Design and Characterization of a Test Stand for Performance Evaluation of Flat Filter Media

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Abstract

Filtering efficiency (FE) and initial differential pressure (dP) are two important parameters used in the design of filters. Pleating of filter media during filter pack assembly can account for a large drop in Filtering Efficiency (FE) of high efficiency particulate air (HEPA) filters. The FE of the flat, non-pleated media can be used as a benchmark for filter design to determine how well a filter has been assembled. Comparing FE data of flat media to that of filter packs also provides insight to how well future filter designs will perform with various media types. This paper presents the development of a test stand at the Institute of Clean Energy Technology (ICET) at Mississippi State University (MSU)to perform FE testing on flat media coupons at various flowrates. These flowrates correspond to differing face velocity in full filter packs. This information helps to determine how much media should be included in a filter pack of a given flowrate design. The challenge aerosol used was dioctyl phthalate, a standard in air filter FE testing. The test stand design allows the concentration of the aerosol to be adjusted such that the test coupon would be challenged with the same concentration and particle size distribution (PSD) at different media velocities. To determine FE of the filter media and PSD of the challenge aerosol, a laser aerosol spectrometer (LAS) and a scanning mobility particle sizer (SMPS) are used simultaneously. The test stand also records the differential pressure (dP) across the filter coupon during the test. The American Society of Mechanical Engineers (ASME) code AG-1 regulates nuclear quality HEPA filters and designates a maximum initial dP. The dP of each clean filter coupon is recorded at each media velocity prior to aerosol challenge.

Introduction

The Institute of Clean Energy Technology (ICET) is experienced at testing and evaluating AG-1 HEPA filters and has presented and published numerous literature on the subject. Testing has included axial filters [1] and radial filters [2, 3]. Multiple test stands have been developed and built on site [4, 5]. ICET has performed evaluation of HEPA filters for many different projects related to nuclear particulate containment. One such project is the performance evaluation and qualification of newly designed HEPA filters for the Hanford Waste Treatment Plant (WTP).

ICET is currently under contract to Bechtel National, Inc. (BNI) to evaluate designs of AG-1 Section FK radial flow HEPA filters for the WTP. To aid in the iterative filter design process, evaluation of filter media samples is required. A test stand has been designed and built to provide the means to evaluate filter coupons of multiple media types.

The advantage of testing flat media is the ability to test at different media velocities to determine the most efficient operating condition. The flat media testing will provide data at various velocities to help determine the ideal amount of media to include in a filter pack.

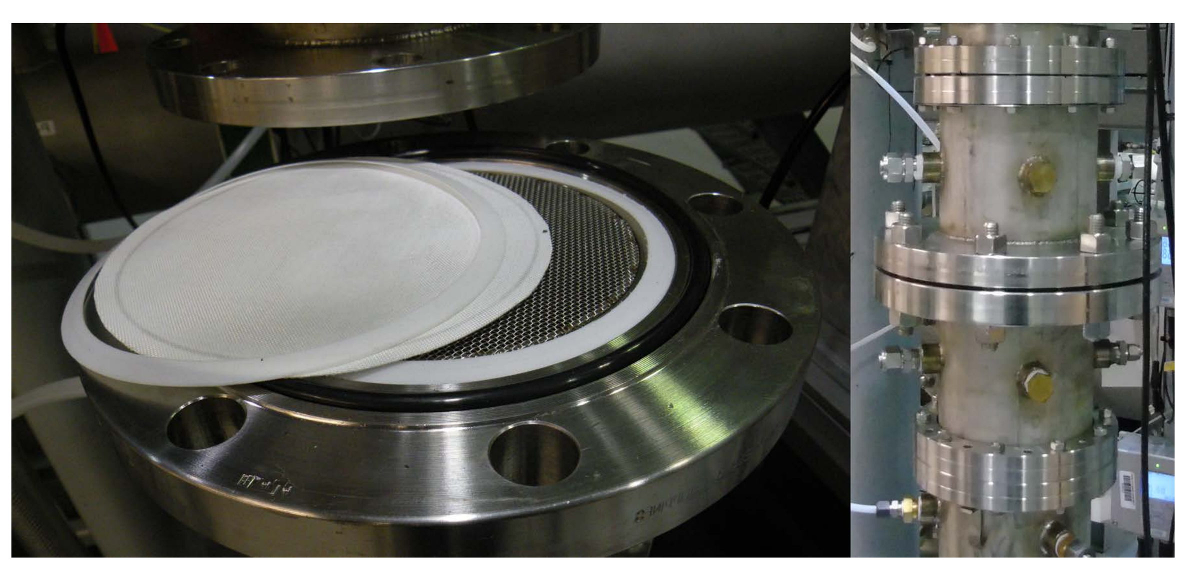

Figure 1. The flat sheet coupon housing (right) clamps a coupon in place with two Teflon gaskets (left).

Test Stand Design Criteria

•Media is to be tested in flat form as circular coupons and in small-scale filter pack form called quadrant packs. Each requires a separate housing.

•The test plan requires the flat sheet coupons to be tested at media velocities of 0.9, 1.5, 2.1, 3.0, and 4.6 m/min(3, 5, 7, 10, and 15 ft/min). These values were chosen to cover a wide range of potential filter pack media surface areas. The quadrant packs are to be tested at 2.55 m^3/min(90 cfm), regardless of media velocity.

•Filtering efficiency is to be determined with DOP. Quadrant pack testing also requires loading with hydrated alumina, $Al(OH)_3$ Therefore the test stand design must support aerosol generation and introduction with liquid and powder sources.

•The dP across the filter coupon must be recorded throughout each test to determine a curve of clean media and to quantify filter loading. Temperature, relative humidity and flowrate of the test stand are to be monitored and recorded.

•Aerosol samples to be taken upstream and downstream of the filter and measured with a Laser Aerosol Spectrometer (LAS) and a Scanning Mobility Particle Sizer (SMPS) simultaneously.

Design of Test Stand

- The test stand was constructed with six inch diameter stainless steel pipe. An upstream and downstream section are joined by either the flat media coupon housing or the quadrant pack housing. Figure 2 is a schematic of the test system.
- The flat media coupon housing consists of two halves made with stainless steel tubing and flanges. Figure 1 shows a coupon set on the support screen on the left and the coupon clamped between the two halves on the right.
- A port at the top of the test stand facilitates injection of the challenge aerosol.
- Ports for sampling exist just above the housing and at the bottom of the stand. These can be seen in the photograph of the test stand, Figure 4.
- Airflow is drawn through the test stand by vacuum pump and controlled by a mass flow controller via the PLC during flat media testing. Figure 3 is a screen capture of the PLC control interface.

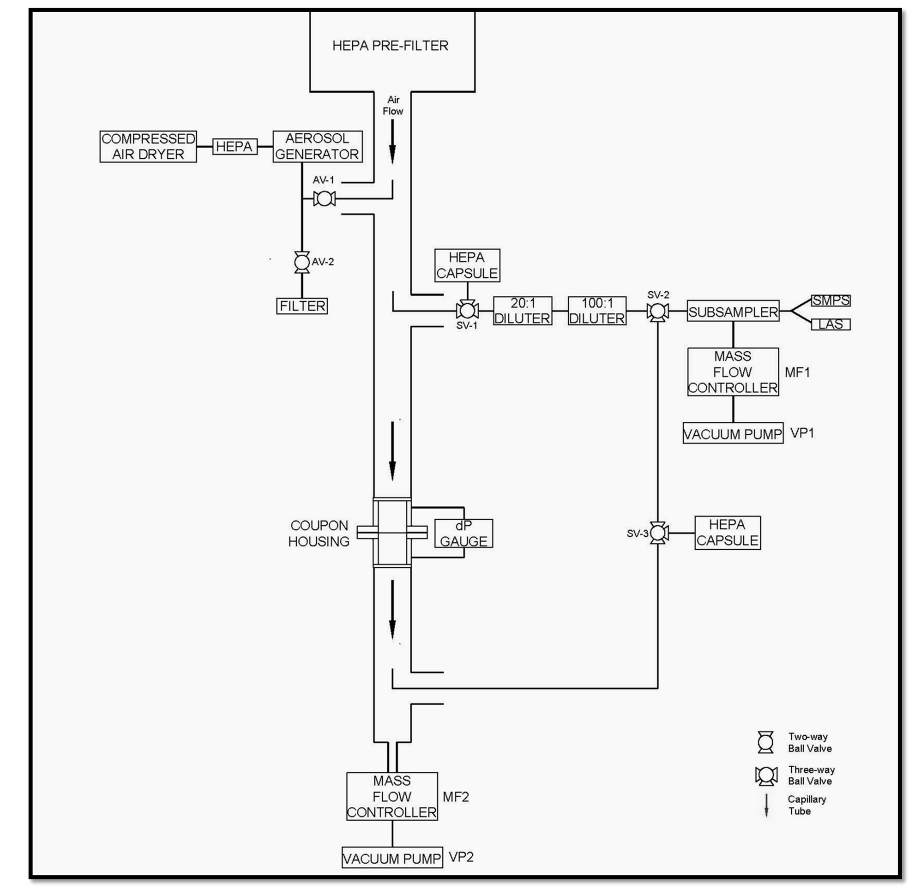

Figure 2. Schematic of Test Stand for Evaluation of Flat Sheet and Quadrant Pack.

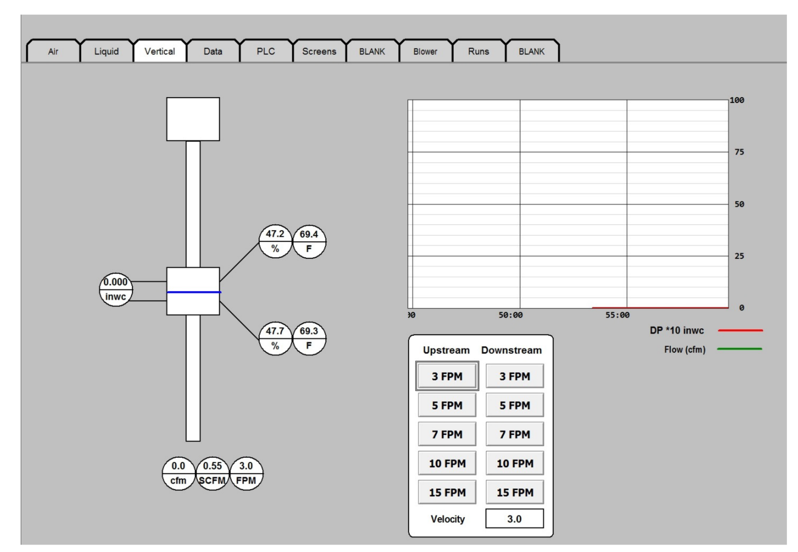

Figure 3. The control screen of the PLC displays the sensor data and allows the set point of the flow controller to be selected.

- Air is drawn by an induced draft fan controlled by the PLC via measurement via a venturi during quadrant pack testing.
- Inlet air is pre-filtered with a 12"x12"x12" HEPA filter.
- The sampling valve train allows for easy switching between sampling upstream and downstream and allows for purging of the sample lines between samples.
- The instruments used in the system are a TSI 3340 Laser Aerosol Spectrometer (LAS) and a Scanning Mobility Particle Sizer (SMPS) comprised of a TSI 3082 Electrostatic Classifier (EC), a custom 95cm Differential Mobility Analyzer (DMA), and TSI 3775 Condensing Particle Counter (CPC).
- Two aerosol diluters with ratios 20:1 and 100:1 are used to reduce the particle concentration to a level the LAS can measure.
- A mass flow controller, vacuum pump, and isokinetic splitter are included to draw the necessary extra flow through the diluters.
- Sensors include a dP gauge across the housing, relative humidity and temperature probes above and below the housing, the mass flow controller for the flat media flow, and the dP gauge for the quadrant pack flow venturi.
- All sensor data is recorded continuously by the PLC.
- A custom DOP aerosol generator was built. It is a six-jet Laskin nozzle with variable air pressure supply, shown in Figure 5.
- Fine tuning of the challenge concentration was achieved through the use of a bypass valve in the injection pathway. The excess DOP is dumped into a spare HEPA filter.

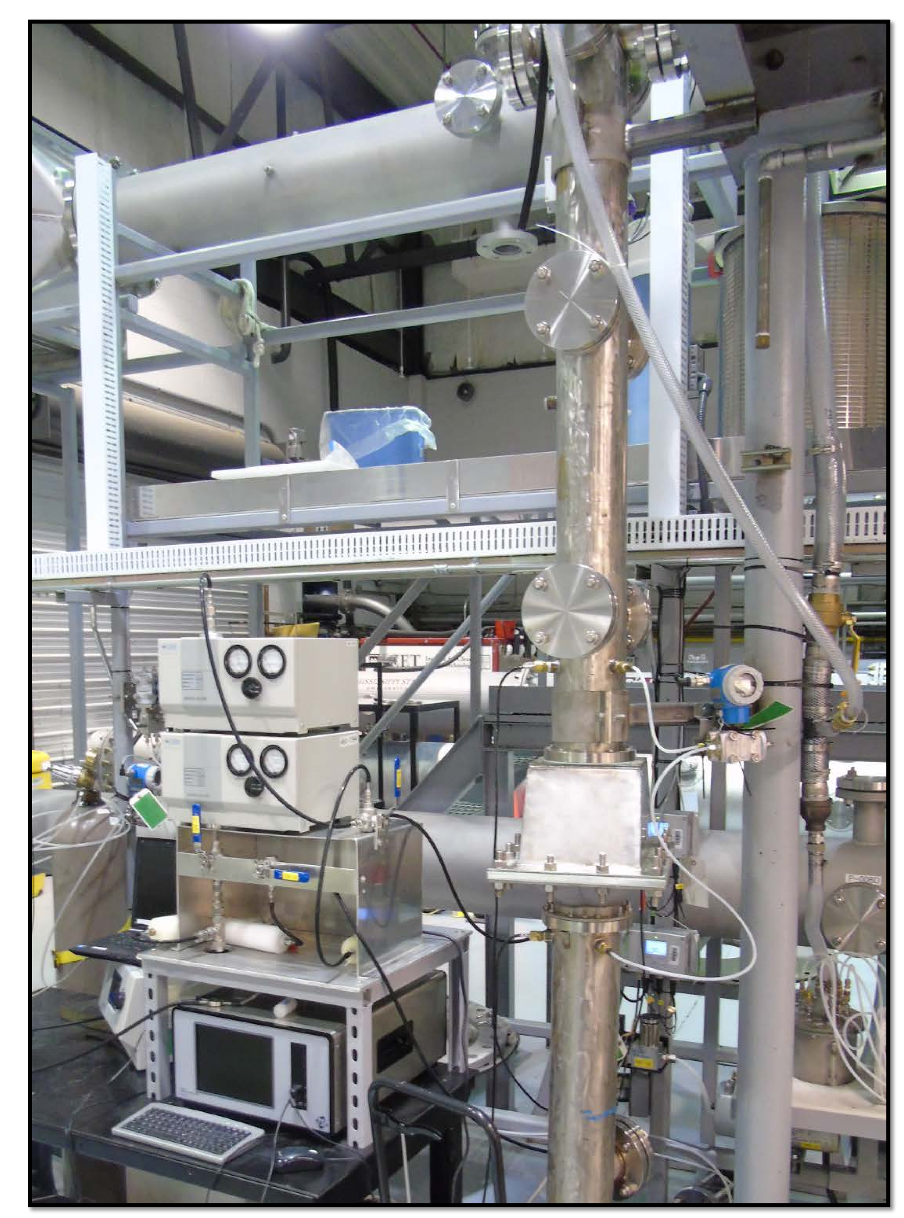

Figure 4. The vertical test stand with quadrant pack housing in place. The sampling system can be seen on the left.

Figure 5. Custom DOP Laskin Nozzle Aerosol Generator.

References

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Giffin, P. K., Parsons, M. S., Rickert, J. G., and Waggoner, C. A., 2011, "Results from Evaluation of ASME AG-1 Section FK Radial Flow HEPA Filters," *Proceedings of Waste Management 2011 Conference*.
Giffin, P. K., Parsons, M. S., Unz, R. J., and Waggoner, C. A., 2012, "Large-scale generic test stand for testing of multiple configurations of air filters utilizing a range of particle size distributions," *Review of Scientific Instruments*, **83**(5).
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Results

The SMPS reports normalized concentration values as particles per cubic centimeter (#/cc). The LAS reports raw counts per bin. This data is reduced into concentration data for comparison. Log-normal curve fits are created for better analysis of the discrete data points that the instruments export. An example plot showing the upstream and downstream particle concentration is shown in Figure 6. The data scatter on the SMPS downstream sample is due to the concentration being at or below the lower concentration threshold of the SMPS's capability. Figure 6 shows that the data points at the top of the plot are those from the upstream samples and are much higher in number concentration due to the filtering efficiency of the coupon. The values of the upstream data are calculated by applying the dilution ratio to the data reported by the instruments.

Penetration fraction is the most desired result of these tests. It is calculated by dividing the downstream concentration by the upstream concentration. This is done with each bin. An example plot showing penetration data and a lognormal curve fit can be seen in Figures 7 and 8. The peak of the curve indicates the most penetrating particle size (MPPS).

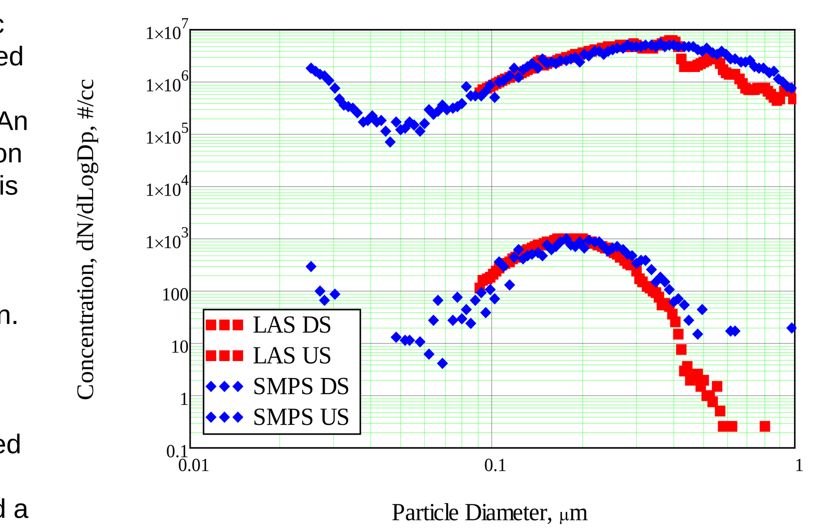

Figure 6. Particle size distribution of upstream (US) and downstream (DS) aerosol samples.

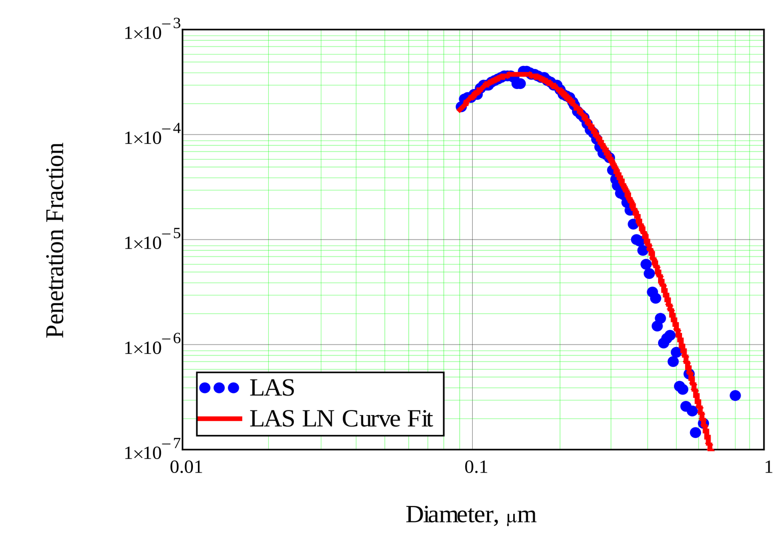

Figure 7. LAS penetration data points with a log-normal curve fit.

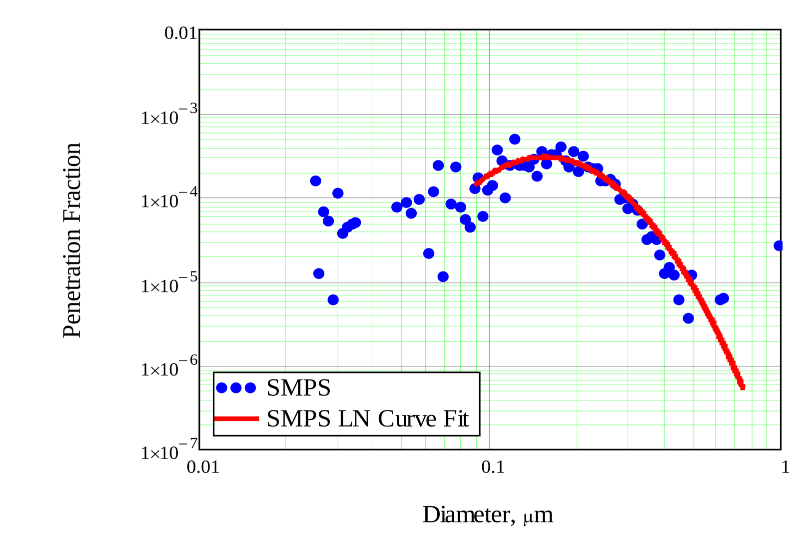

Figure 8. SMPS penetration data points with log-normal curve fit.

Penetration of particles that are 0.3 µm in diameter is a commonly used parameter of HEPA filters. In particular, the very definition of a HEPA filter relies on the FE value of 0.3 µm particles. To get the most accurate value for this parameter, an exponential curve fit is created from the penetration data in the particle diameter range of 0.23 – 0.35 µm. Figures 9 and 10 show the exponential curve provides a better fit to the data than the lognormal curve. The plots include the discrete data points, both curve fits, and a marker indicating the calculated value at 0.3 µm.

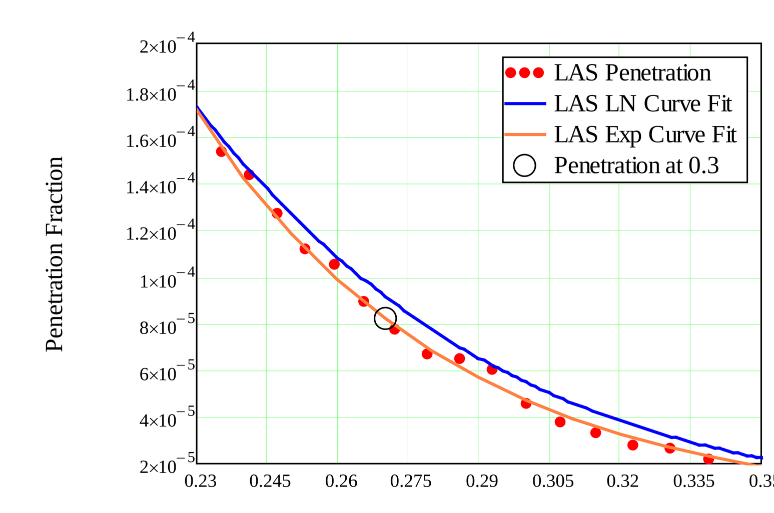

Figure 9. Lognormal curve fit of LAS penetration data with exponential curve fit of limited domain bracketing the 0.3 µm particle diameter.

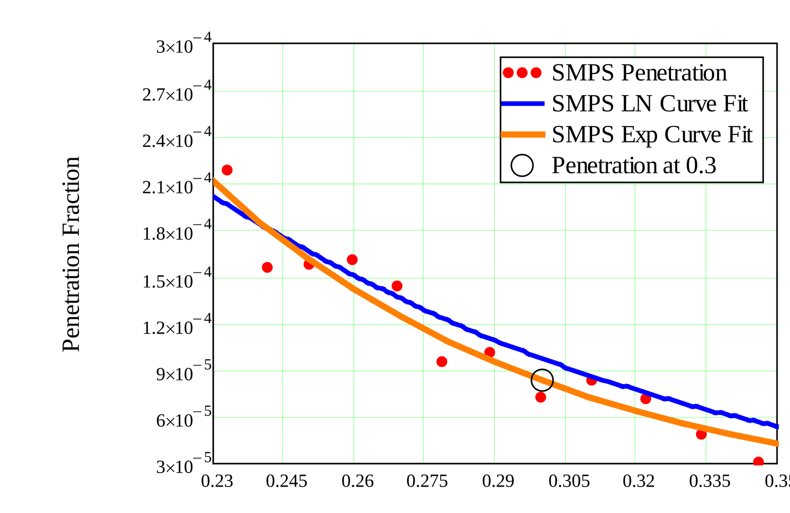

Figure 10. Lognormal curve fit of SMPS penetration data with exponential curve fit of limited domain bracketing the 0.3 µm particle diameter.

Conclusions

- A test stand for evaluating the performance of filter media samples was designed, built, and characterized.
- The system is capable of testing coupons of flat sheet samples and small scale filter packs called quadrant packs.
- Up and downstream aerosol samples are analyzed with a SMPS and a LAS and the resulting data is used to determine penetration, most penetrating particle size, and filtering efficiency.
- Flat sheet coupons can be tested at a range of media velocities to predict the best surface area to be included in full filter packs.
- The results show the sampling system and test stand are able to produce the desired data with high quality.
- The requirements set forth for this testing system were achieved with the design presented here.

Future work will include evaluating the multiple media types and quadrant pack filter pleating design strategies prescribed in ICET's test plan for the project with BNI. These data will aid BNI in the selection of media to be used in the construction of radial flow HEPA filters for the Hanford WTP.

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