Comparison of Filtration Efficiency Measurements between TSI Model 8160, TSI Model 3140, and ATI 100P Filter Test Stands

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Abstract

The penetration result obtained on a filter test stand depends on several factors. Two of these are challenge aerosol size distribution and the particle detector used to measure the particle size and concentration. Some filter testers employ a monodisperse aerosol challenge while others use a polydisperse challenge. Some particle detectors are based on particle counting while others are based on light scattering detection. Johnson and Smith[1] have shown that small differences in these factors can have a dramatic effect on the penetration value obtained. Other factors that affect the penetration are the fiber diameters in the filter media tested and the face velocity of the test. The goal of this study was to present a correlation between the MPPS penetration as measured by the TSI CertiTest 8160 and the penetration values obtained by the TSI model 3140. We also present a correlation of MPPS penetration with filter media face velocity that may be useful for extrapolation purposes. For the HEPA and sub-HEPA grades the 100P penetration was measured to estimate the particle size this test stand is measuring compared to the 8160.

Introduction

The age of high efficiency filtration began after WWI when protection of troops from poisonous gas attacks became a priority for the military. In the area of filter testing, LaMer and Sinclair[2] developed a filter test stand using a thermally generated di-octyl-phthalate (DOP) smoke cloud to challenge the filter and optical photometers to determine aerosol concentration upstream and downstream of the filter. At that time the DOP smoke was thought to be an aerosol of monodisperse 0.30 micrometer spheres. This instrument became the basis for US MIL-STD-282[3] and subsequently MIL-STD-51079 and MIL-STD-51068 for testing HEPA filter media and HEPA filters. Later Hinds[4] et al determined that the hot DOP aerosol generated by the Sinclair test stand was not monodisperse, but was actually a polydisperse aerosol having a count mean diameter of 0.23 micrometers. Even so, MIL-STD-282 has remained the accepted industry standard for testing HEPA filter media. In recent years ATI has developed a cold DOP aerosol test stand, model 100P, to replace the Q-127 thermal DOP test stand. ATI reports that the cold DOP aerosol generated by the 100P has a count mean diameter of 0.22 micrometers and geometric standard deviation of 1.6.

With the introduction of filter test stands based on laser particle counters and condensation particle counters combined with differential mobility particle sizers in the 1980's, new filter efficiency test stands were developed to meet the needs of the booming electronics industry. The newer particle counter based test stands could accurately measure filter efficiencies of up to 99.999998 percent on particles ranging in size from 0.075 to 10 micrometers for laser particle counters and 0.015 to 0.40 micrometers for condensation particle counters. These test stands allowed the generation of fractional penetration curves that experimentally demonstrated Langmuir's[5] theory that there is a particle size for which filtration efficiency of a filter medium is minimum. Two standards that reference reporting the penetration at the most penetrating particle size (MPPS) are IEST-RP-021 and the European standard, EN1822.

The CertiTest 8160 is a filtration test stand that utilizes monodisperse challenge aerosol and condensation particle counters (CPC's) to detect the aerosol concentration upstream and downstream. This filter tester has the capability of measuring a fractional penetration curve for particle sizes in the range of 0.015 to 0.4 micrometers. The Model 3140 is a new generation of TSI 8140 tester. It is also a CPC based filtration test stand, but only provides a single penetration measurement for a fixed particle size distribution aerosol challenge.

While fractional penetration curve testing can readily be carried out using the CertiTest 8160, it is a relatively slow, time-consuming process, requiring sequential tests at a number of particle sizes. A faster test method is needed for real time quality control testing. An alternative is the use of a flat sheet test stand such as the TSI model 3140 which uses a fixed challenge aerosol having a mean particle size diameter of 0.18 µm and geometric standard deviation of 1.6. The test time for the 3140 is a fraction of the test time required for the 8160. We have previously published this type of correlation based on testing with the older TSI model 8140[6]. Since H&V has recently acquired model 3140 test stands at two manufacturing locations, we wished to verify that our earlier correlation was still valid.

## Experimental

Three different test stands were used for this study, the TSI model CertiTest 8160, TSI model 3140, And ATI model 100P. The TSI filter test stands are CPC based and the ATI is photometer based. The model 8160 is the most sophisticated of the three test stands. A polydisperse aerosol of DOP is first generated by atomization and evaporation from an isopropanol solution. This aerosol is then passed through an electrostatic classifier that allows only a tunable monodisperse aerosol of the desired particle size to challenge the test filter medium. Upstream and downstream samples of air are fed to separate CPC's for penetration determination for that particle size. A fractional penetration curve as a function of particle size is obtained by sequentially testing particle sizes in the range of interest. This test stand can measure fractional penetration to a precision of $10^{-8}$ percent over a particle size range of 0.015 to 0.4 micrometers at flow rates of 5 to 100 liters per minute.

The TSI model 3140 is somewhat less sophisticated than the 8160. This instrument generates a polydisperse aerosol by atomization of DOP liquid. The challenge aerosol is then passed through a coarse fibrous filter medium that narrows the size distribution of the aerosol such that it has a 0.18 micrometer count mean diameter with geometric standard deviation equal to 1.6. Air samples upstream and downstream of the test sample are withdrawn and passed through CPC's to determine penetration. With this test stand penetration may be obtained to a precision of $10^{-7}$ percent at flow rates from 5 to 100 liters per minute.

Both of these instruments require purge times long enough to guarantee steady state and sampling times long enough to achieve satisfactory particle count statistics. The sample area for both instruments is 100 $cm^2$. One noticeable improvement on the 3140 is that the mass flow meter is temperature and pressure compensated to provide accurate volumetric flow at low flow rates. The older model 8140 utilized an orifice flow meter that was not accurate below 15 liters per minute.

The ATI 100P is a light scattering photometer based test stand that utilizes a cold generated DOP aerosol as the challenge. The aerosol generated by the 100P is also narrowed such that it has a count mean diameter of 0.22 micrometers with a geometric standard deviation of 1.6. Aerosol cloud concentration is measured by a light scattering photometer and penetration is calculated from these concentrations. This test stand was developed as a new generation version of ATI's Q-127, a photometer based test stand that utilized thermally generated DOP as the aerosol challenge. This instrument has been historically believed to measure the penetration of 0.30 micrometer particles and is the basis for testing HEPA filter media referenced by MIL-STD-282.

Multiple samples of ULPA, sub-ULPA, HEPA, and sub-HEPA filter media were obtained. These were first tested on the 8160 at face velocities of 1.5, 2.5, 3.5, 4.5, and 5.3 cm/sec for 0.075, 0.090, 0.12, 0.15, 0.18, 0.22, 0.26, and 0.30 micrometer particle diameters. The same area of each sample was then retested at the same face velocities using the model 3140. In addition the HEPA and sub-HEPA samples were tested at 5.3 cm/sec using the 100P.

Regression analysis was done on each data set obtained on the 8160 to fit the model

$$\ln(Pen) = A(\ln D)^2 + B(\ln D) + C \qquad (1)$$

Where Pen = Penetration fraction

And D = Particle Diameter

The MPPS is then easily determined by setting the derivative equal to zero, so that:

$$\ln(MPPS) = \frac{-B}{2A} \qquad (2)$$

Where MPPS = Most Penetrating Particle Size

And substituting back into the model we get:

$$\ln(Pen_{MPPS}) = C - (B^2/4A) \qquad (3)$$

## Results and Discussion

Figures 1 through 5 show the average fractional penetration curves at each face velocity for the test samples. The average 3140 penetration for each face velocity is plotted as a straight line on the curves. The curves suggest good correlation of MPPS penetration with 3140 penetration at the lower face velocities. Since the particle size distribution of the 3140 is certainly not monodisperse, one would expect that the 3140 penetration would be somewhat less than the 8160 MPPS penetration, and our results confirm this at the higher face velocities. Our earlier work showed that the penetration of the model 8140 was equal to or higher than the model 8160 depending on face velocity, while the results of this study suggest that the penetration given by the model 3140 is equal to or less than the 8160 depending on face velocity. Possible factors that account for these differences are improvement in the flow measurement accuracy of the 3140, and differences in diluters and individual CNC responses between the 8160 and the 3140.

Figures 6 to 10 compare the average fractional penetration values for the samples at each face velocity to the fitted curves at that velocity. In general, the second order fits for fractional penetration are quite good, with the average $R^2$ value equal to 0.97 for 75 data sets of 9 points apiece. We also tested the HEPA and sub-HEPA sample sets at 5.3 cm/sec on the P100 filter test stand. The penetration for the HEPA and sub-HEPA samples intersected the 8160 fitted curve at 0.299 and 0.309 micrometers respectively. Although this is a very limited data set, there is a good indication that the P100 does provide the 0.3 micrometer penetration that conforms to MIL-STD-282.

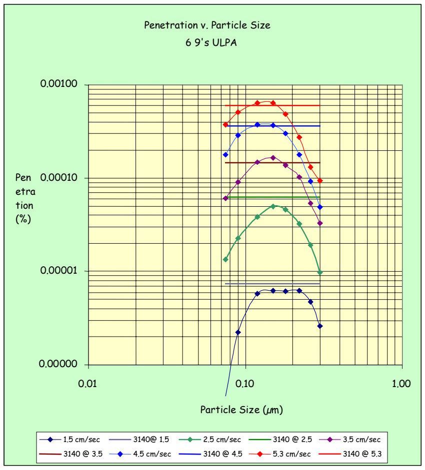



Figure 1.

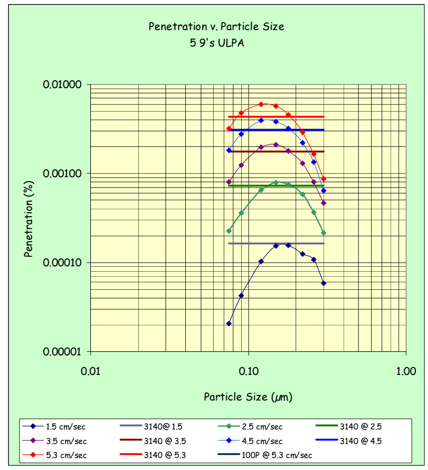
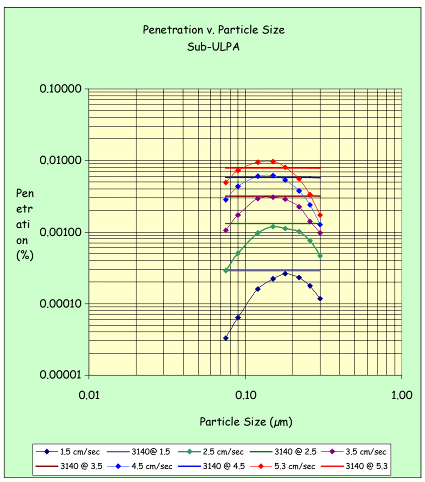



Figure 2.

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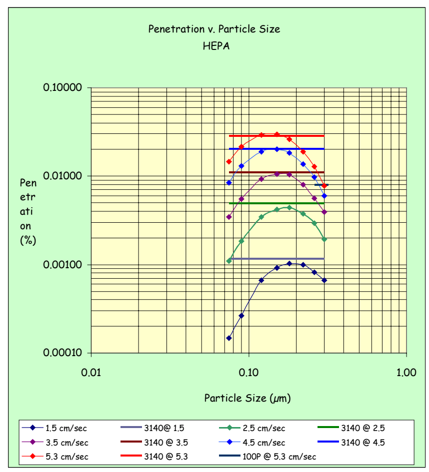



Figure 4.

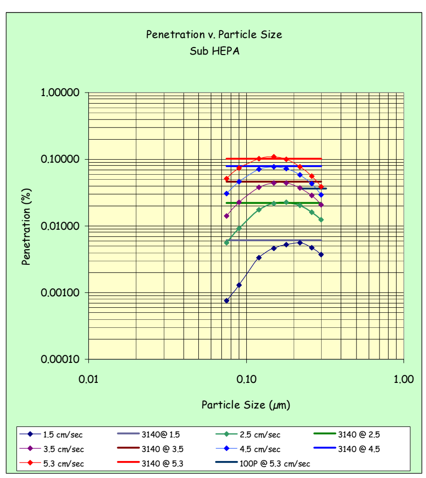



Figure 5.

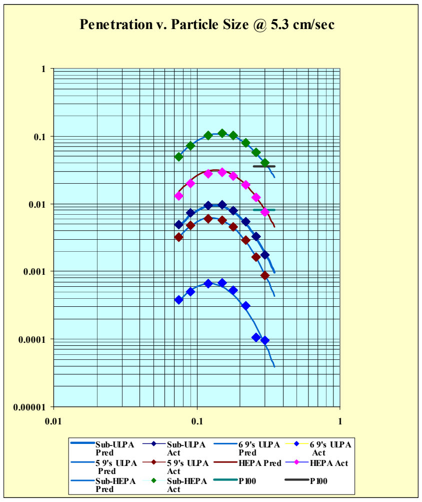



Figure 6.

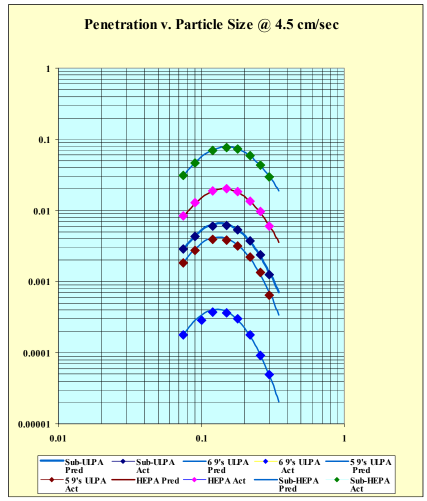
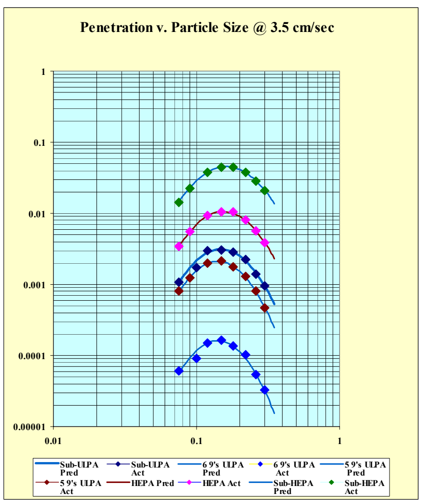



Figure 7.

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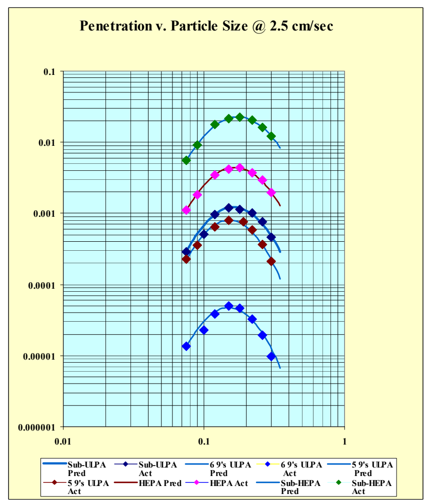


Figure 9.

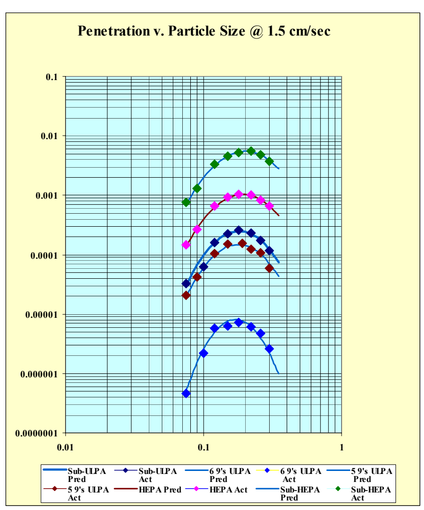


Figure 10.

Figure 11 is a plot of the predicted 8160 MPPS penetration from the fitted curves versus the 3140 penetration results. The curve suggests a good correlation between the values over five orders of magnitude, but the 8160 predicted penetration is about 10 percent higher than the 3140 values. This offset may be the result of the differences shown earlier at the higher face velocity test conditions.

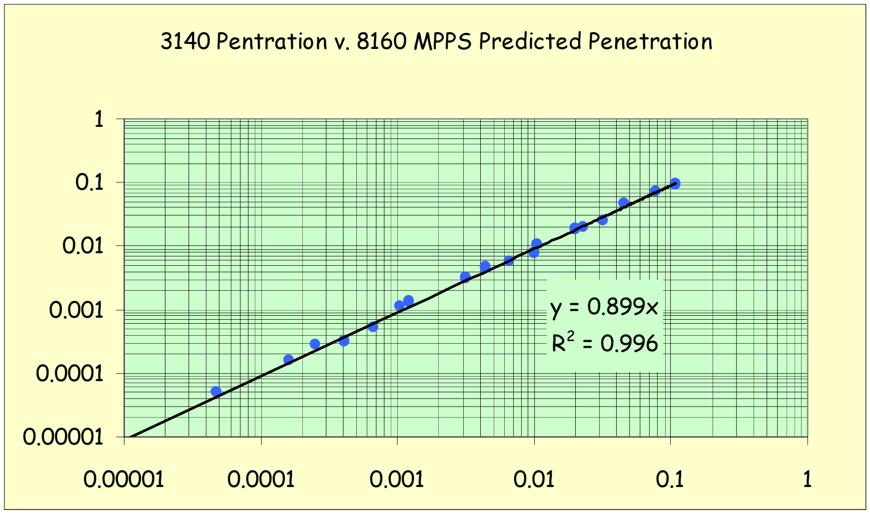


Figure 11.

Since the filter media face velocity for most applications is at or below 3.5 cm/sec, the correlation may still be considered quite useful.

Since the correlation to MPPS penetration was so good, it was decided to further investigate the correlation the 3140 penetration as a function of face velocity. To do this we fit the 3140 data to the power law model for filter media was previously presented[7] :

$$\ln Pen = \ln Pen_r \,(V/V_r)^N \qquad (4)$$

Where Pen = Penetration fraction at face velocity, V

and $Pen_r$ = Penetration fraction on the same sample at the reference velocity, $V_r$.

The $R^2$ values for these regressions were all above 0.997. Figure 12 is a graph showing the dependence of penetration on face velocity. The lines for each grade are nearly parallel with N values ranging from –0.22 to –0.27. There is some indication that as the efficiency of the filter media is reduced the slope, or N value, increases. The HEPA and sub-HEPA grades have N values equal to -0.25 and -0.27 which were the two highest values obtained.

The determination of the N value for a filter medium allows measurement of penetration of flat sheet filter media at a standard face velocity and estimation of the MPPS penetration at lower application face velocities.

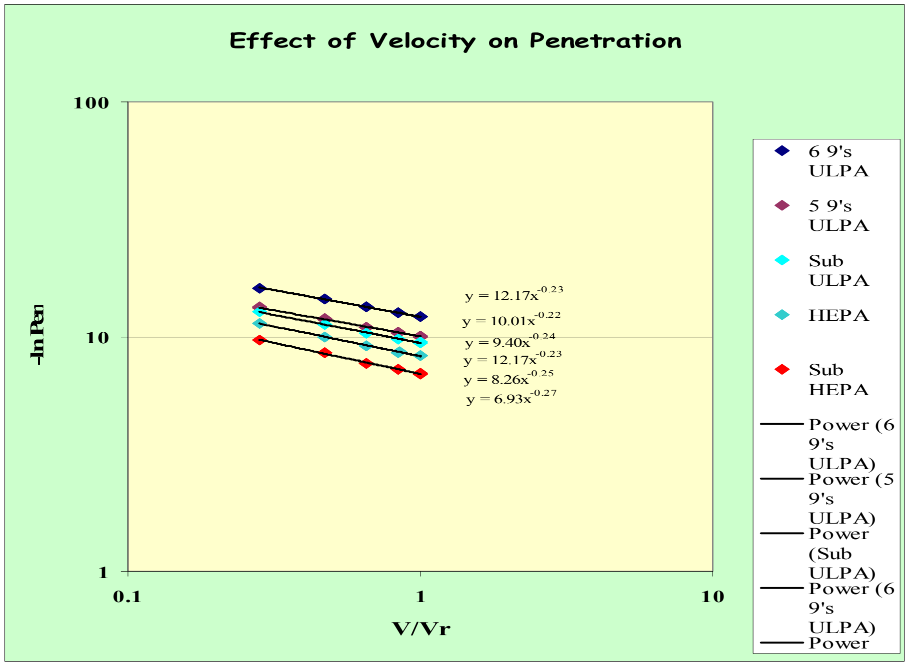


Figure 12.

Conclusions

Comparison of 3140 penetration to 8160 fractional penetration has shown a good correlation between the 3140 result and the 8160 MPPS penetration over several orders of magnitude. This study did show a 10 percent offset between the two results. The plan is to investigate this further in the future. In addition, we have confirmed that the ATI model 100P produces penetrations that correlate to the 0.30 micrometer particle size of the 8160 fractional penetration curve and is an acceptable alternative to the Q-127 filter tester.

The 3140 penetration is related to face velocity by a power law model. This can be a useful tool for specifying media penetration performance at reasonable test equipment operating parameters.

References


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