Design and Characterization of a Modular Filter Test Stand

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Work Described is being Underwritten by the United States Department of Energy (DOE) Under Contract Number: DE-EM0003163

Abstract

The performance of a filter may essentially be reduced to consider two main performance characteristics: 1) the filtering efficiency and 2) the filter's resistance to air flow. However, both the efficiency and resistance change as a function of the properties of the air, filtration velocity, and other factors such as the properties of the filtration media itself. Therefore, exploring the resulting effects from exposing different filtration medias to a range of conditions and flow rates is desirable. This work provides an overview of a modular test stand design, and the characterization results of the primary assembly. A discussion of the particle sampling apparatus, generators, and other necessary instruments is also given to provide a full measure of the installed capabilities. However, the modular nature of the test stand offers a unique opportunity to rapidly prototype new testing capabilities that may be required for future work. Furthermore, the size of the test stand itself is small, inferring that the amount of time for testing is reduced from the potential size of the test articles as well as setup of the stand and achieving a steady state condition. This in turn provides an increase in the amount of gathered data over a shorter timespan than its larger scale counterparts at the Institute for Clean Energy Technology. While the test stand is capable of testing full sized filters, flat sheet HEPA filter media was used in this study for characterization purposes. Additionally, to control the test stand, a program is built using LabVIEW NXG to provide a user-interface with the test stand, real-time flow characterization, and feedback calculations for automation and effective data collection (temperature, relative humidity, static pressure, etc.). The program's primary input, volumetric flow rate, dictates the automatic tasks based upon collected data, such as temperature and relative humidity, to maintain the input flow rate regardless of the ambient conditions. These results include the filter efficiency at standard conditions, as well as at elevated temperatures. The uncertainty in the results is also discussed, and the impacts from the design of the test stand on the collected data are investigated. Finally, potential future improvements are discussed, as are the possible research applications.

Introduction and Objectives

- High Efficiency Particulate Air (HEPA) filters are considered to be the last line of defense against potential releases of radioactive particles in nuclear facilities [1].
- Understanding when a HEPA filter will fail or needs to be replaced is essential to maximize workplace safety.
- Performing penetration and loading tests on the filter media exclusively can be used to aide in the improvement of filter medias.
- A better understanding of the pressure drop (dP) and its relationship to deposited particle mass can be found by measuring the dP over the duration of the test while continuously sampling the aerosol concentration.
- The evolution of the dP across the filter can be compared to theoretical models such as the Generalized Loading Model proposed by Bergman [2].

Objectives:

- Design, construct and characterize a test stand capable of meeting the given testing criteria as follows:
  - Air flow range of near zero to 20 actual cubic feet per minute (ACFM).
  - Temperature range of room temperature to 250°F.
  - Constantly inject both liquid and solid particles.
  - Efficiently sample well-mixed aerosols from the air stream.
  - Provide high quality data that can be used in order to improve the design of various filter medias and generate models of filter loading.
  - Allow for data to continuously be analyzed by users during testing.
  - Generate desired results based on elements such as aerosol sampling configuration and desired volumetric flow rate.

Constructed Test Stand

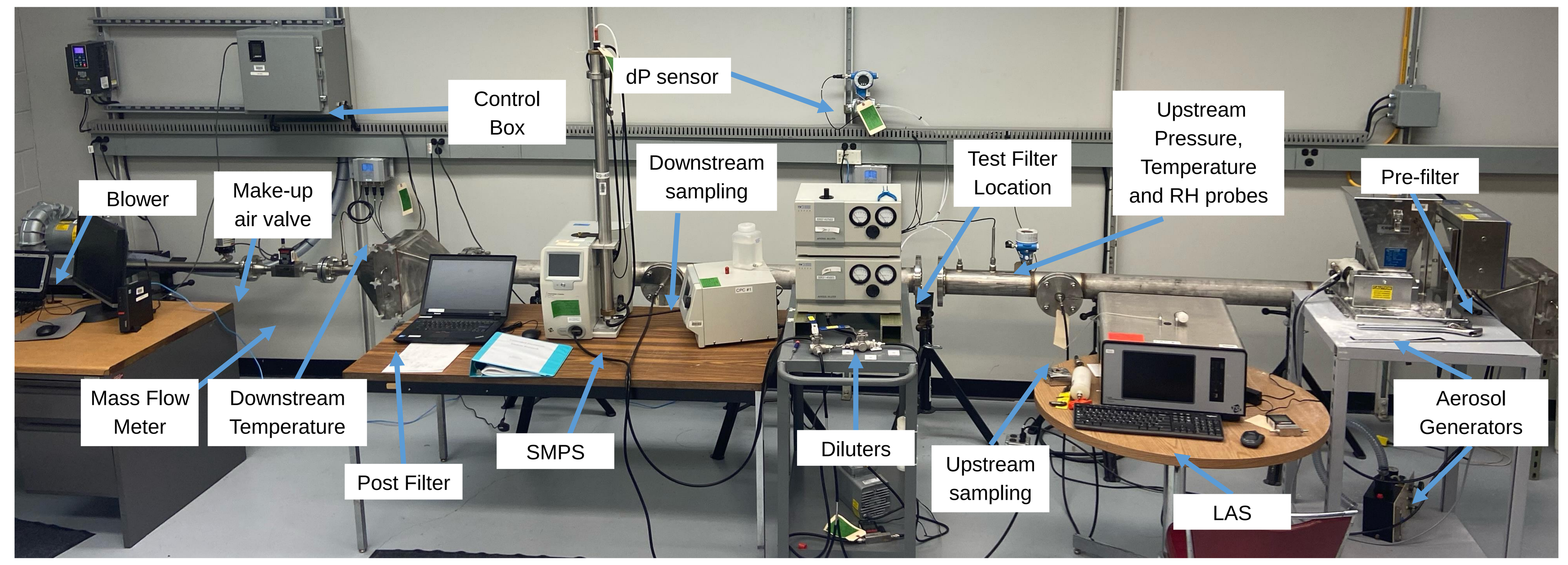

Figure 1: Constructed Filter Media Test Stand

The completed test stand is pictured above in Figure 1.

- A duct size of 4 inches was selected to reduce the footprint of the test stand.
- A single powder feeder is used to generate the solid aerosols and inject them into a manifold for even distribution across the duct flow area.
- An atomizer is used to generate liquid aerosols. The same injection manifold is used.
- The sampling system consist of custom-built probes, 100:1 and 20:1 diluters, Laser Aerosol Spectrometer (LAS), and a Scanning Mobility Particle Sizer (SMPS).
- Experimental data allows the use of the theoretical model of HEPA filter loading that is used for experimental study on HEPA filters [2].
- The test stand is controlled by a LabView program that uses a National Instrument Compact Data Acquisition system.

$$\Delta P = k_i * \frac{V}{\rho_{pD} * D_p^{n}} * \frac{M}{A} + \Delta P_o$$

- ΔP = dP of the loaded filter
- ΔP_o = initial dP of the clean filter
- k_i = constant, dependent on the type of loading
- V = air velocity at the filter face
- ρ_{pD} = particle deposit density
- D_p= diameter of the particle
- n = 1 for depth loading, 2 for surface loading
- M = mass of the particle deposits
- A = surface area of the filter

Test Stand Design

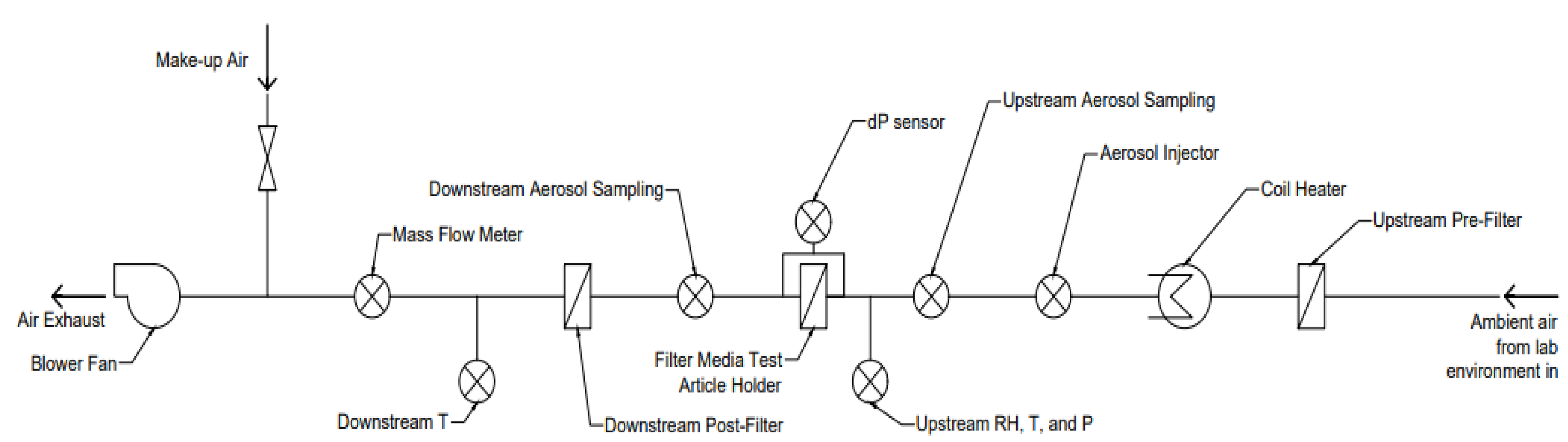

Figure 2: Test Stand Instrument Diagram

An instrumentation diagram is provided in Figure 2.

- Pre-filter in order to ensure no particles from the lab environment enter the test stand.
- 2-kilowatt heater coil to achieve desired air temperature.
- Static pressure, temperature, and relative humidity (RH) probes at the filter face to calculate the ACFM.
- Custom design test filter holder as shown in Figure 3.
- Make-up air valve for the blower at low flows.
- 1.5 horsepower (HP) blower to pull air through the test stand.

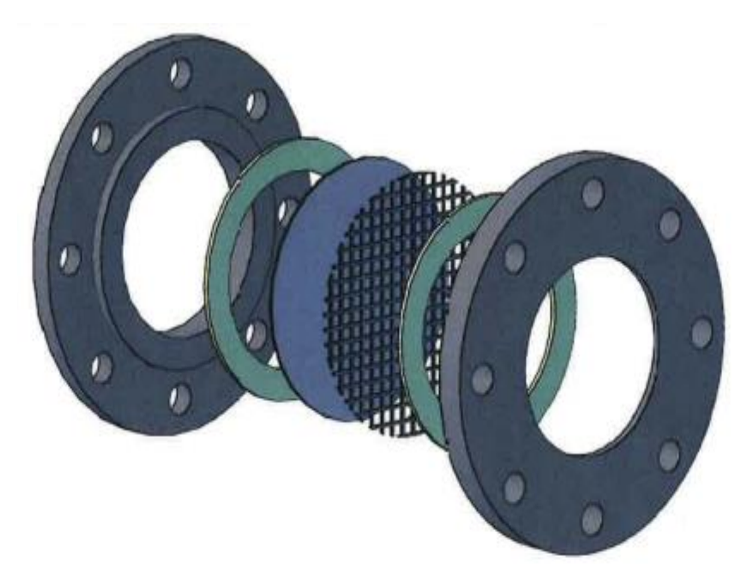

Figure 3: Test Filter Holder

References

1. Berry, G., Parsons, A., Morgan, M., Rickert, J., and Cho, H., 2022, "A Review of Methods to Reduce the Probability of the Airborne Spread of COVID-19 in Ventilation Systems and Enclosed Spaces," Environ. Res., 203, p. 111765.
2. Bergman, W. (2006) "HEPA Filter Particle Loading" Aerosol Science, Stanwood, WA.
3. DOE-HDBK-1169-2003, Nuclear Air Cleaning Handbook. (2003), 20585.

User-Software Interface

Figure 4: User-Software Interface

- As seen in Figure 4, the application allows the user to constantly analyze vital flow characteristics during tests such as pressure differential.
- The prime mover automation implementation allows for the prime mover to be run based on the desired volumetric flow rate.
- The volumetric flow rate is constantly converted from standard flowrate to actual flowrate during testing.

Results

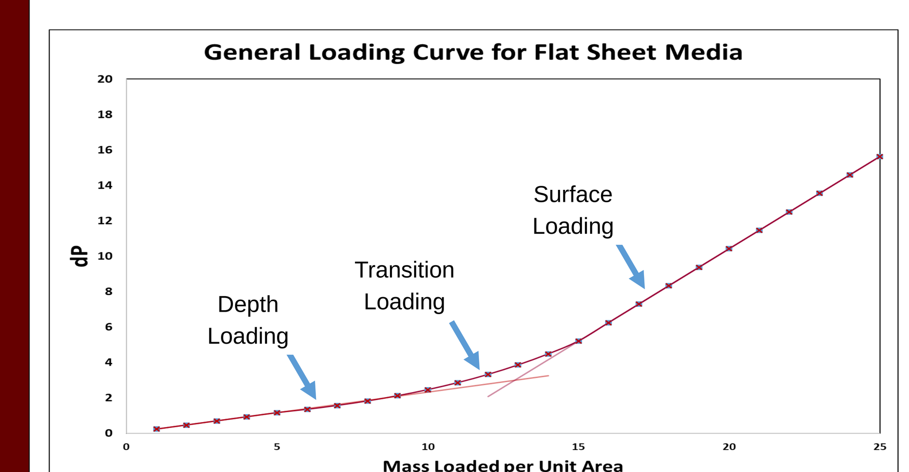

Figure 5: General Flat Sheet Media Pressure Drop Curve

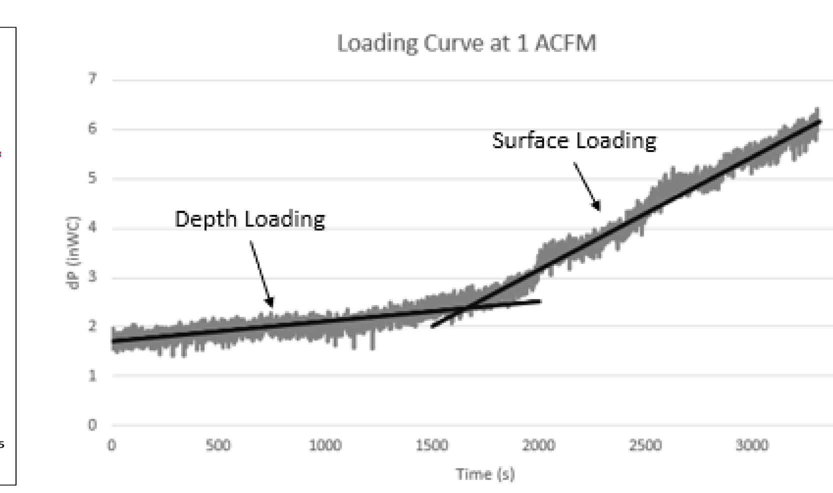

Figure 6: Actual Pressure Drop Curve

- The curve generated from LabVIEW data in Figure 5 can be compared to the general filter loading curve on filter media for validity, as the collected data displays a similar pressure drop curve in relation to a different parameter [2].
- Figure 6 provides an actual loading curve generated from the test stand. The selected challenge aerosol was Aluminum Trihydroxide (AL(OH)3). This test was conducted at 1 ACFM with an average concentration of 3.93E+05 particles/ccm.
- Penetration test with both Al(OH)3 and Polyalphaolefin (PAO) challenge aerosols have resulted in efficiency results of >99.97%. These results follow the expectation set by the DOE Nuclear Air Cleaning Handbook [3].

Conclusion and Future Work

- The test stand meets the given design criteria and generates data similar to the expected models.
- Improvements that can be made to the test stand include improving the control program to reduce the amount of lagging and improving the consistency of the powder feed rate.
- Data generated from this test may be used for a multitude of purposes. For example, this data may be used to compare to models constructed for predictive purposes. The long-term goal is to be able to install sampling instruments into ducts, then predict when a filter will require replacement.

Acknowledgments

Funding for these activities has been provided by Department of Energy Contract Number: DE-EM0003163. I would also like to acknowledge the contributions made by the Institute for Clean Energy Technology's staff.