Interrelationship between Pore Openings of Geotextiles and Methods of Evaluation

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ABSTRACT: Designing a geotextile as a filter requires information on the largest pore openings, O_{95}, the porosity and the pore-size distribution of the geotextile. In this paper, the O_{95} and pore-size distribution for twenty-two nonwoven geotextiles using six different techniques (dry, wet, and hydrodynamic sieving, bubble point, mercury intrusion and image analysis) are presented. Considerable differences in O_{95} values have been found as determined from different methods, indicating that these results are a function of the technique rather than a unique property of the geotextile.

1 INTRODUCTION

Proper design is essential to the successful use of a geotextile as a filter. A properly designed geotextile filter will ensure good retention for erodible materials and will have adequate discharge capacity for the life of the structure. There are three basic filter criteria that are used for the proper selection of a geotextile filter: a retention requirement, a permeability requirement, and a resistance requirement. The ability of a geotextile to meet these criteria is primarily a function of the largest pore openings, porosity and the pore-size distribution of the geotextile.

Despite the importance of the largest pore openings and the pore-size distribution for geotextile selection, the pore openings are difficult to measure. The pore openings which are obtained experimentally are dependent on the technique used for their measurement. Numerous techniques have been developed: indirect methods such as dry sieving (Calhoun, 1972; Gerry and Raymond, 1983), hydrodynamic sieving (Fayoux, 1977), wet sieving (Saathoff and Kohlhase, 1986), bubble point method (Miller et al., 1986; ASTM F-316), and mercury intrusion porosimetry (Prapaharan et al., 1989; ASTM D-4404), direct methods such as image analysis (Rollin et al., 1977; Faure et al., 1990; Bhatia et al., 1993, 1994), and mathematical models (Lombard and Rollin, 1987). Varying results of pore-size distribution are often obtained within and between the existing test methods (Rollin, 1986; Smith, 1993). Existing geotextile retention criteria are typically based on the larger pore openings of the geotextile, such as O_{95} and O_{90} (the pore size at which 95% and 90% of the pores are finer, respectively), however, there are also criteria which are based on the finer pore openings of the geotextile, such as O_{50} (the pore size at which 50% of the pores are finer).

In this paper, relationships will be presented that can be used to relate and compare the results of O_{95} from different methods. The importance of these relationships for the design of geotextiles for filtration will be discussed.

2 METHODS AND MATERIALS

Six methods for evaluating the pore-size distribution of a geotextile were compared: dry sieving, hydrodynamic sieving, wet sieving, bubble point method, mercury intrusion porosimetry, and image analysis. The study was performed using a total of twenty-two different nonwoven geotextiles.

The dry sieving method was performed in accordance with the United States Standard Test Method for Determining the Apparent Opening Size (AOS) of a Geotextile (ASTM D-4751). In the test, glass beads are sieved through a geotextile to determine the fraction of particle sizes for which 5% or less, by weight, passes through the geotextile. The tests were expanded to include a wide range of glass bead sizes in order to evaluate the pore-size distribution of the geotextiles.

The hydrodynamic sieving method was performed in accordance with the Canadian draft Filtration Opening Size

(FOS) of Geotextiles (CAN/CGSB-148.11). The method is based on hydrodynamic filtration, where a glass bead mixture is sieved through a geotextile by alternating water flow that occurs as the result of the immersion and emersion of the geotextile in water. Hydrodynamic sieving is used to evaluate the FOS or O_{95} of a geotextile.

The wet sieving method was performed in accordance with the procedure described by Saathoff and Kohlhase (1986). In the test, a glass bead mixture is sieved through a geotextile while a continuous water spray is applied. By evaluating the mixture of particles passing through the geotextile during the test, the O_{95} of the geotextile can be evaluated.

The bubble point tests were 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). The bubble point method is based on: (1) a dry porous material will pass air through all of its pores when any amount of air pressure is applied to one side of the material; and (2) a saturated porous material will only allow a fluid to pass when the pressure applied exceeds the capillary attraction of the fluid in the largest pore. Because smaller and smaller pores pass air as the air pressure is increased, the largest opening, O_{95}, and pore-size distribution of the geotextile can be evaluated.

The mercury intrusion porosimetry method was performed in accordance with the draft Standard Test Method for Determination of Pore Volume (ASTM) and Pore Volume Distribution of Geotextiles by Mercury Intrusion Porosimetry. Mercury intrusion porosimetry is based on the theory of the Washburn equation, which relates the pressure required to force a non-wetting fluid (mercury) into the pores of a geotextile with the radius of the pores intruded. As a result, the pore-size distribution of the geotextile can be evaluated.

Image analysis is a technique used for the direct measurement of pore spaces within a cross-sectional plane of a geotextile. Direct measurements were made in a two-dimensional plane and were projected in the third dimension. Fig. 1 shows the fibers in a cross-section of geotextile and how the pore spaces are measured.

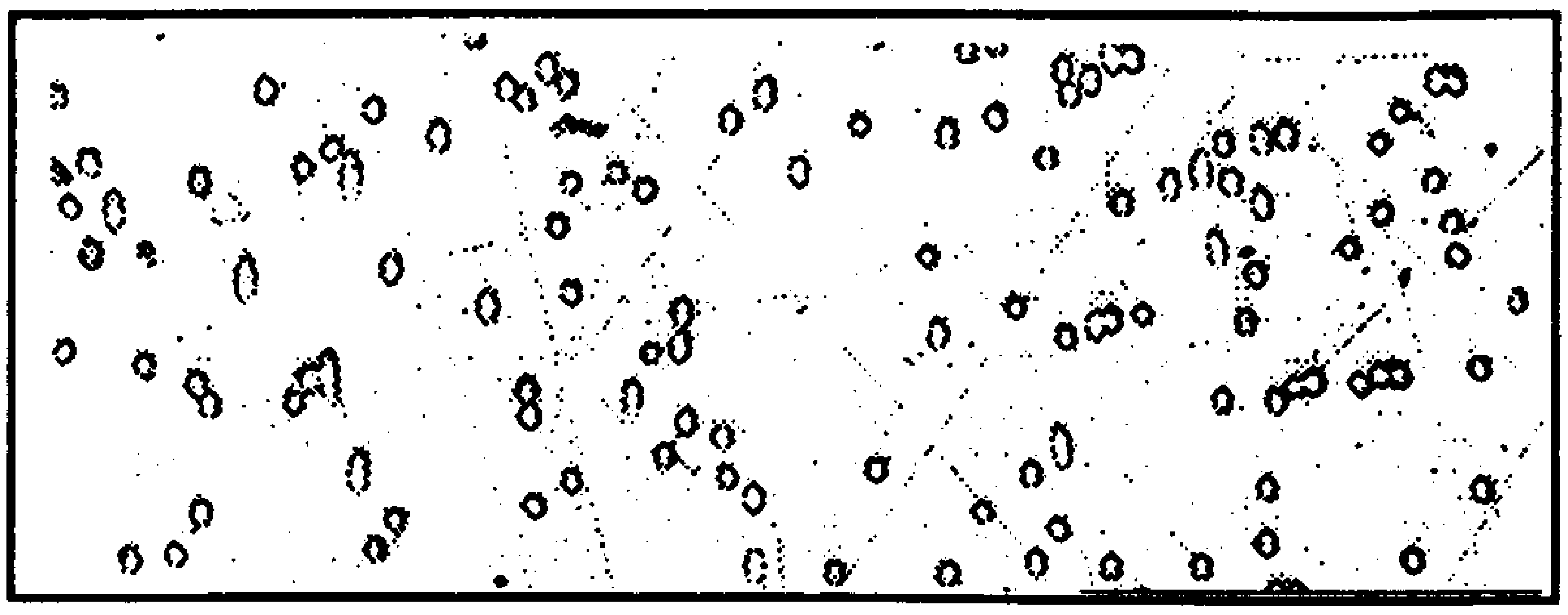

Figure 1. Image analysis cross-section.

In Table 1, a comparison is made showing the differences between test methods.

Table 1. Comparison of pore-size distribution methods.

Test Method	Test Mechanism	Test Material	Sample Size (cm^2)	Time for 1 Test
Dry Sieving	Sieving-Dry	Glass beads Fraction	434	2 hr.
Hydrodynamic Sieving	Alternating Water Flow	Glass beads Mixture	257	24 hr.
Wet Sieving	Sieving-Wet	Glass beads Mixture	434	2 hr.
Bubble Point	Comparison of Air Flow Dry vs. Saturated	Porewick	22.9	20 min.
Mercury Intrusion	Intrusion of a Liquid into at Pore	Mercury	1.77	35 min.
Image Analysis	Direct Measurement of Pore Spaces in Cross-section of the Geotextile	None	1.5	2-3 days

Twenty-two nonwoven geotextiles from four different manufacturers were selected for this study. Geotextiles were selected based on fiber type and manufacturing process. Three different types of nonwoven geotextiles were included:

(1) polypropylene, continuous filament, needle-punched geotextiles (manufacturer C),
(2) polypropylene/polyester, staple fiber, needle-punched geotextiles (manufacturers B and D), and
(3) polypropylene, continuous filament, heat-bonded geotextiles (manufacturer E).

The five geotextiles selected from manufacturer B ranged from 115.59 to 669.31g/m^2 in mass per unit area and 0.90 to 4.54mm in thickness. The six geotextiles selected from manufacturer C ranged from 131.11 to 562.36g/m^2 in mass per unit area and 1.32 to 4.44mm in thickness. The five geotextiles selected from manufacturer D ranged from 184.46 to 524.7g/m^2 in mass per unit area and 1.17 to 3.72mm in thickness. The six geotextiles selected from manufacturer E ranged from 57.74 to 271.04g/m^2 in mass per unit area and 0.32 to 0.63mm in thickness.

Linear relationships were found between geotextile mass per unit area and thickness. However, the relationships were not the same for geotextiles manufactured from different processes and fiber types (Smith, 1993).

3 RESULTS

The six techniques were used to evaluate the pore-size distribution of over 339 geotextile specimens (94 dry sieving, 99 hydrodynamic sieving, 44 wet sieving, 50 bubble point, 40 mercury intrusion porosimetry, and 60 image analysis). No test method was found to be suitable for all types of geotextiles. Each method had limitations.

Dry sieving tests were hindered by glass beads becoming trapped within the geotextiles and by electrostatic effects which affected glass beads below 0.09mm. The heat-bonded geotextiles (E1-E6) performed the best with this method. These geotextiles are very thin and leave little chance for glass beads to become trapped within the pore structure. Other geotextiles (staple fiber B1-B5, D1-D5 and the continuous filament, mechanically-bonded C1-C6) had fairly high variability in results. The variability was most likely due to the trapping of glass beads within the geotextile and to electrostatic effects.

Hydrodynamic sieving tests were limited by time required for each test and the mixture of particles used. The heat-bonded geotextiles (E1-E6) showed the least variation in results and the mechanically-bonded, continuous filament geotextiles (C1-C6) showed the greatest with this method. During this test fine glass beads were often blocked from passing through the geotextile.

Wet sieving tests were hindered by glass beads clumping together during the test, preventing particles from passing through the geotextile. The nonwoven, continuous filament, mechanically-bonded geotextiles (C1-C6) showed the least variation in results and the nonwoven, continuous filament, heat-bonded geotextiles (E3-E6) showed the greatest with the wet sieving method. In many tests glass bead clumping and slight sagging of geotextiles during the tests were problems.

Bubble point tests are dependent on the interpretation of results. The staple fiber, mechanically-bonded geotextiles (B1-B6, D1-D5) showed the least variation in results and the heat-bonded geotextiles (E1-E4) showed the greatest. The method showed little difference in results for geotextiles of various thicknesses of the same manufacturing process.

Mercury intrusion porosimetry results are effected by mercury displacing fibers in the pore structure of the geotextile during the tests. All test results for different geotextiles of different thicknesses fell within a narrow range. The test results for a particular manufacturer did not vary for geotextiles of different thicknesses.

Image analysis tests were time consuming. In addition, there is no standard method for evaluating image analysis results. Results for the geotextiles tested were fairly repeatable.

Each one of the six methods used in this study may be used to evaluate the distribution of pores in a geotextile. Whether or not these techniques evaluate this property in a useful and correct manner is, however, questionable. In general, the sieving methods are designed to measure O_{95} or O_{90} of geotextiles; however, bubble point, mercury intrusion, and image analysis can provide not only O_{95} but a complete pore-size distribution. In Fig. 2, the complete pore-size distribution evaluated by each method is given for nonwoven, continuous filament, mechanically-bonded geotextile C3. The results varied considerably between methods for a given geotextile.

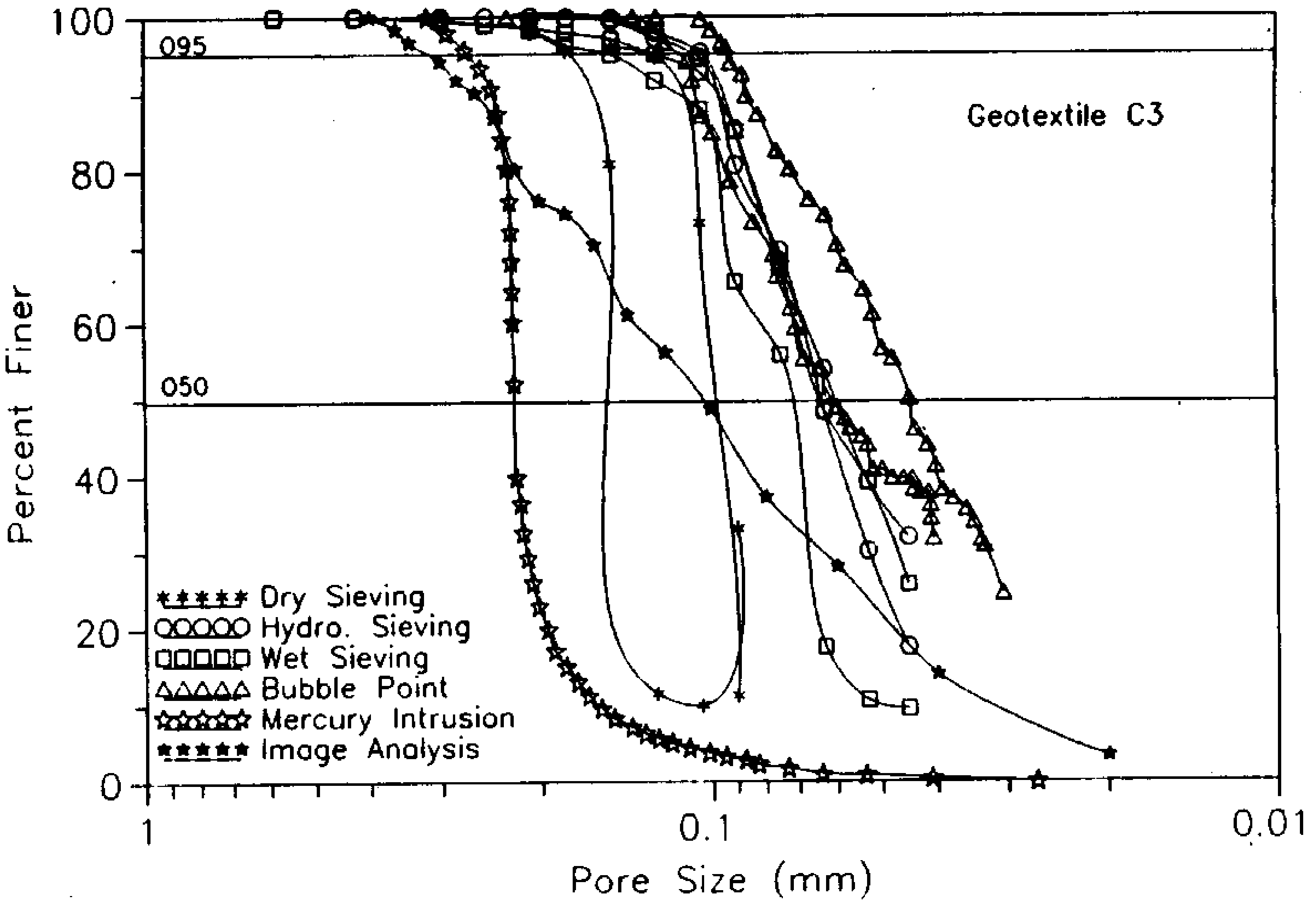

Figure 2. Comparison of results obtained by different methods for geotextile C3.

In general, the image analysis, mercury intrusion, and dry sieving methods showed larger pore openings than the other methods. The hydrodynamic sieving, wet sieving, and bubble point methods showed smaller geotextile pore openings within a relatively narrow range, with the bubble point results generally on the lower end of this range. The hydrodynamic and wet sieving methods produced very similar results for all geotextiles.

In this paper, the relationships between only O_{95} results were compared for the six test methods. O_{50} results were not considered because of the wide variation in results and the applicability of measuring O_{50}. The dry sieving O_{95} results were selected as the base for the comparison because it is the standard test method in the United States.

Nearly identical relationships were obtained for hydrodynamic sieving versus dry sieving and wet sieving versus dry sieving O_{95} results, see Figs. 3 and 4, respectively. There were difficulties performing wet sieving tests with geotextiles E1 and E3 (very thin geotextiles), therefore the results are not included.

The differences in results are most likely due to using glass bead fractions in the dry sieving tests and glass bead mixtures in the hydrodynamic and wet sieving tests. When fractions are used, each particle has an equal

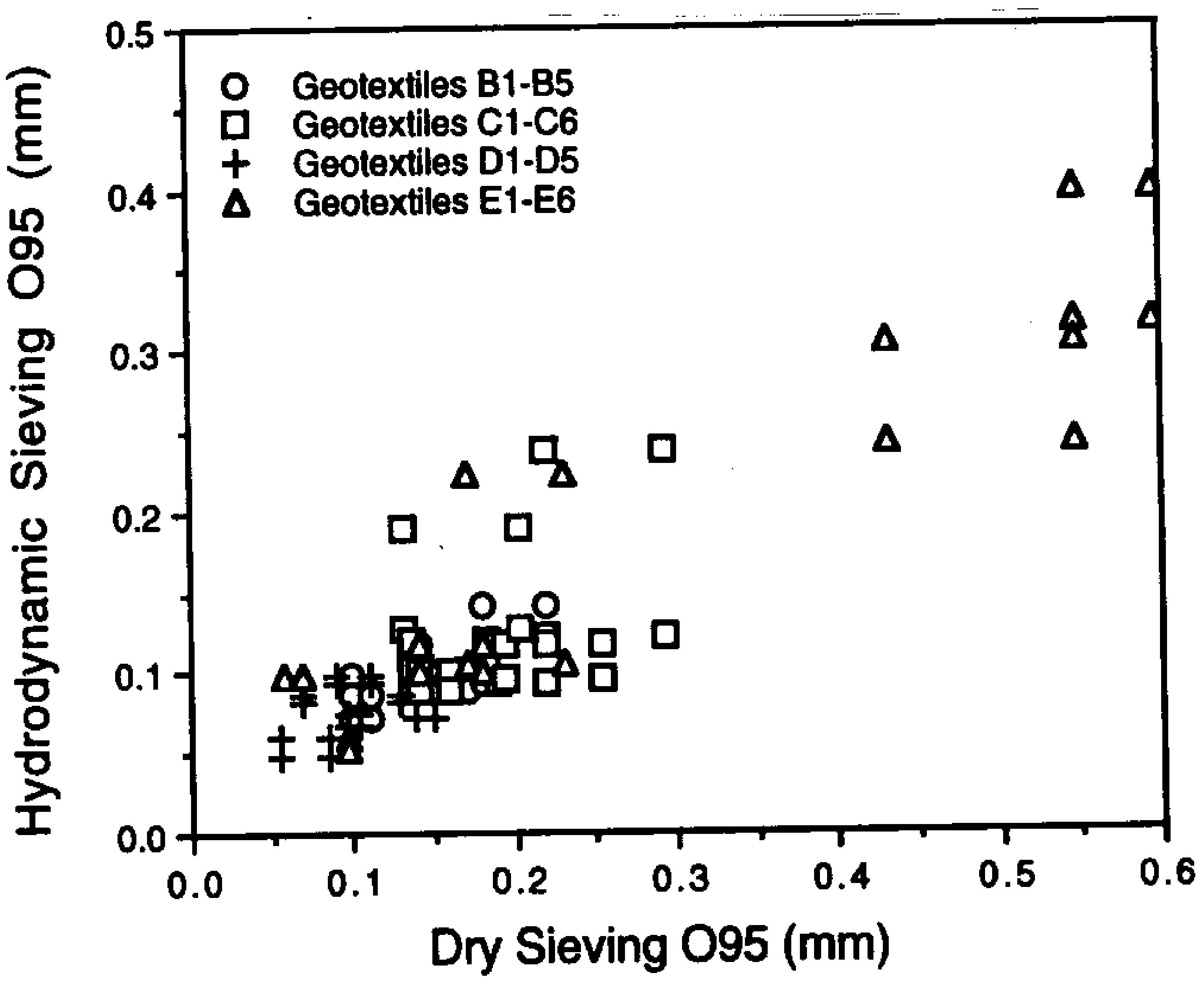

Figure 3. Comparison of O_{95} results between dry sieving and hydrodynamic sieving.

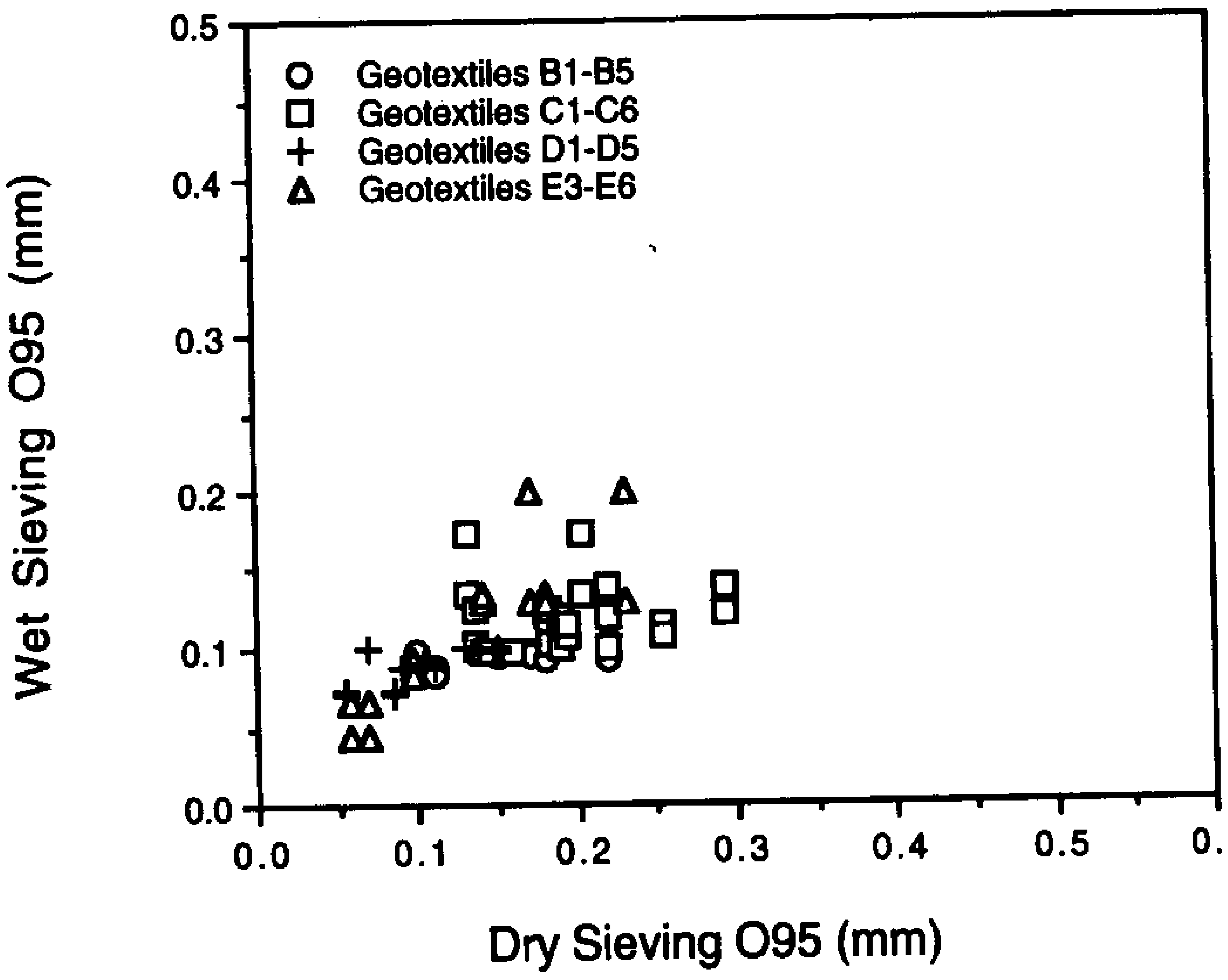

Figure 4. Comparison of O_{95} results between dry sieving and wet sieving.

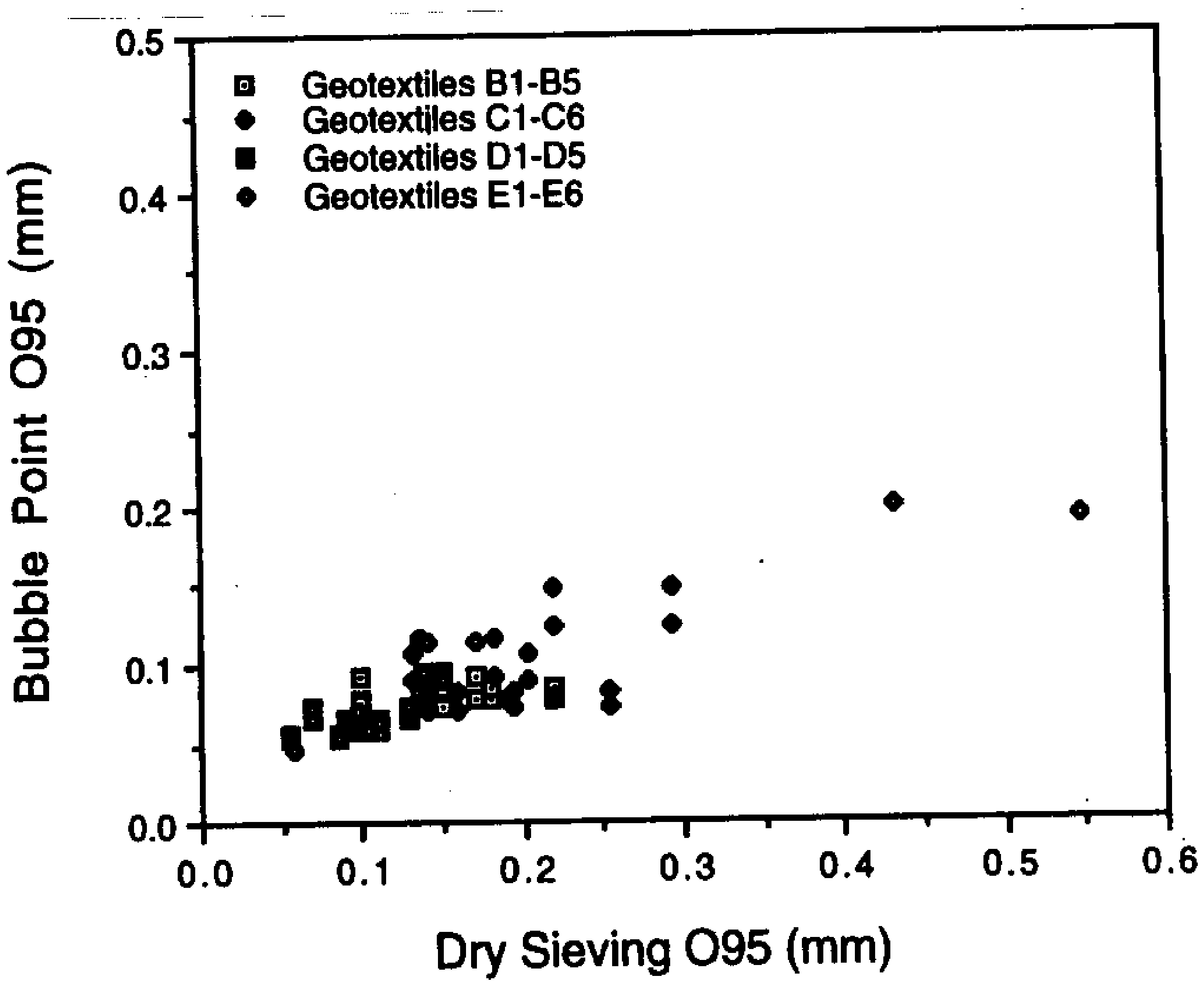

Figure 5. Comparison of O_{95} results between dry sieving and the bubble point method.

opportunity to pass through the geotextile, unlike when mixtures are used. There is also a mathematical difference in the determination of O_{95} using a % of the fraction versus a % of the aggregate mixture. For geotextiles with O_{95} values less than 0.1mm, a linear relationship was observed between dry, wet and hydrodynamic sieving results. For geotextiles with AOS larger than 0.1mm, O_{95} from hydrodynamic and wet sieving were 60-75% of O_{95} from dry sieving results.

The relationships between dry sieving and bubble point O_{95} results are shown in Fig. 5. In comparison with dry sieving results, there was little variation in bubble point results, with the exception of the heat-bonded geotextiles. The bubble point method gives repeatable results, however, there is little difference in results for geotextiles of various thicknesses. This is found in needle-punched geotextiles, where air flow finds the largest pore channels of the geotextile, which are very similar because of similar manufacturing processes. However, this method showed differences in results for heat-bonded geotextiles due to the melting of fibers in the heat-bonding process, therefore the cross-section of geotextiles of various thicknesses are different. Bubble point O_{95} results were generally 60% lower than dry sieving results. The bubble point method results were always the smallest of all the methods.

The relationships between dry sieving and mercury intrusion porosimetry O_{95} results are shown in Fig. 6. The mercury intrusion results showed little difference in O_{95} results in comparison to the dry sieving method. These results may be due deformation of fibers in the mercury intrusion test during intrusion.

The relationships between dry sieving and image analysis O_{95} results are shown in Fig. 7. The image analysis results showed larger pore openings in the geotextiles than did the

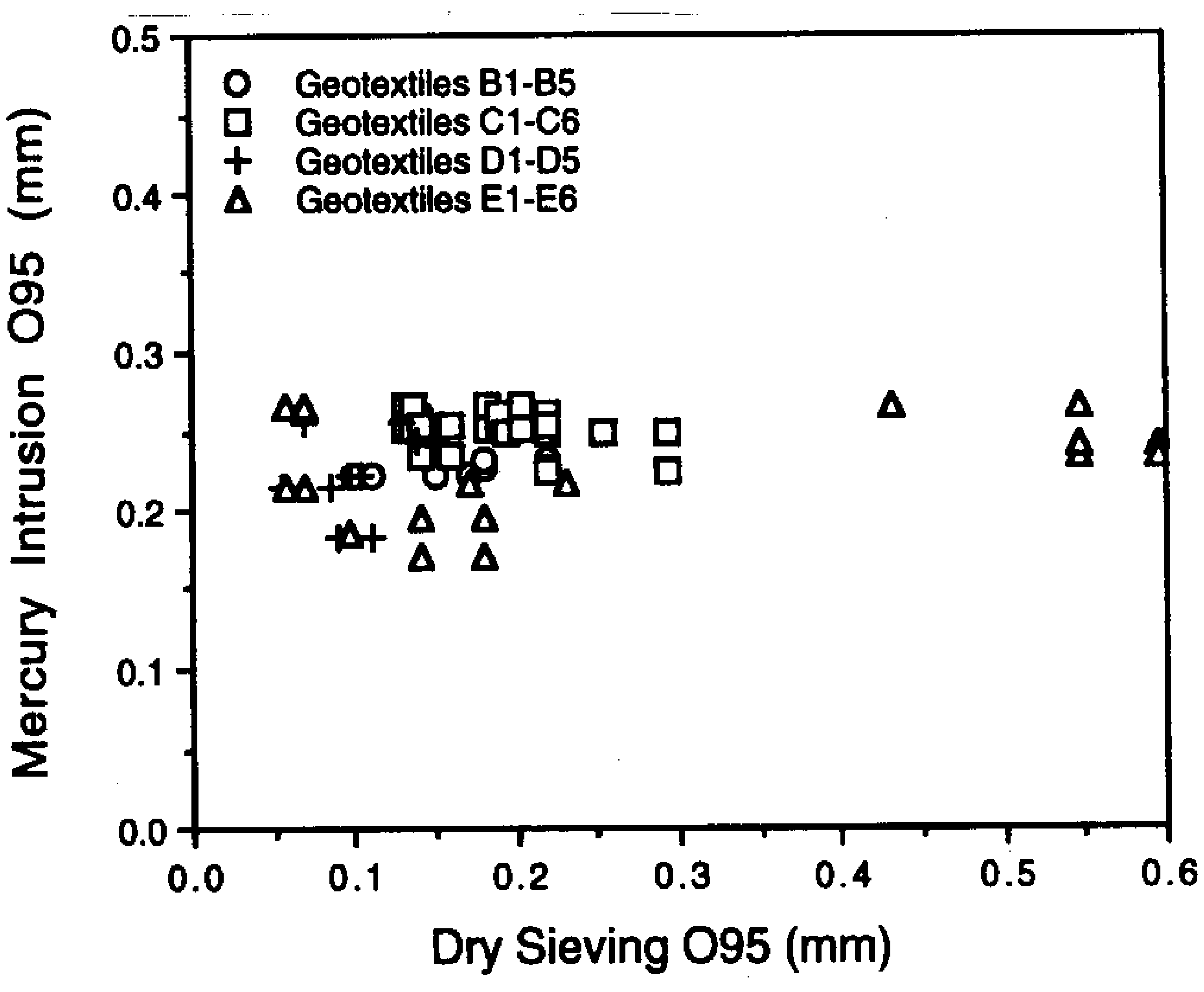

Figure 6. Comparison of O_{95} results between dry sieving and mercury intrusion porosimetry.

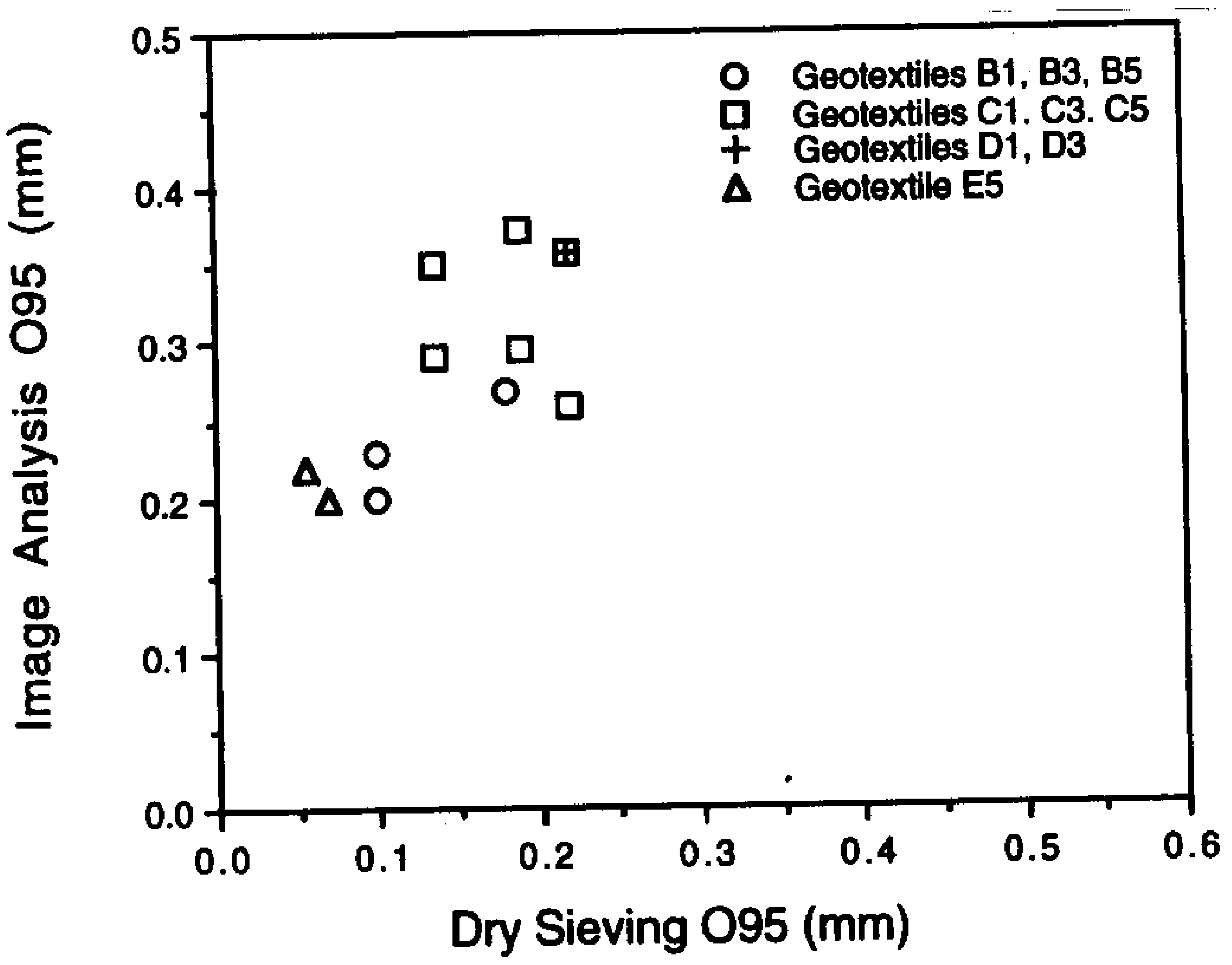

Figure 7. Comparison of O_{95} results between dry sieving and image analysis.

dry sieving method. The image analysis technique is used to directly measure the pore spaces in a two-dimensional cross-section (Bhatia et al., 1993, 1994). There is no particle interaction affecting results like in the dry sieving method. However, the results from this method are influenced by interpretation of pore spaces in a plane, and the measurements were made on only the cross-sectional plane. For all geotextiles, the results from image analysis covered the entire range of results for all other methods (see Fig. 2).

4 DISCUSSION

The dry, wet, and hydrodynamic sieving methods are established for measuring the largest openings of a geotextile. The dry sieving test can be modified to get a complete pore-size distribution, however, there are more electrostatic effects with finer glass beads, therefore, the accuracy of results decreases.

In general, the dry sieving method resulted in larger O_{95} as compared to hydrodynamic and wet sieving, whereas hydrodynamic and wet sieving methods gave similar results. The difference between dry, wet, and hydrodynamic sieving increases with increasing O_{95} values. The relationships between these methods were different for continuous filament heat-bonded geotextiles than that for staple and continuous filament needle-punched geotextiles.

The bubble point, mercury intrusion, and image analysis methods can ideally provide an entire pore-size distribution of the geotextile. However, each of these methods will give the same result for a geotextile of different thickness but similar cross-section. A thickness factor could be introduced for a given geotextile to take into account tortuosity. For all fabrics tested, the mercury intrusion gave the largest pore-size distribution and bubble point the smallest, whereas the results from image analysis were always in the middle of these two (see Fig. 3). The O_{95} values from bubble point were, in general, smaller (50-80%) than that of dry sieving results. The results from mercury intrusion were similar for all different geotextiles, thus resulting in a horizontal band between O_{95} (dry sieving) and O_{95} (bubble point). The O_{95} values from image analysis were always larger (40-60%) than that of dry sieving results.

5 CONCLUSIONS

Despite the importance of the largest pore openings and the pore-size distribution of geotextiles for filter design, no standard method exists which can be used to measure O_{95} and pore-size distribution. The pore openings which are obtained experimentally are dependent on the technique used for their determination.

Based on the results for twenty-two different nonwoven geotextiles by six different methods, the following general conclusions were drawn.

1. The AOS (O_{95}), the largest opening size measured using the dry sieving method, was generally larger than O_{95} measured from the wet and hydrodynamic sieving methods. However, the results from wet and hydrodynamic sieving were similar. It is believed that despite some limitations, both wet and hydrodynamic sieving methods are better techniques than dry sieving. However, empirically designed criteria that are based on the dry sieve methods would have to accordingly be corrected.
2. The bubble point, mercury intrusion, and image analysis methods gave a complete pore-size distribution of the geotextiles. For the tested geotextiles, mercury intrusion gave similar results and the largest values of O_{95} for all geotextiles, whereas the bubble point method always gave the smallest O_{95} values as compared to other methods. The O_{95} results from image analysis were always larger than O_{95} results from dry sieving. The authors feel that more work is needed to study the bubble point and image analysis techniques before the results from these techniques can be used in design.

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