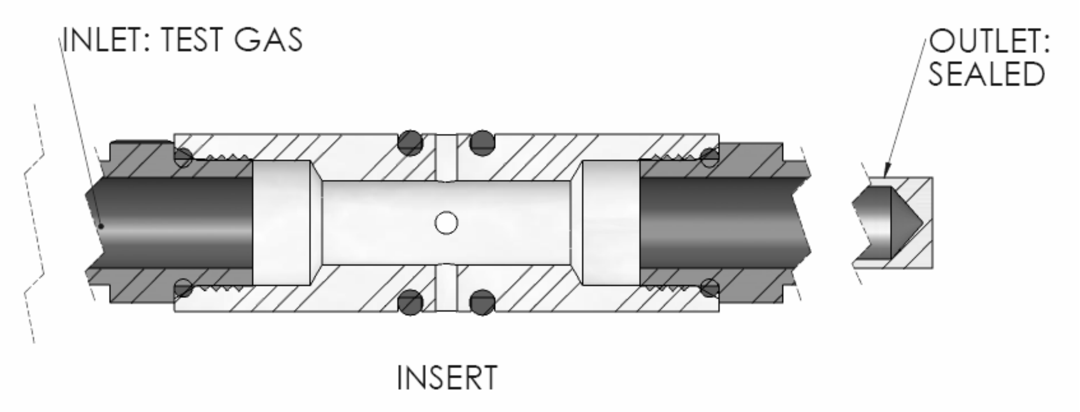

Figure 3. The insert

The tube with closed end is inserted inside the cartridge and the insert is pushed in until the test location is within the two circumferential o-rings on the insert (Figure 4).

The o-rings are such that air tight seals are made between the insert and the inside surface of the cartridge and that the insert can be pushed from one end of the cartridge to the other. A variety of inserts have been developed and successfully used to measure pore structures of different kinds of cartridges as a function of cartridge length.

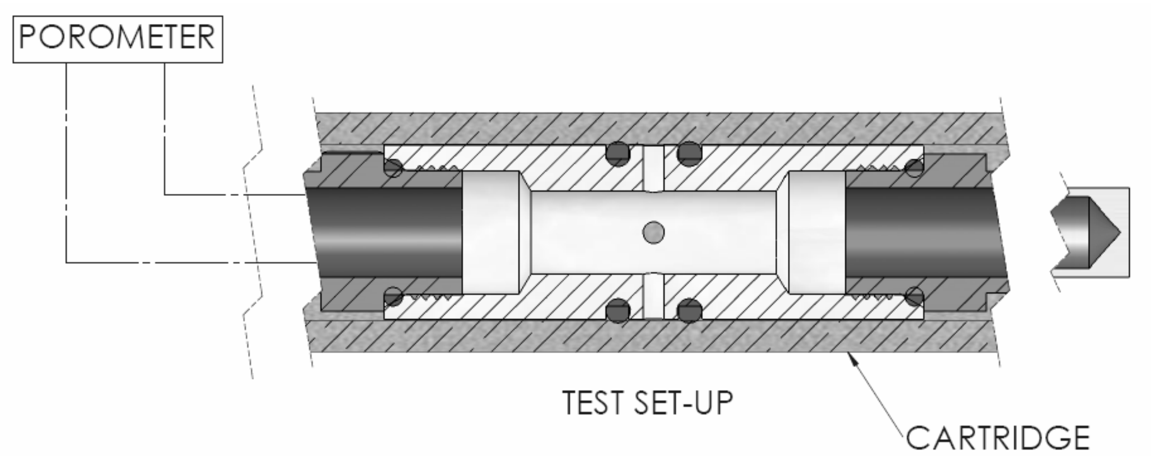

Figure 4. The insert placed inside the cartridge for performance of a test at a location along the length of the cartridge

For performing a test, the assembly of the cartridge and the insert is connected to the porometer. The insert is moved to the desired test location. The porometer increases the pressure of the test gas in small increments. The gas is constrained to flow through the pores in the wall of the cartridge at the desired location. Gas flow rate through the selected part of the cartridge is measured as a function of differential gas pressure. The gas pressure is then reduced to atmospheric pressure, the test area is wetted with a wetting liquid, and gas pressure is slowly increased. Differential gas pressure and gas flow rates through the wet location are measured. The measured gas flow rates and differential pressures are converted into through pore throat diameters, the largest through pore throat diameter, mean flow through pore throat diameter, pore distribution, and gas permeability of the selected annular location on the cartridge wall. Pore structure characteristics at different locations are determined by moving the insert to the desired location. The pore structure characteristics of the cartridge were determined as a function of its length by performing tests at locations with increasing length. Any sudden variation in the pore structure was also detected simple by measuring flow rate as a function of length.

RESULTS AND DISCUSSION

Gas Flow Rate with Increasing Differential Gas Pressure

A long cylindrical cartridge with a wall thickness of about 3/16th inch was investigated. The Teflon insert had four 1/8th inch diameter radial holes and two circumferential o-rings about 7/16th inch apart. The stainless steel tubes attached to the two ends of the insert were long enough for the insert to be placed any where along the length of the cartridge. The fully automated PMI Capillary Flow Porometer was used to supply compressed air to the insert through the stainless steel tube and acquire the required data (Figure 4). The wetting liquid Silwick™ was used to wet the cartridge. The measured flow rates through the central part of the cartridge in dry and wet conditions are shown in Figure 5 as dry curve and wet curve respectively.

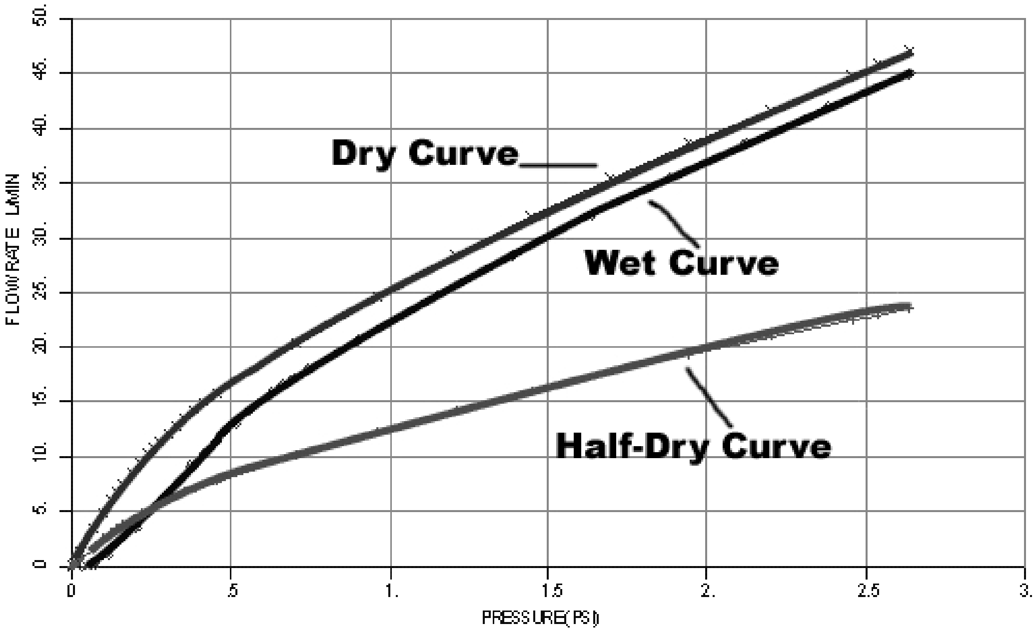

Figure 5. Gas flow rates measured as functions of differential gas pressure through the cartridge at the central part of its length

Through Pore Throat Diameter

The largest through pore throat diameter (bubble point pore diameter) is computed using the bubble point pressure, the differential pressure for initiation of flow through wet sample (Figure 5). The mean flow through pore throat diameter is obtained from the mean flow pressure (Figure 5), which is the pressure at which the gas flow rate through the wet sample is the same as half of the gas flow rate through the dry sample. From the data in Figure 5 for the middle of the length of the cartridge, the Bubble Point Pore Diameter is 227.6 µm and Mean Flow Pore Diameter is 30.62 µm.

Through Pore Distribution

The pore distribution is given in terms of the distribution function, f.

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

where Fw and Fd are gas flow through wet and dry samples respectively at the same differential pressure. The distribution function computed from data in Figure 5 for the center of the length of the cartridge is shown in Figure 6. The distribution function is such that area under the function in any pore diameter range yields percentage gas flow through pores in that range. This flow distribution has been shown to be close to the pore number distribution [4]. The distribution function shows that pores exhibiting appreciable flow have through pore throat diameters of about 5 to 60 µm.

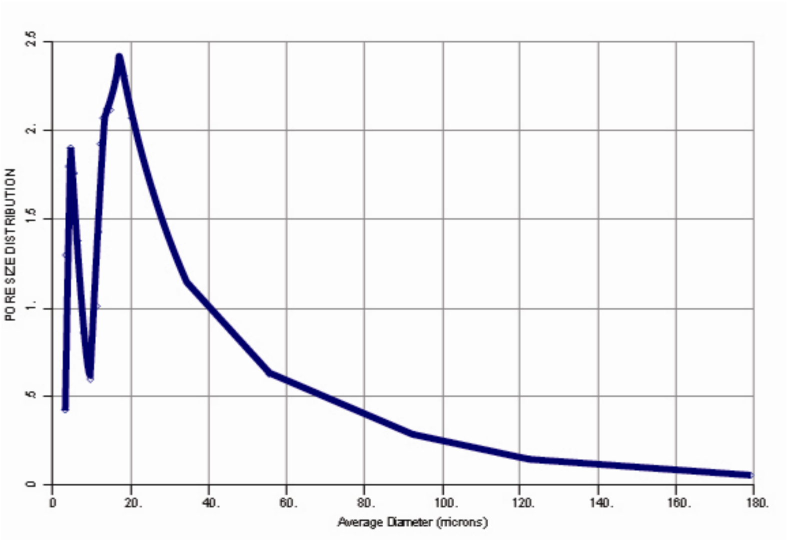

Figure 6. Pore distribution in the center of the length of the cartridge

Effect of Test Area Location on the Cartridge

By sliding the insert inside the cartridge all the important pore structure characteristics at the other locations on the cartridge were measured. Pore structures in this cartridge changed appreciably with length of the cartridge. Even the gas flow rates observed at the center, left, and right, and reproduced in Figure 7 demonstrate the differences in pore structures. The differences in the structure at the three locations are listed in Table 1.

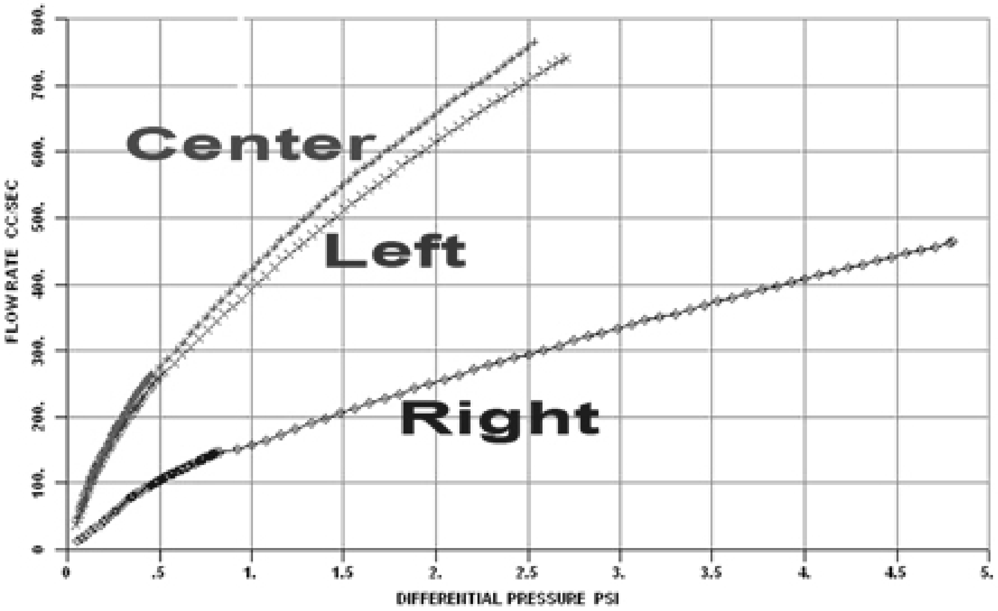

Figure 7. Gas flow rates through the center, left, and right of the cartridge

Table 1. Differences in the pore structure at three locations along the length of a cartridge

Pore structure Characteristic	Left	Center	Right
• Bubble point pore diameter	140 %	100 %	75 %
• Mean flow pore diameter	94 %	100 %	148 %
• Gas flow rate at 2 psi	95 %	100 %	39 %

The left has a few larger pores compared with the large pores in the center. Otherwise, the pore structure on the left is almost the same as the pore structure in the center because the mean flow pore diameters and the gas flow rates are the same. However, the pore structure on the right is considerably different from that in the center. The largest pores on the right are smaller than those on the center. The mean pore diameter is much larger than that at the center. Larger mean flow pore diameter implies higher gas flow rate. However, much smaller gas flow rate of 39 % indicates that the pore density on the right is much lower than that on the center. These structural features can not be detected by any other technique.

SUMMARY AND CONCLUSION

1. The unique technique for measurement of pore structure using flow porometry at any location along the length of a filter cartridge has been described.
2. Pore structure of a cylindrical cartridge has been successfully measured as a function of cartridge length using the PMI Capillary Flow Porometer.
3. A quick scan along the length of the cartridge shows the presence of major defects in terms of variation in flow rate.
4. The simple attachment to a porometer can enhance its ability to determine pore structure characteristics of a cartridge as a function of its length

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