ANALYSIS OF MANUFACTURER SUPPLIED 'AIR-AEROSOL' MIXING DATA COLLECTED FOR QUALIFYING PERFORMANCE OF COMMERCIAL HEPA FILTER TESTABLE HOUSINGS*

Ronald C. Scripsick
Los Alamos National Laboratory
Industrial Hygiene and Safety Group
Los Alamos NM 87545

Abstract

Commercial testable housing (CTH) manufacturer data on challenge concentration uniformity was analyzed and interpreted. Results found challenge concentration uniformity was between values observed in well-mixed systems and those found for an operating HEPA filter air cleaning system in a nuclear facility. Acceptance limits on in-place filter test results were found in a range such that photometer test methods can be used.

Introduction

Replacement, upgraded and new HEPA filter aerosol emission control systems for nuclear facilities rely heavily on so-called commercial testable housings (CTHs). These are commercially available filter housings that, among other features, provide for in-place leak testing of individual filters (see Figure 1). The housings typically include test aerosol injection ports, sampling ports, and engineered flow obstructions to promote mixing. The injection and sample ports are frequently fitted with manifolds intended to reduce effects that spatial variation of aerosol concentration or concentration heterogeneity may have on uncertainty in in-place filter test results. The flow obstructions or aerosol mixers are intended to reduce these heterogeneities.

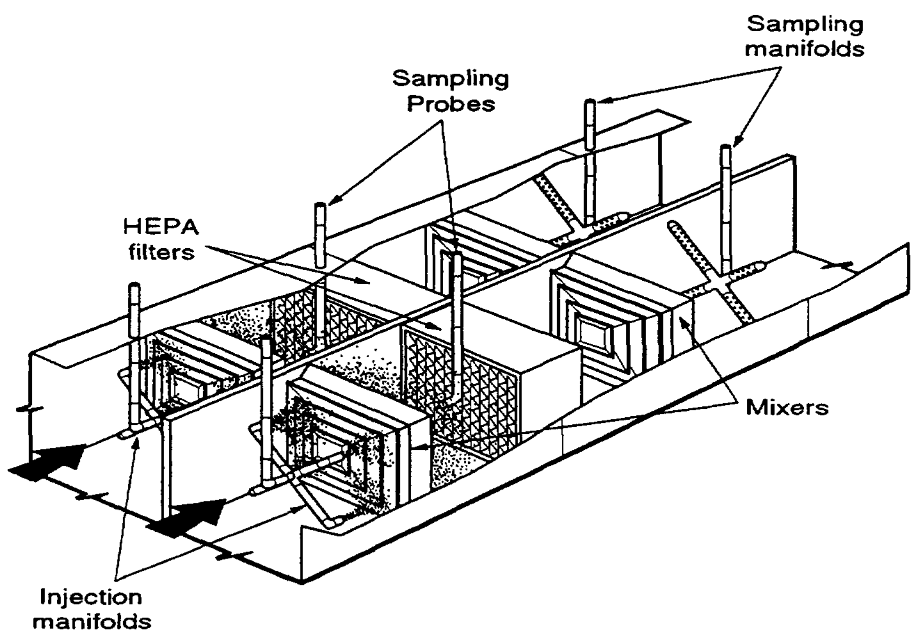

Figure 1 Diagram of commercial testable housing (CTH) showing components for aerosol injection, sampling, and mixing.

*Support for this work comes from the US Department of Energy, the Office of Defense Programs (DP-45). The Program Manager is James W. Slawski.

The 'Air-Aerosol Mixing' testing requirements of ASME N510 (Section 9) are commonly included as part of the system performance qualification of CTHs.[1] The intent of this testing is to determine whether challenge aerosol concentration heterogeneity (H_{Uf}) meets system performance acceptance criteria for HEPA filter stages that include multiple HEPA filters. The test procedure calls for concentration measurements to be made at the center of each filter over the plane just upstream of the filters, called the challenge plane. The ASME acceptance criteria are that no measurement shall exceed ±20% of the mean concentration determined from the average of the measurements. For CTHs, measurements are made in the challenge plane at locations uniformly spaced over the filter face. Generally, acceptance is determined using the ASME criteria.

Development of an uncertainty expression for in-place filter testing showed that challenge concentration heterogeneity can be a dominate factor in test result uncertainty.[2,3] To demonstrate this finding, the expression was used to predict test result uncertainty ($H_{\hat{P}}$) over a range of H_{Uf} for a filter system that otherwise meets requirements of ASME N510:

$$H_{\hat{P}} = \left[H_{Uf}^2\left(1 + h_D^{-2}\right) + \frac{H_P^2}{h_D^2} + \frac{H_Q^2}{h_D^2} \right]^{1/2} \quad (1),$$

where, H_{Uf} = challenge concentration heterogeneity = $\frac{S_{Uf}}{\overline{X}_{Uf}}$, S_{Uf} = the standard deviation of concentration measurements in the challenge plane, and $\overline{X}_{Uf}$ = the mean of the concentration measurements, h_D = the downstream mixing factor, which is the ratio of the concentration heterogeneity in the plane immediately downstream of the filter bank to that in the downstream sampling plane, H_P = penetration heterogeneity = $\left(\hat{P}^{-1} - 1\right)^{1/2}$, $\hat{P}$ = the penetration point estimate, H_Q = the challenge flow velocity heterogeneity = $\frac{S_Q}{QA}$, S_Q = the standard deviation of flow velocity measurements in the challenge plane, Q = the system volumetric flow rate, and A = the area of the challenge plane. Results of the analysis are shown in Figure 2 for a penetration point estimate of 5×10^{-4} penetration. Predicted values of the $H_{\hat{P}}$ varied with H_{Uf} and were within 14% of the values of H_{Uf}.

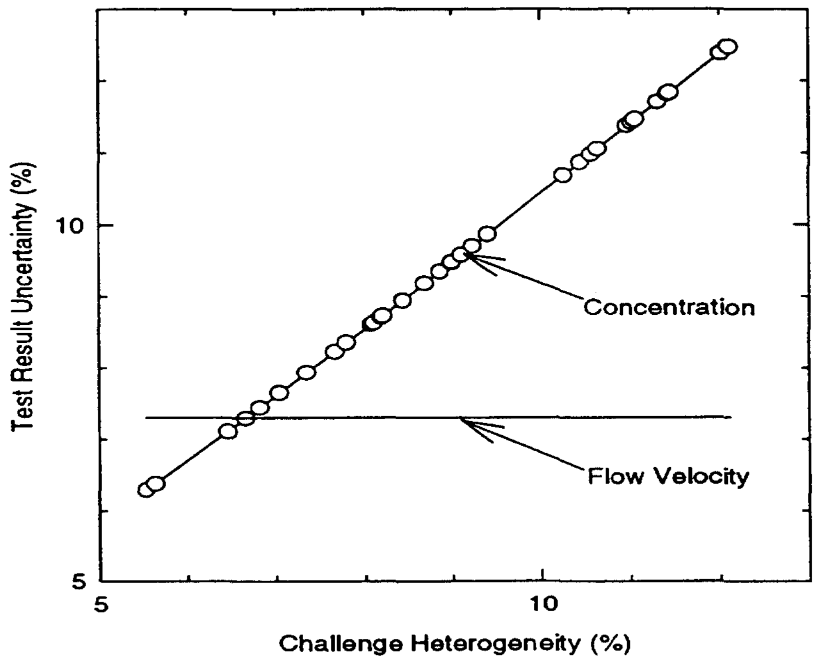

Figure 2 Plot of predicted test result uncertainty over a range of heterogeneity values.

A similar analysis was performed to evaluate the predicted dependence of $H_{\hat{p}}$ on the challenge flow velocity heterogeneity, H_Q. In contrast to the results of the concentration heterogeneity analysis, test result uncertainty ($H_{\hat{p}}$) showed almost no dependence on H_Q (see Figure 2).

To assess the potential impact on CTH in-place filter tests results, challenge concentration uniformity data provided by filter housing manufacturers was reviewed and analyzed. Data on aerosol concentration profiles over the challenge plane was obtained from manufacturer test reports. Challenge aerosol concentration heterogeneity was calculated using these data. Values of test result uncertainty were approximated from heterogeneity values using the uncertainty expression developed at Los Alamos.[2,3] Uncertainty estimates were used to predict test result acceptance limits that assure compliance with a system performance acceptance limit of 5×10^{-4} penetration.

Methods

CTH manufacturers as part of the qualification of CTH designs perform determinations of challenge concentration uniformity. Data from qualification of test sections produced by Charcoal Service Corporation (CSC) Inc., Bath, NC (currently CSC Flanders Inc.) were analyzed in this study. These data were found in two reports issued by the company as documentation of the qualification of the designs of their test sections.[4,5] The reports describe tests and list test results as evidence for meeting requirements of ASME N510, Section 9. The CSC tests for 'Air-Aerosol Mixing' involved injecting a test aerosol through the CTH injection port and measuring relative aerosol concentration over the challenge plane. Test aerosol was produced using an Air Techniques Inc. Model TDA-5A aerosol generator. Relative aerosol concentration measurements are made with an Air Techniques Model TDA-2A photometer.

Two distinct housing designs were tested. One is a '1 high X 2 wide', two-stage system.[4] Upstream test geometry for this design is shown in Figure 3. The injection manifold consists of two horizontal tubes with exit holes along the length of each tube. A shroud/diffuser combination is used for the challenge mixer. A single point sample is collected in the challenge plane.

A total of 32 tests on this design were reported. Independent tests were performed on each filter in each stage. Tests were repeated for each of four airflow inlet configurations and for seismic and non-seismic versions of the housing. In each test, aerosol concentration measurements were made at 16 uniformly spaced locations within the challenge plane.

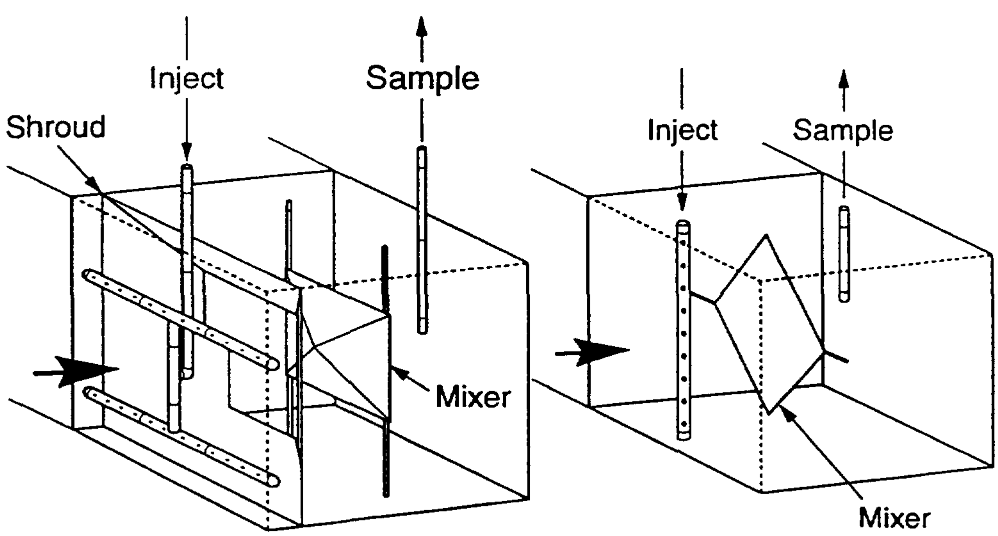

Figure 3 Upstream test geometries for CTH designs. Diagram on left is for the two-stage system. The diagram on the right is for the single stage system.

The other CTH design is a '1 high X 2 wide' single stage system.[5] Upstream test geometry for this design is also shown in Figure 3. The injection manifold is a single, vertical tube. The challenge aerosol mixer is a single diffuser plate. A single-point sample is collected within the challenge plane at the center point of the filter.

Two tests of this design were reported, one for each filter. Each test consisted of 9 aerosol concentration measurements made at uniformly spaced locations within the challenge plane.

Analysis of Manufacturer's Results

In the manufacturer's reports, data for each test included individual challenge concentration measurements, the mean concentration, and the ASME limits corresponding to ±20% of the mean. As part of the analysis performed in this study, computations of the mean concentration and ASME limit values were repeated. In addition, values of the challenge concentration heterogeneity, H_{Uf}, test result uncertainty, $H_{\hat{P}}$, and the test result acceptance limit were determined.

Of the total of 530 relative concentration measurements reported by the manufacturer, none were reported outside the ASME limits. The repeated computations showed 18 measurements that exceeded the ASME limit. Inspection of the data showed differences between manufacturer's results and those of the repeated calculations were related to rounding methods. The manufacturer's results were reproduced when ASME limits determined from rounded averages were rounded again and then compared to concentration profile measurements.

Values of challenge concentration heterogeneity (H_{Uf}) were calculated as the ratio of the standard deviation of concentration measurements over the mean the measurements. A total of 34 values were determined. In Figure 4 these heterogeneity values are plotted against the number of relative standard deviations corresponding to an absolute deviation of 20% of the mean. The 20% deviation represents the ASME limit. The heterogeneity values range from approximately 6% to just over 12%. In terms of standard deviations, the 20% deviation limit ranges from approximately 1.5 standard deviations to just over 3.5 standard deviations. Individual filter data sets which contain one or more of the concentration measurements that were determined to exceed the ASME acceptance criteria are plotted as triangles in Figure 4. These values of H_{Uf} range from approximately 8% to just over 12%.

The computed values of H_{Uf} were used to estimate test result uncertainty ($H_{\hat{P}}$) according to Equation 1. Results of these computations are shown in Figure 2 for $h_D = 1500$, $\hat{P} = 5 \times 10^{-4}$ penetration, and $H_Q = 6.7\%$. Test result uncertainty varied from approximately 6% to over 12%. Values of $H_{\hat{P}}$ exceeded the corresponding values of H_{Uf} by 3% to 14%.

Interpretation of Analytical Results and Discussion

Review of CTH manufacturer concentration measurements showed that some of the measurements were marginally above the ASME limit of 20% deviation from the mean. A disadvantage of the ASME approach of specifying an absolute deviation limit is that, because of the random variability inherent in concentration measurements, values outside these limits have some probability of being observed even though overall uniformity may be acceptable. Presumably, the likelihood of an observation being above some critical deviation level, i.e. 20%, increases with the heterogeneity. Existence of such an association is supported by the data shown in Figure 4, where data sets including observations above the ASME limit are associated with the higher values of challenge concentration heterogeneity. Observation of values outside the limits could lead to 1) rejection of an otherwise acceptable system or system design or 2) repeated testing of a more marginal system design until an acceptable data set is obtained.

System acceptance based on concentration heterogeneity limits would be less affected by single concentration measurements. However, under such a heterogeneity limit approach, systems could be accepted that have local areas within the challenge plane where concentration deviations of more than 20% of the mean exist. One option could be to combine the two approaches by specifying limits on local concentration deviations and an upper-bound on acceptable concentration heterogeneity.

Values of challenge concentration heterogeneity observed for the CSC CTHs span the 3 standard deviation (H_{Uf} = 6.67%) and 2 standard deviation (H_{Uf} = 10%) levels of the ASME limit (see Figure 4). The values are bracketed by values of concentration heterogeneity reported in the literature. Values of concentration heterogeneity in the range of 2-3% have been reported by Wood [6] for gas mixing downstream of a blower, and by Eddins et al [7] for aerosol concentration uniformity in a research wind tunnel. Scripsick et al [3,8] reported challenge concentration heterogeneity for a laboratory HEPA filter test system in the 3-5% range. A challenge concentration heterogeneity of approximately 15% was reported by Scripsick et al [3] for a nuclear facility multiple HEPA filter system.

Test result acceptance limits as defined above can provide an objective rationale for judging whether in-place filter test results support the conclusion that system performance meets acceptance criteria.[9] According to this rationale, penetration point estimates below the test result acceptance limit are judged to provide clear evidence that limits on system performance are being met.

For the CTHs, test result limits were found in the 3-4 x 10^{-4} penetration range for a system performance acceptance limit of 5 x 10^{-4} penetration. Using this rationale, the results indicate that in-place filter test results below approximately 3 x 10^{-4} penetration provide evidence that CTH system performance meets the acceptance limit.

For judging system acceptance, the test result limit can be compared to the minimum quantifiable limit (MQL) of the test measurement method. Systems with a test result limit above the method MQL are acceptable for use with that method. The CTHs were all found to have test result limits above 3 x 10^{-4} penetration. By this rationale, these systems could be used with a photometer measurement method having an MQL of approximately 5 x 10^{-5} penetration.

Application of the results of this study is limited to the CTH designs from which the data were obtained. Studies are needed on other CTH designs to determine the extent to which results of this study are applicable to other designs. Independent studies are needed to collect data on the designs represented in this study and other designs to objectively determine the levels of uncertainty in in-place filter test results from CTHs.

Conclusion

Uniformity of challenge aerosol concentration of the CTHs, based on analysis of manufacturer's data, was found to be between that observed in laboratory systems and for gases downstream of a blower, and that observed for a nuclear facility multiple HEPA filter air cleaning system. Values of test result uncertainty and test result acceptance limit indicate that tests performed on these systems can provide evidence useful in judging acceptability of system performance. The observed range of test result acceptance limit is sufficiently above the minimum quantifiable limit for the photometer method of in-place filter testing that the photometer can be used to perform these tests. Results of this study need to be substantiated with independent determination of challenge concentration heterogeneity for the CTHs designs reviewed here as well as for designs of other available CTH units.

References

1. The American Society of Mechanical Engineers: "Testing of Nuclear Air Treatment Systems: An American National Standard" (ASME N510-1989), New York (1989).

2. B.V. Mokler and R.C. Scripsick, "High Efficiency Filter Systems-General Observations, 1992-1993," Los Alamos National Laboratory, (LA-12763-SR), Los Alamos, New Mexico (1994).

3. R.C. Scripsick, R.J. Beckman, B.V. Mokler, W.C. Hinds, V.A. Martinez, "In-Place Filter Testing Geometry Effects on Test Result Uncertainty: Single Stage Systems," In review: *American Industrial Hygiene Association Journal* (1998).

4. Charcoal Service Corporation (Currently CSC Flanders, Inc.), "Qualification of Test Sections," Research and Development Report No. RD-89-04, Bath, North Carolina (1989).

5. Charcoal Service Corporation (Currently CSC Flanders, Inc.), Research and Development Report No. RD-92-060, Bath, North Carolina (1992).

6. Wood, G.O., "Characterization of Gas Mixing in an Exhaust Stack.," *American Industrial Hygiene Association Journal 56(8):* 788–793 (1995).

7. Eddins, P.M., P. Gao, H.K. Dillon, and W.E. Farthing, "A Compact Wind Tunnel for Evaluating Aerosol Samplers," *Applied Occupational Environmental Hygiene,* 11(1):44–55 (1996).

8. Scripsick, R.C, "Leaks in Nuclear-Grade, High-Efficiency Aerosol Filters," Ph.D. Dissertation, University of California, Los Angeles, Los Angeles, CA, (1994). Also published as a Los Alamos National Laboratory Report (LA-12797-T), Los Alamos, New Mexico (1994.)

9. Scripsick, R.C., R.J. Beckman, and B.V. Mokler, "Uncertainty in In-place Filter Test Results," *Proceedings of the 24th DOE/NRC Nuclear Air Cleaning and Treatment Conference,* CONF-960715, pp. 676-682, U. S. Department of Energy, Washington, DC (1997).