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Environmental Technology Protocol Verification Report

General Ventilation Filters

Prepared by

RTI

Research Triangle Institute

Under a Cooperative Agreement with

EPA U.S. Environmental Protection Agency

ETV ETV ETV

Notice

This document has been subjected to the U.S. Environmental Protection Agency's quality assurance and administrative reviews and has been approved for publication.

The EPA, through its Office of Research and Development (ORD), partially funded and managed the extramural research described here under Cooperative Agreement No. CR 822870.

Mention of trade names or commercial products does not constitute endorsement or recommendation by EPA for use.

The appendices are not included in the electronic version of this report. They contain raw data and the test method. Those interested in obtaining this information may contact

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Environmental Technology Verification Protocol Verification Report

General Ventilation Filters

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Acronyms and Abbreviations

ALA	American Lung Association
ARI	American Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASTM	American Society of Testing and Materials
CARB	California Air Resources Board
CBD	Commerce Business Daily
CV	Coefficient of Variance
EPA	Environmental Protection Agency
FTC	Federal Trade Commission
GSA	General Services Administration
HEPA	High efficiency particle absorption
IEST	Institute of Environmental Sciences and Technology
ITS	Intertek Testing Services
NAFA	National Air Filtration Association
OPC	Optical particle counter
QAPP	Quality Assurance Project Plan
RTI	Research Triangle Institute

1.0 INTRODUCTION

Throughout its history, the U.S. Environmental Protection Agency (EPA) has evaluated technologies to determine their effectiveness in preventing, controlling, and cleaning up pollution. EPA has expanded these efforts by instituting the Environmental Technology Verification (ETV) Program to verify the performance of a larger number of innovative technical solutions to problems that threaten human health or the environment. EPA created ETV to substantially accelerate the entrance of new environmental technologies into the marketplace. ETV supplies technology buyers and developers, consulting engineers, states, and U.S. EPA regions with high-quality, objective data on the performance of new technologies. This encourages more rapid protection of the environment with better and less expensive approaches. EPA selects its partners from both the public and private sectors, including federal laboratories, states, universities, and private sector facilities. Verification organizations oversee and report verification activities based on testing and quality assurance protocols developed with input from all major stakeholder/customer groups associated with the technology area.

The goals of the ETV pilot programs are to verify the environmental performance characteristics of commercial-ready technology through the evaluation of objective and quality assured data, to provide potential purchasers and permitters with an independent and credible assessment of what they are buying and permitting, and to establish “pilot” programs with partners. The pilot programs are intended to become self-sustaining.

2.0 APPROACH

The Indoor Air Products (IAP) program is focused on products that fall into three general technology areas: pollution prevention, contamination removal, and instrumentation. The goal of the IAP pilot program is to develop and verify the testing program infrastructure, not the products themselves. Producing specific product verification reports could reduce the value of the private certification programs.

To achieve this goal, the task was broken down into six separate steps:

1. **Select product sector**
   General ventilation air filters were chosen as one of several products for the IAP pilot. A standard test method being developed by American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE, 1998), ASHRAE Proposed Standard 52.2P, *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size,* is expected to be issued in 1999. Purchase specifications are expected to call out performance levels consistent with ASHRAE 52.2P testing. While EPA does not have regulatory responsibility for indoor air, the Federal Trade Commission (FTC) is interested in ASHRAE 52.2P relative to verifying advertising claims.

2. **Organize stakeholder group for the sector**
   The stakeholder group included representatives of the National Air Filtration Association (NAFA) and the American Refrigeration Institute (ARI), non-regulatory groups within EPA, General Services Administration (GSA), the Federal Trade Commission (FTC), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the American Lung Association (ALA), and the California Air Resources Board (CARB). Manufacturers and vendors within the industry were also represented.

3. **Develop test protocols**
   The protocol consisted of portions that were developed by RTI and EPA and other portions developed by the industry. RTI and EPA developed the test method and set standards for laboratory proficiency and quality. Industry specified the product definition, and procedures for acquisition, shipping, and handling.

4. **Include multiple laboratories**
   A notice placed in the *Commerce Business Daily* June 15, 1998, required laboratories to inform RTI of their intent to participate by July 15, 1998. Participation was open to any independent laboratory meeting the proficiency standards set by RTI.

5. **Conduct testing at participating labs**
   Testing was conducted between December 1998, and January 1999. Preliminary results were presented at the Stakeholders meeting held in Chicago January 22, 1999.

6. **Transition to independent private certification program**

3.0 TEST PROCEDURE

RTI used its own method for testing the fractional filtration efficiency of general ventilation filters. In summary, a filter is placed in a test rig equipped with samplers that detect the concentration of a generated aerosol both upstream and downstream of the filter. The ratio of upstream to downstream concentrations is an indication of the effectiveness, or efficiency, of the filter. The efficiency test is repeated following a conditioning step, and after each of four dust loading steps. The RTI method can be found in Appendix A, page A-i.

Although the RTI and ASHRAE 52.2P methods are very similar, there are key differences in the system qualification tests, the conditioning step, and the data reduction.

1. Eight tests are required for system qualification under the RTI test method. These tests include air flow uniformity, aerosol concentration uniformity, downstream mixing, aerosol generator response time, upper concentration limit, 100% efficiency, correlation ratio, and duct leakage. These tests are a subset of the qualification tests specified in ASHRAE 52.2.

2. The purpose of the conditioning step is to determine the minimum efficiency curve of the filter. Such conditioning initially decreases the efficiency of electrostatically charged filters by removing the charge without building up a dust cake. The conditioning aerosol is generated by a three-nozzle twelve jet Laskin nozzle for eight hours. This produces a challenge particle concentration of 120,000 particles per cubic centimeter. Very fine particles with a diameter less than 1 µm of solid phase potassium chloride are generated from a 1% aqueous solution. This differs from the ASHRAE 52.2P conditioning step, which uses standard ASHRAE dust as the conditioning aerosol.

3. In the RTI method, the penetration associated with a particle sizing channel is calculated as the ratio of downstream concentration to upstream concentration, corrected for the background concentration values and the correlation ratio. This data reduction method differs from that in ASHRAE 52.2P.

4.0 PARTICIPATING LABORATORIES

Three laboratories indicated their interest in participating to RTI and all three laboratories successfully met the qualifying criteria. As outlined in the CBD announcement, labs were required to have the necessary equipment and analytical capability, a quality management system in place, and an understanding of quality assurance and control. The participating labs were:

- Intertek Testing Services (ITS)
  Cortland, NY
- NSF International (NSF)
  Ann Arbor, MI
- Research Triangle Institute (RTI)
  Research Triangle Park, NC

5.0 TEST MATRIX

Three different types of filters were chosen for the testing reported. The purpose of the testing was to determine if the method was repeatable between labs and whether the results were reproducible with different filter types within a lab. All three labs tested electrostatically charged filters. Because of schedule restraints, only one lab also tested three high efficiency filters and three medium efficiency filters. The test matrix is illustrated in Table 1. The laboratories were assigned a random identification number.

Table 1. Test Matrix

Filter	Lab 1	Lab 2	Lab 3
Electrostatically charged	3	3	3
High efficiency	3	—	—
Medium efficiency	3	—	—

6.0 DATA QUALITY ISSUES

Quality assurance was integrated into the method by including system qualification tests and ongoing quality tests.

In addition, each lab prepared a Quality Assurance Project Plan (QAPP). This document detailed how documentation and records would be kept, data acquisition procedures, data management, procedures for assessments and audits and for implementing corrective actions. Also included in the QAPP were any deviations from the RTI test method, such as rig dimensions or configuration. The QAPP for RTI is included as Appendix B.

6.1 System Qualification Tests

Prior to testing, each lab was required to submit the results of its system qualification tests. These results are summarized in Table 2.

Table 2. Summary of System Qualification Test Results for Participating Labs

Parameter	**Required**	**Lab 1**	**Lab 2**	**Lab 3**
Air flow uniformity	CV < 10%	5.2%	3.6%	2.29%
Aerosol conc.	CV < 15%	5.4%	5.7%	11.6%
Downstream mixing	CV < 10%	5.8%	9.5%	9.59%
100% Efficiency	> 99% (all sizes)	100%	99.98%	99.92%
Correlation ratio	0.3 – 1.0 µm; 0.90-1.10 1.0 – 3.0 µm; 0.80-1.20 3.0 – 10 µm; 0.70-1.30	PASSED	PASSED	PASSED
Duct leakage	<1.0%	< 0.33%	< 0.67%	1%

6.2 Filter Qualification Tests

Quality control checks are included in the test method. Before each test run, a zero count baseline is established for the optical particle counter (OPC) by measuring high efficiency particle absorption (HEPA)-filtered air. A correlation ratio test, identical to the test performed for system qualification, is conducted before every test run to ensure that the bias between upstream and downstream particle counts is within acceptable limits. Background particle counts are measured before and after each efficiency test.

Other quality control tests are conducted on a routine basis. The sizing accuracy of the OPC is checked by sampling an aerosol containing monodispersed polystyrene latex spheres of known size. This is a calibration check that is performed daily. On a monthly basis, a HEPA filter is tested following the same procedure for filters to verify the ability to measure 100% efficiency.

6.3 Technical Systems Assessments

The purpose of the on-site assessments was two-fold: to evaluate and improve assessment tools developed under this pilot program, and to document the labs' quality systems with respect to the testing of air filters.

A basic checklist was developed from the test method and then tailored for each site visit using the lab's own QAPP. For an item to be included on the checklist, supporting documentation was required in either the test method or QAPP. For example, the checklist could not include verification of data against acceptance criteria because this was not included in either the test method or QAPP. The test method was revised to include this step in the procedure and outlined the calculations necessary to determine if the data met acceptance criteria.

By highlighting areas where additional documentation was needed in either the test method or QAPP, the on-site assessments were used to effectively evaluate the checklist. The revised checklist, incorporating changes and improvements suggested by the site visits, is given in Appendix C.

The on-site assessments were performed in December 1998 by RTI's Quality Assurance Officer and a technical representative.

Based on the information available to the assessment team, it appeared that all components reviewed would be able to support the quality of data required for this program. Common issues identified during the assessments include:

1. further clarification of the distinctives of the RTI test method relative to ASHRAE 52.2P,
2. the need for all test equipment to be under the control of calibration services,
3. the need for operator training and experience with the test method, and
4. the need for completing an integrated system for tracking test products and results.

7.0 RESULTS

7.1 Discussion

The results from the tests are presented graphically to illustrate how the efficiency of the filter tends to increase as particle size increases. The graphs also illustrate that dust loading increases the efficiency over all particle sizes.

Figures 1 and 2 show the results of the electrostatically charged filters tested by Lab 1. In both tests, conditioning the filter results in a drop of 5-10% efficiency for particle sizes less than 1 µm. For particle sizes greater than 1 µm, the effect of the conditioning step is negligible. Loading the filter with ASHRAE dust increases the efficiency. Results for only two filters are shown because problems encountered with the conditioning step invalidated the test results for the third filter.

The raw data for Lab 1's test of Charged Filter 1 are provided in Appendix D. The raw data for Lab 1's test of Charged Filter 2 are provided in Appendix E.

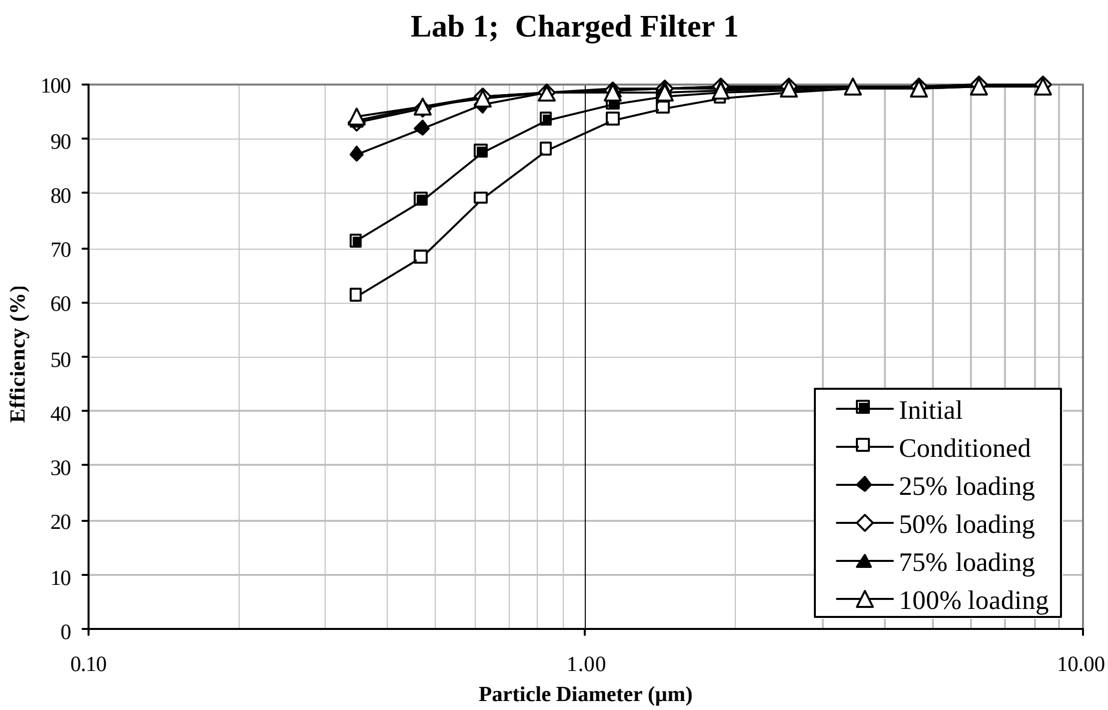

Figure 1. Family of Efficiency Curves for Electrostatically Charged Filter #1 Tested by Lab 1

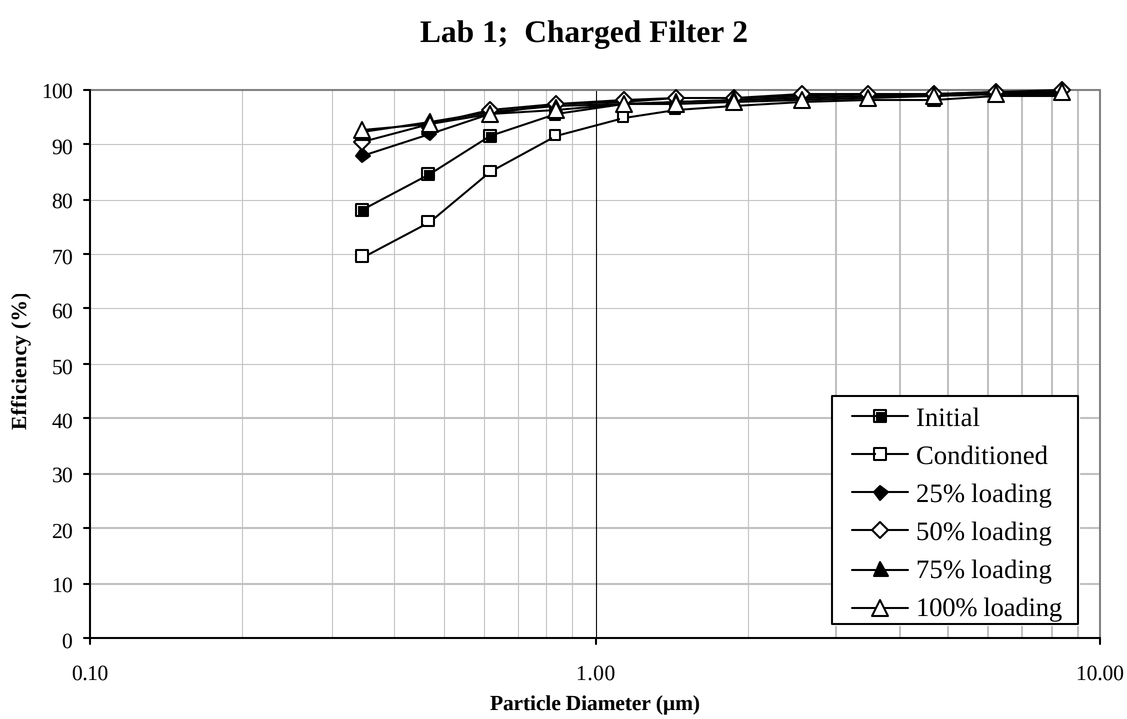

Figure 2. Family of Efficiency Curves for Electrostatically Charged Filter #2 Tested by Lab 1

Figures 3-5 show the results of the electrostatically charged filters tested by Lab 2. Again, the conditioning step caused problems. Instead of conditioning for 8 hours with a 1% KCl solution, Lab 2 exposed the first filter for 11 hours to a 6% KCl solution. This resulted in a larger particle size than intended, and that caused an increase in the efficiency of the filter, rather than the decrease that was expected.

The deviation from the test method was noted and the results of the conditioning step are not included in the graph. The data for the subsequent loading steps are valid because the effects of the conditioning step are negligible when compared to the effects of dust loading.

The raw data for Lab 2's test of Charged Filter 1 are provided in Appendix F. The raw data for Lab 2's test of Charged Filter 2 are provided in Appendix G. The raw data for Lab 2's test of Charged Filter 3 are provided in Appendix H.

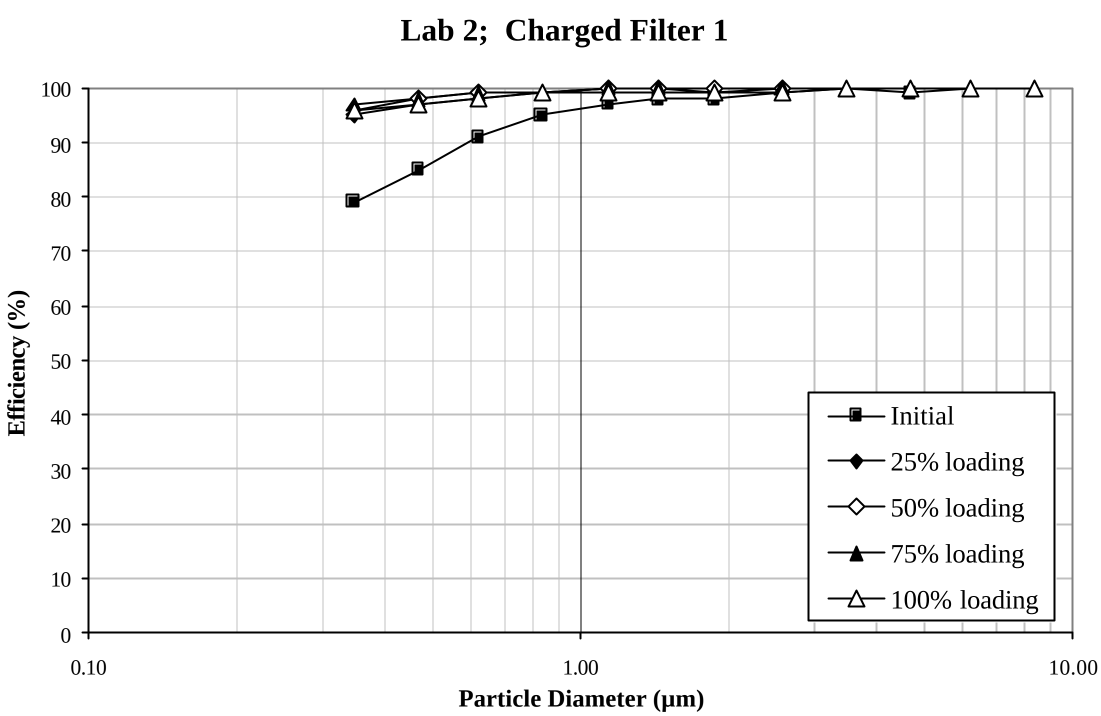

Figure 3. Family of Efficiency Curves for Electrostatically Charged Filter #1 Tested by Lab 2

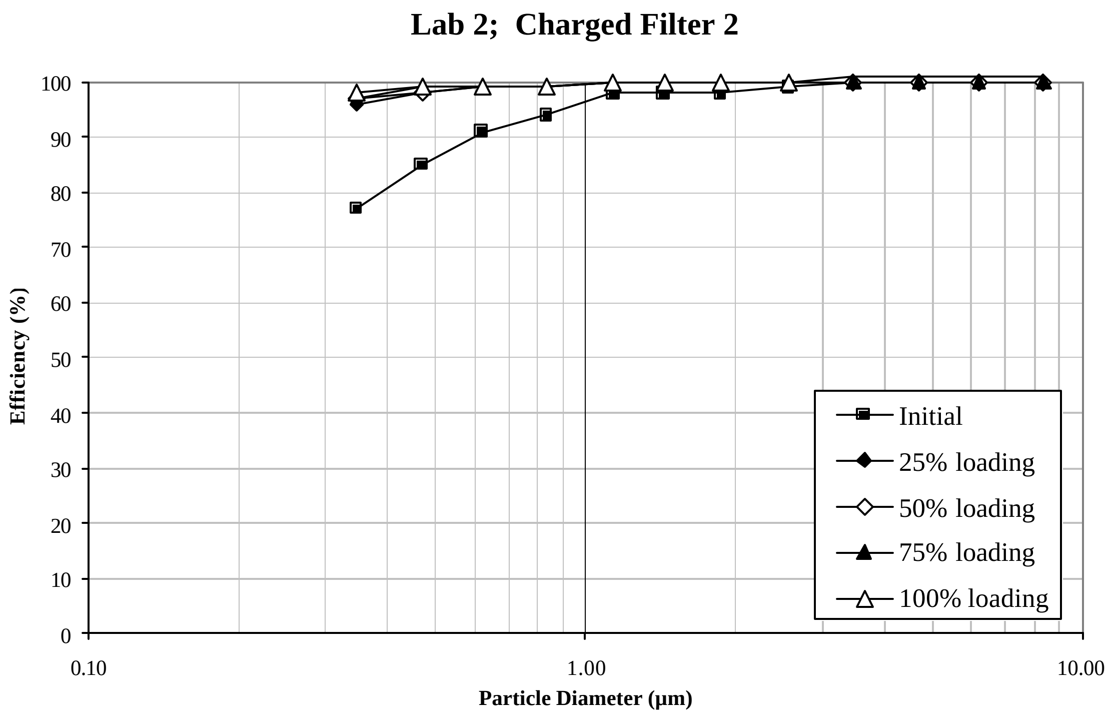

Figure 4. Family of Efficiency Curves for Electrostatically Charged Filter #2 Tested by Lab 2

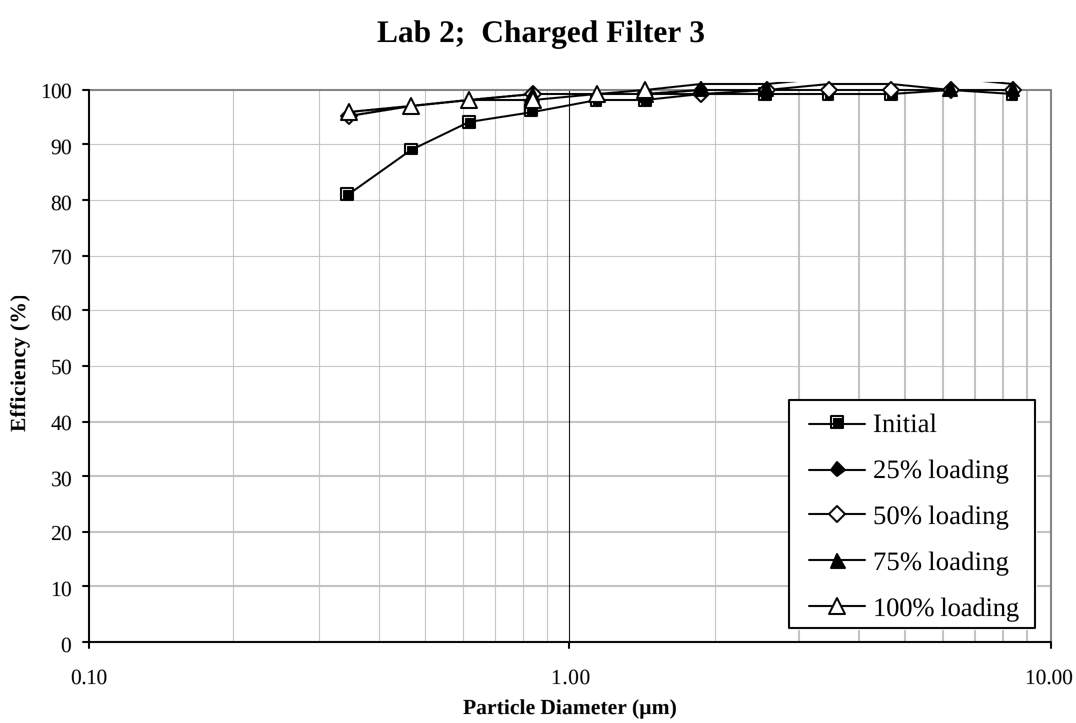

Figure 5. Family of Efficiency Curves for Electrostatically Charged Filter #3 Tested by Lab 2

Figures 6-8 show the results of the electrostatically charged filters tested by Lab 3. The conditioning step was performed as specified, and the results show a loss in efficiency following conditioning. Loading the filter with ASHRAE dust also increased the efficiency of the filter.

The raw data for Lab 3's test of Charged Filter 1 are provided in Appendix I. The raw data for Lab 3's test of Charged Filter 2 are provided in Appendix J. The raw data for Lab 3's test of Charged Filter 3 are provided in Appendix K.

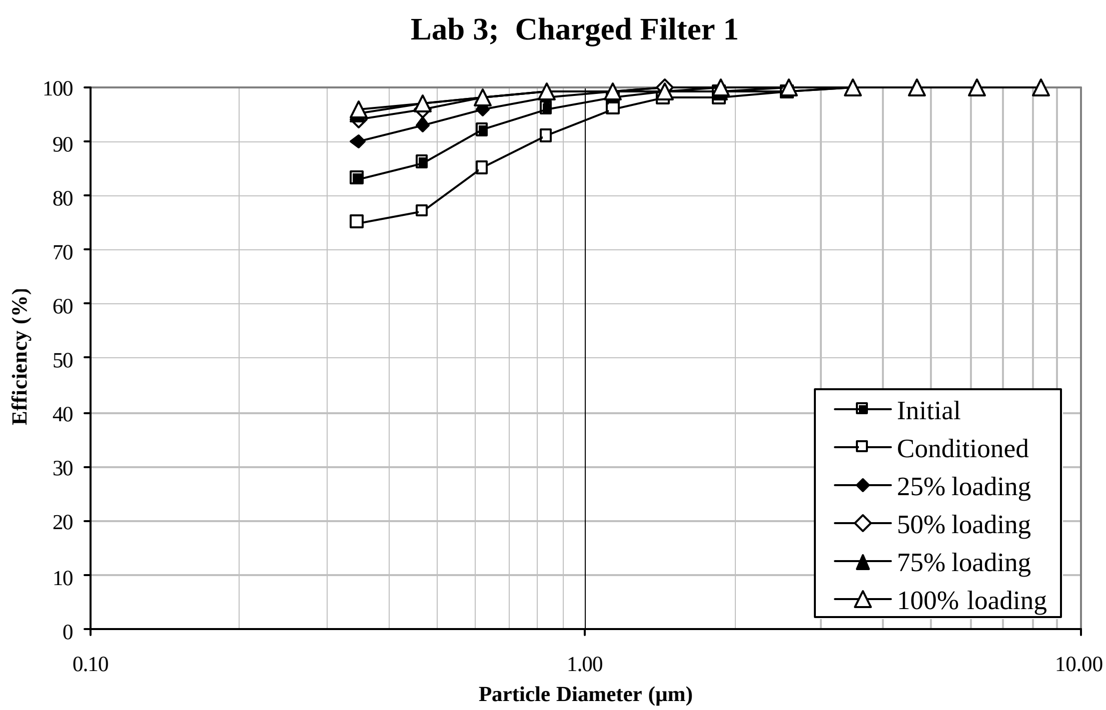

Figure 6. Family of Efficiency Curves for Electrostatically Charged Filter #1 Tested by Lab 3

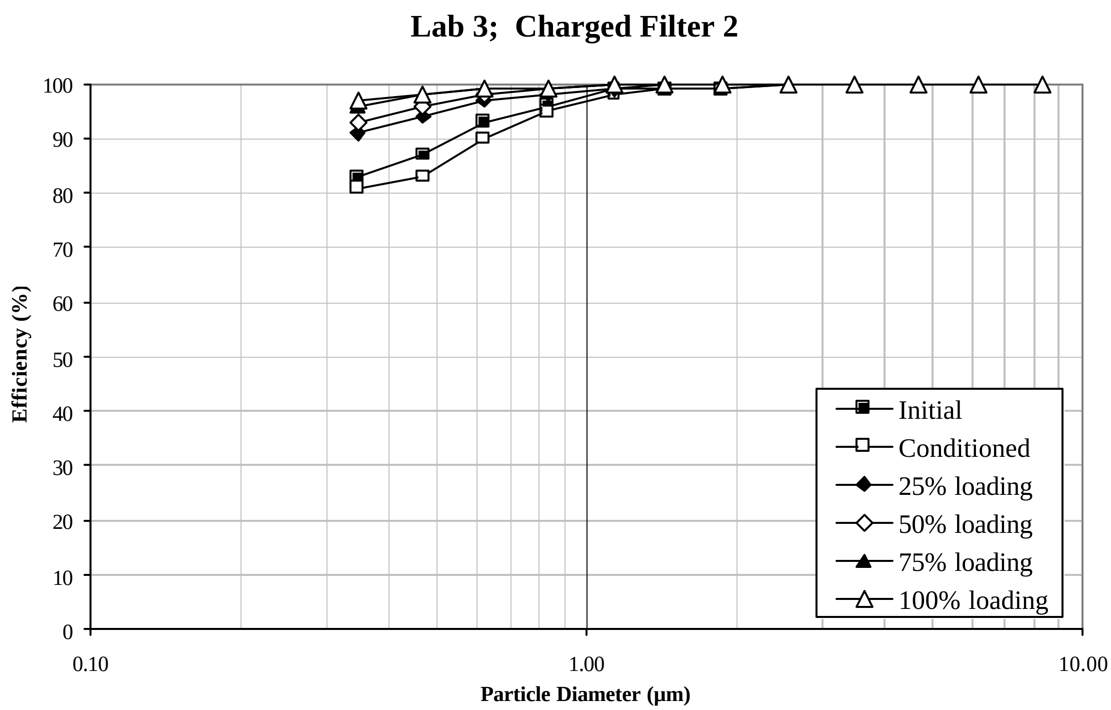

Figure 7. Family of Efficiency Curves for Electrostatically Charged Filter #2 Tested by Lab 3

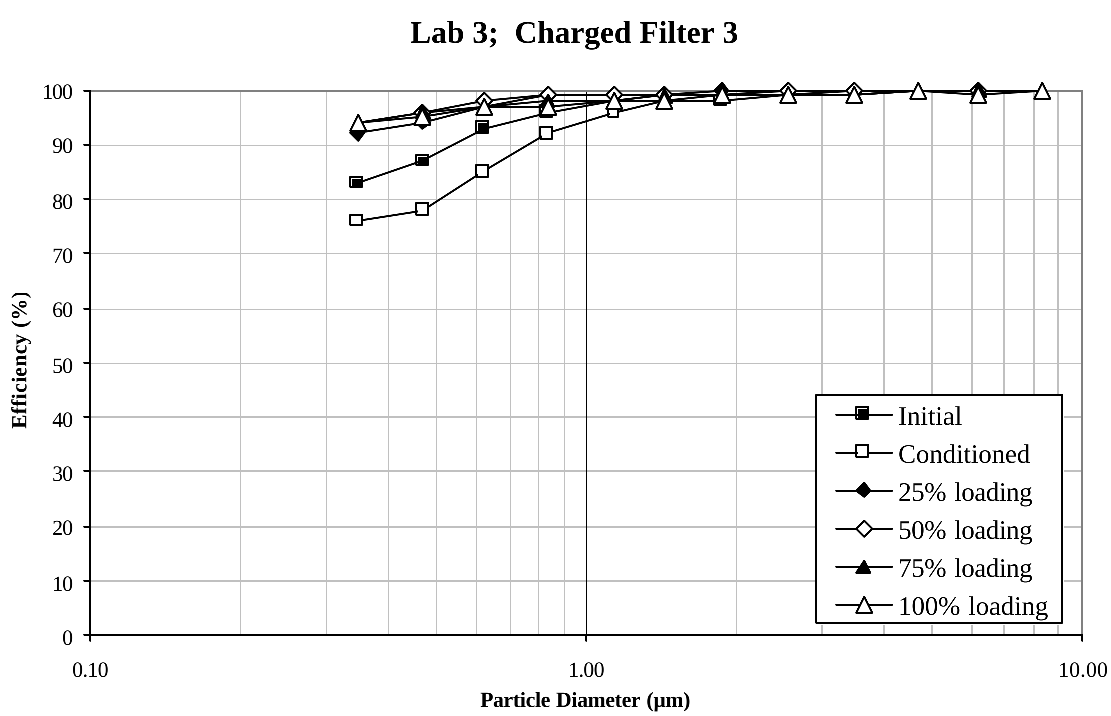

Figure 8. Family of Efficiency Curves for Electrostatically Charged Filter #3 Tested by Lab 3

Figure 9 is a compilation of the results in a single graph. The chart shows only the averaged values for the initial efficiencies. For Lab 1, this is an average of two filters. Labs 2 and 3 tested three filters each. There is excellent correlation between the three labs.

Figures 10-12 show the results of the medium efficiency filters tested by Lab 1. The initial and conditioned curves illustrate particle bounce – the leveling of the curves for particle sizes larger than about 1.2 µm. The larger particles have sufficient mass and inertia to penetrate the filter while smaller particles are caught. Again, loading the filter with ASHRAE dust increases the efficiency. Unlike the charged filters, conditioning resulted in a small increase in efficiency.

The raw data for Lab 1's test of Medium Efficiency 1 are provided in Appendix L. The raw data for Lab 1's test of Medium Efficiency 2 are provided in Appendix M. The raw data for Lab 1's test of Medium Efficiency 3 are provided in Appendix N.

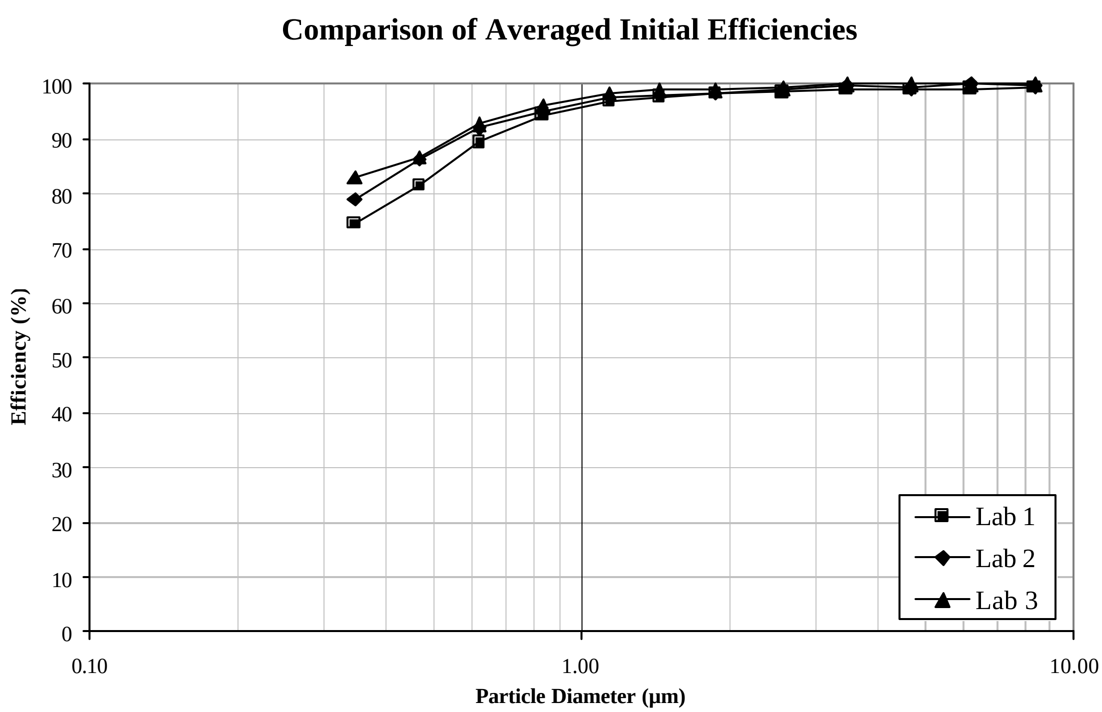

Figure 9. Comparison Between Labs

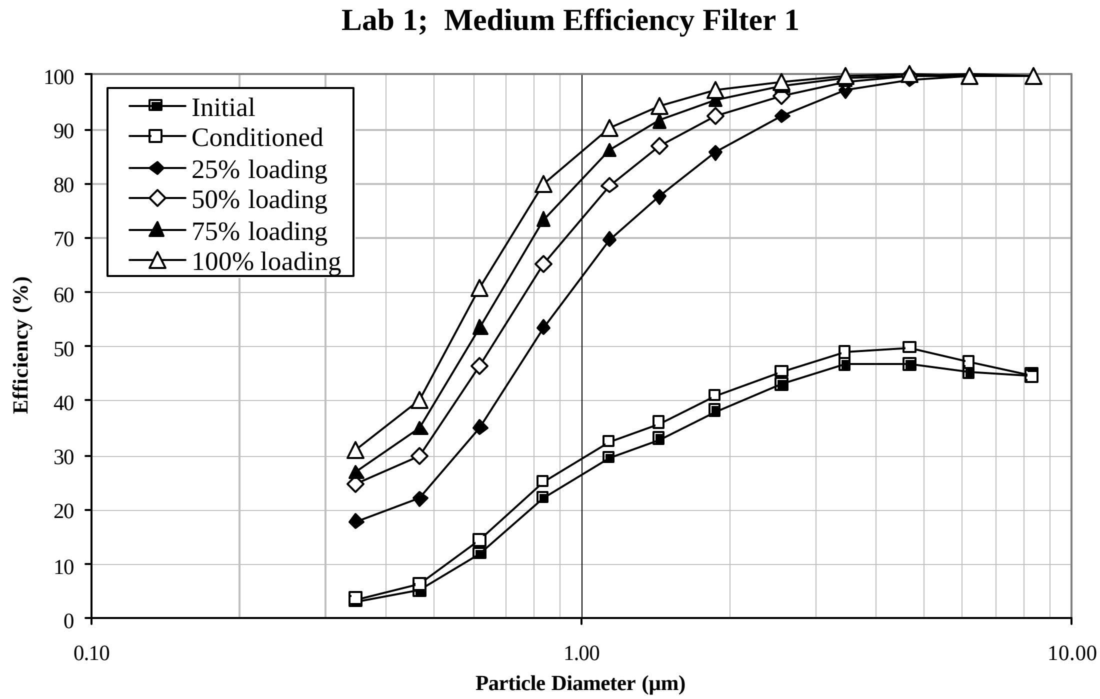

Figure 10. Family of Efficiency Curves for Medium Efficiency Filter #1 Tested by Lab 1

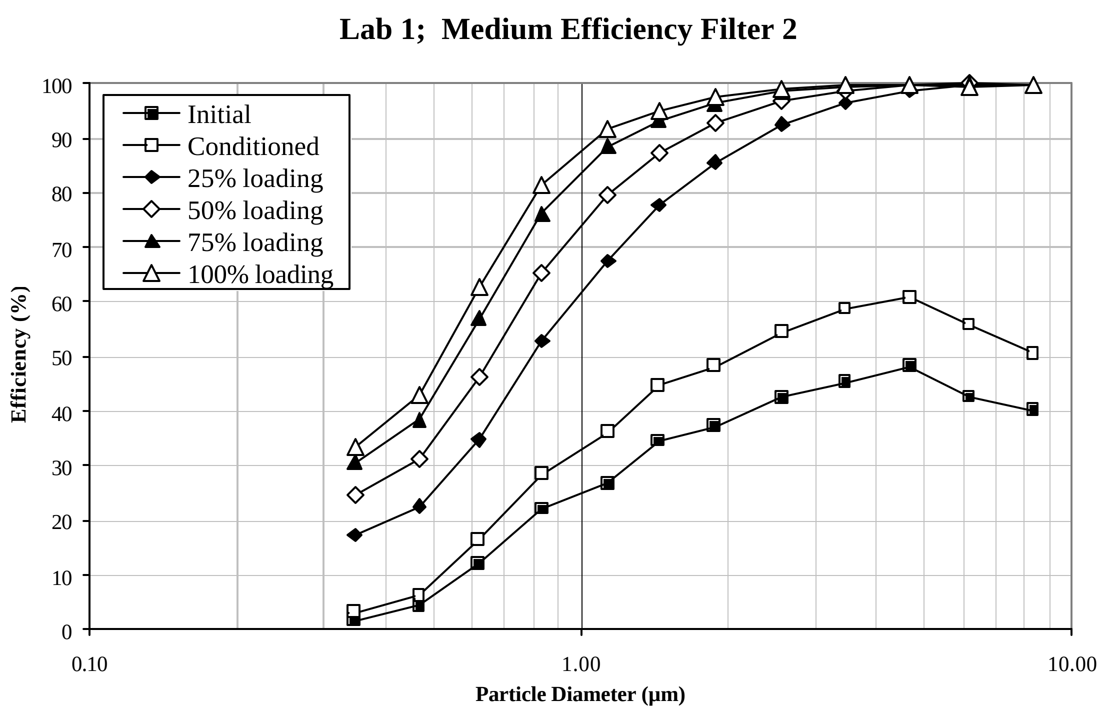

Figure 11. Family of Efficiency Curves for Medium Efficiency Filter #2 Tested by Lab 1

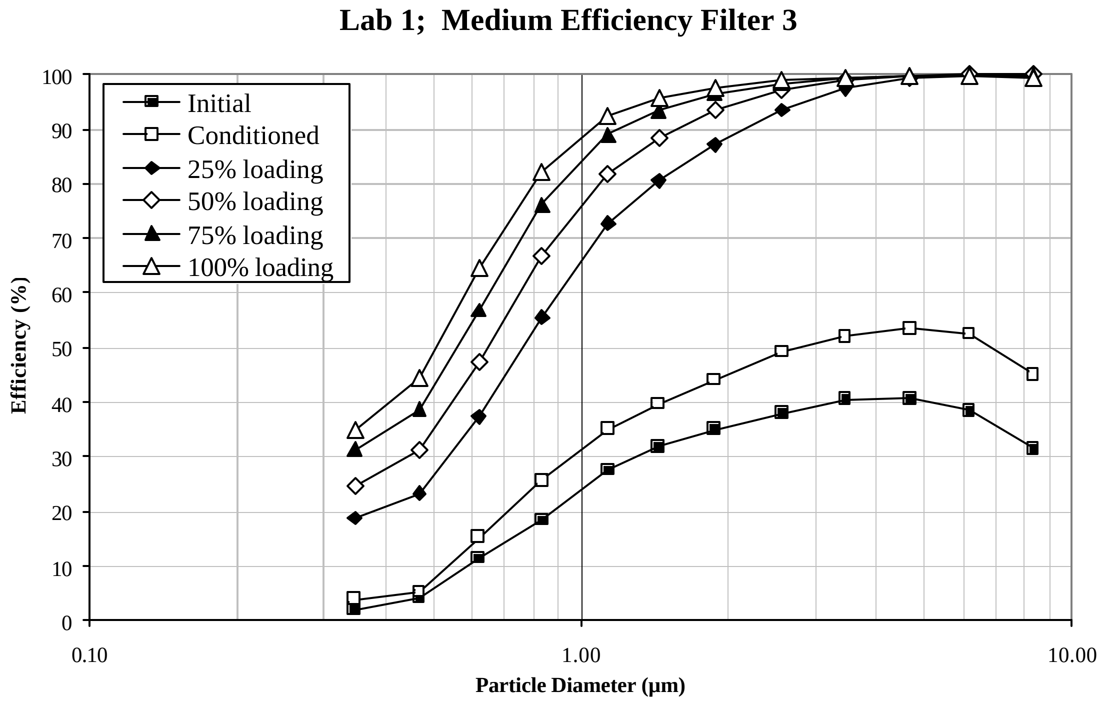

Figure 12. Family of Efficiency Curves for Medium Efficiency Filter #3 Tested by Lab 1

Figures 13-15 show the results of the high efficiency filters tested by Lab 1. The results for all three filters are nearly identical, suggesting high reproducibility. Again, loading the filter with ASHRAE dust increases the efficiency. Unlike the charged filters, conditioning resulted in a small increase in efficiency.

The raw data for Lab 1's test of High Efficiency 1 are provided in Appendix O. The raw data for Lab 1's test of High Efficiency 2 are provided in Appendix P. The raw data for Lab 1's test of High Efficiency 3 are provided in Appendix Q.

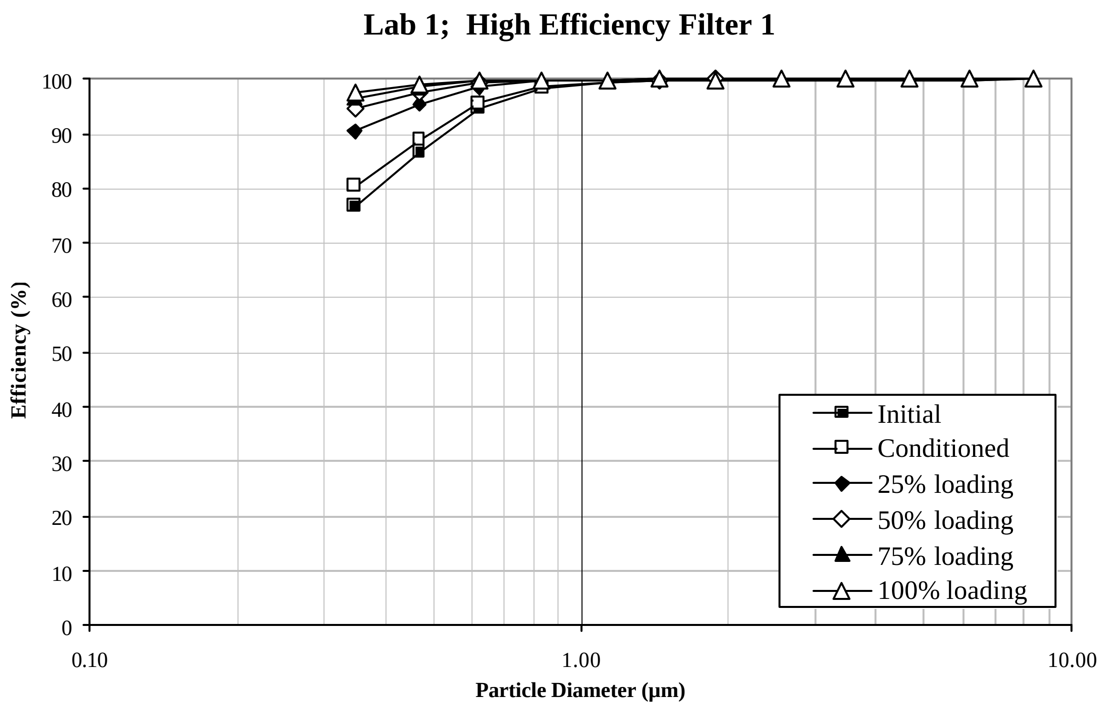

Figure 13. Family of Efficiency Curves for High Efficiency Filter #1 Tested by Lab 1

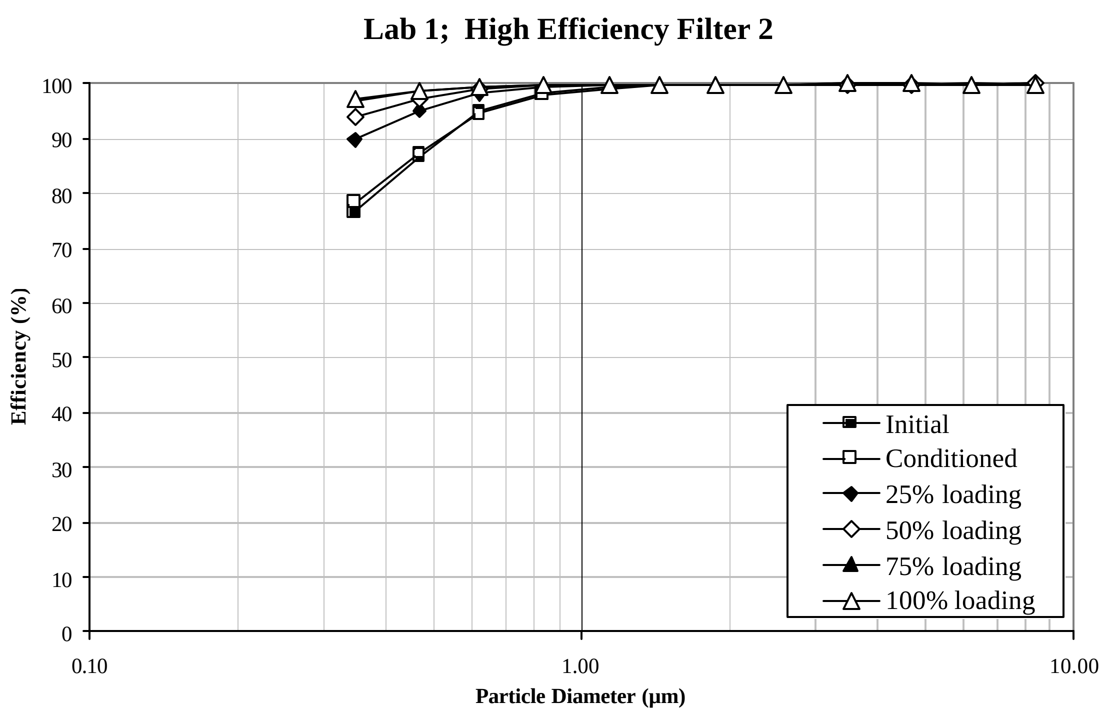

Figure 14. Family of Efficiency Curves for High Efficiency Filter #2 Tested by Lab 1

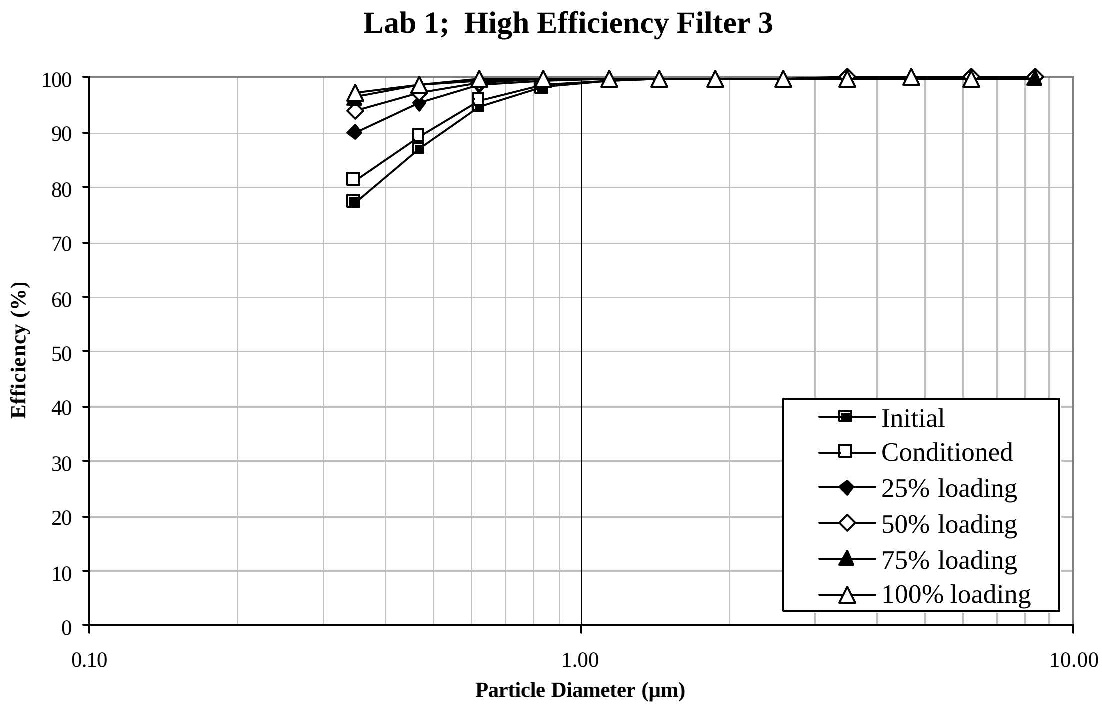

Figure 15. Family of Efficiency Curves for High Efficiency Filter #3 Tested by Lab 1

7.2 Analysis

The results of the electrostatically charged filters tested by the three labs were analyzed following the method described in *Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method* (ASTM E691). The statistical analysis examines the consistency of the test results from laboratory to laboratory and the consistency of results within a laboratory from one laboratory to another.

Such a statistical analysis is necessary because not every factor that may influence the outcome of a test can be completely controlled. Some differences may result from unavoidable random errors while others may result from the inherent variability of the test procedure itself.

Different factors that may contribute to variability in the application of a test method include the operator, the equipment used, the calibration of the equipment, and the environment (temperature, humidity, etc.). The reproducibility measure *h* considers these four factors as sources of variability and reflects what precision might be expected when randomly selected samples are sent to random "in-control" laboratories. The repeatability measure *k* reflects what precision might be expected when these four factors are kept or remain nearly constant.

The *h* and *k* values for the three labs were determined for all twelve particle sizing channels. The values for the initial efficiency test results are shown in Tables 3 and 4. The critical values for *h* and *k* were taken from Table 12 of ASTM E691, where *p* is the number of laboratories and *n* is the number of samples. For $p = 3$ and $n = 3$, $h_{critical} = 1.15$ and $k_{critical} = 1.67$. Values that exceed the critical values are in bold typeface. Values that approach the critical values are underlined. It should be noted that the relative inexperience with the test method is likely to skew the results towards higher values.

Table 3. Initial Efficiency – *h*†

	Particle Sizing Channel											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Lab 1	-1.03	-1.15	-1.12	-1.00	-1.08	-0.71	-0.80	-1.10	-1.14	-1.10	-1.05	-1.03
Lab 2	0.07	0.47	0.31	0.00	0.17	-0.44	-0.31	0.25	0.42	0.25	0.12	0.07
Lab 3	0.96	0.68	0.81	1.00	0.90	1.14	1.12	0.85	0.72	0.85	0.94	0.96

†Critical value = 1.15

Table 4. Initial Efficiency – *k*†

	Particle Sizing Channel											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Lab 1	1.58	1.50	1.42	1.37	1.30	0.81	0.87	1.54	1.52	1.58	1.59	1.17
Lab 2	0.70	0.84	0.92	0.99	0.94	0.89	0.98	0.54	0.70	0.54	0.69	1.27
Lab 3	0.07	0.20	0.36	0.36	0.65	1.24	1.13	0.57	0.45	0.44	0.00	0.00

†Critical value = 1.67

The data are shown graphically in Figures 16 through 19.

For *h* graphs, a pattern of all negative values in one lab balanced by all positive in another lab is not unusual. A mix of positive and negative values within a lab may be cause for investigation. In this case, the mix may result from inexperience with the test method and may not necessarily reflect a shortcoming with the method itself.

For *k* graphs, high *k* values for one laboratory as compared to the others represent imprecision within that laboratory. Very small *k* values may indicate a very insensitive measurement scale or other measurement problem.

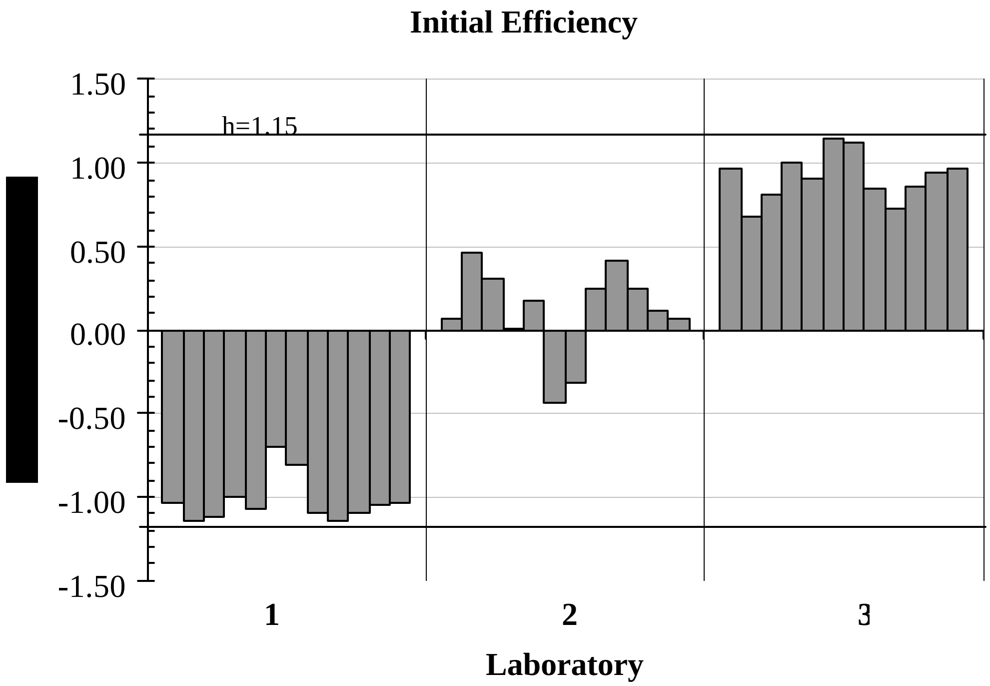

Figure 16. Initial Efficiency – Reproducibility h: Particle Sizing Channels Within Laboratories

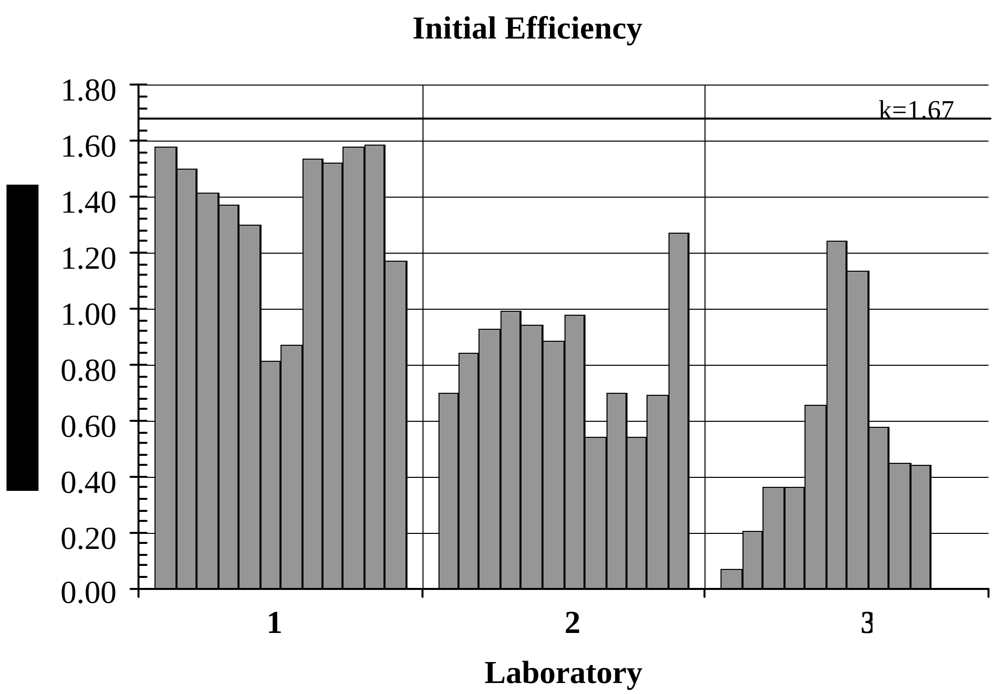

Figure 17. Initial Efficiency – Repeatability k: Particle Sizing Channels Within Laboratories

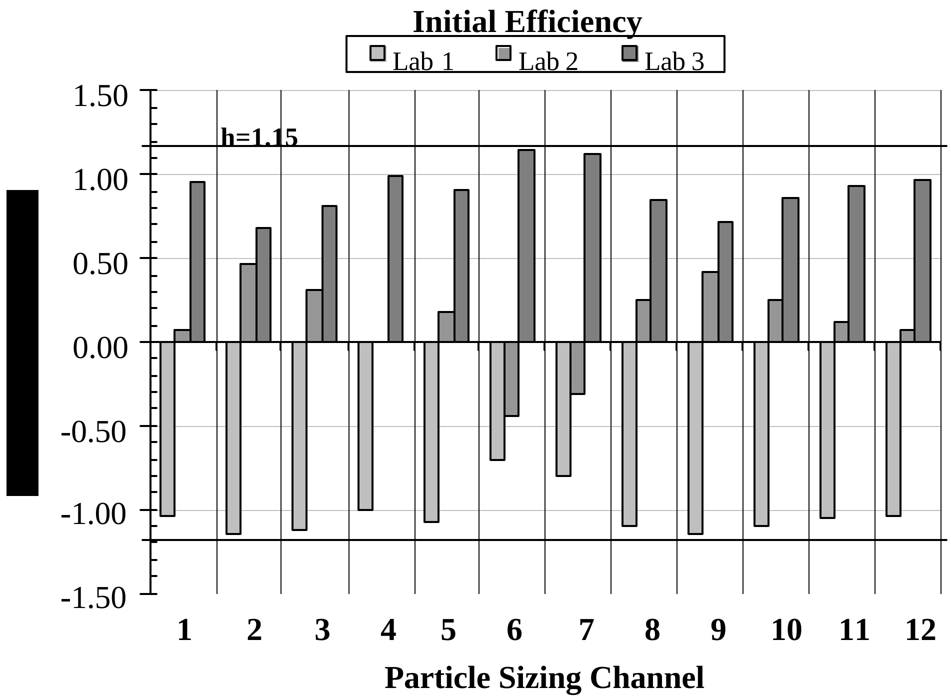

Figure 18. Initial Efficiency – Reproducibility h: Laboratories Within Particle Sizing Channels

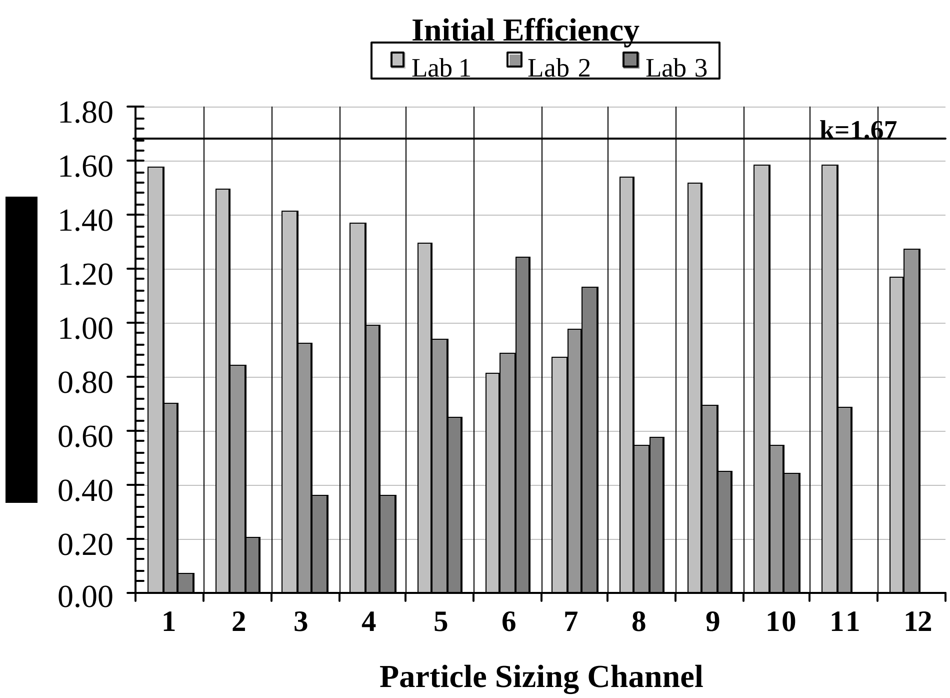

Figure 19. Initial Efficiency – Repeatability k: Laboratories Within Particle Sizing Channels

8.0 CONCLUSIONS

The results indicate that all three labs were able to successfully implement the test method and to meet the QA requirements. The method produced repeatable results within laboratories and reproducible results between laboratories within the variability of the method.

9.0 RECOMMENDATIONS

The following should be considered as the program moves toward privatization.

- Test method is complex and requires a learning curve.
- Full qualification testing must be completed prior to testing.
- Onsite evaluation invaluable to assess how well the test rig meets system requirements and identify potential problems.
- QA/QC as incorporated is critical to test method.
- Operators should be experienced with test method.
- Deviations from the procedure must be accurately reported.
- Because the test is destructive, surplus filters should be available to allow for unforeseen circumstances.
- Conditioning step difficult for all three labs to implement within constraints of study.

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