LA-UR-15-21350
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Title: Define and Quantify the Physics of Air Flow, Pressure Drop and Aerosol Collection in Nuclear Grade HEPA Filters

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Intended for: Proposal to DOE Nuclear Safety R&D committee

Issued: 2015-02-23

NSR&D Program Fiscal Year (FY) 2015 Call for Proposals

Project Name: Define and Quantify the Physics of Air Flow, Pressure Drop and Aerosol Collection in Nuclear Grade HEPA Filters

Site: Los Alamos National Laboratory

Program Office: Department of Energy, Los Alamos, NM

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Proposal Submission Date: Feb. 27, 2015

<u>Project Name:</u> Define and Quantify the Physics of Air Flow, Pressure Drop and Aerosol Collection in Nuclear Grade HEPA Filters

Abstract

Objective:

Develop a set of peer-reviewed and verified analytical methods to adjust HEPA filter performance to different flow rates, temperatures and altitudes. Experimental testing will measure HEPA filter flow rate, pressure drop and efficiency to verify the analytical approach.

Nuclear facilities utilize HEPA (High Efficiency Particulate Air) filters to purify air flow for workspace ventilation. However, the ASME AG-1 technical standard (Code on Nuclear Air and Gas Treatment) does not adequately describe air flow measurement units for HEPA filter systems. Specifically, the AG-1 standard does not differentiate between volumetric air flow in ACFM (actual cubic feet per minute) compared to mass flow measured in SCFM (standard cubic feet per minute). More importantly, the AG-1 standard has an overall deficiency for using HEPA filter devices at different air flow rates, temperatures, and altitudes.

Technical Approach:

The collection efficiency and pressure drops of 18 different HEPA filters will be measured over a range of flow rates, temperatures and altitudes. The experimental results will be compared to analytical scoping calculations. Three manufacturers have allocated six HEPA filters each for this effort. The 18 filters will be tested at two different flow rates, two different temperatures and two different altitudes. The 36 total tests will be conducted at two different facilities: the ATI Test facilities (Baltimore MD) and the Los Alamos National Laboratory (Los Alamos NM).

The Radiation Protection RP-SVS group at Los Alamos has an aerosol wind tunnel that was originally designed to evaluate small air samplers. In 2010, modifications were started to convert the wind tunnel for HEPA filter testing. (Extensive changes were necessary for the required aerosol generators, HEPA test fixtures, temperature control devices and measurement capabilities.) To this date, none of these modification activities have been funded through a specific DOE or NNSA program.

This is expected to require six months of time, after receipt of funding.

Benefits:

US DOE facilities that use HEPA filters will benefit from access to the new operational measurement methods. Uncertainty and guesswork will be removed from HEPA filter operations.

I. INTRODUCTION

Purpose

The US DOE complex must be able to specify and understand the measurement units for air flow through HEPA filters. An experimentally verified analytical method could be used to revise the ASME AG-1 CONAGT Code on Nuclear Air and Gas Treatment, and / or the DOE Nuclear Air Cleaning Handbook (DOE-HDBK-1169-2003).

Scope

The Los Alamos National Laboratory has developed an experimental facility to develop a performance-based air flow metric (volumetric flow or mass flow) for operating HEPA filters. This would solve a current deficiency in the ASME AG-1 CONAGT Code on Nuclear Air and Gas Treatment. In the AG-1 standard, the measurement and specification of air flow has been confused between volumetric flow (ACFM, 'actual cubic feet per minute') and mass flow (SCFM, 'standard cubic feet per minute').

A recent example of this confusion occurred at a DOD facility where an HVAC control unit was holding the air flow at a constant mass flow value (i.e. 1000 SCFM). When the air temperature increased on a hot summer day (e.g. 110 ^{o}F) compared to a cold winter day (e.g. 0 ^{o}F), the fan capacity had to be increased by 25% (percent). Since the HEPA filter was rated at a volumetric flow of 1000 ACFM, when the control device was set to maintain the air flow at 1000 SCFM, it was telling the fan to deliver the same number of air molecules (i.e. the mass flow) through the filter, regardless of the air temperature. As a result, the fan's volumetric air flow rate was forced by the flow controller to increase to 1085 ACFM on the summer day compared to 870 ACFM on the winter day.

If the system designers truly wanted this behavior, then this would acceptable. For example, a chemical process is often scaled to a certain number of moles (mass flow), but HVAC systems are typically scaled in terms of the number of air changes per hour (volumetric flow).

In the current version of the ASME AG-1 CONAGT standard, there are no guidelines or explanations for choosing ACFM or SCFM as measurement units, or for predicting HEPA filter air flows or pressure drops for differing operating conditions.

Business Case

There are a large number of HEPA filters in use across the DOE, and many staff personnel are involved with these technical issues. This is illustrated by:

(1) **<u>The total annual DOE market for HEPA filters.</u>** The ATI Test company, under DOE contract, has tested an average of 2,500 HEPA filters per year for the past 16 years. These filters are immediately put into service across the DOE complex, and are built and operated according to ASME AG-1. The filters are used for either 5 years or 10 years, depending if their operating conditions include the possibility of liquid wetting of the filter material (Salisbury 2014). Each filter has a retail cost of $600, but that value does not reflect installation or disposal costs. This quantity of HEPA filters does not include all of the HEPA filters used in DOD facilities, nor in other federal, state, university or commercial applications.

(2) **<u>The DOE personnel responsible for periodic HEPA testing.</u>** The 2013 DOE Filter Test Facility workshop drew representatives from 21 DOE facilities and 6 vendors (Hrbek 2014).

Linkage

<u>The proposed development of the performance-based metric for air flow measurement in HEPA filters could be used to revise the following documents:</u>

(1) ASME AG-1 Code on Nuclear Air and Gas Treatment.

(2) DOE-HDBK-1169-2003 DOE Nuclear Air Cleaning Handbook.

II. <u>TECHNICAL DESCRIPTION</u>

Technical Approach

In Figure 1, a photograph of the Los Alamos aerosol wind tunnel indicates various components of the device. (The overhead duct is visually distorted in the panorama view.)

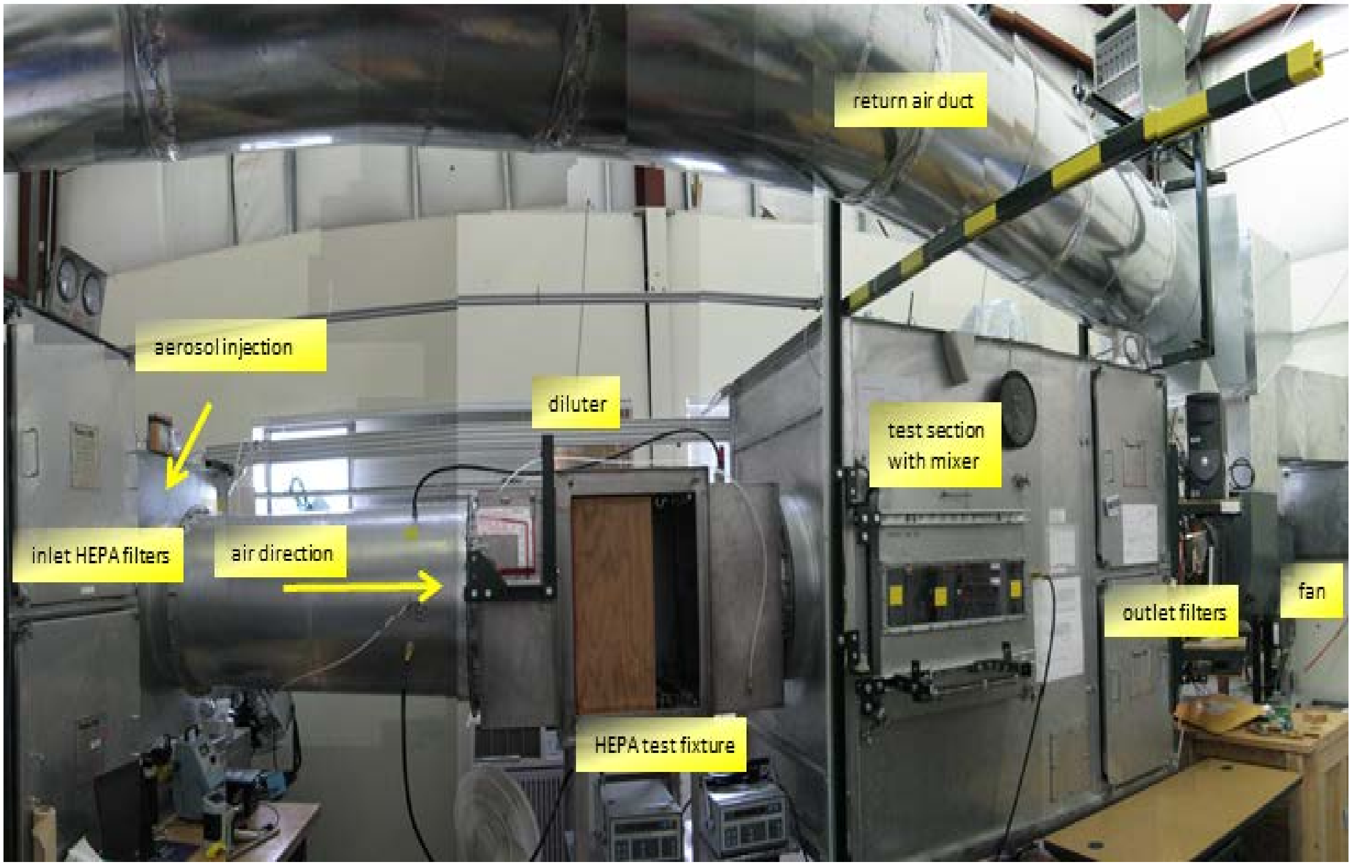

Figure 1. The Los Alamos aerosol wind tunnel requires completion and integration of three systems (i.e. mixer, diluter and performance-based air flow measurement).

A set of paired and certified measurements from the two different test altitudes are necessary to compare the volumetric flow and mass flow quantities. Experimental results from Los Alamos (at an ambient pressure 76% of sea level) would be compared to a set of HEPA filter measurements from ATI Test (at sea level). The tests summarized in Table 1 would therefore be performed for the 18 filters that have already been procured.

Table 1. Test summary for the HEPA filter intercomparison.

Test on filters rated at 1500 ACFM.					Test on filters rated at 1000 ACFM.			
Q_A		deg ^{O}F	Q_S		Q_A		deg ^{O}F	Q_S
ACFM	P_A/P_S	T_{ACTUAL}	SCFM		SCFM	P_A/P_S	T_{ACTUAL}	ACFM
1500	0.76	70	1140		1000	0.76	70	1316
1500	0.76	120	1042		1000	0.76	120	1440

When the volumetric (ACFM) flow rate is held constant for a HEPA filter, then the air velocity at the filter face would be held constant and the velocity of impinging aerosol particles would also be constant from one condition to the next. Filtration theory (single fiber efficiency c.f. Hinds 1999) indicates that filter face velocity is the dominant independent variable for preserving filter efficiency from one condition to another (Moore and Veirs 2012). The proposed test matrix would supply experimental data to illustrate this effect.

A comparison of the filtration efficiency would require a nanoparticle spectrometer, since HEPA filter performance is defined at a test aerosol of 0.3 µm diameter. (Note: A single channel photometer can be used to measure gross aerosol leakage through a HEPA filter, but a single-channel photometer cannot differentiate aerosols by size diameter.)

Los Alamos has just purchased a TSI model Nanoscan SMPS #3910 for this purpose, and this instrument could be shared with ATI Test, since they do not own one of these instruments.

Table 2. An instrument inventory comparison between the Los Alamos and ATI Test facilities.

Aerosol Measurement Instruments in Inventory	Single Channel Photometer (ATI model 2HN)	0.1 µm (nanoscale) spectrometer (TSI model 3910)
Los Alamos	yes	yes
ATI Inc.	yes	no

Because the ASME AG-1 code does not distinguish or specify the flow measurement unit that should be used, an end user of a HEPA filter cannot be confident that the filter is being used at the optimum flow.

The end goal of the project is to create a peer-reviewed and verified analytical method to explain HEPA filter collection efficiency to different flow rates, temperatures and altitudes.

A preliminary analytical approach has been developed by the authors of this proposal. This method recognizes the distinction in pressure drop generated by viscous forces compared to inertial forces (Fox and McDonald 1978, and Bergman 2008). When an air filter is used at one altitude and then moved to a different altitude, the pressure drop will be affected according to the slip correction factor of air flow around the individual fibers in the air filter (Cunningham 1910, Stern, Zeller and Schekman 1960, and Hinds 1999).

The preliminary HEPA method contains a (possibly) new formulation of the nondimensional Reynolds number. This is the ratio of the inertial force to the viscous force on an object, and contains the density, velocity, dimensional and viscosity values of the system. This preliminary formulation was used to plot the relation to the measured (Bergman 2008) pressure drop across HEPA filters, in a manner that seems to give a more usable relationship, compared to past approaches.

When an analytical method is created, it should be optimized for design and description purposes. As an example, an initial design method for cyclonic air pollution samplers (Moore and McFarland 1990) was not as user-friendly as the later improved version (Moore and McFarland 1993). In the later method (with 70 journal citations to date), the authors reformulated the pertinent nondimensional numbers that describe the air sampler performance. The earlier method (with 22 journal citations to date) required an unwieldy iterative solution, and the later method not only eliminated this issue, but also expanded the applicability of the design method to a larger number of system geometries. (Both design methods used the air sampler air flow, physical size dimensions and aerosol size diameter as input parameters.)

For the current (2015) proposal, the preliminary analytical method has the possibility to improve the ability to explain HEPA filter collection efficiency performance at different flow rates, temperatures and altitudes.

Technical Description (Milestones)

(1) A set of HEPA filters will be collected at Los Alamos for testing. Several filters were purchased three years ago for this project, and we expect to use these same unused filters.

(2) The second part of the paired tests will be performed at ATI Test (Maryland). Air flow measurements will be compared between the two sites with an ASME compliant orifice plate flow calibrator. Filter performance measurements will be compared between the two sites.

(3) Monthly status reports will be written.

(4) A final report of the work will be prepared at the completion of the project. It is expected that one or possibly two publishable articles could be produced from this effort.

Technical Description (Transition Plan)

Completion of the peer-reviewed and verified analytical methods would be the first-year goals for this project. We would consult with the ASME AG-1 committee members Scott Salisbury (Los Alamos staff member), Werner Bergman (Aerosol Science) and Andy Stillo (Camfil Farr Inc).

III. COST AND SCHEDULE

This project is expected to require six months, after the receipt of funding.

LANL Personnel: Murray E. Moore and Austin D. Brown.

Name	Education	Months on project	Fraction of effort	Costs, $K
Murray E. Moore	PhD, PE	6	0.05	$13
Austin D. Brown	BSME, May 2014	6	0.50	$61
M&S				$5
Travel by LANL to ATI Test (Moore and Brown)				$3
Travel by Bergman (ASME Chief Scientist)				$7
TOTAL Project				$89

IV. RESEARCH TEAM

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Note: Four years of student experience with HEPA filters and nuclear filter projects.

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Mr. Chris Hart
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