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# Bubblepoint Testing of Geotextiles: Apparatus and Operation

**ABSTRACT:** A simple, inexpensive device for measuring geotextile pore sizes, using ASTM D 6767, is described and its operation is outlined with guidance for correct operation. The accuracy and consistency of the test are shown. The test appears to have better consistency than the apparent opening size (AOS) test, avoids the inherent and operator-dependent problems of the AOS test, and further, describes the entire pore size distribution of a geotextile, making it useful for developing a more complete filter criterion. Suggestions are made for improving ASTM D 6767.

**KEYWORDS:** bubblepoint test, $O_{95}$, apparent opening size, filtration, pore size distribution, geotextile

## Introduction

The established method of measuring a pore size in filtration geotextiles is ASTM D 4751, Standard Test Method for Determining Apparent Opening Size (AOS) of a Geotextile. There are many problems associated with this test, such as difficulty of operation, operator dependence, and inconsistency of results. Common operator problems include sieving for durations other than the prescribed time, sieving the wrong bead size first, using different geotextile samples for all bead sizes, and failing to soak the sample in water prior to testing. Test problems include the buildup of static electricity between the beads and the sample and clogging of the geotextile by the beads and water. In addition, the AOS test gives no information about the smaller pore sizes, yet they are the first to clog and ruin a filter (Carroll 1983).

A more recent method for determining the pore size of geotextiles is the bubblepoint test (BPT), ASTM D 6767. Advantages of the BPT include cost efficiency and consistency. Additionally, the BPT gives a *distribution of pore sizes* rather than a single value, as the AOS test does. A pore size distribution is preferable because soils are composed of a distribution of grain sizes. A filter chosen because of its pore size distribution will be more likely to perform properly than a filter chosen because of a single opening value, such as the 95% opening size ($O_{95}$) measured by the AOS test.

A BPT apparatus has been developed that is simple to use, inexpensive, precise, and accurate. This paper discusses the design and operation of the BPT apparatus, examines the consistency and accuracy of tests performed with the apparatus, compares AOS and BPT data for various geotextiles, and makes suggestions for improving ASTM D 6767 (2002).

## Background

In civil engineering applications, geotextiles are used as groundwater filters, retaining soil while allowing water to pass through. The grain size distribution of the soil can be determined and an appropriate geotextile is chosen based on its pore sizes. Pore sizes are the primary criteria used to select a geotextile for filtration (Mlynarek 1999). It is important to select the correct geotextile so that optimum soil retention and water permeability criteria are met. Presently, there are numerous methods for determining the pore sizes in filters: the AOS test, wet, dry, and hydrodynamic sieving, mercury intrusion porosimetry (MIP), capillary liquid extrusion, and image analysis. However, different test methods can give different results (Falsye et al. 1985; Prapaharan et al. 1989; Bhatia and Smith 1994; Bhatia and Smith 1995; Bhatia et al. 1996). Gourc and Faure (1992), Wates (1980), Faure et al. (1986) and Dierickx and Van der Sluys (1990) discuss the various advantages and disadvantages of these common test methods.

The most popular and widely accepted test for evaluating the pore size in geotextiles is the AOS test (ASTM D 4751 2004), a dry sieving method which uses glass beads to evaluate one pore size. The test is performed by placing a geotextile on a supporting screen, placing glass beads of uniform diameter on top of the geotextile, and shaking the system for 10 min. Once a test is performed with a percent passing of greater than 5 %, the test is repeated using larger bead sizes until the percent passing is 5 % or less. The results of these tests are plotted, and the bead size that corresponds to 5 % passing is designated the AOS ($O_{95}$) value. The AOS of the geotextile is calculated by averaging the AOS values from five samples of the geotextile. The AOS value can be expressed as an opening diameter ($O_{95}$) or in terms of an equivalent U.S. sieve number (AOS).

Though widely used, there are several problems associated with the AOS test. Dierickx and Miles (1996) question the reproducibility of the $O_{95}$ value and note that pore sizes less than 0.1 mm are not measured accurately by dry sieving. Fischer et al. (1996) note that it is a random event whether a glass bead falls through a pore during the test, and that the weight of the different size beads seems to influence which beads find a hole to fall through. In addition, water trapped in pores (resulting from soaking) clogs those pores and can prevent bead passage. Dierickx (1993) notes there are several opening sizes ($O_i$) used in filter design, suggesting confusion in the profession. The most significant shortcoming in regard to filtration is that the AOS test attempts to characterize a geotextile's filtration property using a single number, and does not relate directly to clogging potential (Carroll 1987).

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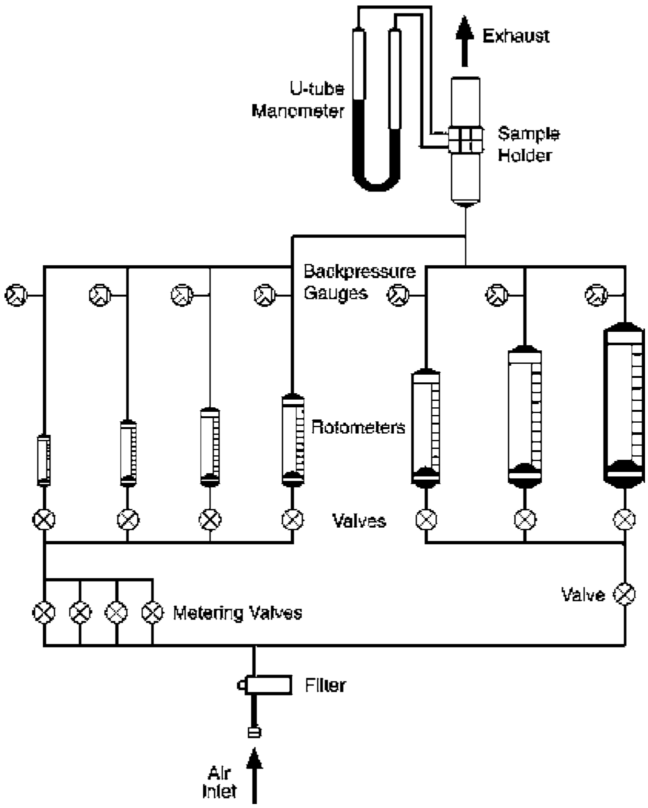


FIG. 1—*Schematic of BPT apparatus.*

FIG. 2—*BPT apparatus.*

The BPT is a form of capillary flow testing that has been used since the early 20th century to determine the pore sizes of porous materials (Bechhold 1908; Washburn 1921). More recently, it has been used with textiles and geotextiles (Miller and Tyomkin 1986; Bhatia and Smith 1995, 1996; Fischer 1994; Fischer et al. 1996). In the BPT, air is directed through a dry geotextile sample at various flow rates, and the corresponding pressure differences across the geotextile are recorded. The geotextile is then saturated with a fluid and air is once again directed against the sample. As the airflow rate is increased, the pressure difference across the sample increases. The increasing pressure difference expels liquid from the geotextile pores according to pore size, beginning with the largest and ending with the smallest pores. By comparing the airflow rates and corresponding pressure differences of the dry sample to that of the initially saturated sample, a pore size distribution can be calculated. The BPT actually measures the smallest constriction of a continuous pore, which is advantageous as these constrictions are what govern filtration (DeMello 1977).

## The Bubblepoint Apparatus

### *Overview of the Bubblepoint Test Apparatus*

A bubblepoint testing apparatus has been developed that is easy to construct and inexpensive to build with off-the-shelf products and common tools. A schematic of the apparatus is shown in Fig. 1, and a photograph is shown in Fig. 2. The bubblepoint test apparatus directs air through a system of valves that regulate flow, then through a system of rotometers that measure the flow, and finally through the geotextile. The pressure difference across the geotextile is measured by a manometer.

The 1999 cost to construct the BPT apparatus was less than US$3000 (excluding air supply), considerably less than commercially available devices which can cost more than US$ 12 000. Assembly was straightforward except for minor custom machining of the sample holder. All other parts came from common hardware vendors.

### *Details of the Bubblepoint Test Apparatus*

*Filtering the Air*—Before the air enters the BPT apparatus, it passes through a filter to minimize entry of foreign objects (oil, dust, etc.), as these objects can affect the flow of air through the apparatus and clog the geotextile. Because the BPT uses very large volumes of air, even small concentrations of particles can clog the geotextile.

*Air Entry Apparatus*—Air enters the machine through the largest diameter tubing available, which should have as short a length as possible, so that a maximum airflow is allowed to reach the apparatus. After the filter, the hose is divided into two, with one hose leading to the larger rotometers, and one hose leading to the smaller rotometers. This is done so that the larger rotometers, the ones that measure the higher flows and involve higher air velocities, have a more direct link to the air source, reducing head losses. To accomplish this, part of the air flows directly to the rotometer cutoff valves in front of the largest rotometers. The largest pipe size possible is preferred, especially in areas with higher airflows. The apparatus described here was originally built with 9.5-mm (3/8-in.) diameter tubing, and most of that was later upgraded to 12 mm (1/2-in.) tubing, resulting in a significant decrease in head loss.

*Metering and Cutoff Valves*—Various sizes of metering valves control the airflow to the open rotometer(s). Metering valves are used because precise airflow control is needed. Very small changes in airflow can make a large difference in the pressure difference across the sample, particularly at small airflows. It is very difficult to make the exact changes in airflow necessary without using metering valves.

These metering valves lead to another set of rotometer cutoff valves in front of a series of rotometers of increasing size. The rotometer cutoff valves are ball valves, since ball valves produce less head loss than gate valves. These seemingly minor methods of reducing head loss (increasing the size of the piping, decreasing the length of the piping, and the use of ball valves) produce significant increases in performance. Mitigation of head losses allowed airflows up to 2000 L/min to be maintained, and with this airflow capability, the device measured pores an order of magnitude smaller than the minimum 0.1 mm measured by Vermeersch and Mlynarek (1996).

*Rotometers*—The rotometers measure the flow rate of air entering the sample holder, ranging from 0.00838 to 3400 L/min. The higher flow rates are needed to measure small openings in the geotextile. Bhatia et al. (1996) noted the inability of their apparatus to do this, due to insufficient airflow. All high flow rotometers exhaust into larger 4.00 cm (1.57 in.) inside diameter pipes (see Fig. 2).

*Backpressure Gage*—All rotometers have backpressure gages connected at their outlets to measure the buildup of backpressure in the pipes. Backpressure is the difference between the pressure at the exhaust of the rotometers and atmospheric pressure. Backpressure must be accounted for to correct the rotometer, which is calibrated at atmospheric pressure at the exhaust. Even with all of the precautions taken to reduce pressure head loss, there is always some backpressure, especially at the higher airflows.

*Manometer*—A manometer is used to measure the pressure head loss (pressure difference) across the sample. Flexible tubing connects the manometer to ports on the sample holder. These ports are quick-connect fittings glued into holes drilled in the sides of the inlet and exhaust pipes of the sample holder system. The part of the quick-connect that extends into the piping is cut away flush with the inside to reduce head loss.

Two tubes connect the manometer to the sample holder: one at the inlet side of the geotextile sample and one at the exhaust side. These tubes are connected as close as possible to the geotextile sample, for greater accuracy. While some BPT apparatuses simply assume the exhaust pressure to be atmospheric, having both the inlet and exhaust sides of the geotextile sample connected to the manometer gives a more accurate pressure difference (Fischer 1994).

The top of the fluid in the manometer should be higher than the geotextile sample, which helps prevent wetting fluid from entering the manometer. The manometer must be large enough to measure the maximum pressure difference created during a test. A maximum manometer value of 1000 mm of water is recommended.

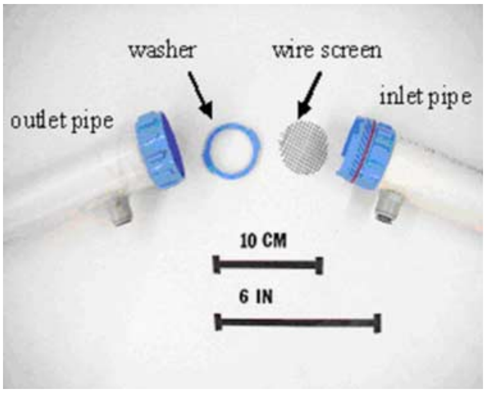


FIG. 3—*BPT apparatus sample holder.*

## *Sample Holder*

The sample holder system (Fig. 3) is connected just above the pipe into which the rotometers exhaust. The system has three parts: a 30-cm (12-in.) long inlet pipe, the sample holder itself, and a 30-cm (12-in.) long exhaust pipe.

These particular lengths of inlet and exhaust pipes help to keep the pressure and airflow uniform across the surface of the sample, so that every pore in the sample is exposed to the same airflow.

The sample holder is 4.00 cm (1.57 in.) in diameter and exposes 12.57 $cm^2$ (1.95 $in.^2$) of the geotextile to the airflow. There are four parts: the inlet pipe, a wire screen, a washer, and an exhaust pipe. The inlet pipe supports the sample and is attached to the top of the 30-cm (12-in.) long inlet tube. A wire screen (wire diameter of 0.045 cm and hole size of 0.084 $cm^2$) and a keyed washer are placed on top of the sample. The wire screen prevents the sample from being deformed upwards due to the airflow. The keyed washer prevents the sample from being twisted when the top and bottom portions of the sample holder are screwed together. The sample is not supported underneath because the air pushes the sample upward, so no support is needed. The exhaust pipe screws securely into the sample supporter of the inlet pipe, and connects to the bottom of the 30-cm (12-in.) long outlet tube. Three O-rings in the top and bottom of the holder seal the connection, so that air must flow through the sample. The interior of the sample holder is the same diameter as that of the inlet and exhaust pipes (4.00 cm, 1.57 in.) because, as Fischer (1994) showed, differences in the diameters of the sample holder and the inlet pipe can produce incorrect results. ASTM D 6767 does not mention this important point, and shows diagrams (ASTM D 6767 Figs. 1–3) in which the diameters of the sample holder and inlet pipe are different sizes. If the inlet pipe is smaller than the sample diameter, the sample holder should be preceded by at least 30 cm (12 in.) of pipe the same diameter as the sample, to promote uniform airflow through the sample. The exhaust pipe diameter should match the sample diameter for the same reason. Two sample holders are recommended—one for the dry run (the geotextile sample is dry) and one for the wet run (the geotextile sample is initially saturated).

## Bubblepoint Test Procedure

### Sample Preparation

*Cutting the Geotextile Sample*—The sample is cut from a larger geotextile sheet with a 4.60-cm (1.81-in.) diameter die. The die gives a more exact shape and produces less sample distortion than cutting with a knife or scissors. The sample should be representative of the larger geotextile. Judgment must be used when selecting nonwoven samples since the density of the geotextile can vary. The test sample should have a diameter slightly smaller than the sample holder and large enough to cover the O-rings. It must be small enough to lie flat in the holder (maximum of 4.86 cm (1.91 in.)) without being so small as to allow circumferential air leaks (minimum of 4.00 cm (1.57 in.)). ASTM D 6767 recommends that the geotextile sample be soaked in water for 1 h prior to testing and allowed to dry. However, this can lead to inaccurate results depending on the wetting fluid used in the test. Due to the small pore sizes of geotextiles, not all water will evaporate readily at room temperature. If a fluid other than water is used as the wetting fluid, a hybrid wetting fluid is created (intended wetting fluid and residual water). Since this produces a composite surface tension not accounted for in the data reduction, inaccurate results will be computed.

*Sample Holder Assembly*—After the sample is prepared (including wetting for the case of the wet run, described later), it is quickly placed in the sample holder. The wire screen and washer are placed on the sample, the exhaust pipe of the sample holder is screwed securely into the inlet pipe, and the entire sample holder is attached to the inlet and exhaust pipes of the apparatus. The flexible tubes from the manometer are connected to either side of the sample.

### Sample Testing

*General Procedure for Wet Run and Dry Run*—The dry run is done first because it is difficult to dry a sample after a wet run. Two sample holders (wet, dry) are recommended, to reduce fluid contamination of the dry sample.

The test begins with all valves closed. Low air pressure is introduced (138 kPa (20 psi)) to the apparatus and the cutoff valve for the smallest rotometer is opened fully. Then the smallest metering valve is opened slowly, allowing air to pass through the first rotometer and the sample. When the airflow stabilizes, the rotometer value (airflow), the backpressure value, and the manometer value (pressure difference across the sample) are recorded. At the beginning of the test, data points should be recorded approximately every 8 to 12 mm of water change in the manometer. Pressure increments of up to 100 mm or more are used for the highest airflows.

As each rotometer's capacity is reached, the next larger one is opened and the previous rotometer is closed, in that order. The new rotometer is always opened before the previous one is closed so that airflow is not completely cut off during the transfer. This avoids compressing air in the lines, which would cause an airflow burst leading to inaccurate results.

When the maximum airflow is reached (or when the maximum manometer reading is reached—whichever comes first) all of the valves should be closed in the reverse order from the way they were opened, and the geotextile is removed from the holder and saturated.

*Saturating the Geotextile*—Prior to the wet run, the geotextile must be saturated in a wetting fluid. It is important to have as few air bubbles as possible in the sample during the wet run because the BPT theory assumes complete saturation (ASTM F 316 2003). The sample is saturated by slowly sliding it into the wetting fluid at approximately a 45° angle while allowing the fluid to soak into the sample by capillarity. This was found to be more effective than simply soaking or even soaking followed by vacuuming. The sample is submerged in the fluid for about 5 min.

*Wet Run*—Once the geotextile sample has been saturated with the wetting fluid, the wet run procedure is identical to the dry run procedure, with one exception. During the wet run, the readings of the manometer will fall dramatically as fluid is expelled from the sample. As fluid is expelled, the pressure difference across the sample decreases, and the manometer reading decreases. *Data should not be recorded as the manometer level decreases.* This is because the airflow rate through the sample and the corresponding pressure buildup across the sample are needed to correctly calculate the pore sizes. When the pressure drops due to the opening of a pore from the release wetting fluid, the indicated pressure is no longer the true pressure that corresponds to the airflow. The airflow should be increased so that the pressure difference is raised back to the highest previous level before data are recorded.

## Data Analysis

### Pore Diameter

Pore size is determined from the Washburn (1921) equation, described in ASTM D 6767, ASTM F 316 and by Bechhold (1908). The Washburn equation describes the equilibrium of a fluid under a pressure gradient in a porous medium with circular openings; in this case, the geotextile pore openings of diameter, $d$. Pore size is related to the fluid and material properties and the pressure difference across the sample, thus:

$$d = \frac{4TB\cos\theta}{P} \tag{1}$$

where

$d$ = diameter at pressure, P (mm)
$T$ = surface tension of the wetting fluid (N/m)
$B$ = capillary constant (0.715) (see ASTM D 6767)
$\theta$ = equilibrium contact angle
$P$ = pressure difference across the sample (Pa)

When the contact angle is zero, and with constants and unit conversions, the equation becomes:

$$d = \frac{2860 * T}{P} \tag{2}$$

TABLE 1—*Description of geotextiles in Fig. 4.*

| Geotextile | Fibers | Manufacturing Process | Mass/Area ($g/m^2$) (mfg data) | Denier |
|---|---|---|---|---|
| 1 | Polypropylene Staple | Needlepunched Nonwoven | 103 | NA |
| 2 | Continuous Polypropylene | Needlepunched Nonwoven | 135 | 8–10 |
| 3 | Polypropylene Staple | Needlepunched Nonwoven | 405 | 4–7 |

### *Flow*

For the larger rotometers, the indicated flow in L/min is read directly. For the smaller ones, a conversion chart provided by the manufacturer gives the indicated flow based on the rotometer number and the value read. The true flow is calculated with the formula:

$$Q_2 = Q_1 \sqrt{\frac{P_B + 14.7}{14.7}} \tag{3}$$

where

$Q_2$=true flow in L/min
$Q_1$=indicated flow in L/min
$P_B$=reading from backpressure gage in psig

The flow rate versus pore size is plotted on a semi-log scale for both the dry and wet runs. From this graph, wet and dry flow rates are read at given pore sizes.

The percent finer of a given pore size is calculated from:

$$\%f = \left(1 - \frac{Q_{2,W}}{Q_{2,D}}\right)100 \tag{4}$$

where

$\%f$=percent finer
$Q_{2,W}$=true airflow from the wet run (L/min)
$Q_{2,D}$=true airflow from the dry run (L/min)

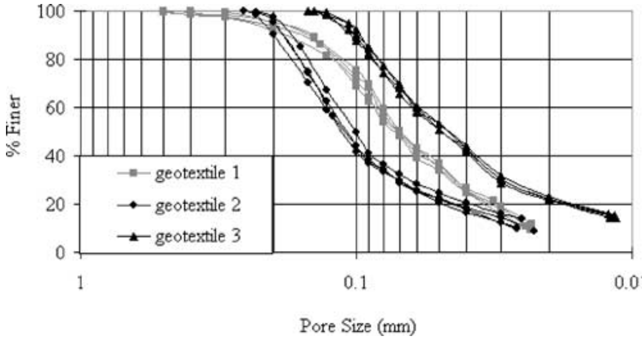


FIG. 4—*BPT pore size distributions, showing repeatability.*

Finally, the results are presented as a semi-log graph of the percent finer versus the pore size. The entire process of sample preparation, dry and wet run tests, and data reduction can be accomplished in approximately 1 h.

## Consistency of the BPT

To examine the consistency of tests performed with the BPT apparatus, three samples each of three different geotextiles were tested. The samples are described in Table 1. The results of the BPT on each of these geotextiles are shown in Fig. 4.

Figure 4 shows that the BPT apparatus provides consistent results for multiple runs on different geotextiles. As other examples will show, the BPT apparatus is consistent in describing porous material.

## Accuracy of the BPT

To assess the accuracy of the BPT apparatus, tests were performed on round and square hole screens of known sizes. The results for tests performed on US Sieve No. 100 and 200 square screens (0.150-mm and 0.075-mm openings, respectively) are shown in Fig. 5. The results from a round hole screen (0.140-mm diameter) are shown in Fig. 6.

Figures 5 and 6 show that the pore size distributions down to the

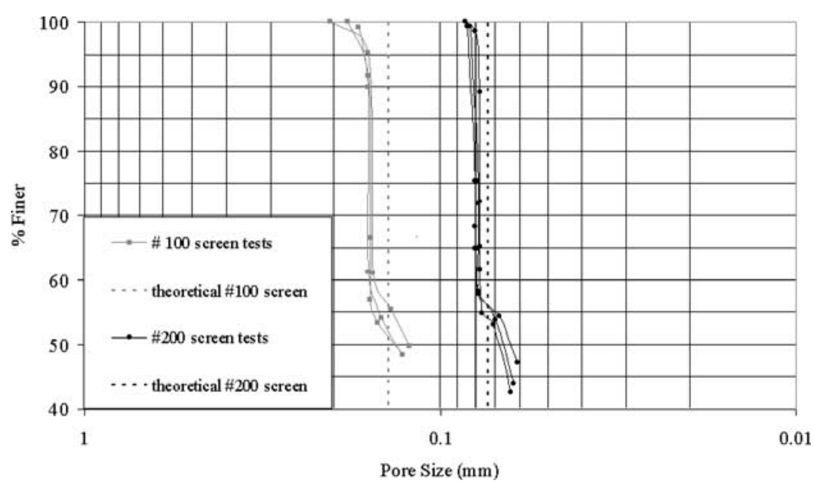


FIG. 5—*Pore size distribution from BPT on square hole wire screens.*

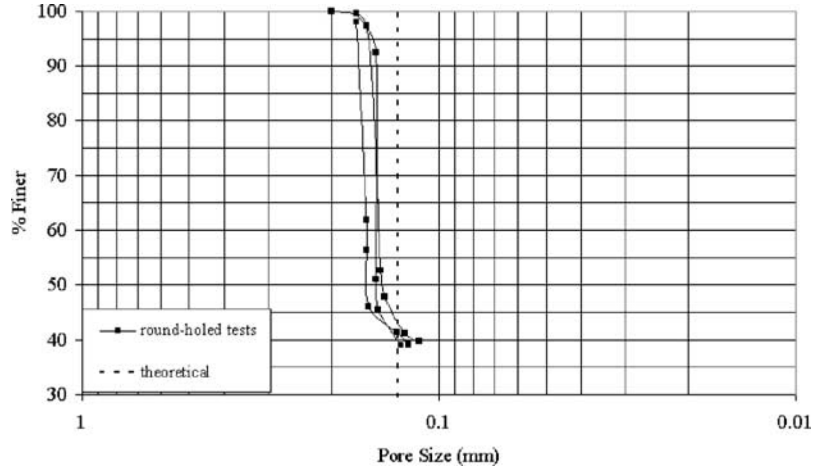


FIG. 6—*Pore size distribution from BPT on a round hole screen.*

40–55 % passing level agree well with the actual pore diameter of the screens. Fischer (1994) notes a similar trend.

The largest discrepancy between the BPT measured and actual screen hole sizes is about 0.02 mm, for the No. 100 screen. The BPT measured hole size for the No. 200 screen is about 0.005 mm different than the actual screen size.

The No. 100 screen and the round hole screen have approximately the same size holes, and they have very similar BPT pore size distributions. This suggests that the Washburn equation assumption of round holes is a valid assumption for pore sizes near the 0.1 mm hole size, that is within the range of geotextile pore sizes measured in this study. The BPT measurements are more accurate with smaller holes.

The accuracy of the No. 100 screen tests and the increased accuracy of the No. 200 screen tests suggest that the application of the Washburn equation for geotextiles (which do not have round or square holes) may be appropriate, with increased accuracy for smaller pores. In addition, consistency is observed for all cases.

## Results Comparing the AOS and the BPT

### *Accuracy of AOS* $O_{95}$ *vs. BPT* $O_{95}$

Elton et al., 2001 performed a comparison between AOS data and BPT data. The geotextile properties are shown in Table 2 and the AOS and BPT tests results are shown in Figs. 7 and 8.

The BPT results are much more consistent in describing the pore sizes than the AOS results. The BPT test results consistently give smaller pore sizes compared to the AOS results. In both Figs. 7 and 8, the BPT $O_{95}$ values (value of which 95 % of the pores are smaller than) are about 0.2 mm smaller than the AOS test. Fischer (1994) note that $O_{95}$ values from the BPT test were similar to a range of manufacturer-provided AOS data, even though the test methods are not measuring pore sizes in the same way. Referring to Figs. 5 and 6, the BPT $O_{95}$ values are shown to be approximately 0.02 to 0.005 mm larger than the actual pore sizes. This information, coupled with the problems associated with the AOS test, indicates that the $O_{95}$ value given by the BPT is likely to be more accurate than the $O_{95}$ value given by the AOS test.

TABLE 2—*Properties for geotextiles in AOS tests.*

| Geotextile | Fibers | Manufacturing Process | Mass/Area (g/m$^2$) (mfg data) | Denier |
|---|---|---|---|---|
| 4 | Polypropylene Staple | Needlepunched Nonwoven | 203 | 4–7 |
| 5 | Polypropylene Staple | Needlepunched Nonwoven | 339 | 5 |

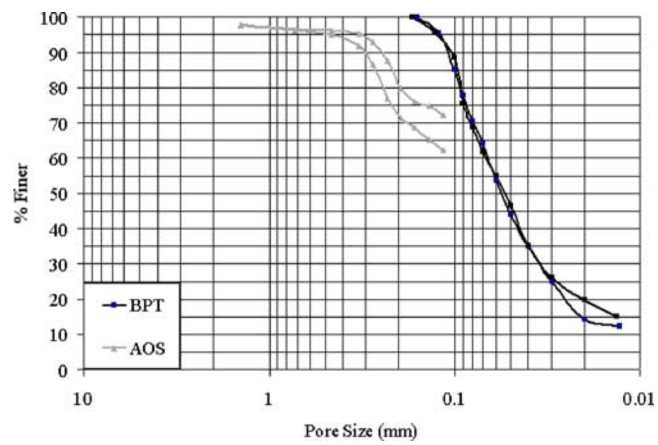


FIG. 7—*Pore size distribution: AOS versus BPT for geotextile 4.*

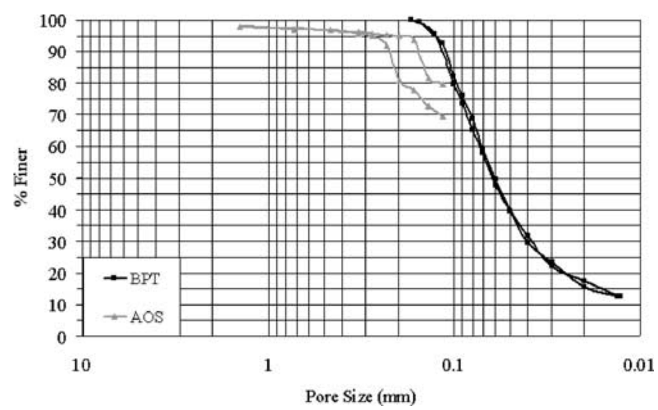


FIG. 8—*Pore size distribution: AOS versus BPT for geotextile 5.*

### *Accurately Describing the Filtering Behavior of a Geotextile*

In Fig. 4, the $O_{95}$ value of geotextiles 1 and 2 are nearly identical; however, the rest of the distribution is different, indicating that these two geotextiles will behave differently as filters. An AOS test performed on these two geotextiles would not reveal this difference, and would describe the two as being similar when they are actually quite different.

## Conclusions

1. The development and operation of a simple and inexpensive bubblepoint test (BPT) apparatus has been described. The BPT apparatus evaluates the pore sizes of geotextiles according to ASTM D 6767.
2. The BPT apparatus gives consistent results. Repeated tests on several geotextiles gave very similar results.
3. The BPT apparatus accurately predicts the hole sizes in screens with holes near 0.1 mm that is within the range of sizes found in many nonwoven geotextiles. The BPT measured hole diameters were about only 0.02 mm larger than the actual hole diameters for a No. 100 screen and 0.005 mm larger for a No. 200 screen.
4. The BPT measured similar diameters for similar sized screens, even though the screens differed in hole shape (one with round holes, one with square holes). This suggests the Washburn equation assumption of round holes is a valid assumption for pore sizes of different shapes near the 0.1 mm hole size.
5. BPT testing of geotextiles shows less variability than comparable AOS testing.
6. The BPT test results consistently give smaller pore sizes compared to the AOS results.
7. Superior speed, precision, and accuracy make the BPT a candidate to replace the AOS method of obtaining $O_{95}$ values.
8. The ability of the BPT to cost-effectively describe pore sizes other than the $O_{95}$ creates the potential for new, more accurate filter design criteria based on the pore size distribution of the geotextile and the grain size distribution of the soil, perhaps similar to that suggested by Fischer et al. (1990).

## Recommendations

The following changes are recommended for ASTM D 6767:

(a) The diameters of the sample holder and the inlet pipe should be equal for even airflow/pressure distribution across the sample.
(b) The diameters of the sample holder and the outlet pipe should be equal for even airflow/pressure distribution across the sample.
(c) The geotextile sample should not be soaked in water before testing, unless water is to be used as the wetting fluid. The only fluid that samples should be exposed to is the wetting fluid.

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