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Standardization of the bubble point method for the pore-size characterization of woven and nonwoven geotextiles

S.K. TU & S.K. BHATIA, Syracuse University, Syracuse, New York, 13244, USA
J. MLYNAREK, SAGEOS, Saint-Hyacinthe, Quebec, CANADA

ABSTRACT: Reliable geotextile opening size and pore-size distribution information is needed for the proper design of geotextile filters. Existing methods, such as dry, wet, and hydrodynamic sieving, are time consuming and often yield erroneous results. Therefore, there is a need for a reliable test method to evaluate the pore sizes of a geotextile. The bubble point method is a current ASTM standard for thin membrane filters (ASTM F316). In both of these industries, the technique has been used for products that have very fine pore openings (between 0.001 and 0.020 mm). However, little work has been done to evaluate the potential use of this method for materials that have larger pore opening, such as geotextiles (between 0.001 and 0.200 mm). Recent work on the bubble point method indicates promising results for characterizing the opening size and pore-size distribution of geotextile filters.

1 INTRODUCTION

In recent years, woven and nonwoven geotextiles have been widely used as filters in civil engineering applications, such as in landfill leachate collection systems, erosion control structures, earth dams, and retaining wall systems. These geotextiles are permeable products used to minimize the migration of soil particles through a drainage system, while also allowing fluid to flow without substantial resistance.

The earliest application of geotextile filters was in 1958, when they were replaced by graded soil filters and gravel blankets by the Carthage Mills Company (Rankilor 1981). Today, geotextiles must be properly designed so that they perform adequately in filtration applications. Design should be based on a comparison of geotextile properties and properties of the surrounding soil. The geotextile properties most directly related to the performance of a geotextile as a filter are its pore openings and pore-size distribution, which are directly related to the amount of water and soil particles that may pass through the geotextile.

There are many different techniques for evaluating the pore openings and pore-size distribution of geotextiles, and each technique may give different results for the same geotextile. The dry sieving (ASTM D-4751), hydrodynamic sieving (CAN/CGSB-148.11), and wet sieving (SW-640550-83) methods are generally used for evaluating only the larger pore openings of the geotextiles. These methods are generally time consuming (Smith 1993). The mercury intrusion porosimetry method (ASTM D-4404) is considered environmentally problematic because of its use of mercury. The bubble point method is a simple and rapid technique that is able to evaluate the larger pore openings and pore-size distribution of geotextiles. The equipment used in bubble point testing is capable of providing information about the degree of clogging within a geotextile and about the permeability of a geotextile (Bhatia & Smith 1995).

In this paper, the bubble point technique is described and the bubble point results are compared with those obtained by other standard test methods (hydrodynamic sieving method). The results are also compared with bubble point results obtained by other researchers using similar techniques, but different equipment. In addition, the results of the stainless steel screen used to calibrate the bubble point technique are compared with those from scanning electron microscope (SEM) images.

2 BUBBLE POINT METHOD

The bubble point method was performed in accordance with Method B of the Standard Test Methods for Pore Size Characteristics of Membrane Filters by Bubble Point and Mean Flow Pore Tests (ASTM F-316).

2.1 *Principle of Bubble Point Method*

The principle of the bubble point method is that a porous material will only allow a fluid to pass when the pressure applied exceeds the capillary attraction of the fluid in the largest pore (Miller et al. 1986), based on the assumption that the pores are cylindrical. There are two steps involved in this method. First, testing a dry specimen in the sample chamber, forcing air through it, and measuring the airflow and pressure differential, which is at increasingly larger airflows. Second, the specimen is saturated with an appropriate wetting liquid (dependent on the surface tension of the liquid), and the air pressure on the downstream face of the wetted specimen is gradually increased. At a critical pressure (one exceeding the capillary attraction of the fluid), the first air bubble(s) pass through the largest pore(s) in the wetted specimen. Based on the theory of capillary flow, the diameter of the largest pore opening is then calculated using equation (1):

$$4\pi d\tau \cos\theta = d^{2}\pi P \qquad (1)$$

where d = maximum pore diameter; τ = surface tension of the wetting liquid; θ = contact angle between the wetting liquid and the porous material; and P = differential pressure being applied.

If cylindrical pore is assumed, the diameter of the largest pore can be simplified using equation (2):

$$d = 4\tau / P \qquad (2)$$

The bubble point method can also measure the complete pore-size distribution of a geotextile by continuously increasing the pressure. Smaller and smaller pores are emptied of liquid as the pressure is increased gradually. The principles of measuring the pore-size distribution of a porous material are: (a) a dry specimen passes air through all of its pores when any amount of air pressure is applied to one side of the specimen; and (b) a saturated specimen passes air through pores only when the capillary attraction of the fluid is exceeded by the air pressure applied. By considering the flow rate for both a dry and a saturated state, the percentage of airflow passing through the material for a particular pore size range (Q) can be calculated using equation (3):

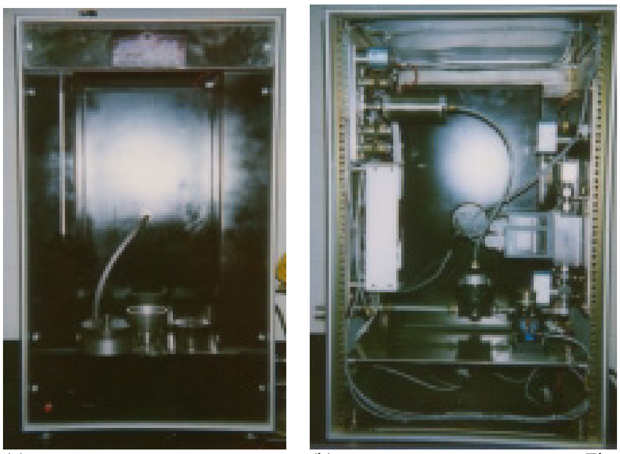
$$Q = [\text{wet flow}_h/\text{dry flow}_h - \text{wet flow}_l/\text{dry flow}_l] \times 100\% \quad (3)$$

where Q = filter flow percentage; h = higher pressure limit; and l = lower pressure limit.

In summary, the maximum pore diameter and the filter flow percentage can be obtained form equation (2) and (3). The percentage of pores of the equivalent pore diameter can then be calculated. By continuing the calculation using equation (3), the complete pore-size distribution of the geotextile can be measured (Bhaita & Smith 1995).

2.2 *Test Apparatus and Procedures*

The test apparatus used for this study is an Automated Capillary Flow Porometer manufactured by Porous Materials Inc. (PMI), Ithaca, NY. It consists of an electronically controlled pressure regulator, two pressure transducers, a fixed needle valve, a motorized metering valve, a drain valve, two mass flow transducers, a penetrometer, and a sample chamber. The standard size of the sample chamber is between 4.5 and 6.1 cm in circular diameter; however, any size sample chamber may be specified. An air compressor is used to supply compressed air for the tests. The controlling computer, an IBM-PC or compatible computer, fully automates the equipment. The equipment occupies a space approximately 0.85 m in height, 0.53 m in width, and 0.46 m in depth and weighs approximately 18 kg (Bhatia & Smith 1995). Photographs of the equipment are given in Figure 1a and b.



(a) (b)

Figure 1. Photographs of the bubble point equipment.

Before a test can begin, the geotextile sample must be trimmed to the size of the sample chamber (between 21 and 46 mm in diameter). A sample must be correctly installed in the sample chamber because air flowing downward through the sample needs to be constrained by two O-rings to vertically flow down and out of the bottom of the sample chamber, instead of horizontal through. When installed, the O-ring of the insert must seal the chamber to prevent air leaking.

Two tests were conducted using the Capillary Flow Porometer, the bubble point test and the capillary flow porometry test. The bubble point test was used to obtain the largest pore opening of a geotextile, and the capillary flow porometry test was used to determine the complete pore-size distribution of a geotextile.

When the bubble point test begins, the computer program allows air from the regulator to pass through a fixed-needle valve, and a flow transducer (low flow) into the top of the sample chamber. As long as the pressure is below the bubble point (the largest pore in a geotextile), the sample seals the chamber and the pressure rises. The sample chamber pressure is monitored and continues to rise slowly. When the sample chamber pressure fails to rise while the flow through the flow transducer is maintained, the program takes the maximum pressure reached as the bubble point.

The capillary flow porometry test determines the mean flow pore size, bubble point, cumulative flow, and pore-size distribution. After a dry sample is installed in the sample chamber and the test has begun, the motorized metering valve is opened in increments. The regulator is raised, increasing the flow into the system, which, in turn, causes the pressure and flow rate through the sample to increase. When either the maximum flow rate or maximum pressure is reached, the regulator is zeroed; metering valve closes, and the dry test is completed. The tested sample has to be fully saturated by pouring wetting liquid in the sample chamber. When the test is continued, the bubble point can be taken when the wetting liquid in the largest pore of the sample is forced out by the supplied airflow. As the airflow keeps increasing, followed by an increase in pressure, smaller and smaller pores are opened in the sample. The complete pore-size distribution, therefore, can be measured automatically.

3 TEST RESULTS AND DISCUSSION

A total of twenty-three geotextiles and one stainless steel screens were tested using the bubble point method. These geotextiles were made of polypropylene (PP), polyester (PET), or a combination of the two. The geotextile manufacturing processes included needle-punched and heat-bonded. Thicknesses varied from 0.32 to 4.20 mm. These geotextiles can be classified to three groups given in Table 1.

Table 1. Tested geotextiles and their properties.

Group	Fiber	MP*	Mass/Area (g/m^2)	AOS (mm)
1	Staple	NP**	200–560	0.040–0.212
2	Continuous	NP**	204–544	0.150–0.212
3	Continuous	HB***	98.34–204	0.090–0.300

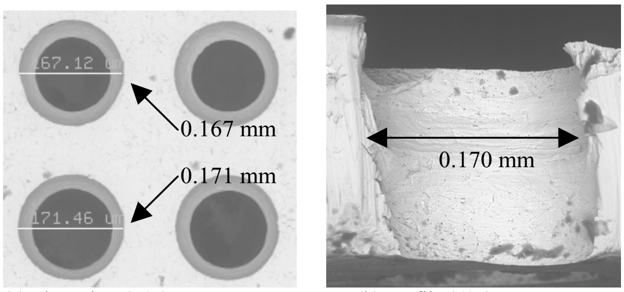
*Manufacturing Process
**Needle Punched
***Heat Bonded

A stainless steel screens with cylindrical holes was selected as the standard metal disks for calibrating the bubble point method. This product features higher tolerance hole sizes and greater dimensional stability than woven and nonwoven geotextiles. The pore opening of this screen was measured as 0.177 mm by the manufacturer.

For saturating the samples, three different fluids were selected as the wetting liquids. They are porewick with a surface tension of 16 dynes/cm, silwick with a surface tension of 20.1 dynes/cm, and mineral oil with a surface tension of 34.7 dynes/cm.

3.1 *Calibration of Bubble Point Method*

The analysis of the stainless steel screen 644 focuses only on the largest openings of the screen because the pores of the screens are close to cylindrical in shape and equally distributed. The microphotographs of screen 644 taken with an SEM are given in Figure 3a and 3b. The average of the largest pore opening (O_{100}) of screen 644 was measured as 0.170±0.010 mm. Based on the profile in Figure 3b, the observation of two different diameters in Figure 3a is because of parallax in the screen.



(a) Plan View (54x) (b) Profile (60x)

Figure 3. Microphotographs of screen 644.

The complete pore-size distribution of screen 644 obtained by the bubble point method is given in Figure 4. Three tests were performed using porewick (16 dynes/cm) as a wetting liquid. For screen 644, the largest pore opening measured by the bubble point method (0.167 mm) compared well with one measured using SEM microphotographs (0.170 mm). Because of the manufacturing process, all pores may not have exactly the same pore diameter but the difference in diameter is not significant (within 0.010 mm) between each pore. The curves of the complete pore-size distribution are consistent and go vertically from 95% to 0% in percent finer after the largest pore is reached. It indicates that the difference in diameter for this screen is small, suggesting that pores in the screen are of the same size. Tests were also performed using silwick as a wetting liquid. The results obtained with silwick were identical to one obtained with porewick. If the bubble point method can give reliable results of pore opening and pore-size distribution for this stainless steel screen, therefore, it is believed that this method can be used for geotextiles with pore opening in size range of 0.02 and 0.20 mm.

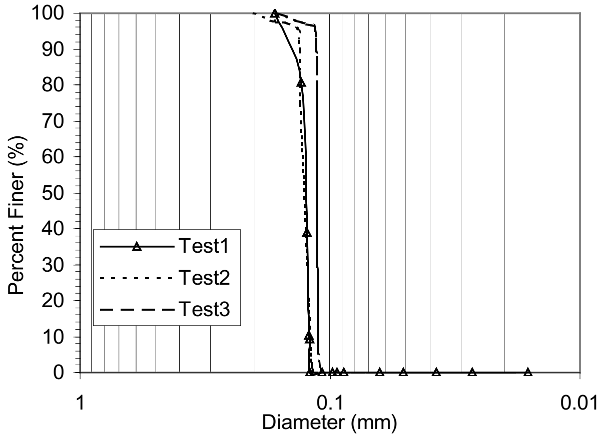


Figure 4. Complete pore-size distribution results for screen 644.

3.2 *Different Wetting Liquids*

It is necessary to run a dry phase as well as a wet phase in the bubble point test. The saturation of geotextiles is an important step before the wet phase can be started. If the sample is not fully saturated, bubble point and pore-size distribution results will be erroneous.

Based on the principle of the bubble point method, the wetting liquid in the pores needs to provide capillary resistance while pressure is applied to one side of the sample. This capillary resistance depends on the surface tension of the wetting liquid. In general, the most commonly used wetting liquids have surface tensions between 15 and 35 dynes/cm.

For this study, the selection of wetting liquids was based on experimental works for sample with the largest pore openings between 0.050 mm and 0.250 mm. All geotextiles were tested using three different wetting liquids. A typical test result for a nonwoven geotextile is given in Figure 5. This staple fiber, needle-punched, nonwoven geotextile was made using the combination of PP and PET. As can be seen, the curves of pore-size distribution are very consistent between 100% and 50% in percent finer, which is larger pore opening in this geotextile. Otherwise, the curves show difference in the range of finer pore openings between 50% and 0% in percent finer. It is believed that three different wetting liquids were able to saturate geotextiles with pore openings in the range of 0.110 mm and 0.050 mm.

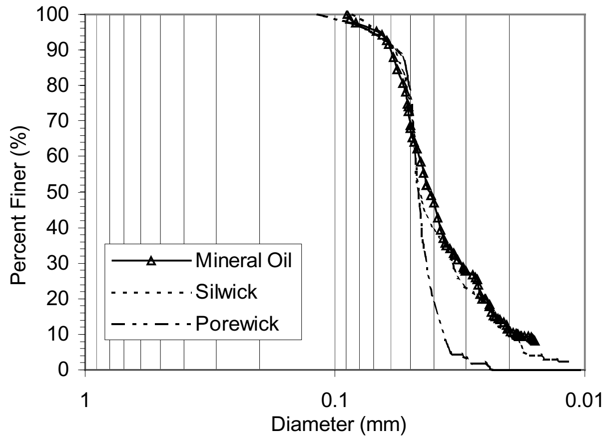


Figure 5. Complete pore-size distribution of a staple fiber, needle-punched, nonwoven geotextile using three different wetting liquids.

The test result of a continuous fiber, heat bonded, nonwoven geotextile is given in Figure 6. It is a very thin nonwoven geotextile (0.32 mm in thickness) with larger pore opening. The bubble point method measured O_{95} value of 0.150 mm using three different wetting liquids (O_{95} is defined as the particle diameter at which 95% by weight is retained on the geotextile). For this product, the complete pore-size distributions using three wetting liquids are consistent in the pore size range of 0.250 mm and 0.060 mm. Otherwise, it also shows difference for the finer pore openings less than 0.060 mm. It is believed that three different wetting liquids were able to saturate geotextiles with pore openings in the range of 0.250 mm and 0.060 mm.

Based on the test results shown above, three wetting liquids were able to saturate geotextiles with pore opening in size range of 0.050 mm and 0.250 mm. A wetting liquid with higher viscosity may provide better saturation of sample when the tested geotextile has very open pores greater than 0.250 mm or very fine pores less than 0.050 mm.

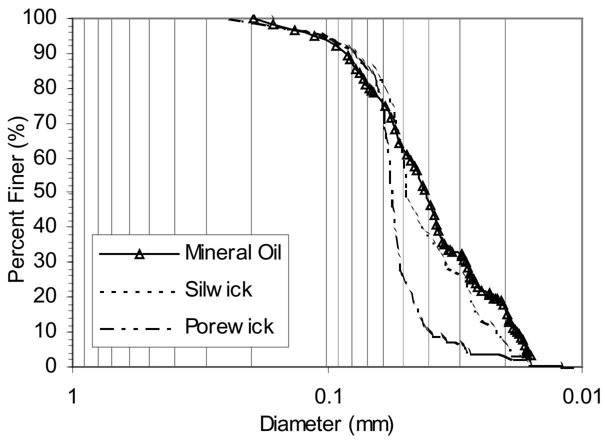


Figure 6. Complete pore-size distribution of a continuous fiber, heat-bonded, nonwoven geotextile using three different wetting liquids.

3.3 *Different Devices*

In the last five years, different researchers have evaluated the effectiveness of the bubble point method using the same principle but different equipment and sample size to measure the pore-size distribution of a variety of geotextiles.

At Syracuse University, an Automated Capillary Flow Porometer is used for the bubble point method, whereas, SAGEOS is using the Coulter Porometer II®. The results shown in Figure 7 are for a staple, needle-punched, nonwoven geotextile with porewick as a wetting liquid. The Syracuse University's equipment requires using a sample size of 21 mm in circular where as SAGEOS is using a sample size of 25 mm (Vermeersch & Mlynarek 1996). As can be seen, the complete pore-size distribution curve is similar but the largest pore opening has difference about 0.12 mm.

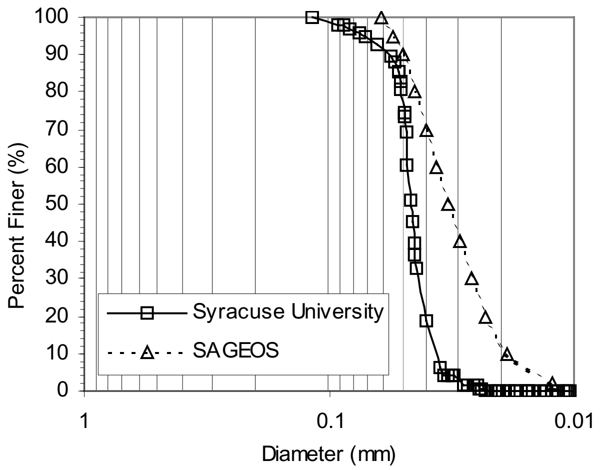


Figure 7. Pore-size distribution of a staple fiber, needle-punched, nonwoven geotextile using two different equipments.

3.4 *Different Methods*

Hydrodynamic sieving method is a Canadian standard test for the Filtration Opening Size of Geotextiles (CAN/CGSB-148.11). This method involves using a mixture of glass beads and is only useful for evaluating the larger pore sizes of a geotextile, such as O_{95} and O_{90}.

The hydrodynamic sieving tests were performed at SAGEOS laboratories, Canada. A comparison between hydrodynamic sieving results and bubble point test results for the same geotextile is given in Figure 8. For O_{95} value, the bubble point method measured the diameter of 0.070 mm and the hydrodynamic sieving method gave the opening of 0.057 mm. The difference is 0.013 mm, which is not significant. For all nonwoven geotextiles, the bubble point test results are slightly greater than the hydrodynamic sieving test results.

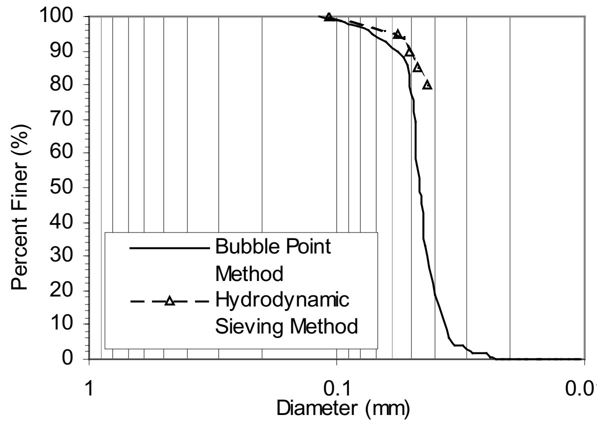


Figure 8. Comparison between hydrodynamic sieving and bubble point test results.

4 CONCLUSIONS

The bubble point method is a simple technique to provide information on the pore openings and pore-size distribution of a geotextile. Based on a comparison of SEM and bubble point results for stainless steel screen 644, it appears that the bubble point method is able to provide an accurate measurement of O_{100} for a porous material with pore openings in the range of 0.02 mm and 0.20 mm. Nonwoven geotextiles are generally in this range of pore openings. It is believed that the bubble point method can also provide accurate results for geotextile product.

Saturation is an important step while running a bubble point test. Based on the results of over 350 tests on woven and nonwoven geotextiles and stainless steel screen with a variety of wetting liquids, the wetting liquids with surface tension between 15 dynes/cm and 35 dynes/cm can saturate the geotextile with pore opening in size range of 0.050 mm and 0.250 mm. In conclusion, the bubble point method is capable of characterizing the pore size and pore-size distribution of geotextiles.

Reference

Bhatia, S.K. & Smith, J.L. 1995. Application of the Bubble Point Method to the Characterization of the Pore-Size Distribution of Geotextiles. *Geotechnical Testing Journal* 18(1): 94-105.

Miller et al. 1986. Quantifying the Porous Structure of Fabrics for Filtration Application. *Fluid Filtrations: Gas* 1: 97-109.

Rankilor, P.R. 1981. *Membranes in Ground Engineering.* Chichester: John Wiley.

Vermeersch, O.G. & Mlynarek, J. 1996. Determination of the Pore Size Distribution of Nonwoven Geotextiles by a Modified Capillary Flow Porometry Technique. SAGEOS scientific and technical publication N°9504.