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Coordinate and Analyze Interlaboratory Testing of Filters under ASHRAE Standard 52.2 to Determine the Adequacy of the Apparatus Qualification Tests

Final Report

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RTI INTERNATIONAL

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1. Introduction

Under contract with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE, Project No. 1088-RP), RTI conducted an interlaboratory study (ILS) of ANSI/ASHRAE Standard 52.2-1999. The standard presents procedures for measuring the filtration efficiency of general ventilation filters over the particle diameter size range from 0.3 to 10 µm in 12 particle diameter size ranges. The filter is first evaluated in its clean condition for filtration efficiency and initial pressure drop. The filtration efficiency of the filter is then evaluated after each of five dust loading steps. From these efficiency measurements and measurements of filter pressure drop, composite efficiency values (the E1, E2 and E3 values of the standard) and the Minimum Efficiency Reporting Value (MERV) are derived. A complete 52.2 test (initial efficiency and efficiency after each of 5 dust loading steps) takes approximately 8 – 16 hours to complete and may span more than one day.

Testing is performed using a polydisperse challenge aerosol spanning the 0.3 – 10 µm size range. One or two multi-channel particle counters are used to measure the aerosol concentrations upstream and downstream of the filter. The ratio of the downstream to upstream aerosol concentrations, taken on a channel by channel basis, is used to compute the filtration efficiency for each of the 12 channels.

Many features of the 52.2 test duct are similar to the earlier 52.1 standard. Key differences include the use of multi-channel particle counters and an artificially-generated test aerosol to provide efficiency determinations as a function of particle size in place of the 52.1 single-valued "atmospheric dust spot efficiency." The 52.2 standard also added the MERV reporting parameter.

To help ensure consistent results, the 52.2 standard includes a series of "System Qualification Measurement Requirements." These include minimum performance specifications for the uniformity of the aerosol and airflow challenge at the test sections, upstream and downstream mixing and operating concentration range for particle counters. The standard also specifies the apparatus maintenance schedule and includes performance and design requirements for the aerosol generation and sampling system. Table 1 lists the apparatus qualification tests, the maintenance requirements and a number of the other design and performance specifications in the standard.

The purpose of the ILS was to determine if the system qualification tests are adequate to provide reliable test results. Testing was performed in two rounds:

> **Round 1** was a trial run during which each lab ran an initial efficiency test on two medium efficiency filters.

Round 2 consisted of six full 52.2 tests: two tests each of low, medium and high efficiency filters. These tests included dust loading.

The interlaboratory study (ILS) followed the American Society for Testing and Materials (ASTM) E 691-99 *Standard Practice for Conducting and Interlaboratory Study to Determine the Precision of a Test Method*. Table 2 provides an overview of the practice.

2. Organization of the ILS

2.1 Administrative:

As the ILS administrator, RTI performed the following tasks:

- Wrote the ILS protocol.
- Recruited test laboratories.
- Reviewed each laboratory's test apparatus qualification results and, when needed, provided guidance on how to perform these tests.
- Worked with project monitoring committee (PMC) on selection of filters for the ILS.
- Purchased sufficient quantities of the selected test filters and the test dust.
- Pre-tested the filters to quantify their uniformity followed by down-selecting to optimize uniformity of filters used in the ILS.
- Reviewed each laboratory's Round 1 results prior to giving approval to proceed with Round 2.
- Reviewed results from the first of the Round 2 filters from each laboratory prior to giving approval to proceed with remainder of Round 2 testing.
- Sent test filters and dust to the laboratories.
- Communicated with provided technical support to the laboratories.
- Followed up with test laboratories regarding any usual results.
- Reviewed laboratory results for correctness of mathematical computations and formulation.
- Performed the ILS statistical analysis of the test results.

Maintaining the confidentiality of the lab-to-data link was an important aspect in fostering lab participation and sharing of results. Thus, throughout the program and in this report, the lab-to-data link remains confidential.

Because RTI also participated in the ILS as one of the test labs (needed because of the small number of participating labs), RTI's ILS coordinator worked independently from RTI's commercial filter testing program and kept test results from other laboratories confidential. The ILS coordinator reported all results to participating labs simultaneously via email and contacted individual labs separately to identify their data.

Table 1. "Controls" specified in ASHRAE 52.2-1999

System Qualification Tests (Section 5.1 of ASHRAE 52.2)

- Air Velocity Uniformity
- Aerosol Uniformity
- Downstream Mixing
- Overloading of Particle Counter
- 100% Efficiency Tests
- Correlation Ratio
- Aerosol Generator Response Time
- Duct Leakage
- Particle Counter Zero
- Particle Counter Sizing Accuracy
- Radioactivity of Aerosol Neutralizer
- Dust Feeder Airflow Rate
- Final Filter Efficiency

Apparatus Maintenance Checks (Section 5.2 of ASHRAE 52.2, excluding those listed above)

- Pressure Drop of Empty Duct
- Background Particle Count
- Reference Filter Check
- Venturi Dimensions of Dust Feeder
- Flow rates, Pressure Drop, Temp, RH, etc
- Cleaning of Test Duct

Specified elsewhere in standard (ASHRAE 52.2 paragraph shown in parentheses):

- Test duct dimensions and layout (4.2)
- Mixing orifice and baffle up and downstream (4.2)
- Limitations on use of diluters (4.4.3)
- Aerosol generator output must be dry particle (4.3.2)
- Aerosol generator output must be charge neutralized (4.3.3)
- Temperature in the duct must be between 50 - 100 ^{o}F (4.2.3)
- Relative humidity in the duct must be between 20 and 65% (4.2.3)
- Sample lines must transmit > 50% of 10 um particles (4.4.1)
- Sample lines must be rigid, conductive, identical geometry up and downstream. (4.4.4)
- Airflow measured with ASME nozzle (4.5)
- Minimum of 0.4 inch pressure drop across ASME nozzle at test flow (9.3)
- Particle counter properties (4.6)
- Dust feeder design and operation (4.7)
- Test aerosol (KCl) and loading dust (ASHRAE dust) (6)
- Calculation procedures (10)
- Data quality requirements: minimum counts, limits on correlation ratio, error limits (10)

Table 2. Overview of ASTM E 691 Standard Practice

Planning the ILS	
ILS Membership:	This group is responsible for the ILS. In this case, it would be RTI working with the PMC.
Basic Design:	Encourages keeping the test design simple and straightforward.
Test Method:	Requires the existence of a test method: ASHRAE 52.2 in our case.
Laboratories:	Requires a minimum of 6 labs for formulating a final precision statement; reasonable cross section of qualified labs; all labs that routinely run method should be encouraged to participate; a "familiarization" step should be included to help new labs become more experienced.
Materials:	Provides recommendations on number of samples; three or more levels are desired (in our case, low, medium and high efficiency filters), randomizing test samples, homogeneity of test samples.
Number of tests:	The usual minimum number of tests per sample is 3 to 4, but may be as low as 2 when it is unlikely that a test sample will be "lost" during testing. Two was specified for this project.
Protocol:	The protocol establishes how the labs interact with the ILS coordinator and how the labs are to carry out their testing.
Conducting the ILS	
Pilot Run:	A pilot run is highly recommended with just one or two materials to ensure that all labs fully understand the method and to allow labs with poor performance to take corrective action prior to full scale run. This corresponds to Round 1 of the ASHRAE project.
Full Scale Run:	Describes sample preparation and labeling, randomization, shipping, follow-up, replacement sets of test units, checking progress and data inspection
Calculation and Display of Statistics	
Calculations:	Determine whether the data are consistent (i.e., identify any outliers), follow up on any inconsistent data, compute precision statistics.
Display of Statistics:	Describes how to tabulate and graph the statistics in meaningful and useful ways. We may use additional means to display the data to convey the results.
Data Consistency	
Inconsistent data	Procedures to aid in identifying variability and inconsistencies between labs and within labs.
Investigation	Check for clerical, sampling and procedural errors.
Task Group Action	If unusual data can be linked to an error by the lab, test lab may repeat the test or the data may be removed from the calculations.
Precision Statement	
Repeatability	After any retesting or removing of data, the repeatability of the method is computed.
Reproducibility	After any retesting or removing of data, the reproducibility of the method is computed.

2.2 ILS Protocol

The first step in conducting the ILS was to write the ILS protocol. The protocol set the ground rules for the study and was given to each prospective lab. The protocol, presented in Appendix A, addressed the following:

- Provided the name, address, and contact information for the ILS Coordinator.
- Identified the test method to be used.
- Described the obligations of the participating laboratories.
- Specified the test schedule and test series.
- Provided forms for recording summary test information.
- Requested that the raw data as well as computed results be provided.
- Requested that each lab keep a record of any special or unusual events that occur during any phase of the testing. Such information may help in interpreting suspect data or for recommending improvement to the method.
- Instructed the labs to notify the ILS coordinator promptly whenever an error in test procedure or other problems arise.
- Requested additional information about the test rig, equipment, instrumentation and procedures that might help resolve measurements inconsistencies.

2.3 Laboratory Participation

RTI actively recruited test labs through announcement of the program at ASHRAE meetings and through email solicitations sent to approximately 100 interested parties including test laboratories and filter manufacturers.

Laboratories participating in the ILS were required to submit detailed substantiation of their test duct qualification results according to the 52.2 standard. Additional details on test duct configuration, aerosol generation system, aerosol sampling system, particle counter specification and design, ASME flow nozzle size, manometer specifications, temperature and humidity instruments, and any other supporting instrumentation was also required. This information was collected to provide a basis for investigating abnormal data.

All laboratories in the study met the ASHRAE apparatus qualification test specifications. However, on several occasions, there was confusion within various labs about how to perform these tests. In these instances, RTI provided guidance on how to perform the qualification tests. It was clear that the standard would benefit by expanding the discussion on how to perform these tests. It also was not clear if one type of particle counter used by two labs met the 52.2 requirements for “wide angle collection optics or other counters demonstrating good correlation in measuring particle size efficiencies.” The counters appear to be based on 90^{o} scattering. The definition of what constitutes “wide angle” or “good correlation” are not given in the standard. Finally, the standard should emphasize that aspects of the test duct that directly influence qualification test results need to remain firmly fixed in place. Three critical elements are the aerosol injection tube and the upstream mixing orifice and baffle plate. The precise positioning of these elements can strongly influence aerosol and airflow uniformity. Given that aerosol and airflow uniformity are performed on a two-year basis, it is important that these be designed and installed with a high level of permanence and robustness; removal of such critical items for daily, weekly or monthly cleaning is not compatible with the required long-term stability.

A total of eight different labs participated in the ILS, seven during Round 1 and seven during Round 2 (Table 3). To maintain anonymity of results, each lab was assigned a random number for reporting data in this report. Table 3 lists the labs simply in alphabetical order; this order does not correspond to the random numbers assigned. The labs included both independent and manufacturer labs. The level of experience of the labs with 52.2 testing ranged from relatively new labs just coming on-line to labs with several years of experience in running the tests.

Table 3. Participating Labs in the ILS*

Laboratory	Round 1	Round 2
Airguard	X	X
Camfil Farr	X	X
CETIAT	X**	X**
Filtration Group	X	X
Intertek	X	X
Jordan	X***	X
Research Products	X	
RTI	X	X

** To maintain anonymity of results, each lab was assigned a random number for reporting data in this report. The labs above are listed in alphabetical order. This order does not correspond to the numerical order of the random numbers assigned.*
*** Participating on an informal basis using an EN 779 duct and procedures.*
**** Began participation after Round 1 reporting was completed.*

One laboratory, CETIAT, participated on an informal basis. CETIAT conducts tests in accordance with the European standard EN779. While EN779 and ASHRAE 52.2 share many commonalities, there are sufficient differences that the results were excluded in the statistical assessment.

2.4. Selection and Purchase of Filters and Dust

RTI worked in close consultation with the Project Monitoring Subcommittee (PMS) on the selection of filters for both Round 1 and Round 2. It was desired that the filters include low, medium and high efficiency filters (i.e., filters of MERV 5-8, MERV 9-12, and MERV 13-16). Furthermore, it was desired to have electret filters in the ILS because these may be more sensitive to the level of charge neutralization achieved for the challenge aerosol. Table 4 summarizes the test filters selected for the ILS.

To help ensure and improve the uniformity of the test filters, RTI pre-tested each test filter for initial filtration efficiency and pressure drop. RTI then selected a subset of the pre-tested filters that were closely matched in efficiency for distribution to the test laboratories.

ASHRAE 52.2 requires loading the filters with ASHRAE dust. RTI purchased 50 pounds of ASHRAE dust from Air Filter Testing Laboratory (AFTL). Prior to preparing the dust, RTI discussed the nature of the ILS with AFTL, and it was agreed that AFTL would prepare the dust from the same batches of raw materials (cotton linters, dust and carbon black). After receiving the dust from AFTL, RTI sent five pounds of the dust to each laboratory.

Table 4. Description and use of the test filters.

Filter Type	Description of filter	Test Flowrate (cfm)	Applicable Rounds
Type 1	24 x 24 x 12" (610 x 610 x 300 mm) glass-fiber media MERV 10 - 11* "High Efficiency"	1970 (0.93 m^3/s)	1
Type 2	24 x 24 x 4 (610 x 610 x 100 mm) electret media MERV 8 – 11* "Medium Efficiency"	1970 (0.93 m^3/s)	1 and 2
Type 3	24 x 24 x 4" (610 x 610 x 100 mm) non-electret cotton polyester media MERV 5 – 7* "Low Efficiency"	1970 (0.93 m^3/s)	2
Type 4	24 x 24 x 12" (610 x 610 x 300 mm) electret media MERV 15 – 16* "High Efficiency"	1970 (0.93 m^3/s)	2

*The MERV range shown is that observed during testing.

2.5 Parameters of Comparison

A full 52.2 test generates a large number of data points that could be used as the basis for ILS. Each 52.2 test consisted of the initial efficiency measurement and the efficiency after each of five dust loadings. For each of these, the efficiency was measured at 12 particle size ranges. From these data, the composite average particle size efficiencies (the E1, E2, E3 values) were computed which, in turn, led to the Minimum Efficiency Reporting Value (MERV). Additionally, there were measurements of filter pressure drop and weight gain.

The primary ILS comparisons were based on the following parameters:

- Measured filtration efficiency at each of the 12 channels for initial and 5 dust loaded efficiencies
- Pressure drop across the clean filter at the test airflow

Additionally, comparisons were made of the derived efficiency-related quantities of:

- The computed E1, E2, E3 values
- The MERV

While not primary parameters, the E1, E2 and E3 values are of interest because they impact the MERV of the filter. The E1, E2, and E3 values are computed from the 12 efficiencies of the composite minimum efficiency curve. Based on the E values and pressure drop, the MERV itself is then selected from a table (Table 5) and is a non-continuous parameter. Because the MERV is not a continuous variable, the MERV determinations were not subjected to the statistical procedures used on the continuous variables.

During 52.2 testing, the filter is loaded with dust. As part of this procedure, the weight gain of the filter is often determined from the pre- and post-test weight of the filter. The weight gain measurement is not part of 52.2-1999 test standard but is often reported along with the 52.2 test results. In this program, while weight gain was of interest, it was not a main focus of the formal ILS.

Table 5
Minimum Efficiency Reporting Value (MERV) Parameters

	Composite Average Particle Size Efficiency (%) In Indicated Size Range				
MERV	**Range 1 0.3 - 1 µm**	**Range 2 1 - 3 µm**	**Range 3 3 - 10 µm**	**Average Arrestance (A_{avg}) by Std 52.1 (%)**	**Minimum Final Pressure Drop***
1	-	-	-	$A_{avg} < 65$	0.3
2	-	-	-	$65 \leq A_{avg} < 70$	0.3
3	-	-	-	$70 \leq A_{avg} < 75$	0.3
4	-	-	-	$75 \leq A_{avg}$	0.3
5	-	-	20 ≤ E3 < 35	-	0.6
6	-	-	35 ≤ E3 < 50	-	0.6
7	-	-	50 ≤ E3 < 70	-	0.6
8	-	-	E3≥ 70	-	0.6
9	-	E2 < 50	E3 ≥ 85	-	1
10	-	50 ≤ E2 < 65	E3 ≥ 85	-	1
11	-	65 ≤ E2 < 80	E3 ≥ 85	-	1
12	-	E2 ≥ 80	E3 ≥ 90	-	1
13	E1< 75	E2 ≥ 90	E3 ≥ 90	-	1.4
14	75 ≤ E1 <85	E2 ≥ 90	E3 ≥ 90	-	1.4
15	85 ≤ E1 <95	E2 ≥ 90	E3 ≥ 90	-	1.4
16	E1 ≥ 95	E2 ≥ 95	E3 ≥ 95	-	1.4

* The minimum final resistance shall be at least twice the initial resistance, or as specified above, whichever is greater.

3. Test Duct Configuration

The ASHRAE 52.2 standard allows several areas for discretion in how the test duct is configured. These include the overall shape of the duct (straight or U-shaped), the use of a single or dual particle counter system, the type of aerosol neutralizer, and the type of particle counter. Table 6 outlines the range of configurations for the participating laboratories.

Table 6. Summary of Variations of Test Rig Configuration

	Round 1*	Round 2
Duct shape	Straight (4), U-shaped (3)	Straight (4), U-shaped (2)
Particle Counter	Single (4), Dual (3)	Single (2), Dual (4)
Brand of OPC	Brand x (5), y (1), z (1)	Brand: x (4), y (2)
Neutralizer	Radioactive (1), high voltage ionizer (5), both (1)	Radioactive (1), high voltage ionizer (4), both (1)

* Includes the EN779 duct.

4. Statistical Methodology

The ILS results were analyzed following ASTM E691-99 "Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method." The primary results of an ILS are quantification of the "repeatability" and "reproducibility" of a test method. These are statistical terms of precision with specific meanings:

> **Repeatability** is a measure of the precision of the method for repeated tests within a given lab, on the same apparatus in a short period of time.
>
> **Reproducibility** is a measure of the precision of the method when comparing results from different labs.

In these definitions, "precision" is a measure of the degree of agreement among the measurements. In this study, several precision indices are applied where appropriate:

- Repeatability standard deviation, S_r
- The 95% confidence interval on repeatability, "$2S_r$"
- Repeatability limit, r
- Repeatability coefficient of variation, "Repeatability CV"
- Repeatability consistency statistic, k

- Reproducibility standard deviation, S_R
- The 95% confidence interval on reproducibility, "$2S_R$"
- Reproducibility limit, R
- Reproducibility coefficient of variation "Reproducibility CV"
- Reproducibility consistency statistic, h

In the following, the term “cell” is used to define a set of replicate results from a given lab at a given level. The statistical computations were as follows:

x = an individual test result
n = the number of test results per cell for each laboratory (2 for this study)
p = the number of laboratories in the ILS (6 for this study)

Cell average: $\bar{x} = \frac{\sum_{1}^{n} x}{n}$

Cell standard deviation: $s = \sqrt{\frac{\sum_{1}^{n} (x - \bar{x})^2}{(n-1)}}$

Average of cell averages: $\dot{x} = \frac{\sum_{1}^{p} \bar{x}}{p}$

Cell deviation: $d = \bar{x} - \dot{x}$

Standard deviation of cell averages: $S_{\bar{x}} = \sqrt{\frac{\sum_{1}^{p} d^2}{(p-1)}}$

The repeatability standard deviation (within a laboratory), S_r :

$$S_r = \sqrt{\frac{\sum_{1}^{p} s^2}{p}}$$

To compute the reproducibility standard deviation (between laboratories), S_R, a provisional value was first computed, S_R*. This value was then compared to the repeatability standard deviation (within laboratory), S_r. If S_r was less than the provisional value, the provisional value was used. If S_r was greater than the provisional value, the provisional value was replaced with the value of S_r. With this approach, the reproducibility standard deviation would always be greater than or equal to the within-laboratory standard deviation:

$$(S_R)^* = \sqrt{(S_{\bar{x}})^2 + (S_r)^2(n-1)/n}$$
$$If\ \ S_r \rangle (S_R)^*\ then\ S_R = S_r$$
$$If\ \ S_r \langle (S_R)^*\ then\ S_R = (S_R)^*$$

The above equations are consistent with a one-way analysis of variance approach in which the total variation is partitioned into components for "between lab" variance and "within lab" variance. The square of the repeatability standard deviation provides an estimate of the within-lab variance component, while the square of S_R provides an estimate of the sum of the two variance components.

Based on the repeatability and reproducibility standard deviations, the "2s" values were computed. For the "2s" limit, 95% of **individual** test results are expected to lie within the confidence interval centered on the mean value.[1]

"$2S_r$" = 1.96 S_r

"$2S_R$" = 1.96 S_R

Based on the repeatability and reproducibility standard deviations, the repeatability limit (r) and the reproducibility limit (R) were computed. For these limits, 95% of all **pairs** of test results are expected to differ by less than the limit.

r = 2.8 S_r

R = 2.8 S_R

The coefficient of variation of a quantity, CV, expressed in percent, is defined as:

CV (%) = 100 x standard deviation / mean

The repeatability and reproducibility standard deviations (S_r and S_R, respectively) are the primary output of the ILS analysis and provide a measure of the precision of the standard. In the following discussion of results from Round 2 testing, S_r and S_R values for filtration efficiency, pressure drop and weight gain will be presented and discussed.

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[1] As stated in ASTM 456-02, "The approximation to 0.95 is reasonably good (say 0.90 to 0.98) when many laboratories (30 or more) are involved, but is likely to be poor when fewer than eight laboratories are studied." Thus, for this project with six laboratories participating in Round 2, the computed repeatability and reproducibility limits ("$2S_r$" and "$2S_R$," and r and R) may be poor estimates. They are, nevertheless, reported herein as part of the recommended ASTM reporting practice and as the best available estimates.

The reproducibility and repeatability consistency statistics, h and k, respectively, are used as a means to help identify outlier values. They were computed as:

$$h = d / S_{\bar{x}}$$

$$k = s / S_r$$

As a tool for flagging possible outliers, "critical values" of h and k were established per ASTM 691 based on the number of laboratories in the study and the number of replicates. Data for which h or k are near or exceed their critical value may indicate an outlier to be removed from the data base prior to performing additional statistical analyses. In this study, while some data exceeded these critical values, all data were included in the statistical analyses.

Note on units: Throughout this report, filtration efficiency is reported in percent with a range of 0% to 100%. By definition, the repeatability and reproducibility standard deviations and limits defined above have the same units as the quantity they are applied to. Thus, when applied to filtration efficiency measurements, the repeatability and reproducibility standard deviations and limits have units of percent filtration efficiency.

5. ILS Results and Analyses

5.1 Round 1

Round 1 represented a trial run prior to initiating the full testing of Round 2. It was an opportunity to work out technical or procedural problems prior to expending the major effort on Round 2. It also allowed a "familiarization" period for labs with limited experience and allowed a determination of whether the ILS procedures and protocols were being followed. The purpose of Round 1was to ensure that the subsequent Round 2 testing would provide the basis for a meaningful assessment of the standard and not be overly influenced by improper implementation of the standard.

In Round 1, the initial efficiency and pressure drop of the Type 1 and Type 2 filters were measured (Table 7). These were medium efficiency filters; one being an electret, the other a non-electret.

Figures 1 – 4 present the Round 1 results with tabulated efficiency data presented in Appendix B. Figures 1 and 3 present the pre-tested initial efficiencies of the filters. The filters shown were selected from a larger number of filters (10 Type 1 and 20 Type 2) to increase the uniformity of the filters sent to the laboratories.

Table 7. Round 1 Test Matrix.
Each lab performed one initial efficiency test on two types of filters.
(7 labs, 2 levels, no replication)

	Filter Type and ID Number	
	Type 1	**Type 2**
Lab 1	Filter #5	Filter #16
Lab 2	Filter #7	Filter #4
Lab 3	Filter #3	Filter #9
Lab 4	Filter #2	Filter #11
Lab 5	Filter #10	Filter #6
Lab 6	Filter #6	Filter #15
Lab 7	Filter #9	Filter #7

Results from the Round 1 testing at the seven participating laboratories are presented in Figures 2 and 4. Overall, the results were free of large deviations between the labs. The results did not show substantial differences in measured efficiency associated with duct shape (straight vs. U-shaped) or type of aerosol neutralizer (radioactive or high voltage ionizer type).

Tables 8 and 9 summarize the secondary parameters derived from the Round 1tests. These parameters consist of the E1, E2, and E3 values, the MERV and the measured pressure drop. When looking at the consistency of the MERV, it is important to note that MERV is not a continuous variable. It is determined from a “look up” table (see Table 5) based on the E1, E2 and E3 values. The difference between MERV values may be a fraction of a percent difference in filtration efficiency in one of the sizing channels. This also applies to a jump from MERV 8 to MERV 11 which can be due to a minor change in the E3 value.

The results from Round 1 were sufficiently consistent that Round 2 was implemented without changes to laboratory or ILS procedures.

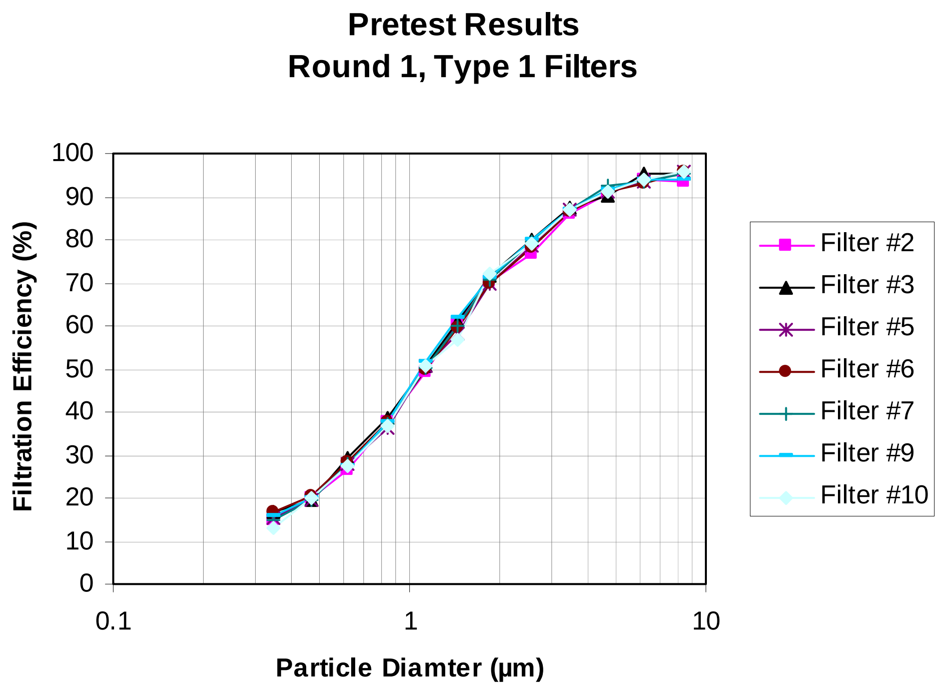


Figure 1. Pre-test filtration efficiency results for the Type 1 filter.

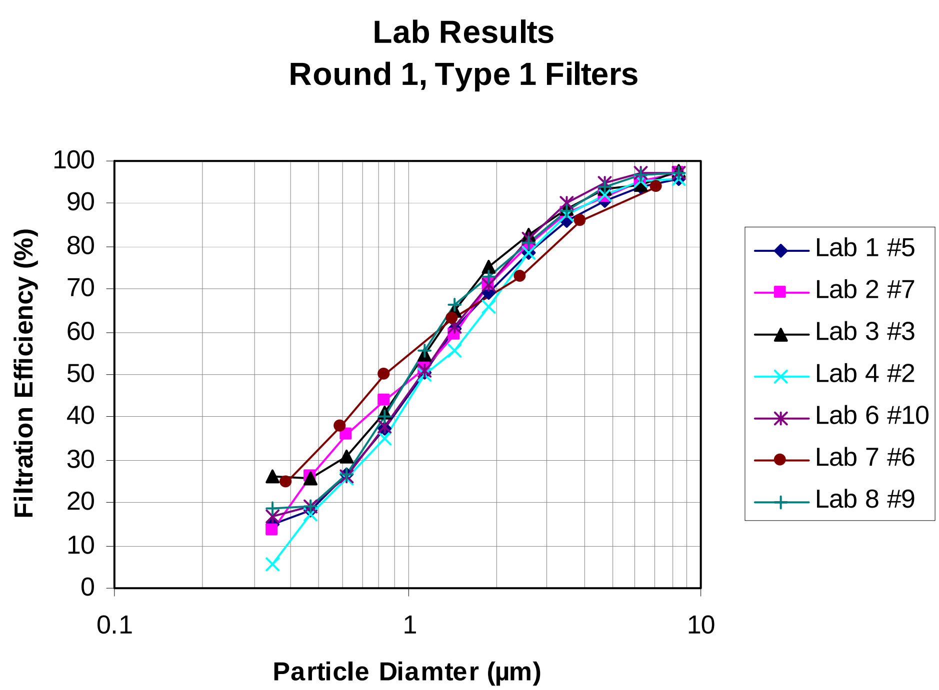


Figure 2. Filtration efficiency results from the Round 1 laboratories for the Type 1 filter.

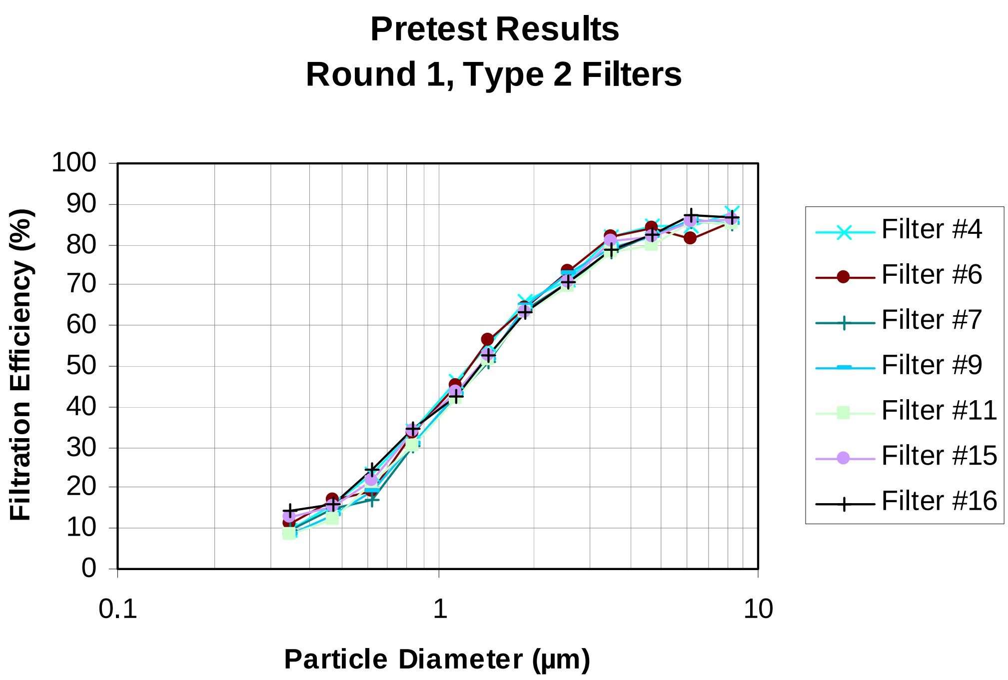


Figure 3. Pre-test filtration efficiency results for the Type 2 filter.

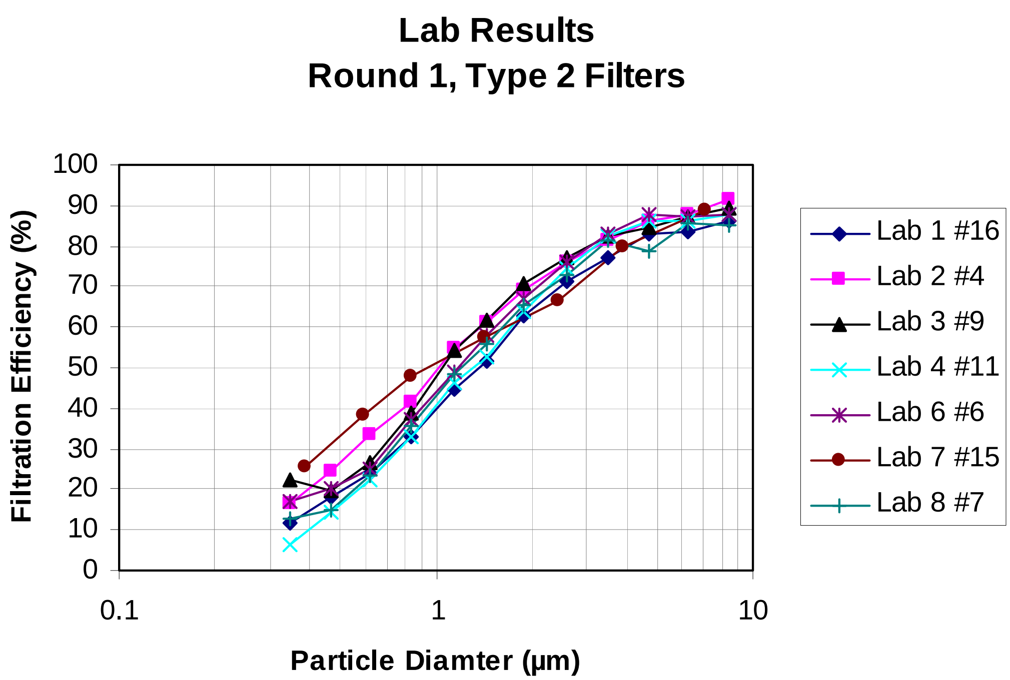


Figure 4. Filtration efficiency results from the Round 1 laboratories for the Type 2 filter.

Table 8. Round 1 secondary parameter summary for Type 1 filter.

Lab	Filter ID	E1	E2	E3	"MERV"*	Pre-test Pressure drop in. H20 (Pa)	Lab Pressure drop in. H20 (Pa)
1	5	24.2	64.7	91.6	11	0.365 (90.8)	0.36 (90)
6	10	25.0	66.3	94.8	11	0.358 (89.1)	0.36 (90)
3	3	30.8	69.5	93.5	11	0.363 (90.3)	0.359 (89.3)
4	2	21.0	62.5	92.6	10	0.361 (89.8)	0.36 (90)
8	9	26.1	68.9	91.0	11	0.358 (89.1)	0.368 (91.5)
2	7	29.9	65.6	92.9	11	0.360 (89.6)	0.38 (95)
7	6	na	na	na	na	0.361 (89.8)	0.37 (92)

** In this comparison, the "MERV" is based solely on initial efficiency values and does not include possible effects of dust loading.*

Table 9. Round 1 secondary parameter summary for Type 2 filter.

Lab	Filter ID	E1	E2	E3	"MERV"*	Pre-test Pressure drop in. H20 (Pa)	Lab Pressure drop in. H20 (Pa)
1	#16	21.7	57.5	82.4	8	0.315 (78.4)	0.318 (79.1)
6	#6	24.8	62.5	86.5	10	0.335 (83.3)	0.350 (87.1)
3	#9	26.8	65.9	85.8	11	0.327 (81.3)	0.350 (87.1)
4	#11	19.1	59.2	85.5	10	0.319 (79.4)	0.34 (85)
8	#7	21.6	60.6	82.7	8	0.312 (77.6)	0.327 (81.3)
2	#4	29.0	65.3	86.6	11	0.321 (79.9)	0.36 (90)
7	#15	na	na	na	na	0.320 (79.6)	0.33 (82)

** In this comparison, the "MERV" is based solely on initial efficiency values and does not include possible effects of dust loading.*

5.2 Round 2

Round 2 consisted of each lab performing six full 52.2 tests: duplicate tests on the Type 2, Type 3 and Type 4 filters (Table 10). Unlike Round 1, these tests included multiple dust loading steps. After completing the first of the Round 2 tests, RTI reviewed each lab's results for reasonableness and proper procedures before giving approval to continue with the remainder of the Round 2 tests.

Table 10. Round 2 Test Matrix.
Each lab performed duplicate full 52.2 tests on three types of filters.
(6 labs, 3 levels, duplicate testing).

	Filter Type		
	Type 2	**Type 3**	**Type 4**
Lab 1	Filter #16 Filter #14	Filter #11 Filter #3	Filter #13 Filter #24
Lab 2	Filter #4 Filter #1	Filter #2 Filter #6	Filter #11 Filter #16
Lab 3	Filter #17 Filter #8	Filter #20 Filter #4	Filter #22 Filter #6
Lab 4	Filter #11 Filter #2	Filter #12 Filter #5	Filter #20 Filter #7
Lab 5	Filter #13 Filter #3	Filter #1 Filter #18	Filter #21 Filter #8
Lab 6	Filter #6 Filter #19	Filter #15 Filter #19	Filter #17 Filter #4

The final pressure drops for the Round 2 tests were specified follows:

- Type 2 filter: 1.0 inch H_2O (250 Pa)
- Type 3 filter: 1.0 inch H_2O (250 Pa)
- Type 4 filter: twice the initial pressure drop or 1.4 inch H_2O (350 Pa) whichever was greater.

However, one laboratory, Laboratory #5, did not follow the prescribed final pressure drops listed above. Laboratory 5 loaded to the following final pressure drops:

- o Type 2 filters: one filter loaded to 0.6 inch (150 Pa), the second filter to 1.0 inch H_2O (250 Pa)
- o Type 3 filter: both filters loaded to 0.6 inch H_2O (150 Pa)
- o Type 4 filter: both filters loaded to 1.4 inch H_2O (350 Pa) (one should have been loaded to 1.52 inch H_2O (380 Pa)).

Therefore, for Laboratory 5, only the results for initial efficiency and efficiency after conditioning were included in the comparison of the filtration efficiency measurements (these results are unaffected by the selected final pressure drop). For completeness, all results for Laboratory 5 are presented in the appendices. For the Laboratory 5 results, it appeared likely that the results from the initial efficiency and the efficiency after conditioning tests would determine the minimum composite efficiency curve, the E1, E2, E3 values, and the MERV; therefore, Laboratory 5 results were included in those analyses.

In accordance with the conditioning step procedures of the 52.2 standard, conditioning was performed by feeding ASHRAE dust until a pressure drop increase of 0.04 inch H_2O (10 Pa) or 30 grams of dust was fed, whichever came first. With only two exceptions, the 0.04 inch H_2O (10 Pa) criterion was the determining factor or was reached simultaneously with the 30 gram limit. The two exceptions were for Laboratory #2 for the Type 3 filter where the dust loading for conditioning was stopped after feeding 30 grams of dust with a pressure drop rise of 0.03 inch H_2O (7 Pa) for both their Type 3 filters.

To facilitate presentation of the Round 2 results, each of the three filter types are reported using the following format.

- A graph showing the pre-test results for initial efficiency measurements on the filters that were sent to the laboratories. All the pre-test measurements were performed at RTI.
- A series of six graphs showing the initial efficiency and efficiency after each level of dust loading for the test laboratories. Each lab has two curves in each figure. In addition to seeing the overall between-lab agreement, the curves are color-coded for each lab so that the degree of replication within each lab can be discerned.
- Tabulated statistical data for the computed mean, S_r and S_R values following ASTM 691-99 for the initial efficiency and each dust load.
- A series of six graphs showing the repeatability and reproducibility standard deviations for initial efficiency and efficiency after each level of dust loading.
- Tabulated E1, E2, E3, MERV, pressure drop and weight gain values and their associated means and repeatability and reproducibility deviations (S_r and S_R).

Results for the Type 2 filter are presented in Figures 5 and 6 and Tables 11 and 12. Results for the Type 2 filter were characterized by high within-laboratory variability.

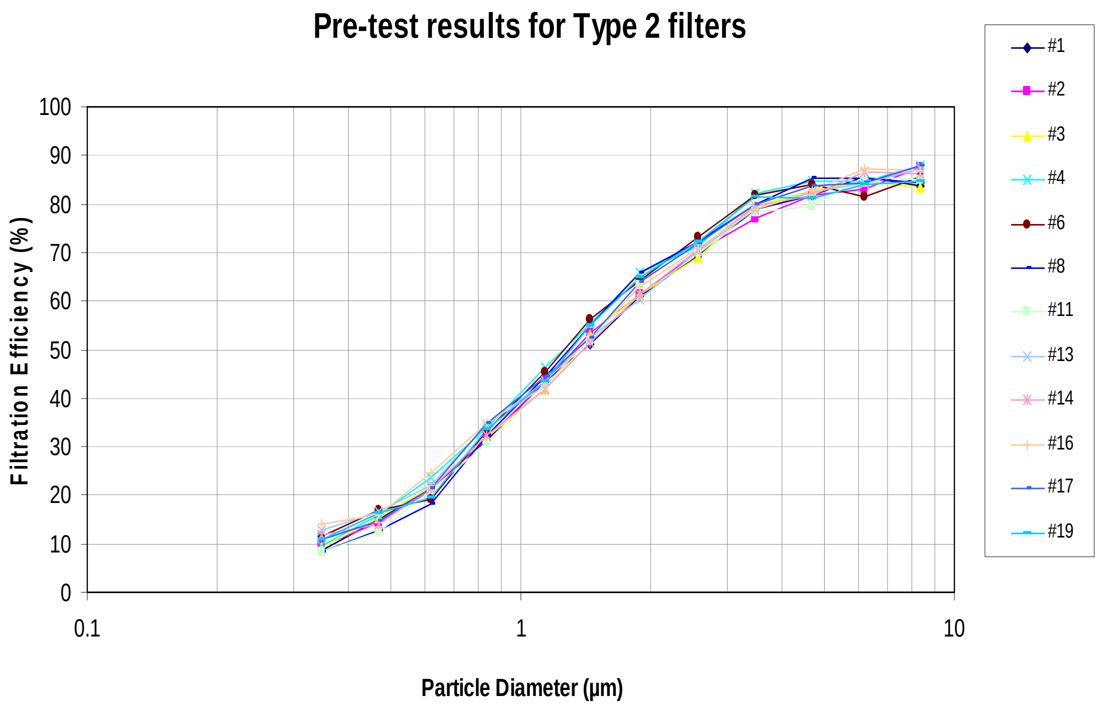
Results for the Type 3 filter are presented in Figures 7 and 8 and Tables 13 and 14. Unlike results for the Type 2 filter, the Type 3 filter results were characterized by relatively low within-laboratory variability.

Results for the Type 4 filter are presented in Figures 9 and 10 and Tables 15 and 16. Owing to the high efficiency of these filters, there variability both within and between laboratories were relatively low.

Appendices D, E and F contain the tabulated efficiency data for each filter for each lab.

Appendix G presents the Round 2 test results in the typical “52.2 test report” format showing the family of filtration efficiency curves associated with each individual 52.2 test.

Appendices H and I present the reproducibility and repeatability consistency statistics h and k, respectively. Although no data points were dropped from the statistical analyses, on occasion individual efficiency values exceeded the critical h and/or k levels.



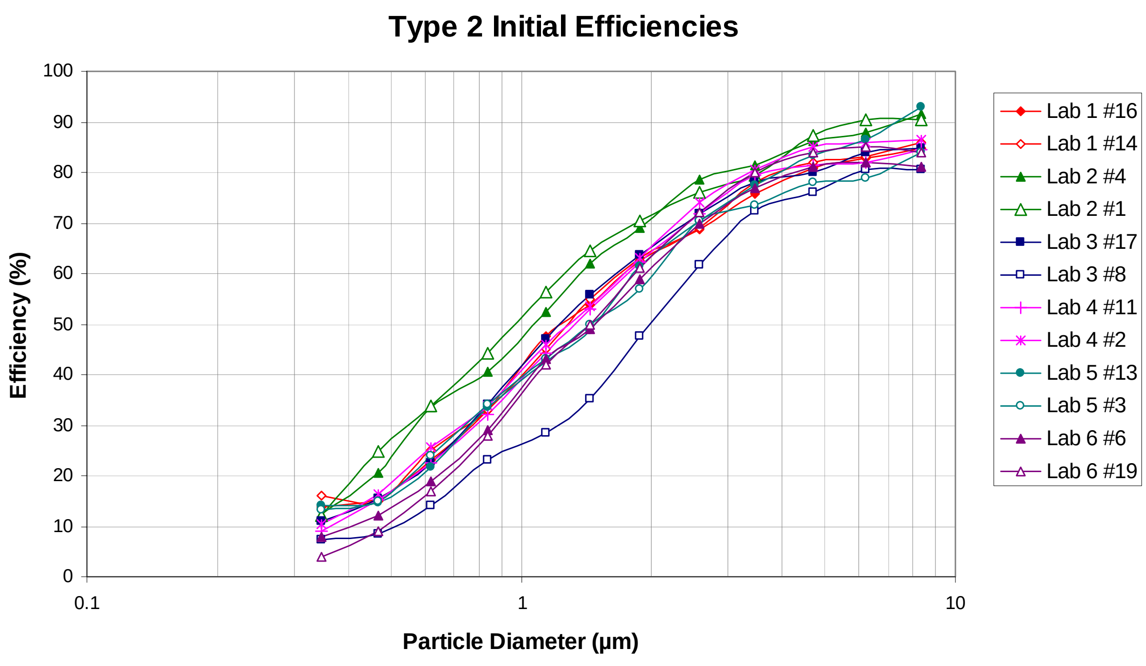
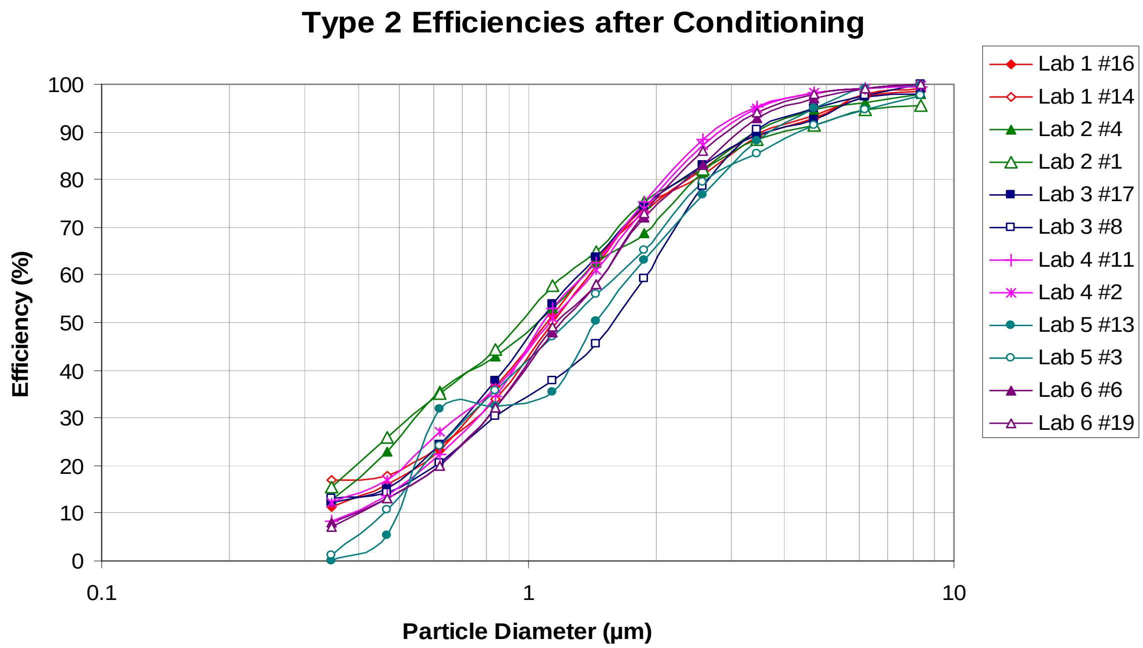


Figure 5. Filtration efficiency results for the Type 2 filter.



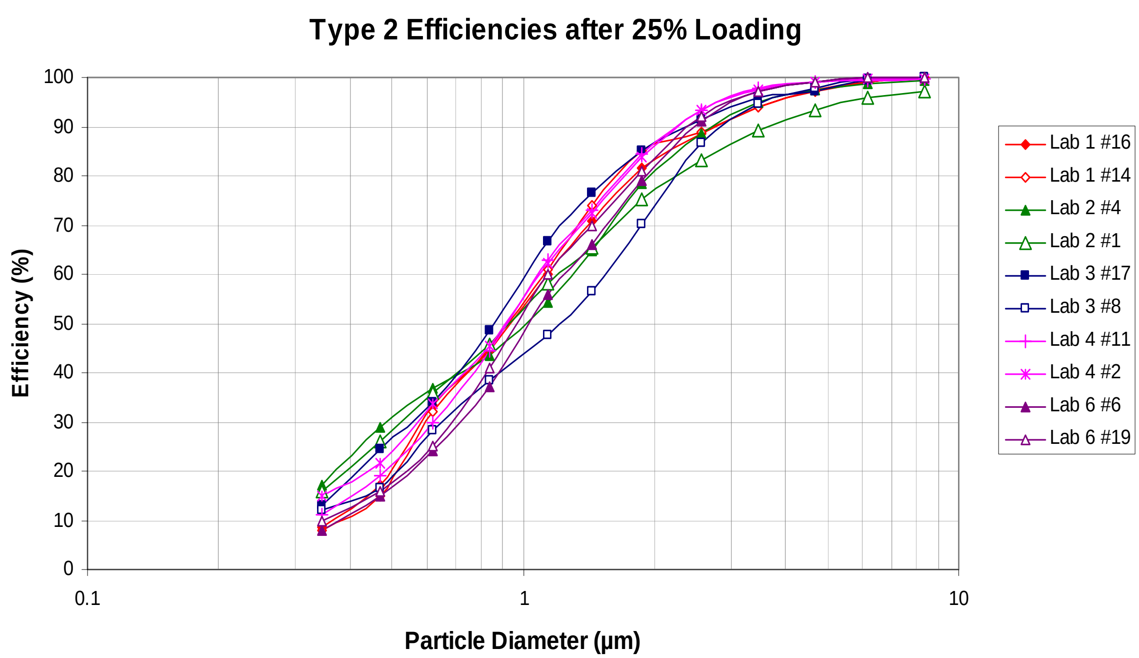
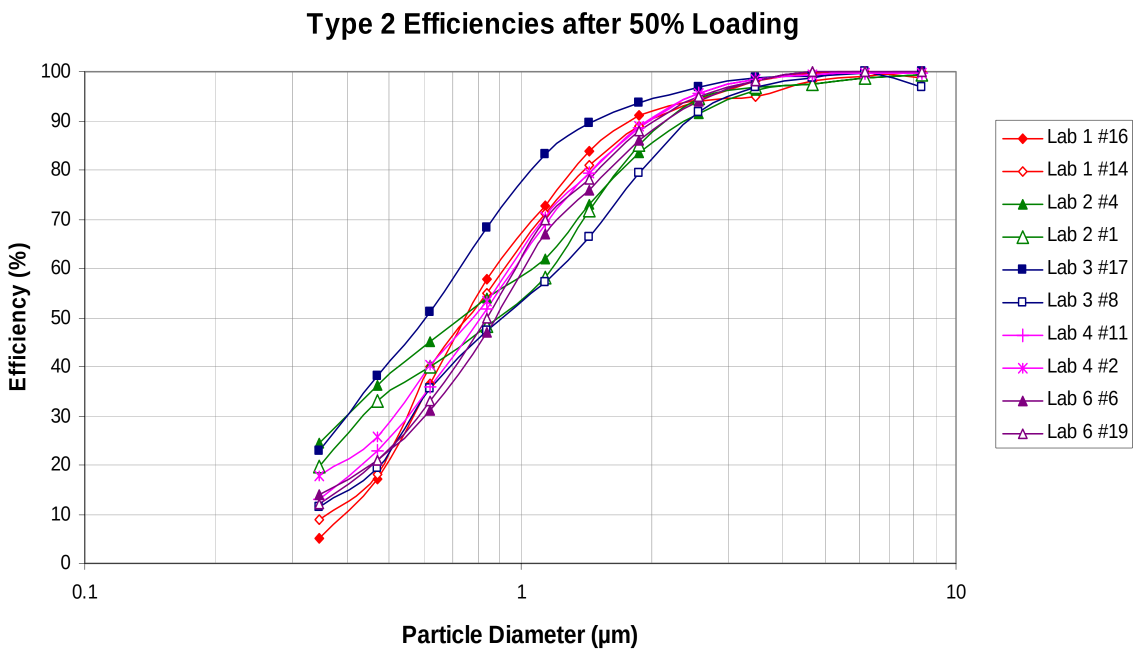


Figure 5. Type 2 filter results (continued).



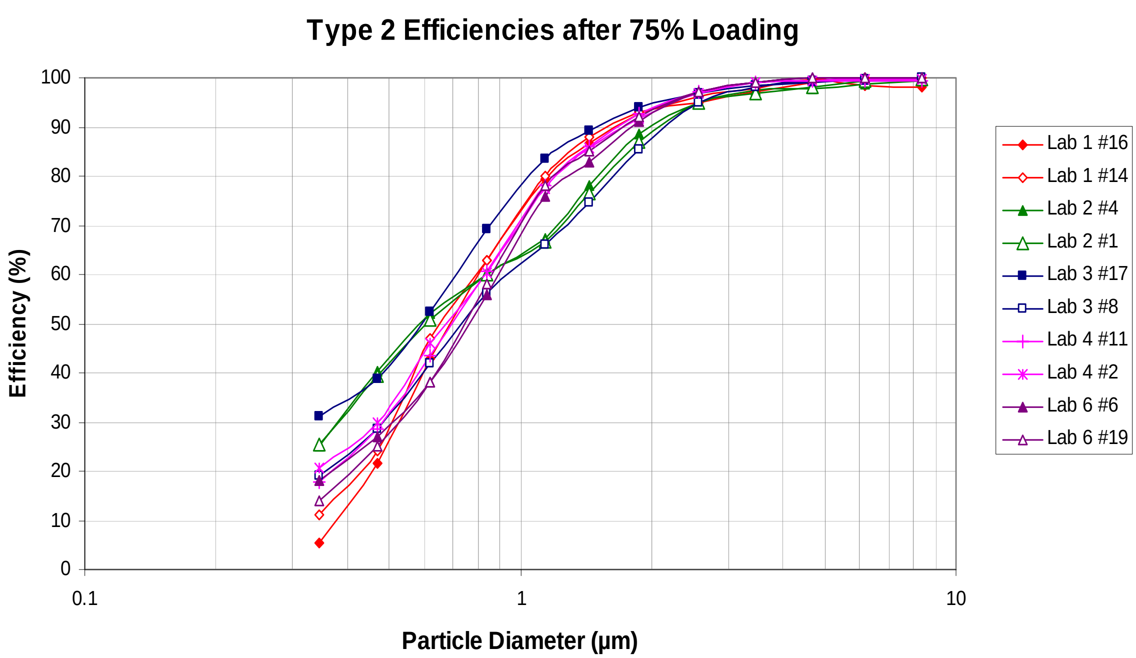


Figure 5. Type 2 filter results (continued).

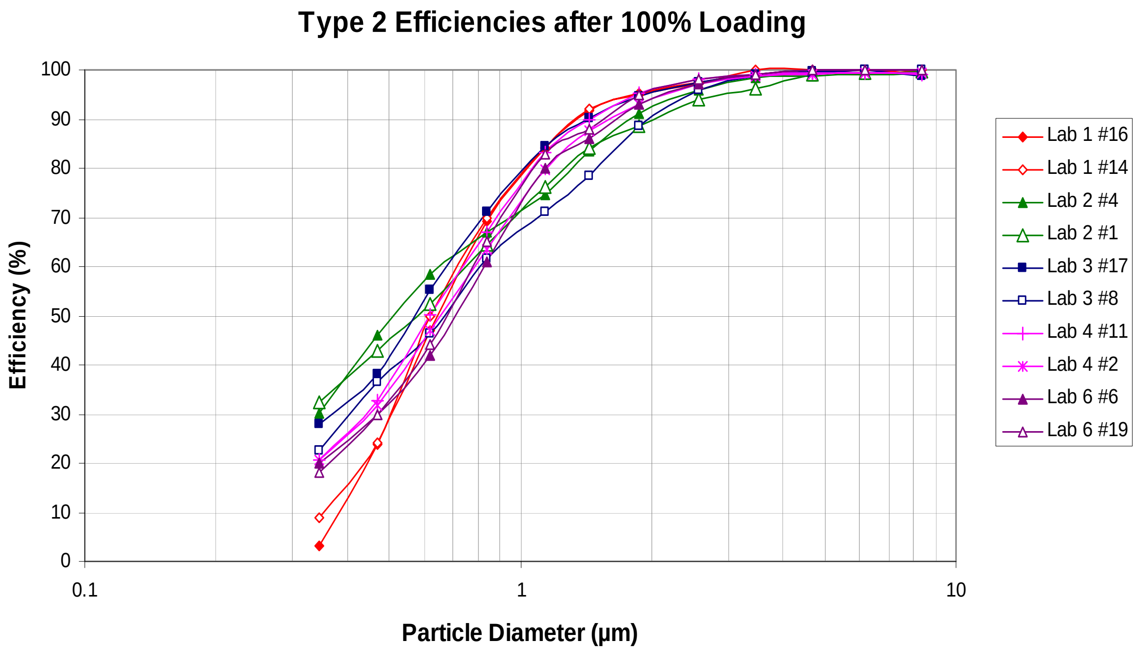
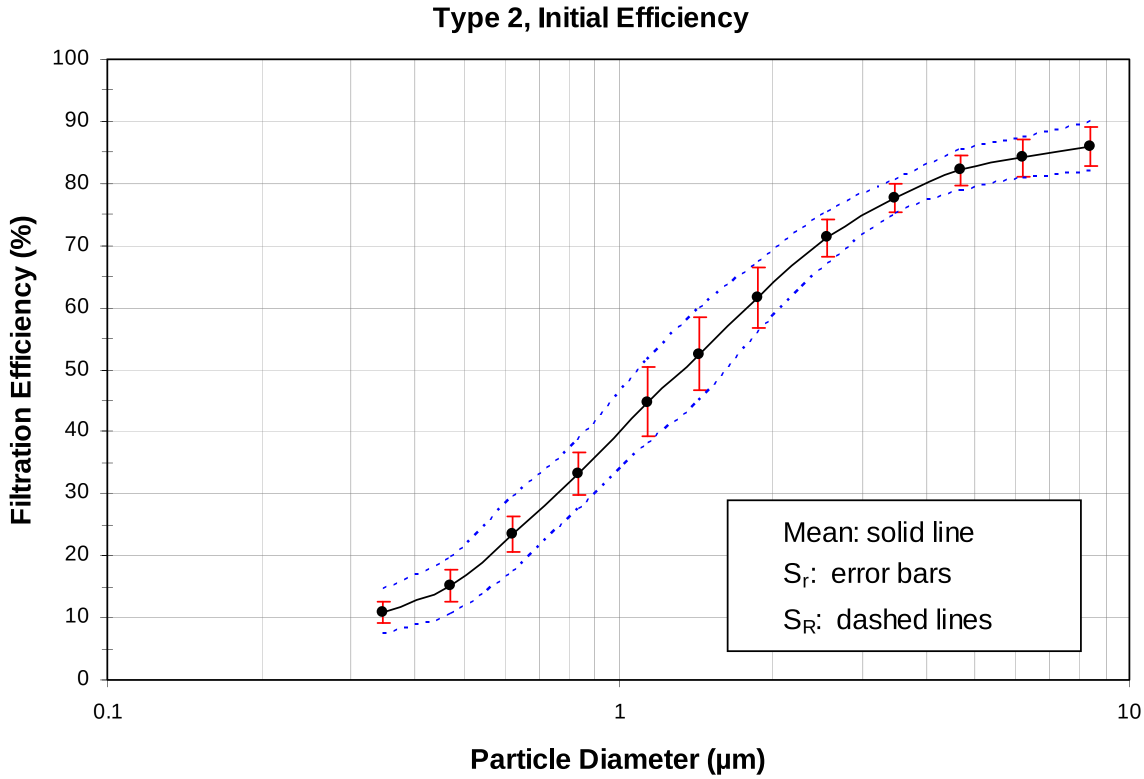


Figure 5. Type 2 filter results (continued).

Table 11.
Summary of the mean filtration efficiency (%) and the repeatability and reproducibility standard deviations (S_r and S_R , respectively, with units of %) for the Type 2 filters for each of the 12 indicated particle sizing channels.

		Precision statistics at the indicated particle size range											
Channel		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Min. Diam. (µm)		*0.30*	*0.40*	*0.55*	*0.70*	*1.00*	*1.30*	*1.60*	*2.20*	*3.00*	*4.00*	*5.50*	*7.00*
Max. Diam. (µm)		*0.40*	*0.55*	*0.70*	*1.00*	*1.30*	*1.60*	*2.20*	*3.00*	*4.00*	*5.50*	*7.00*	*10.0*
Geo. Mean Diam (µm)		*0.35*	*0.47*	*0.62*	*0.84*	*1.14*	*1.44*	*1.88*	*2.57*	*3.46*	*4.69*	*6.20*	*8.37*
Initial	S_r	1.8	2.6	2.8	3.4	5.6	6.0	4.8	3.1	2.3	2.4	2.9	3.1
Initial	S_R	3.5	4.6	6.0	5.6	6.8	7.4	5.8	4.2	2.8	3.3	3.3	4.0
Initial	Mean	11.0	15.2	23.5	33.2	44.8	52.5	61.6	71.2	77.8	82.1	84.1	85.9
Conditioning	S_r	2.3	2.1	2.9	2.6	6.0	5.6	4.8	1.9	1.1	1.5	1.5	1.1
Conditioning	S_R	5.5	5.5	5.8	4.5	6.5	5.9	5.3	3.6	3.2	2.6	1.8	1.4
Conditioning	Mean	9.9	15.4	25.7	35.8	49.0	59.0	70.6	82.4	90.7	94.8	97.5	98.8
25% Loading	S_r	1.5	2.9	2.2	3.6	6.3	6.5	4.9	2.3	1.8	1.3	0.9	0.7
25% Loading	S_R	3.6	5.2	4.6	3.6	6.3	6.5	4.9	3.3	2.6	1.8	1.3	0.9
25% Loading	Mean	11.8	19.9	31.3	43.4	58.9	68.9	80.4	89.7	95.2	97.6	99.1	99.6
50% Loading	S_r	4.4	6.0	5.6	7.1	8.4	7.4	4.7	1.9	1.2	0.7	0.3	1.0
50% Loading	S_R	6.3	7.9	6.0	7.1	8.4	7.4	4.7	1.9	1.2	1.0	0.5	1.0
50% Loading	Mean	14.9	25.2	38.8	53.3	68.1	77.9	87.3	94.3	97.4	98.9	99.6	99.4
75% Loading	S_r	4.4	3.4	3.7	4.1	5.6	4.7	2.8	0.8	0.4	0.3	0.4	0.6
75% Loading	S_R	7.6	7.0	5.5	4.1	6.4	5.2	2.9	1.1	0.9	0.8	0.4	0.6
75% Loading	Mean	18.8	30.3	45.3	60.6	75.3	83.3	90.8	96.1	98.2	99.2	99.5	99.6
100% Loading	S_r	2.7	1.2	3.7	3.6	4.5	3.9	2.3	0.9	0.7	0.3	0.3	0.5
100% Loading	S_R	9.5	7.8	5.2	3.6	4.7	4.3	2.7	1.3	1.0	0.5	0.4	0.5
100% Loading	Mean	20.4	33.6	49.3	65.9	80.0	87.1	92.9	96.7	98.8	99.5	99.6	99.6



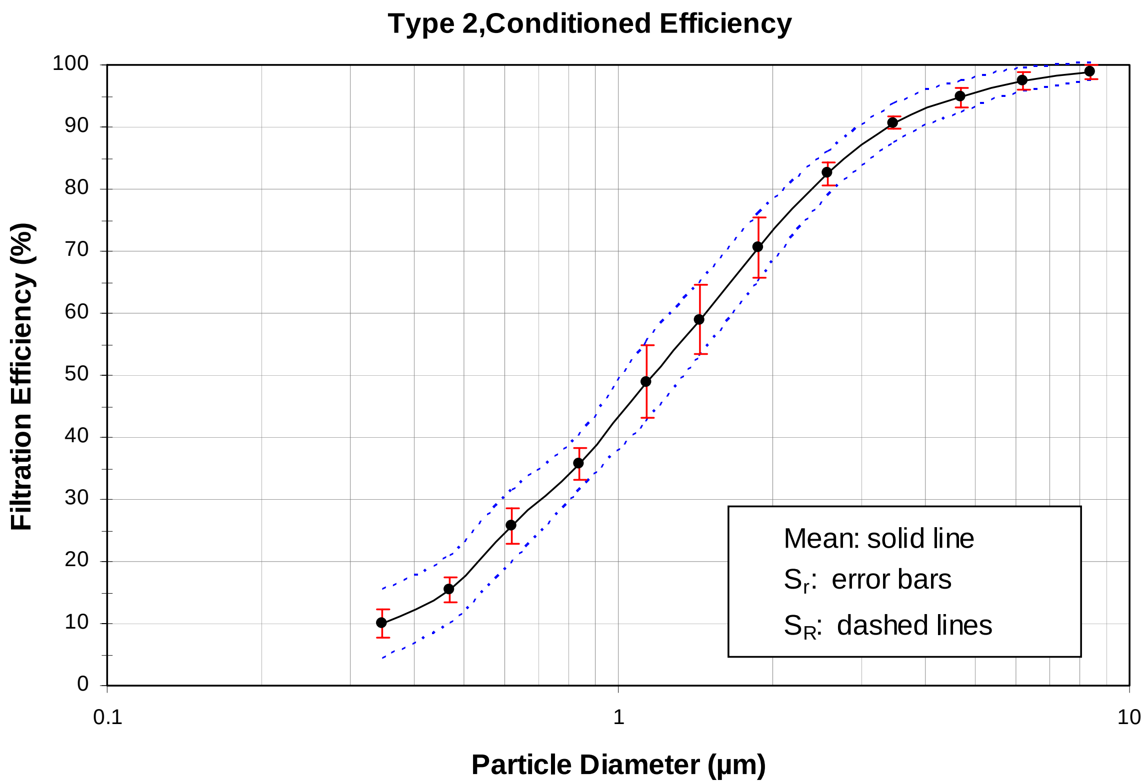
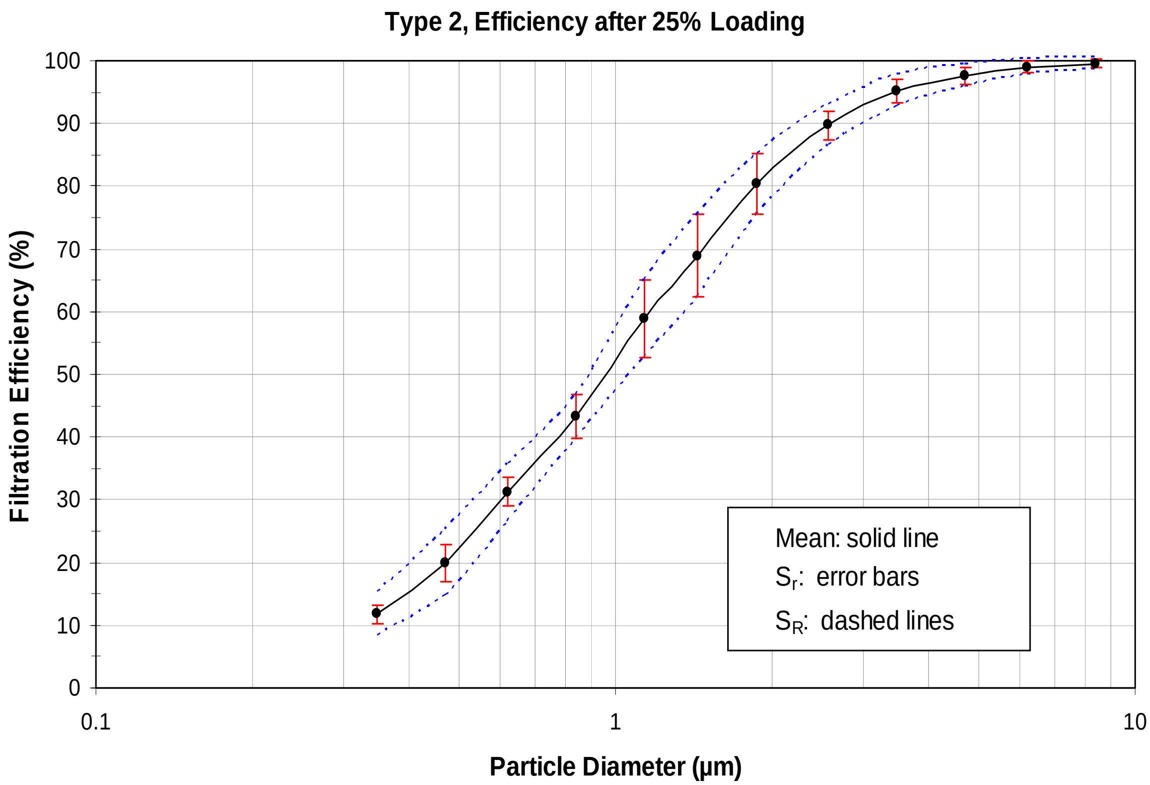


Figure 6. The repeatability and reproducibility standard deviations (S_r and S_R, respectively) plotted relative to the mean for the Type 2 filter.



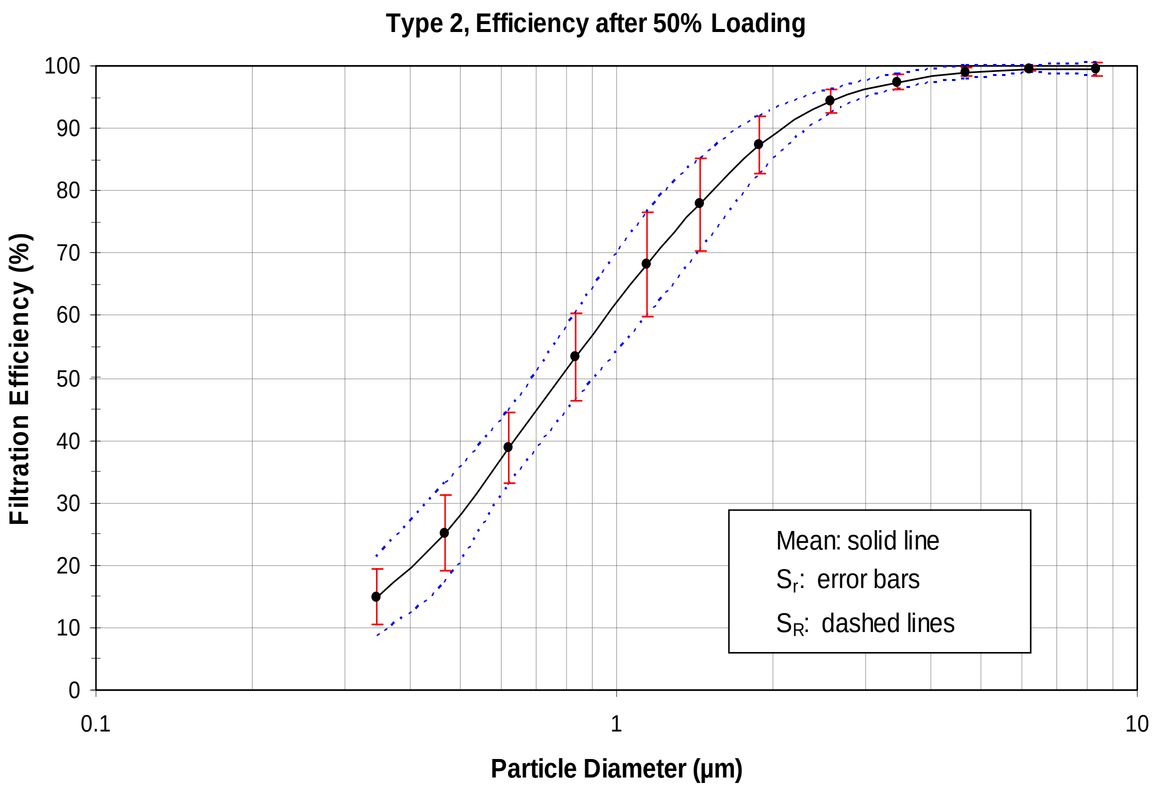
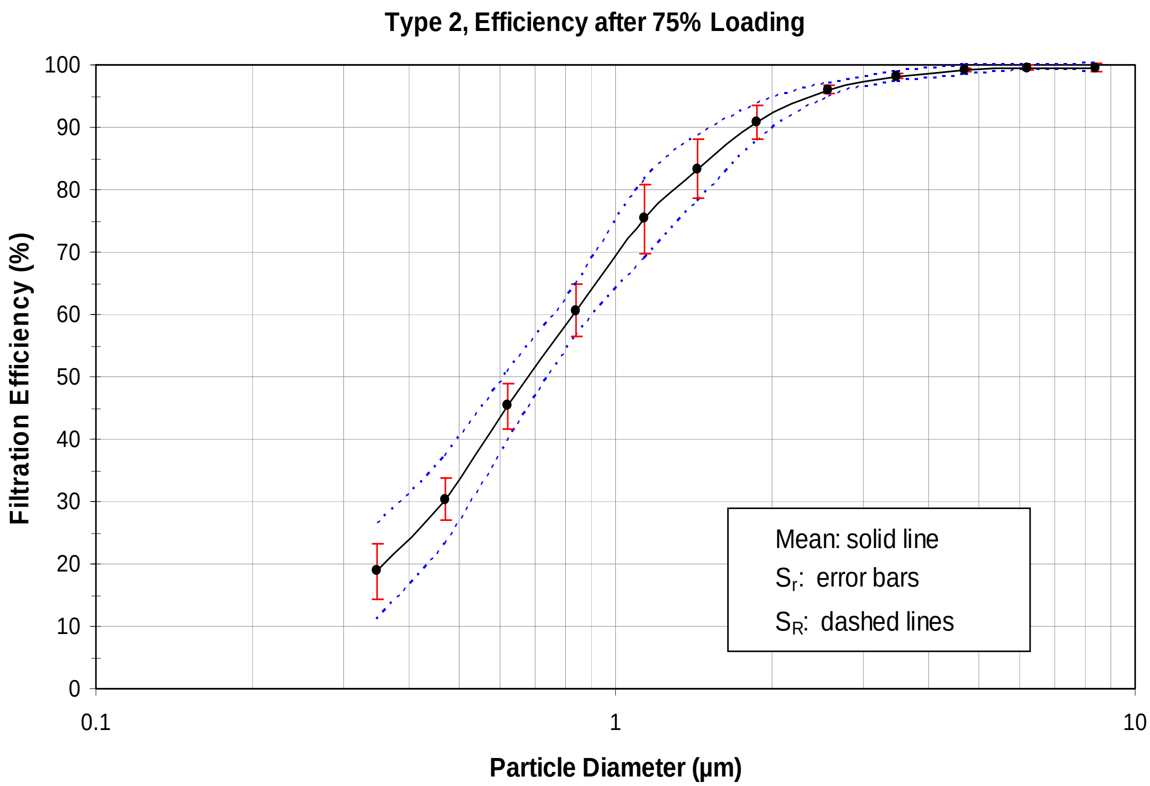


Figure 6. S_r and S_R for the Type 2 Filter (continued).



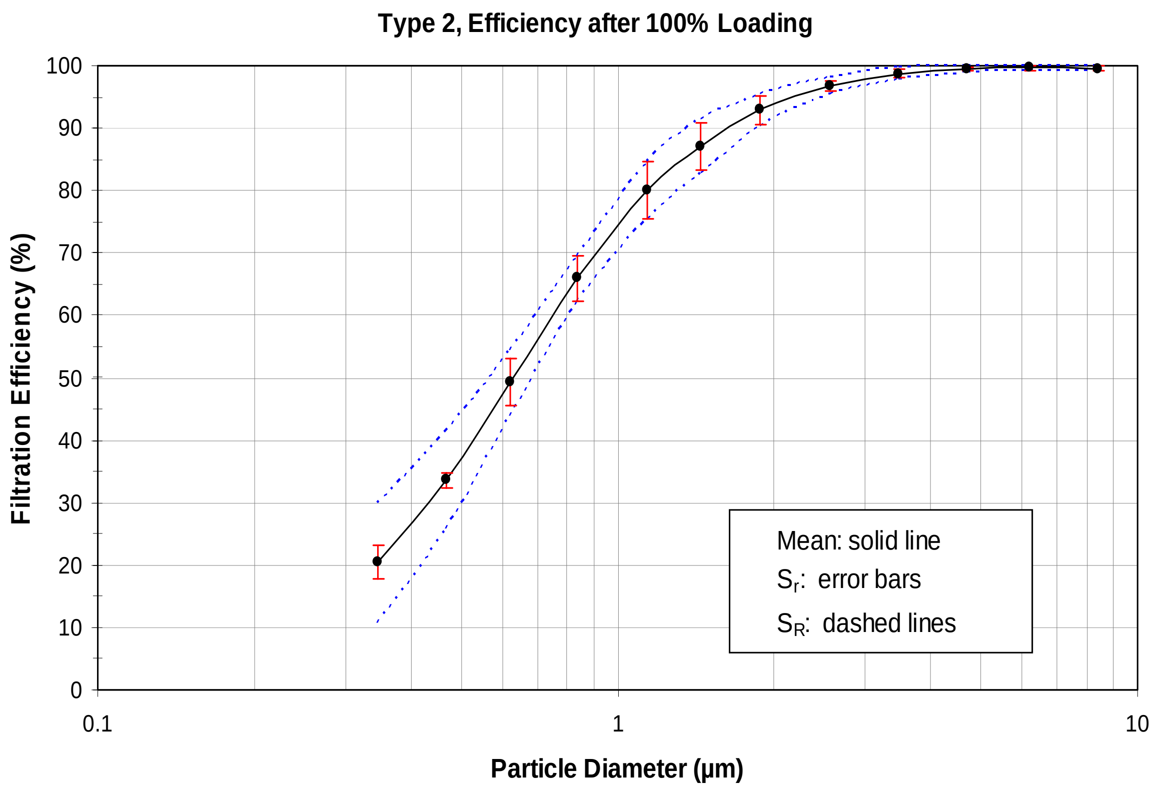
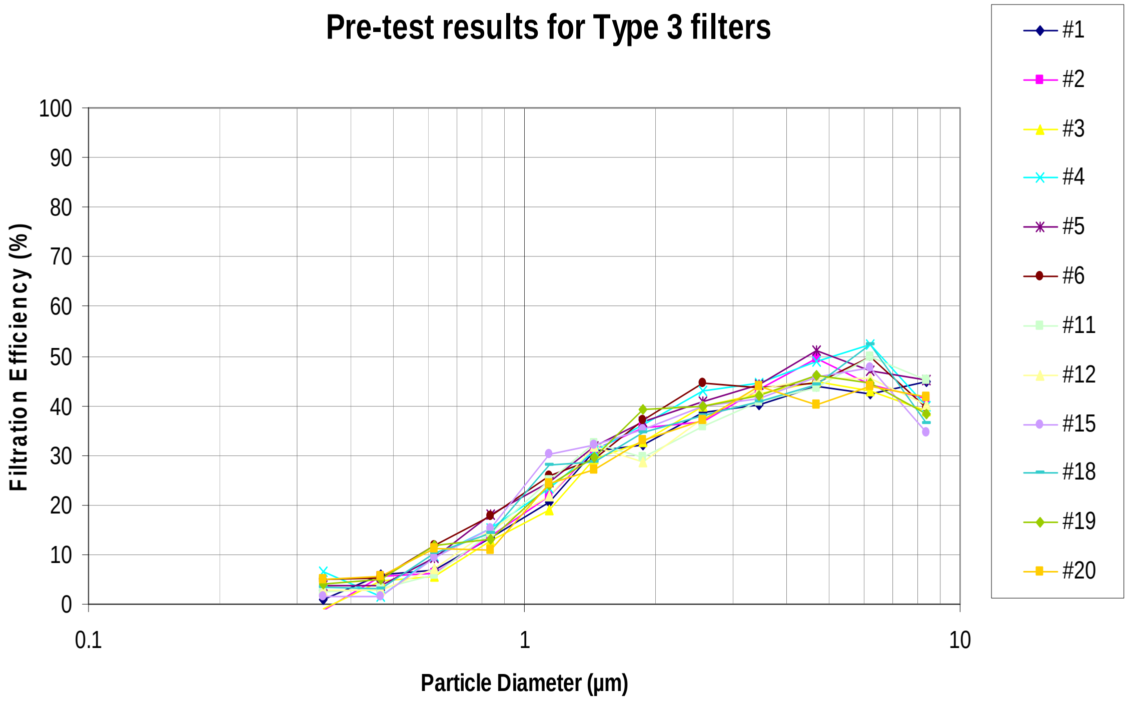


Figure 6. S_r and S_R for the Type 2 Filter (continued).

Table 12. Round 2 secondary parameter summary for Type 2 filters.

		ASHRAE 52.2 Composite Minimum Efficiencies and MERV				Filter pressure drop at test flow rate				
Lab	Filter ID	E1	E2	E3	MERV	Pre-test Pressure drop		Lab Pressure drop		Weight Gain
						in. H_2O	Pa	in. H_2O	Pa	grams
1	#16	19	58	81	**8**	0.315	78.4	0.33	82	213.5
1	#14	20	58	82	**8**	0.309	76.9	0.33	82	198.1
2	#4	27	65	87	**11**	0.321	79.9	0.36	90	183.2
2	#1	29	67	87	**11**	0.321	79.9	0.34	85	188.7
3	#17	21	60	82	**8**	0.319	79.4	0.33	82	190.0
3	#8	13	43	77	**8**	0.325	80.8	0.35	87	185.0
4	#11	19	58	82	**8**	0.319	79.4	0.36	90	179.5
4	#2	15	56	83	**8**	0.331	82.3	0.33	82	203.0
5	#13	15	54	85	**10**	0.312	77.6	0.28	70	n/r
5	#3	18	55	79	**8**	0.310	77.1	0.32	80	n/r
6	#6	17	55	80	**8**	0.335	83.3	0.36	90	231.0
6	#19	15	56	83	**8**	0.328	81.6	0.34	85	194.8
Sr		2.86	4.99	2.45				0.02	4.4	14.7
SR		5.00	6.05	3.04				0.02	5.7	15.9
Mean		19.0	57.1	82.3		0.320	79.7	0.34	84	196.7



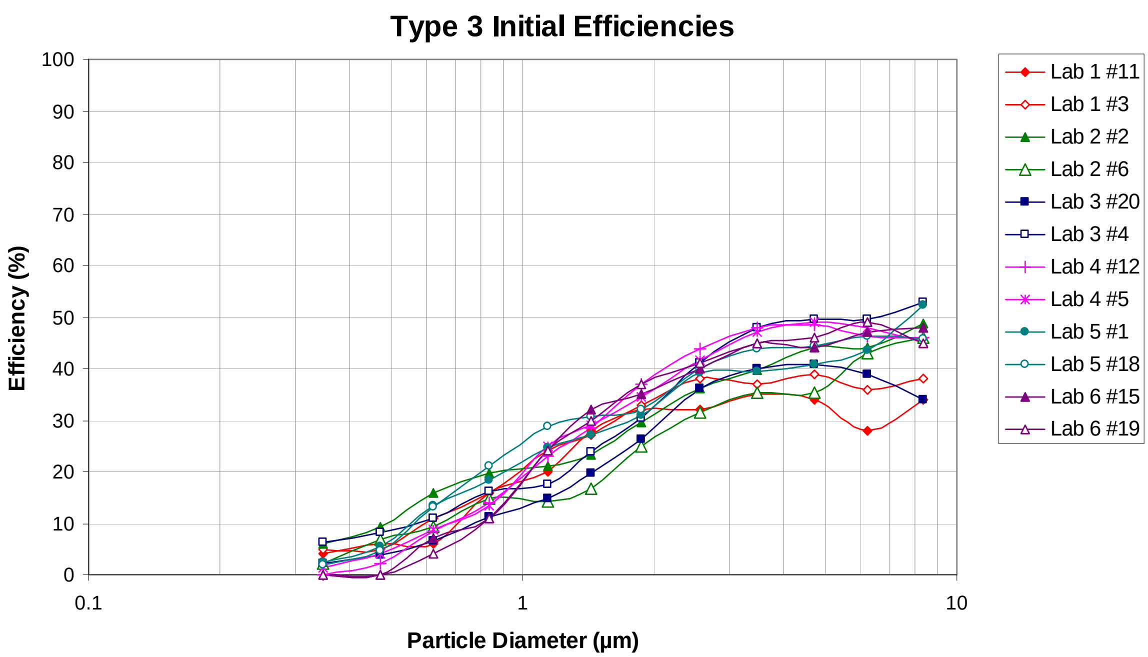
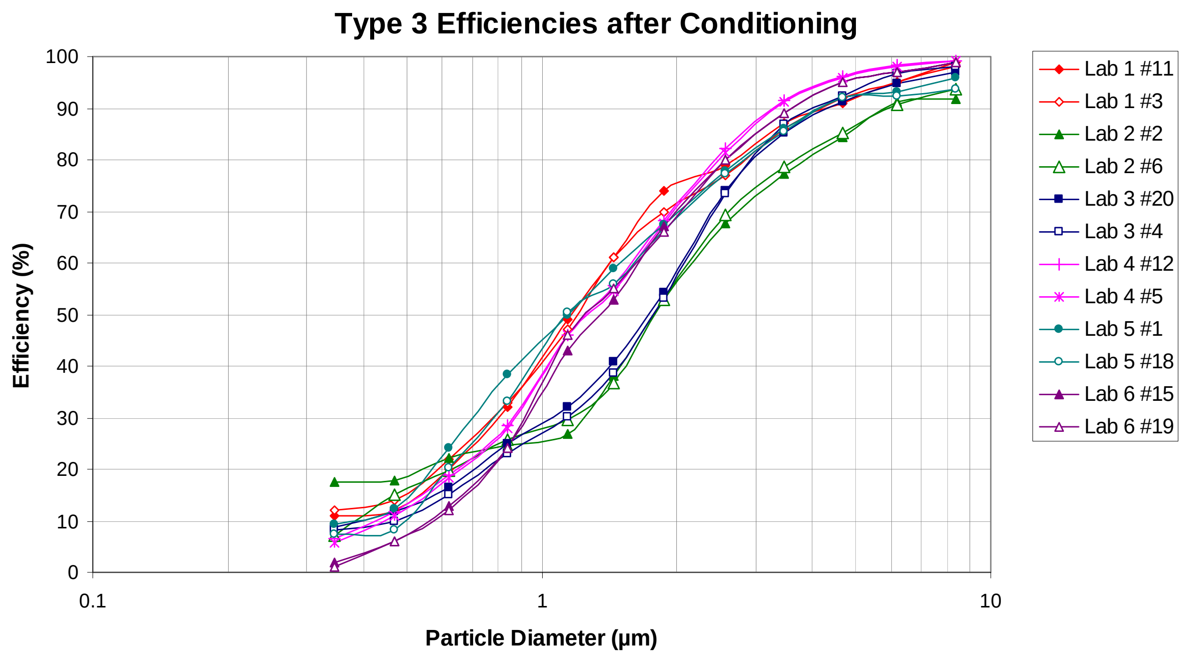


Figure 7. Filtration efficiency results for the Type 3 filter.



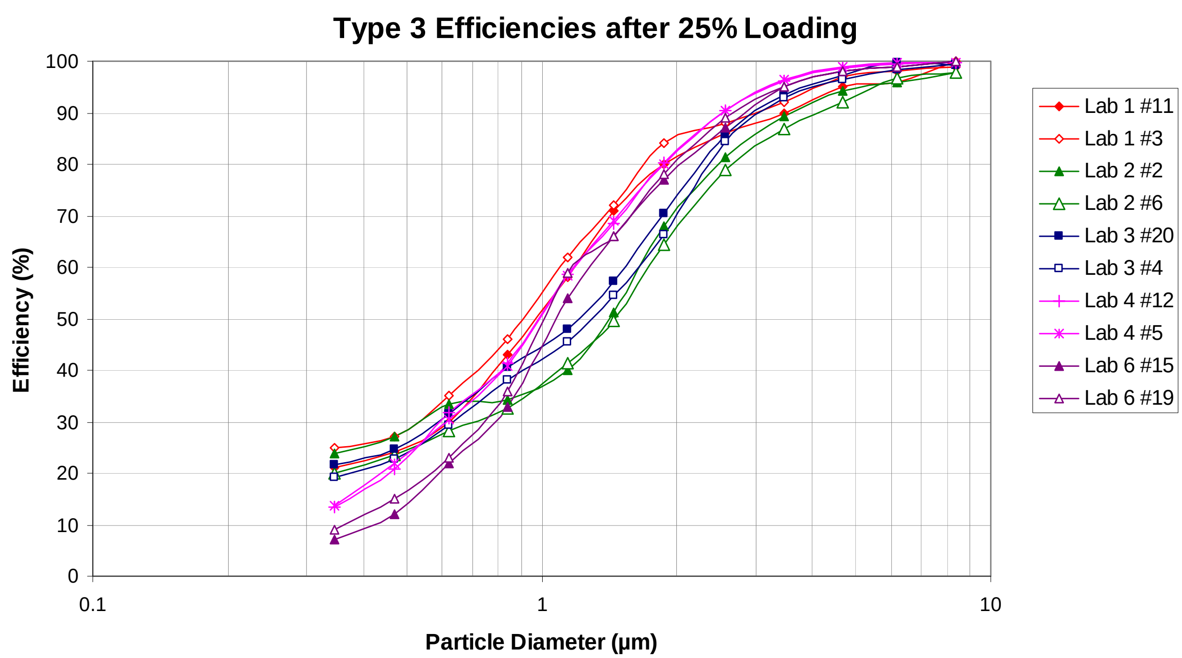
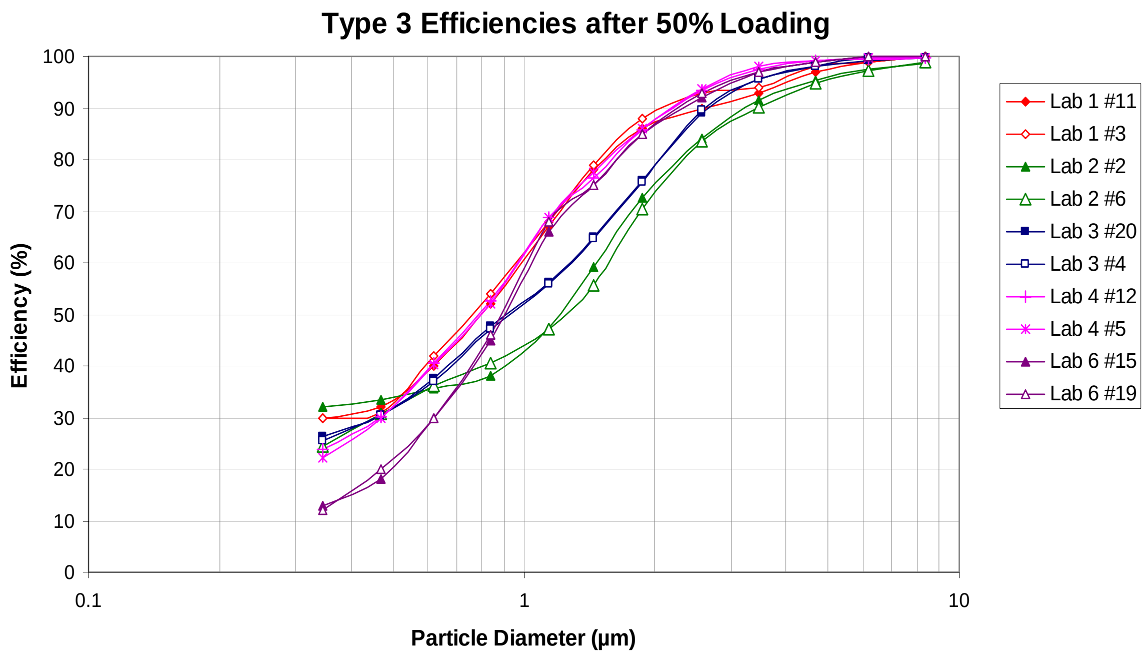


Figure 7. Type 3 filter results (continued).



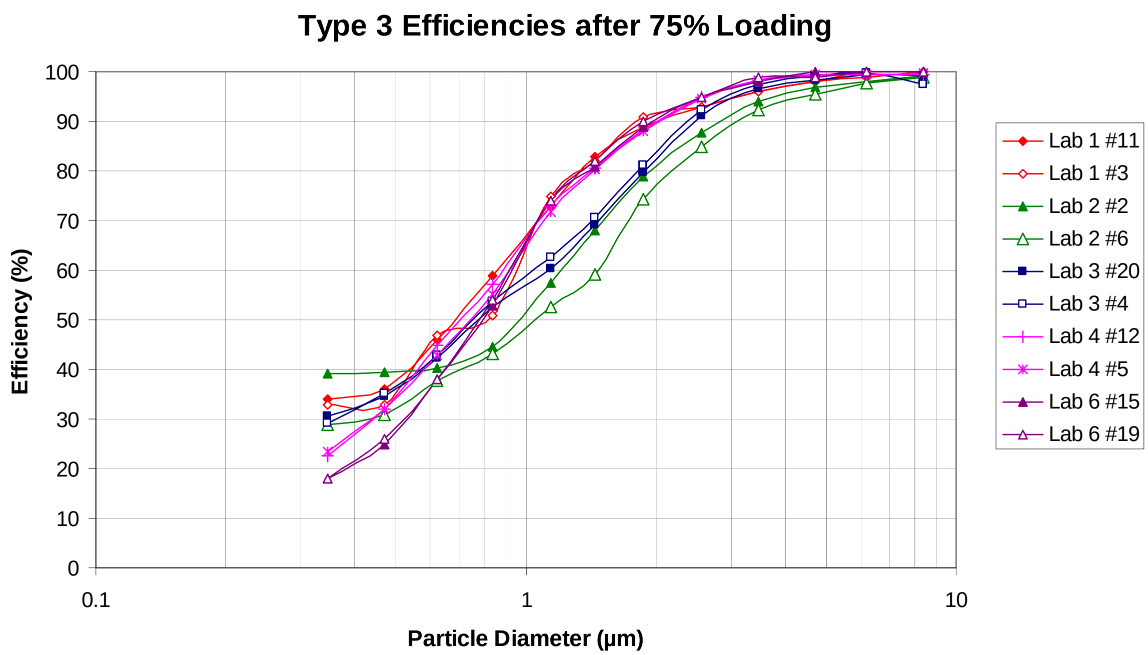


Figure 7. Type 3 filter results (continued).

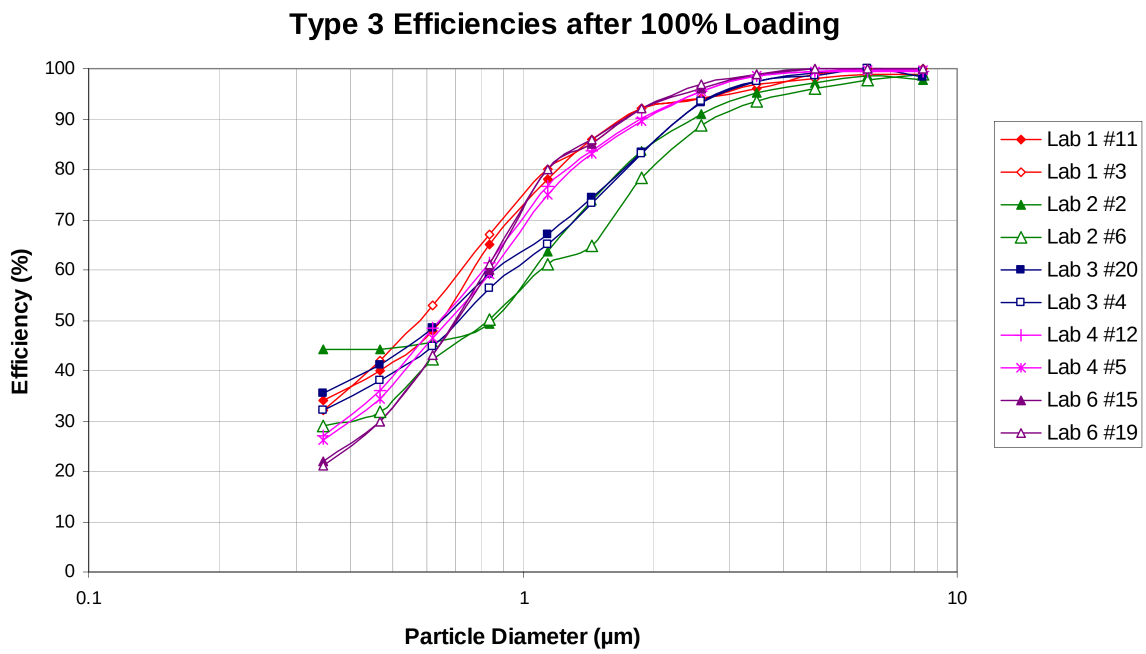
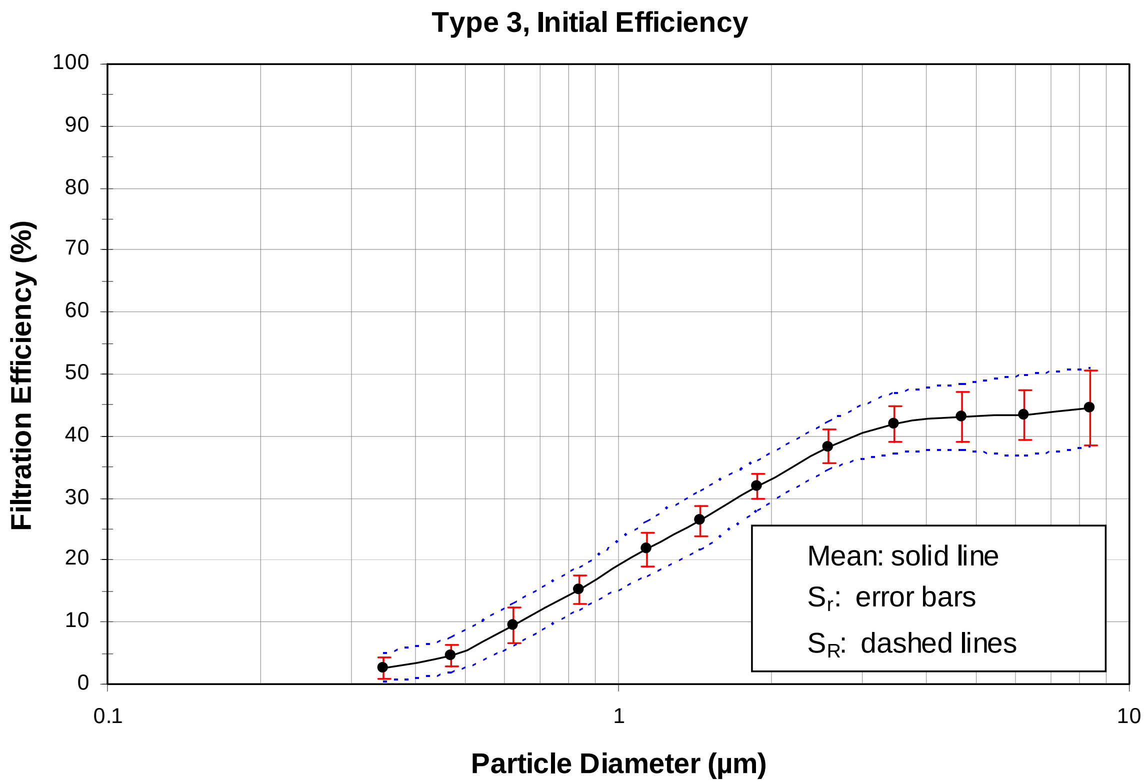


Figure 7. Type 3 filter results (continued).

Table 13.
Summary of the mean filtration efficiency (%) and the repeatability and reproducibility standard deviations (S_r and S_R, respectively, with units of %) for the Type 3 filters for each of the 12 indicated particle sizing channels.

		Precision statistics at the indicated particle size range											
Channel		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Min. Diam. (µm)		*0.30*	*0.40*	*0.55*	*0.70*	*1.00*	*1.30*	*1.60*	*2.20*	*3.00*	*4.00*	*5.50*	*7.00*
Max. Diam. (µm)		*0.40*	*0.55*	*0.70*	*1.00*	*1.30*	*1.60*	*2.20*	*3.00*	*4.00*	*5.50*	*7.00*	*10.0*
Geo. Mean Diam (µm)		*0.35*	*0.47*	*0.62*	*0.84*	*1.14*	*1.44*	*1.88*	*2.57*	*3.46*	*4.69*	*6.20*	*8.37*
Initial	S_r	1.7	1.6	2.9	2.2	2.8	2.6	2.0	2.7	3.0	4.0	4.0	6.1
Initial	S_R	2.3	3.0	3.5	3.5	4.5	4.7	3.9	3.9	4.9	5.2	6.5	6.3
Initial	Mean	2.6	4.6	9.5	15.2	21.7	26.3	31.9	38.3	41.9	43.0	43.3	44.6
Conditioning	S_r	3.1	1.6	1.5	1.7	1.4	1.2	1.3	0.8	0.7	0.5	0.6	1.0
Conditioning	S_R	4.5	3.6	3.9	5.0	9.3	9.8	8.1	4.8	4.6	3.9	2.7	2.7
Conditioning	Mean	8.1	11.3	18.5	28.3	41.3	50.8	63.3	76.6	86.1	91.9	94.9	96.9
25% Loading	S_r	2.0	1.8	2.5	1.6	2.2	1.1	2.2	1.3	1.0	0.9	0.8	0.3
25% Loading	S_R	6.6	5.1	4.3	4.8	8.6	9.1	7.3	3.9	3.4	2.2	1.5	0.9
25% Loading	Mean	17.4	21.8	29.5	38.6	52.5	62.5	74.8	86.1	92.7	96.5	98.2	99.3
50% Loading	S_r	2.5	1.1	0.7	1.1	0.7	1.2	0.9	1.0	0.5	0.4	0.2	0.0
50% Loading	S_R	7.1	5.5	4.4	5.6	9.4	9.1	7.0	3.9	2.9	1.7	1.0	0.5
50% Loading	Mean	23.9	28.6	36.9	47.5	61.3	70.5	81.0	90.2	94.9	97.8	99.1	99.6
75% Loading	S_r	3.3	2.9	1.1	2.7	1.9	2.9	1.7	3.4	0.7	0.6	0.3	0.6
75% Loading	S_R	7.4	4.5	3.6	5.3	8.8	8.7	6.2	4.1	2.3	1.4	0.9	0.9
75% Loading	Mean	27.7	32.4	42.0	52.3	67.3	75.6	84.9	91.2	96.5	98.3	99.3	99.4
100% Loading	S_r	5.0	4.2	2.3	1.4	1.3	2.9	2.6	0.8	0.6	0.5	0.4	0.6
100% Loading	S_R	7.1	5.3	3.4	6.0	8.0	7.7	5.5	2.6	1.9	1.3	0.8	0.8
100% Loading	Mean	30.3	36.8	46.3	58.9	72.7	79.5	87.6	93.9	97.2	98.7	99.5	99.3



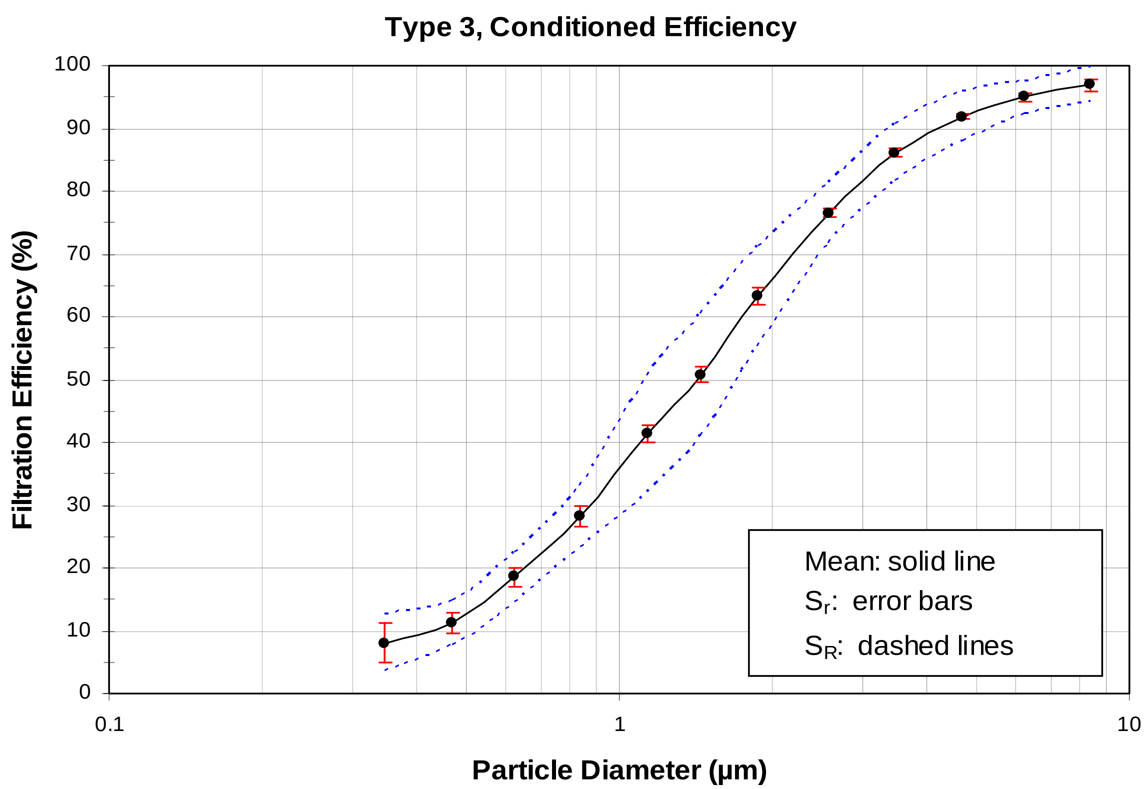
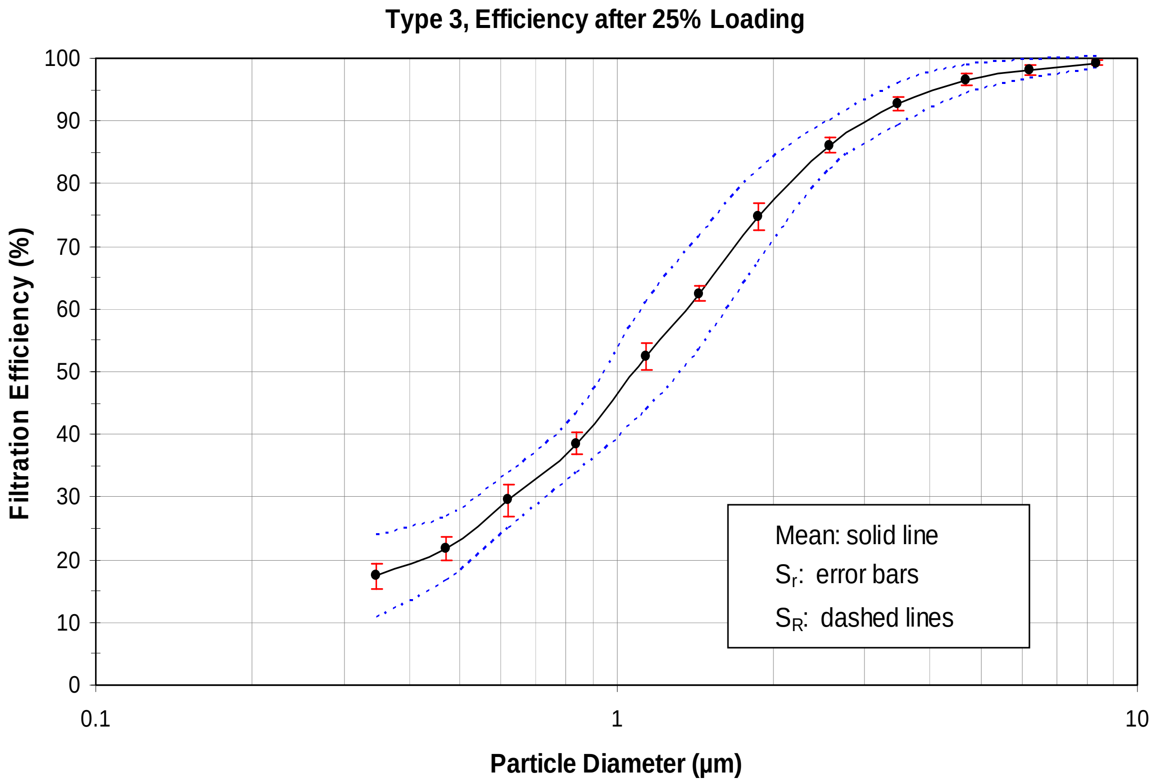


Figure 8. The repeatability and reproducibility standard deviations (S_r and S_R, respectively) plotted relative to the mean for the Type 3 filter.



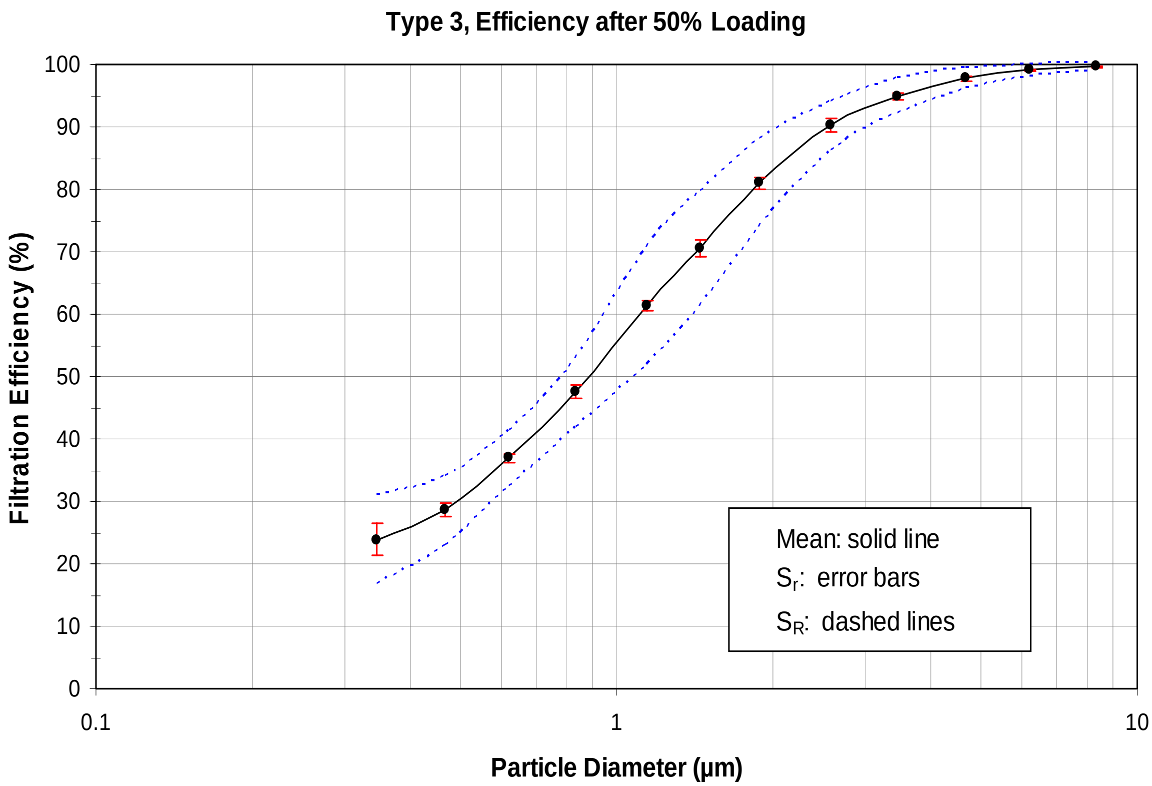
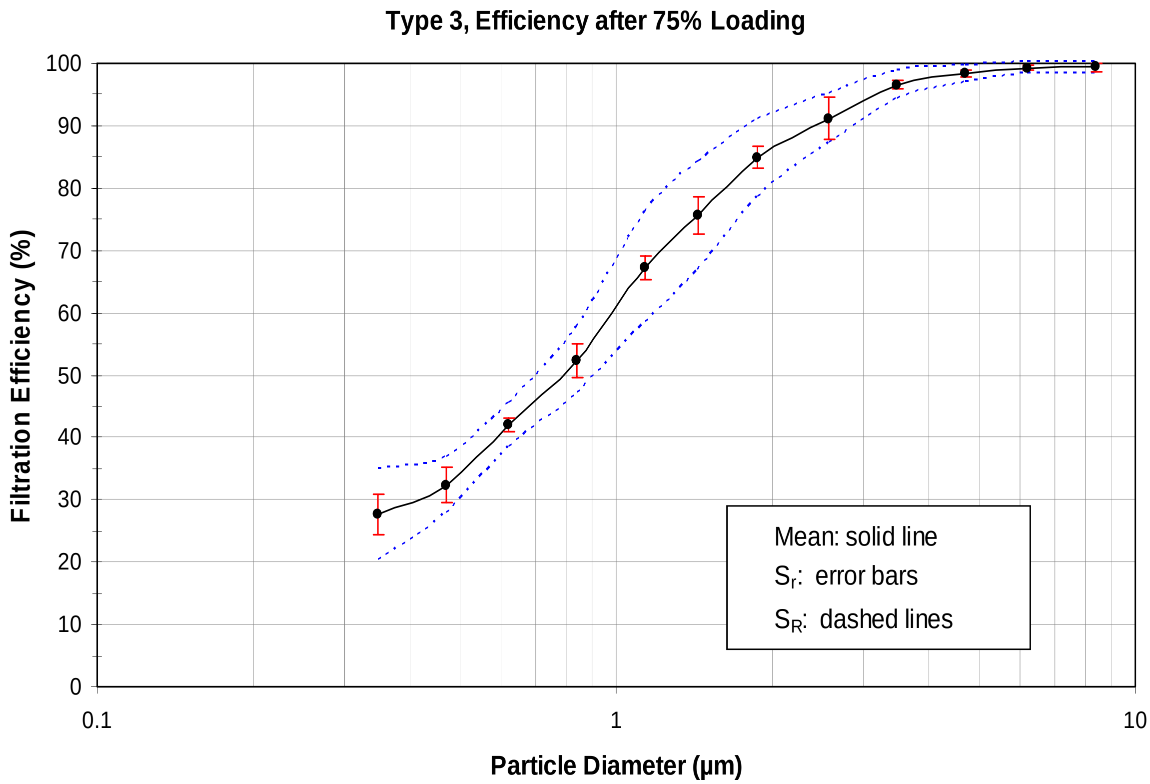


Figure 8. S_r and S_R for the Type 3 Filter (continued).



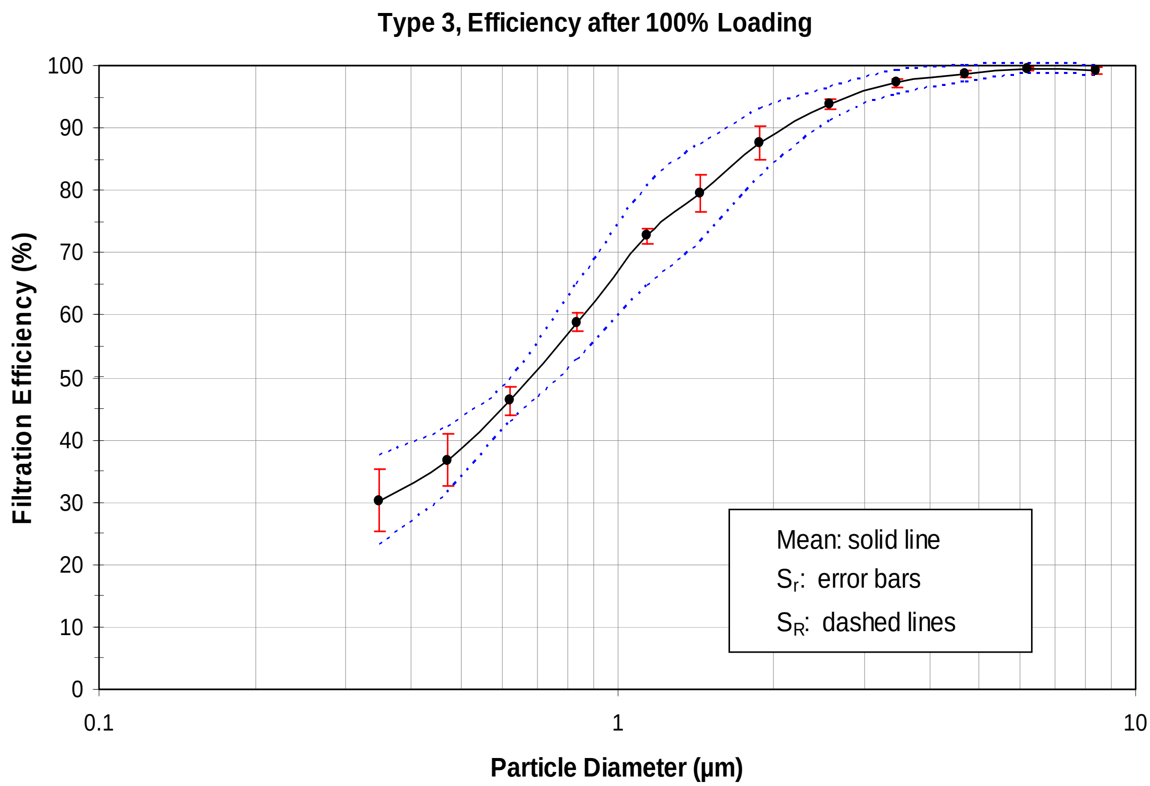
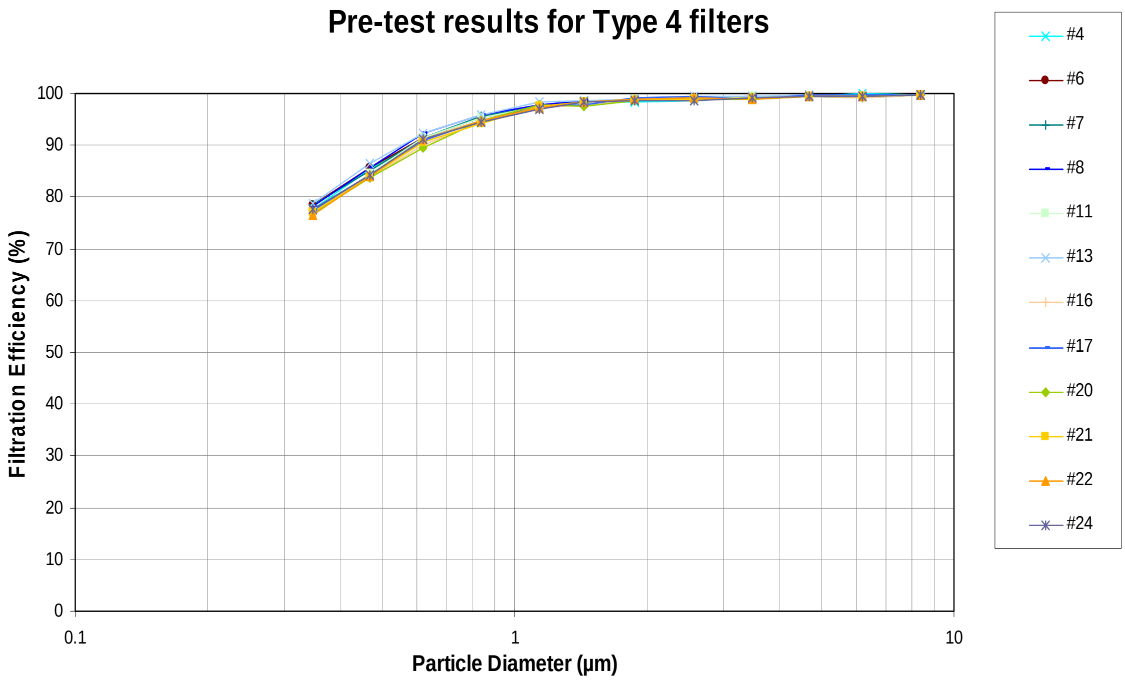


Figure 8. S_r and S_R for the Type 3 Filter (continued).

Table 14. Round 2 secondary parameter summary for Type 3 filters.

		ASHRAE 52.2 Composite Minimum Efficiencies and MERV				Filter pressure drop at test flow rate				
Lab	Filter ID	E1	E2	E3	MERV	Pre-test Pressure drop		Lab Pressure drop		Filter Weight Gain
						in. H_2O	Pa	in. H_2O	Pa	grams
1	#11	8	28	33	**5**	0.285	70.9	0.28	70	237.5
1	#3	9	31	38	**6**	0.285	70.9	0.29	72	250.2
2	#2	13	28	44	**6**	0.300	74.6	0.29	72	244.5
2	#6	8	22	40	**6**	0.300	74.6	0.30	75	247.2
3	#20	6	24	38	**6**	0.280	69.7	0.29	72	230.0
3	#4	10	28	50	**7**	0.295	73.4	0.29	72	285.0
4	#12	6	33	47	**6**	0.290	72.1	0.26	65	255.0
4	#5	7	33	47	**6**	0.300	74.6	0.27	67	280.0
5	#1	10	30	44	**6**	0.292	72.6	0.26	65	n/r
5	#18	10	33	45	**6**	0.280	69.7	0.26	65	n/r
6	#15	5	33	46	**6**	0.282	70.1	0.27	67	220.9
6	#19	4	33	46	**6**	0.273	67.9	0.27	67	225.4
Sr		1.91	2.42	3.94				0.00	1.2	19.6
SR		2.61	3.88	4.98				0.01	3.7	21.7
Mean		8.0	29.7	43.2		0.289	71.8	0.28	69	247.6



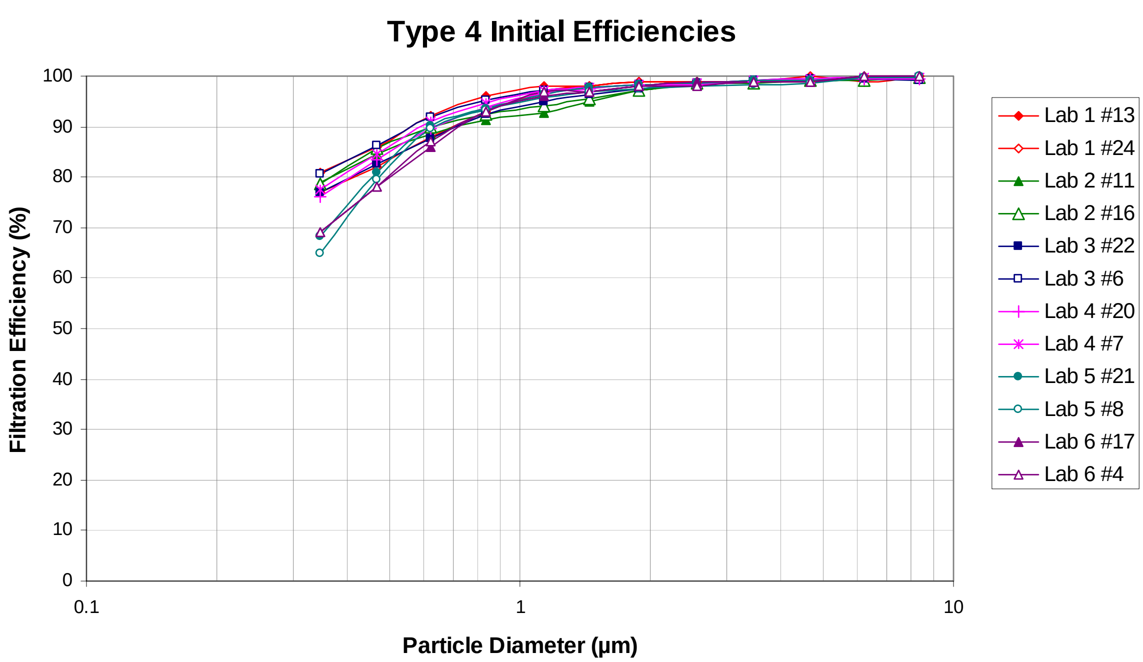
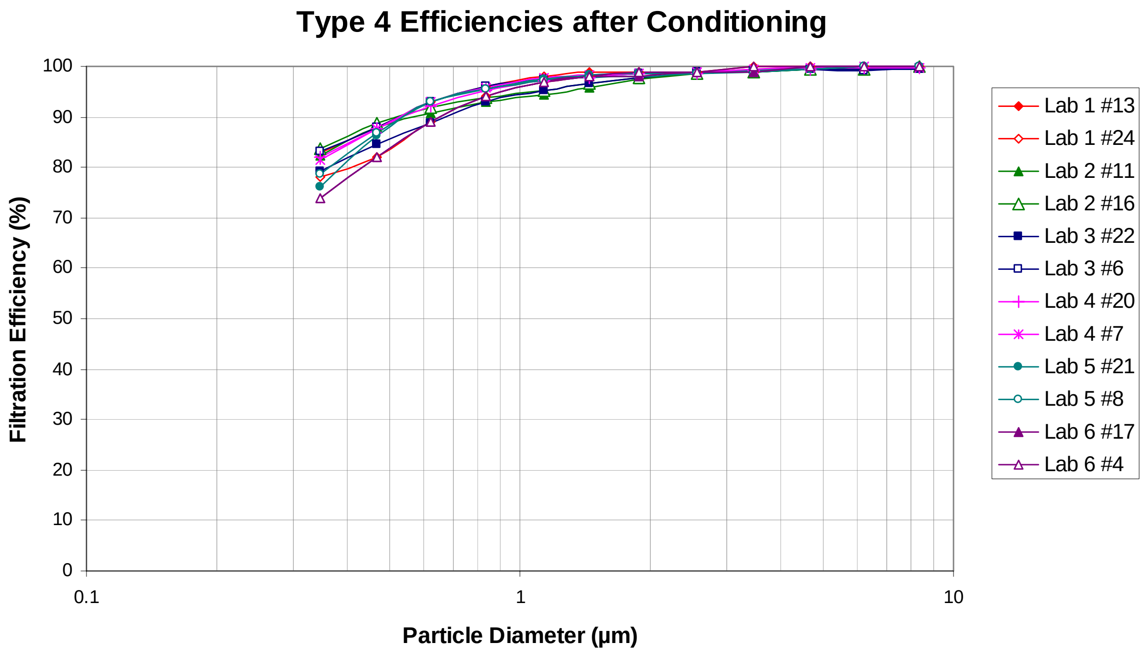


Figure 9. Filtration efficiency results for the Type 4 filter.



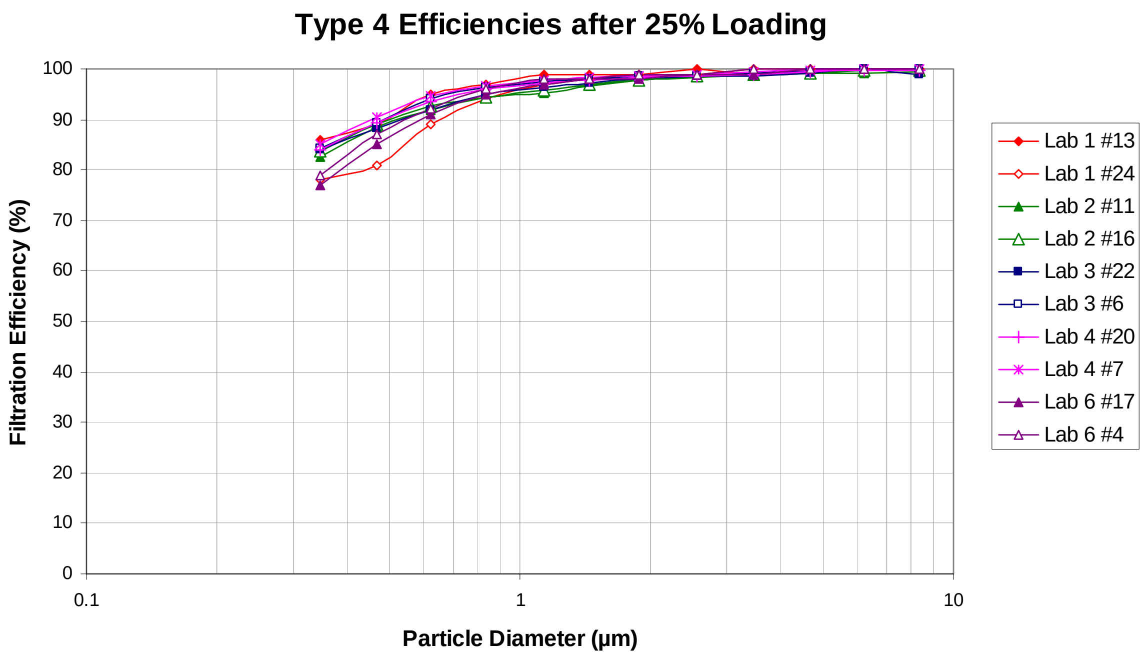
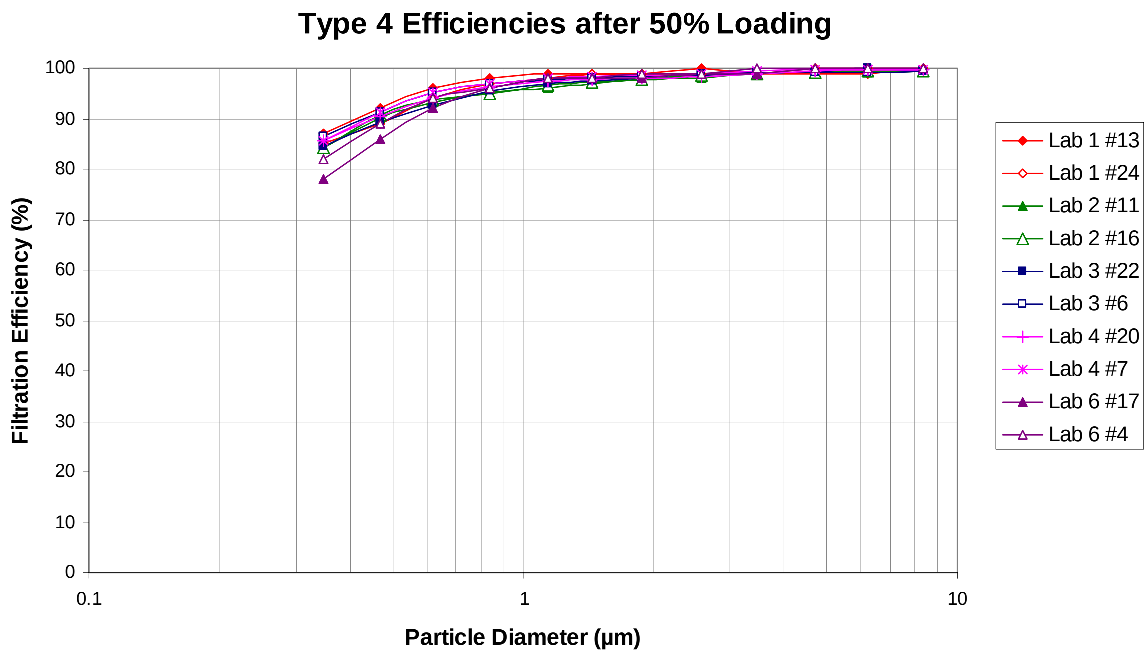


Figure 9. Type 4 filter results (continued).



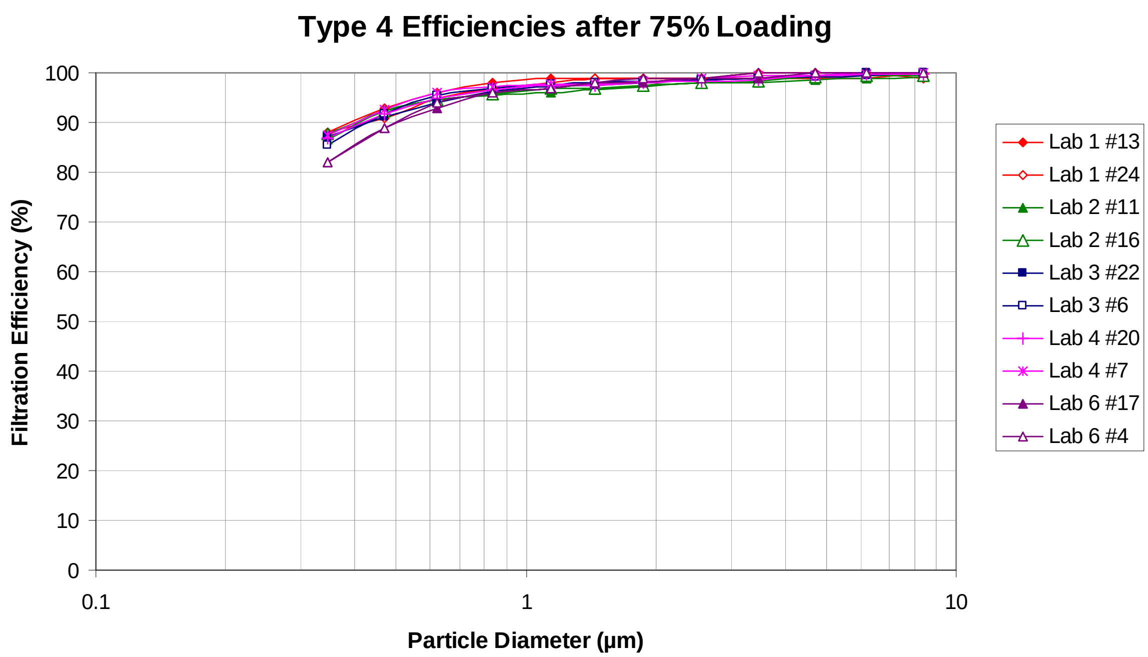


Figure 9. Type 4 filter results (continued).

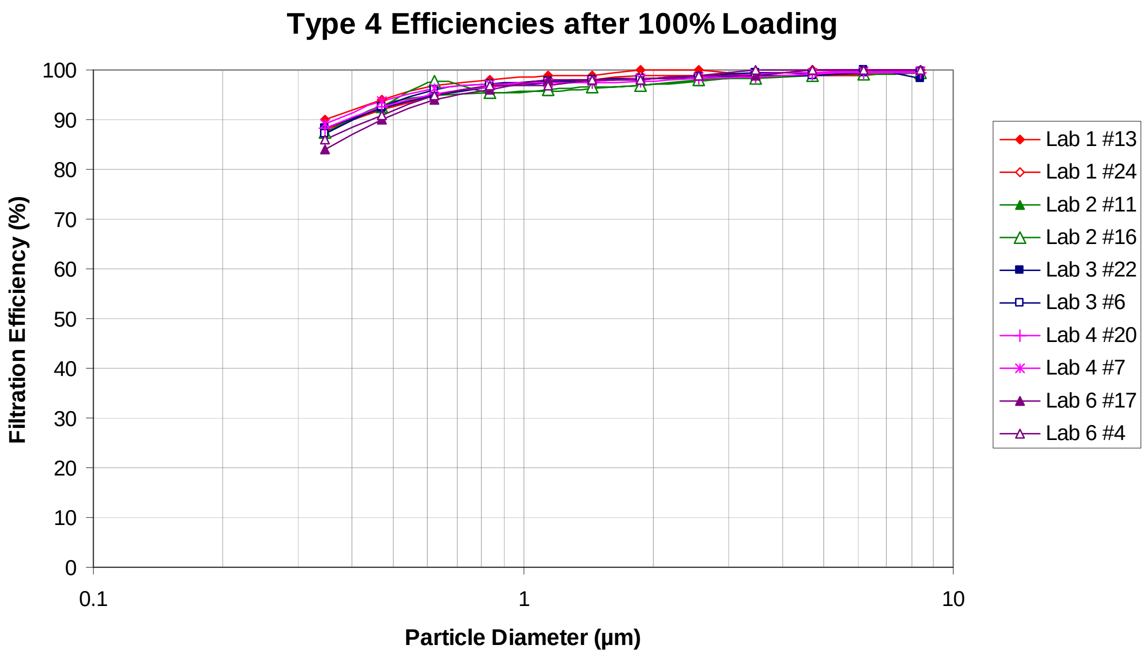
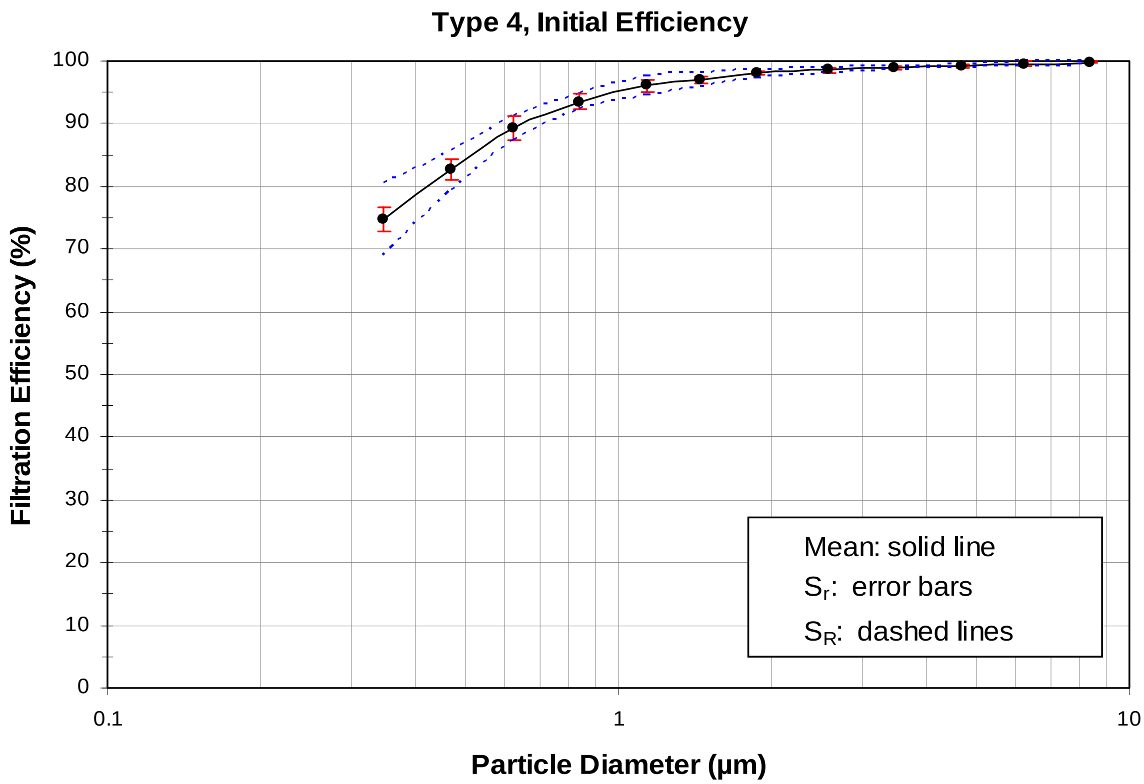


Figure 9. Type 4 filter results (continued).

Table 15.
Summary of the mean filtration efficiency (%) and the repeatability and reproducibility standard deviations (S_r and S_R , respectively, with units of %) for the Type 4 filters for each of the 12 indicated particle sizing channels.

		Precision statistics at the indicated particle size range											
Channel		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Min. Diam. (µm)		*0.30*	*0.40*	*0.55*	*0.70*	*1.00*	*1.30*	*1.60*	*2.20*	*3.00*	*4.00*	*5.50*	*7.00*
Max. Diam. (µm)		*0.40*	*0.55*	*0.70*	*1.00*	*1.30*	*1.60*	*2.20*	*3.00*	*4.00*	*5.50*	*7.00*	*10.0*
Geo. Mean Diam (µm)		*0.35*	*0.47*	*0.62*	*0.84*	*1.14*	*1.44*	*1.88*	*2.57*	*3.46*	*4.69*	*6.20*	*8.37*
Initial	S_r	1.90	1.67	1.82	1.28	0.94	0.53	0.35	0.36	0.25	0.35	0.32	0.15
Initial	S_R	5.70	3.06	1.93	1.31	1.56	1.05	0.65	0.36	0.25	0.35	0.35	0.26
Initial	Mean	74.8	82.6	89.3	93.5	96.1	97.0	98.0	98.5	98.9	99.2	99.5	99.8
Conditioning	S_r	2.00	2.02	1.71	1.05	0.78	0.60	0.39	0.12	0.44	0.10	0.11	0.05
Conditioning	S_R	3.65	2.65	1.85	1.12	1.19	0.93	0.53	0.21	0.44	0.30	0.30	0.18
Conditioning	Mean	79.7	85.9	91.3	94.7	96.8	97.7	98.4	98.8	99.2	99.6	99.8	99.8
25% Loading	S_r	2.66	2.67	2.10	1.12	0.84	0.48	0.38	0.36	0.49	0.14	0.16	0.32
25% Loading	S_R	3.25	2.81	2.10	1.12	1.15	0.75	0.53	0.47	0.49	0.38	0.26	0.33
25% Loading	Mean	82.4	87.7	92.6	95.5	97.1	97.8	98.4	98.9	99.2	99.6	99.8	99.8
50% Loading	S_r	1.56	1.52	1.21	0.53	0.45	0.32	0.39	0.38	0.38	0.34	0.39	0.04
50% Loading	S_R	2.69	1.74	1.21	0.95	0.92	0.74	0.55	0.52	0.38	0.41	0.39	0.30
50% Loading	Mean	84.2	89.9	94.0	96.3	97.6	98.0	98.3	98.8	99.1	99.5	99.6	99.7
75% Loading	S_r	0.64	0.74	0.74	0.45	0.46	0.14	0.36	0.17	0.50	0.35	0.39	0.35
75% Loading	S_R	2.41	1.48	0.95	0.81	0.83	0.81	0.64	0.42	0.63	0.38	0.40	0.39
75% Loading	Mean	86.1	91.4	94.7	96.5	97.4	97.8	98.3	98.6	99.0	99.5	99.6	99.7
100% Loading	S_r	1.00	0.81	1.28	0.51	0.46	0.37	0.39	0.38	0.40	0.36	0.39	0.42
100% Loading	S_R	1.73	1.22	1.28	0.89	1.01	0.84	0.96	0.68	0.47	0.50	0.43	0.51
100% Loading	Mean	87.6	92.4	95.6	96.6	97.3	97.6	98.1	98.7	99.0	99.4	99.6	99.6



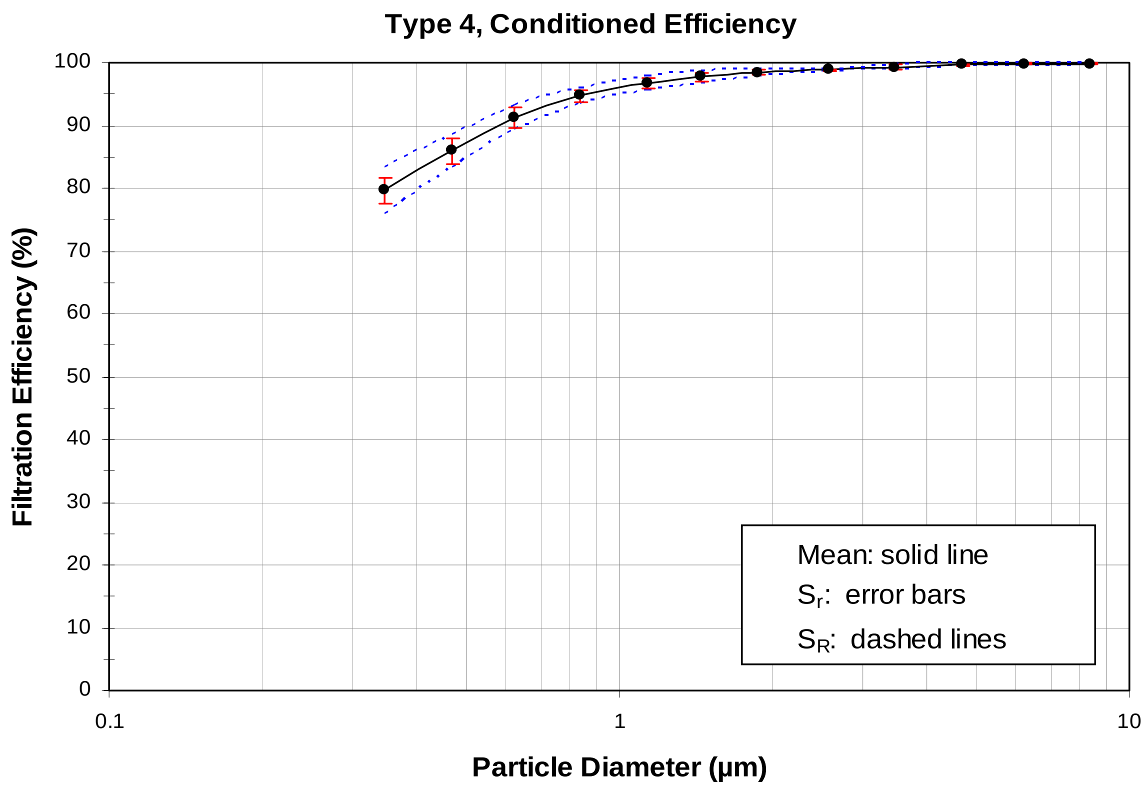
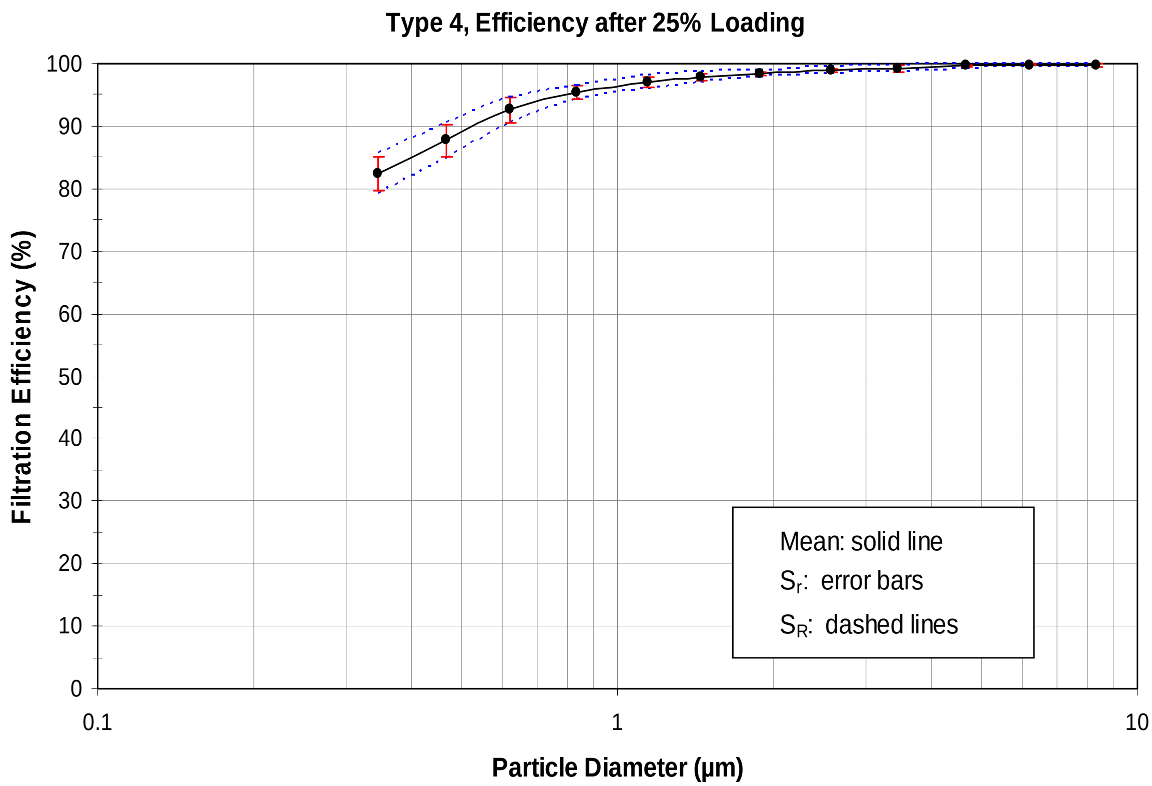


Figure 10. The repeatability and reproducibility standard deviations (S_r and S_R, respectively) plotted relative to the mean for the Type 4 filter.



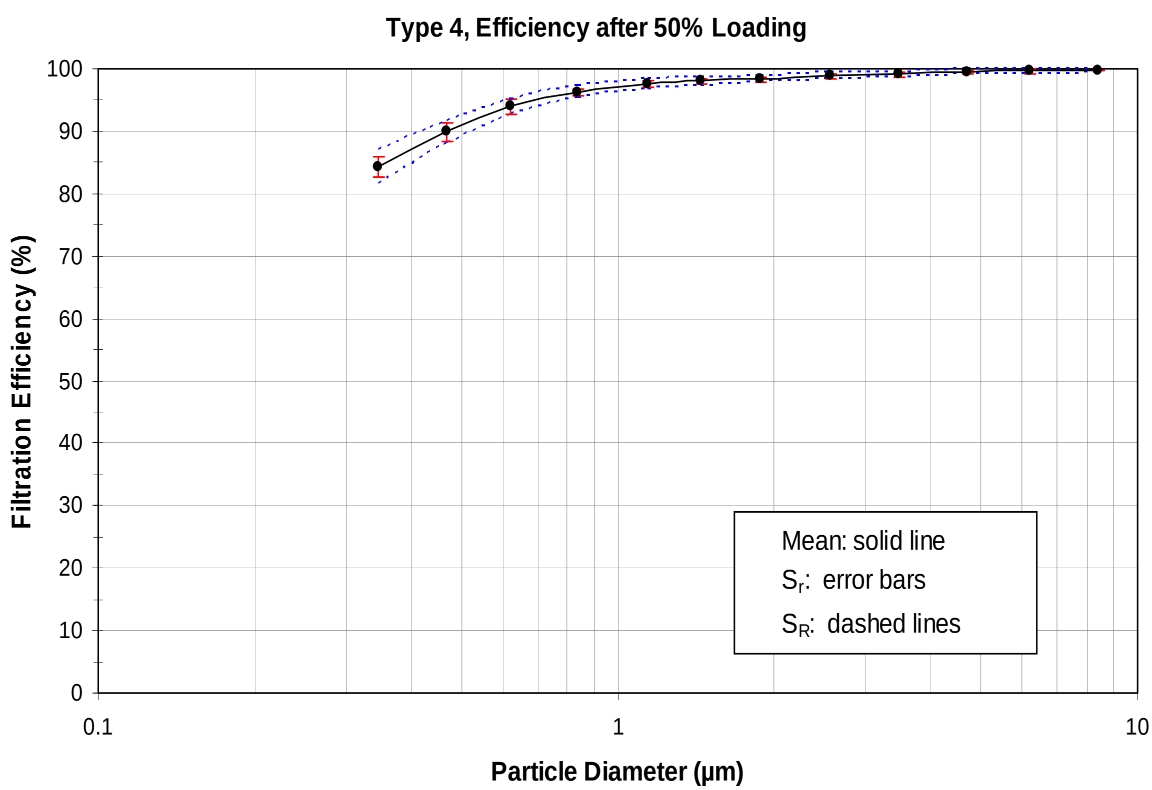
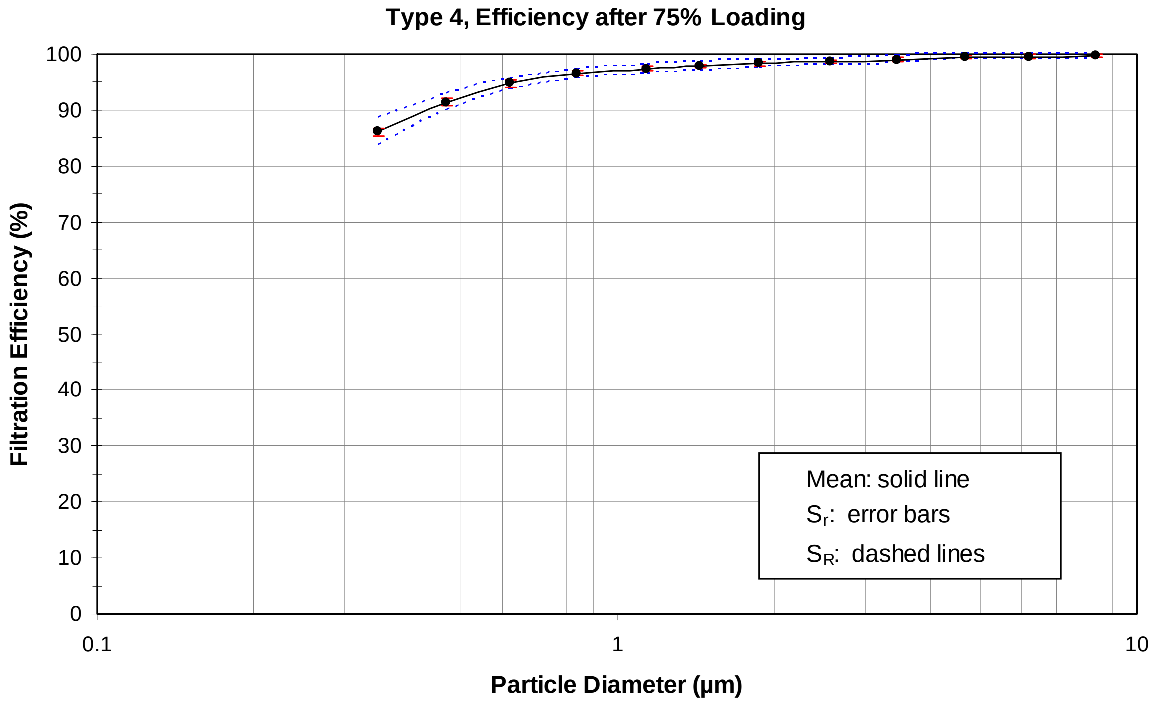


Figure 10. S_r and S_R for the Type 4 Filter (continued).



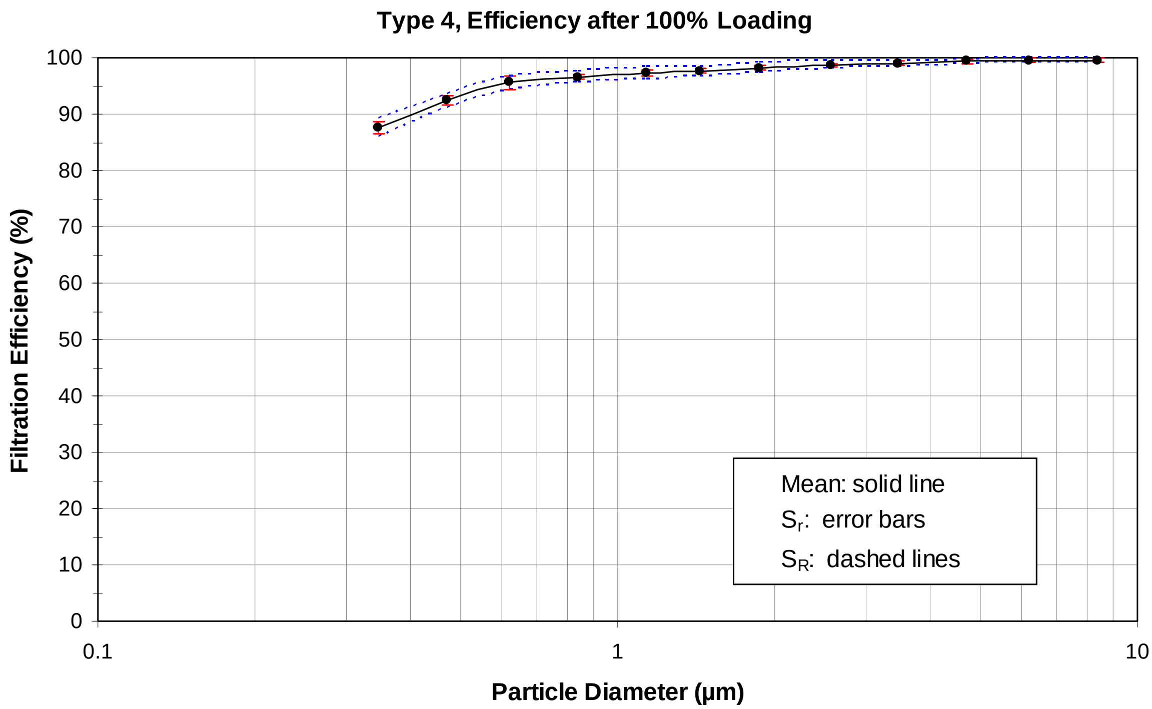


Figure 10. S_r and S_R for the Type 4 Filter (continued).

Table 16. Round 2 secondary parameter summary for Type 4 filters.

		ASHRAE 52.2 Composite Minimum Efficiencies and MERV				Filter pressure drop at test flow rate				
Lab	Filter ID	E1	E2	E3	MERV	Pre-test Pressure drop		Lab Pressure drop		Weight Gain
						in. H_2O	Pa	in. H_2O	Pa	grams
1	#13	89	99	99	**15**	0.795	198	0.79	200	119.0
1	#24	85	98	99	**15**	0.699	174	0.70	170	149.4
2	#11	86	96	99	**15**	0.795	198	0.79	200	115.0
2	#16	87	96	99	**15**	0.761	189	0.76	190	118.2
3	#22	85	97	99	**15**	0.720	179	0.72	180	190.0
3	#6	89	98	99	**15**	0.820	204	0.80	200	110.0
4	#20	86	98	99	**15**	0.725	180	0.72	180	180.0
4	#7	87	98	99	**15**	0.805	200	0.79	200	120.0
5	#21	83	98	99	**14**	0.730	182	0.66	160	n/r
5	#8	82	97	99	**14**	0.810	201	0.76	190	n/r
6	#17	82	98	100	**14**	0.761	189	0.82	200	161.0
6	#4	82	98	100	**14**	0.800	199	0.85	210	112.9
Sr		1.71	0.50	0.00				0.05	12.7	36.4
SR		2.63	0.93	0.41				0.05	13.6	36.4
Mean		85.3	97.6	99.2		0.768	191	0.76	190	137.6

6. Discussion of Anomalies

There were several cases of anomalous results:

- Anomaly #1: Lab 3, Type 2 filter #8: Initial efficiency result did not agree with their "duplicate" filter and was not in good agreement with the other labs.
- Anomaly #2: - Lab 5, Type 2 filter #13: the efficiency after conditioning had an unusual "S" shaped curve.
- Anomaly #3: - For Type 3 filter, after dust loading, the curves show distinct groupings of results.
- Anomaly #4: - For the Type 4 filter, the channel 1 results show two distinct groupings.

6.1 Anomaly #1

Figure 11 shows the initial efficiency results reported by Laboratory 3 for their two Type 2 filters. Pre-testing showed these filters to be closely matched. There was nothing usual in the test data or in the test conditions for the individual tests. The initial pressure drop for both filters was similar (in fact, the pressure drop for filter #17 was slightly lower than filter # 8 which is counter to the measured efficiency relationship.) The lab was contacted about the results and indicated that nothing unusual was noted for the tests.

The lower curve appears to be anomalous compared to results from the other labs. These data also exceeded the repeatability critical value (see Appendix I, page I-2). One cause of lower-than-expected results can be a filter that was not sealed completely to the test rig. It is not known if that is the cause in this case. The 52.2 standard gives no guidance on how to install the test filter or how to inspect/test for an effective seal. Because it appears that the test method was followed diligently by the laboratory, results for both filters were included in the statistical analyses.

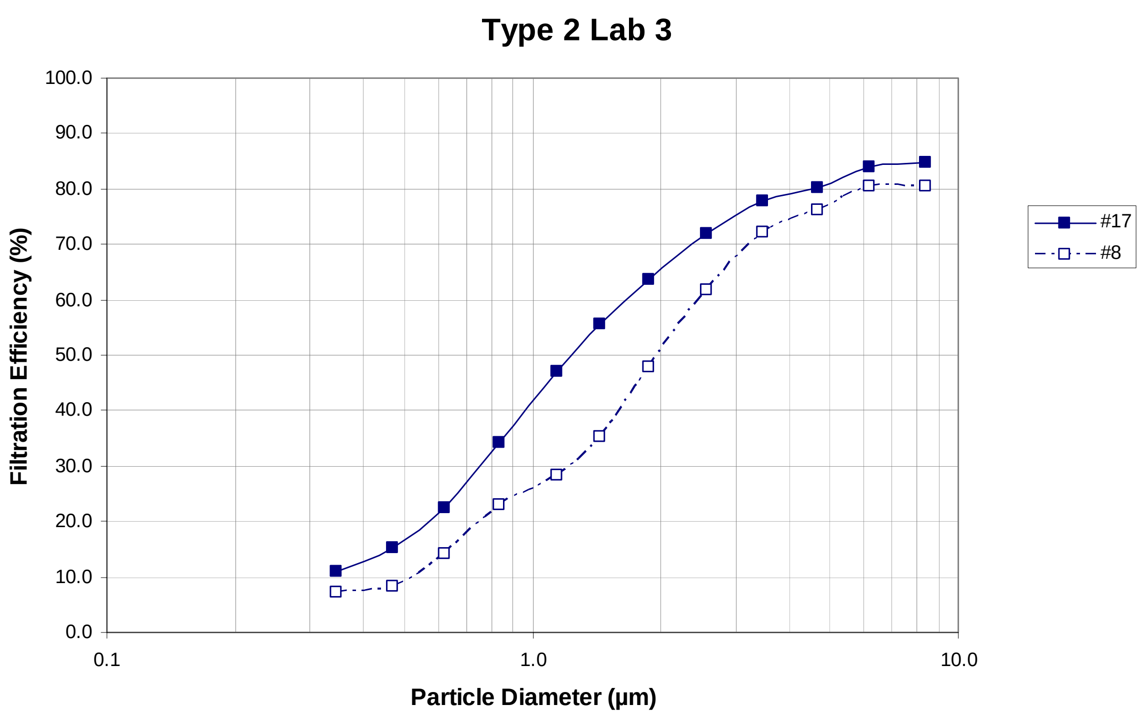


Figure 11. For the Type 2 filter, the measured filtration efficiency of the duplicate filters was not repeatable within one of the laboratories.

6.2 Anomaly #2
The filtration efficiency results from Lab 5 for the Type 2 #13 filter had an unusual "S" shaped curve after conditioning and after the 25% dust load (Figure 12). Such a shape is generally inconsistent with filtration theory. The lab was contacted to determine if there was an explanation for the results. The lab had some difficulty with the particle counting system during this test. Aware of this, they performed additional reference filter tests at that time and reported that the reference filter curves looked "normal" and matched previous reference filter results. Thus, although the lab recognized the shape was unusual, they believed they had properly implemented the test method. This anomaly was not observed in the lab's replicate filter.

Because it appears that the test method was followed diligently by the laboratory, results for both filters were included in the statistical analyses.

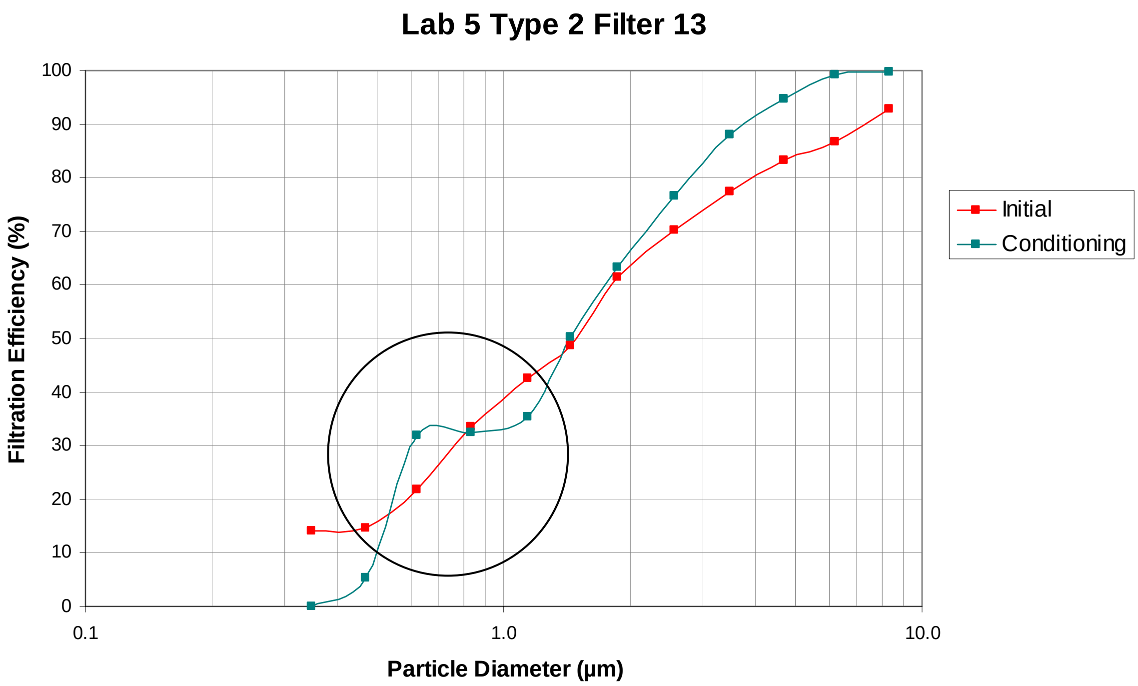


Figure 12. The shape of the filtration curve is quite unusual and was not repeated in the lab's duplicate filter.

6.3 Anomaly #3

For the Type 3 filter the results showed two distinct groupings in the 1 – 3 µm range after the conditioning,. This was also seen after the 50% dust load with an additional split in the 0.3 – 0.7 µm range (Figure 13).

The groupings are not isolated to a brand of particle counter, type of aerosol neutralizer, or duct shape. With no apparent explanation for the divergent results, all the results were included in the analyses.

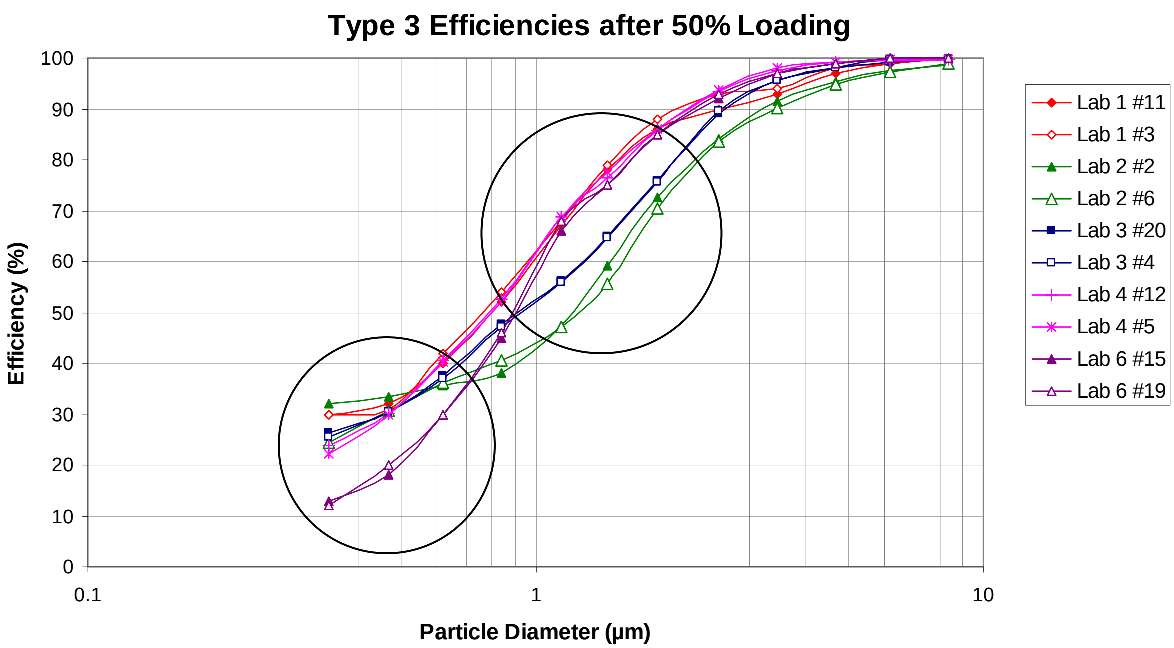


Figure 13. The results fell into distinct groupings in the 0.3 – 0.7 µm range and in the 1-3 µm range. In the 1-3 µm range, Labs 2 and 3 are in the lower cluster. In the 0.3 – 0.7 µm range, results for Lab 6 are in the lower group.

6.4 Anomaly #4

For the Type 4 filter, the channel 1 results (0.3 – 0.4 µm) show two labs distinct from the others (Figure 14). Labs 5 and 6 reported lower efficiencies than the other four labs. Results were repeatable for all labs on their duplicate filters.

The groupings are not isolated to a brand of particle counter, type of aerosol neutralizer, or duct shape. With no apparent explanation for the divergent results, all the results were included in the analyses.

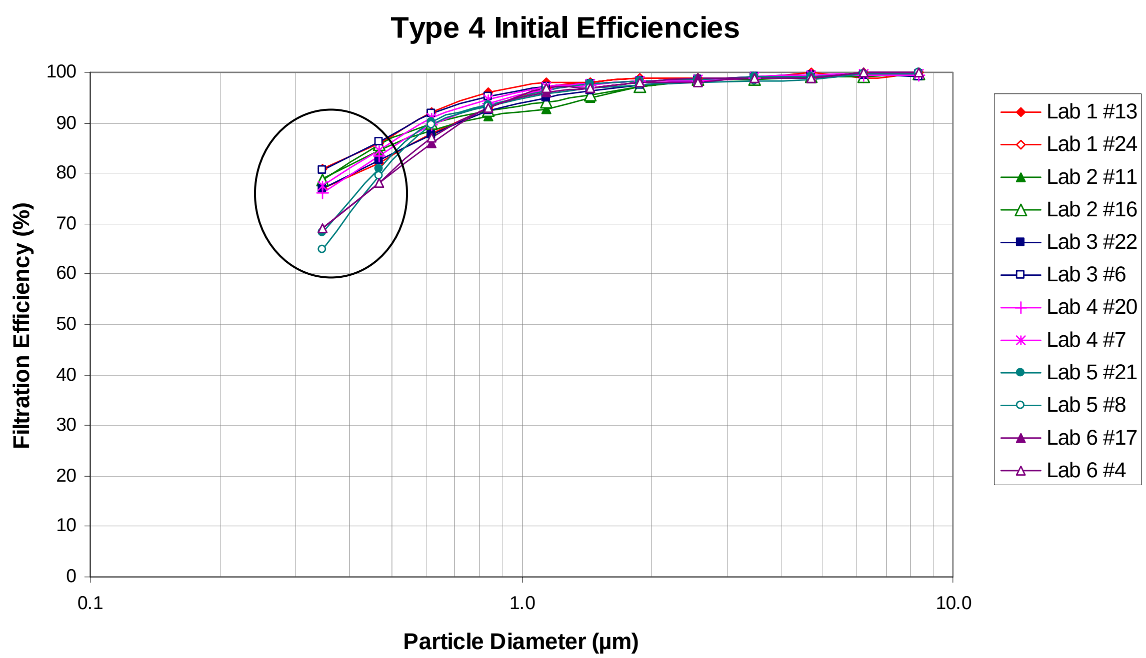


Figure 14. In channel 1, the data fell into two distinct groups (Labs 5 and 6 make up the lower cluster).

7. Results of EN779 duct

The ILS was fortunate to have a European laboratory participate in the study. Their test system conformed to the EN779 standard. The EN779 and ASHRAE 52.2 standards have many commonalities including similar test rig configuration, use of aerosol neutralizers, use of aerosol particle counter to measure upstream and downstream aerosol concentrations, similar system qualification requirements, and similar dust feeder. However, there were sufficient differences that precluded combining these results with the other lab results. These differences included: different and fewer particle sizing channels; the location of the downstream sample probe location and lack of a downstream mixing orifice and baffle plate; and a different data analysis formulation. To eliminate some differences, for these tests the lab used the same test aerosol (dry potassium chloride aerosol) for the tests reported herein and extended the measurements to 10 µm to match the measurement range of the ASHRAE 52.2 standard. For Round 2, the lab tested three filters: one Type 2, one Type 3 and one Type 4 filter. This differed from the labs in the main study where each lab tested two filters of each type.

The initial efficiency results from the EN779 duct are presented in Figures 15 - 17. In the plots, the EN779 results are in the bold solid line, the other lab results are shown with dashed lines. Tabulated results for initial efficiency and efficiency after dust loading are presented in Tables 17- 19. Table 20 presents summarizes the secondary parameters.

Overall, the EN779 results are within, or close to, the range of the other laboratories for the filtration efficiency, pressure drop and weight gain measurements.

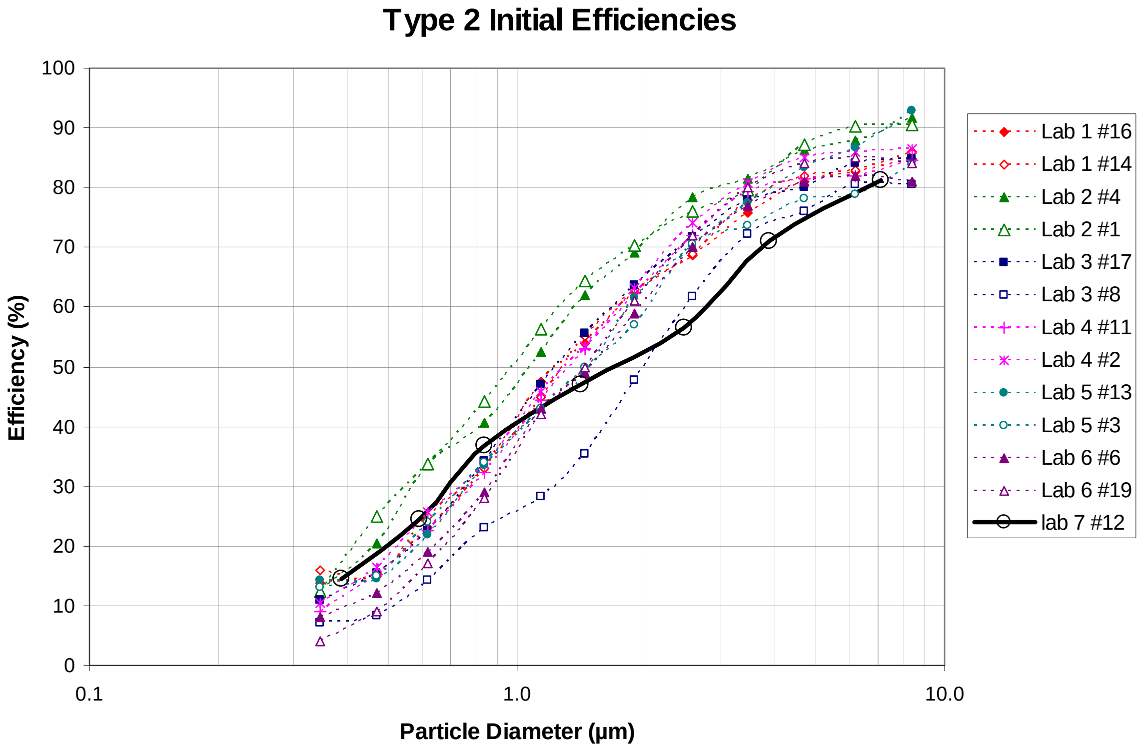


Figure 15. Comparison of initial efficiency measurements for the Type 2 Filters.

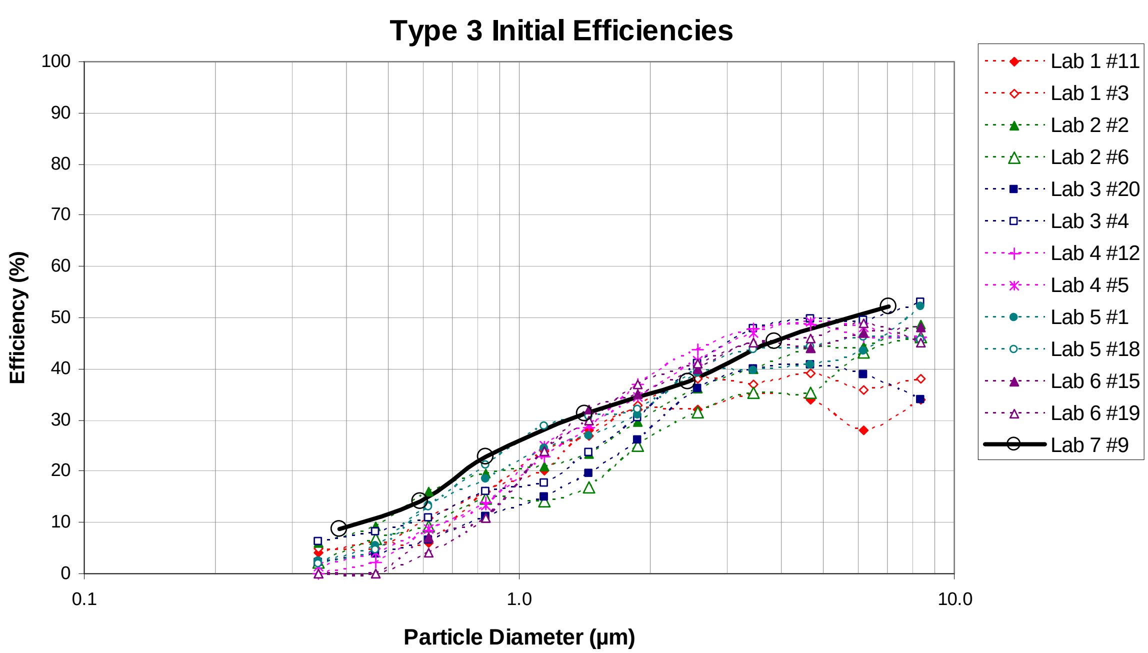


Figure 16. Comparison of initial efficiency measurements for the Type 3 Filters.

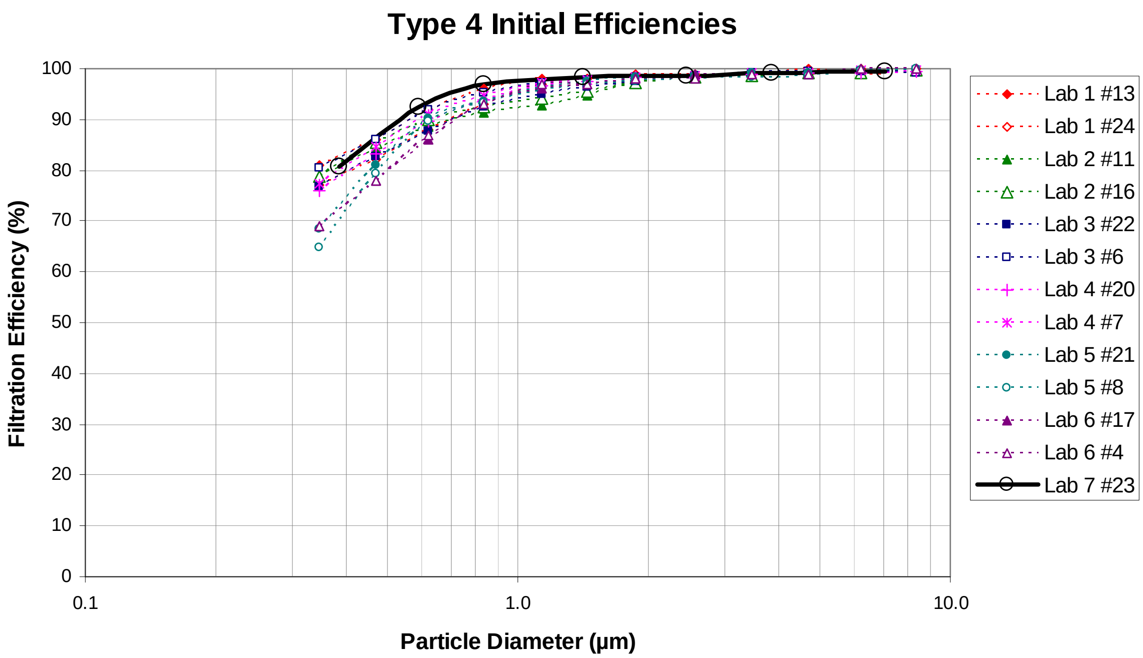


Figure 17. Comparison of initial efficiency measurements for the Type 4 filters.

Table 17. Results for Type 2 #12 filter from EN779 participant.

OPC Channel No.	1	2	3	4	5	6	7
Min. Diam (µm)	0.3	0.5	0.7	1.0	2.0	3.0	5.0
Max. Diam (µm)	0.5	0.7	1.0	2.0	3.0	5.0	10.0
Geo. Mean Diam (µm)	**0.39**	**0.59**	**0.84**	**1.41**	**2.45**	**3.87**	**7.07**
Initial	16.7	27.4	41.9	55.7	66.2	78.1	82.7
Conditioning	18.7	29.8	46.8	64.8	78.6	92.8	99.8
25%	19.8	32.5	50.7	70.2	84.1	94.8	98.3
50%	23.4	37.9	57.2	77.3	88.0	96.9	98.9
75%	29.1	45.1	64.3	82.7	91.4	97.8	99.5
100%	33.6	53.7	74.1	89.1	95.0	98.9	99.5

Table 18. Results for Type 3 # 9 filter from EN779 participant.

OPC Channel No.	1	2	3	4	5	6	7
Min. Diam (µm)	0.3	0.5	0.7	1	2	3	5
Max. Diam (µm)	0.5	0.7	1	2	3	5	10
Geo. Mean Diam (µm)	**0.39**	**0.59**	**0.84**	**1.41**	**2.45**	**3.87**	**7.07**
Initial	8.6	14.1	22.7	31.2	37.6	45.5	52.3
Conditioning	12.9	22.7	38.5	56.7	71.2	87.9	94.7
25%	18.0	28.3	43.1	61.6	76.3	91.4	97.5
50%	22.4	33.0	48.6	65.7	79.8	92.9	98.0
75%	26.6	40.2	57.1	74.7	86.2	95.4	98.7
100%	35.1	52.2	69.8	83.5	91.5	97.6	99.4

Table 19. Results for Type 4 #23 filter from EN779 participant.

OPC Channel No.	1	2	3	4	5	6	7
Min. Diam (µm)	0.3	0.5	0.7	1	2	3	5
Max. Diam (µm)	0.5	0.7	1	2	3	5	10
Geo. Mean Diam (µm)	**0.39**	**0.59**	**0.84**	**1.41**	**2.45**	**3.87**	**7.07**
Initial	80.8	92.5	96.8	98.3	98.7	99.3	99.5
Conditioning	83.6	93.0	96.7	98.4	98.8	99.3	99.4
25%	85.1	93.8	97.0	98.3	98.8	99.3	99.6
50%	85.9	94.4	97.2	98.4	98.8	99.3	99.7
75%	87.0	94.5	96.9	98.0	98.4	99.2	99.4
100%	88.6	95.1	97.0	97.8	98.4	99.0	99.5

Table 20. Round 2 secondary parameter summary for the EN779 laboratory.

Lab	Filter Type	Filter ID	Pre-test Pressure drop		Lab Pressure drop		Weight Gain
			in. H_2O	Pa	in. H_2O	Pa	grams
7	2	12	0.360	89.6	0.381	94.8	154
7	3	9	0.295	73.4	0.293	72.9	243
7	4	23	0.800	199	0.807	201	126

8. Result Summaries

8.1 Filtration Efficiency

It was evident from the filtration efficiency results that within- and between-lab precision improved significantly as efficiency approaches 100%. For example, the Type 4 filter (high efficiency) had relative close agreement as did the Type 2 and 3 for dust loaded conditions where efficiency was approaching 100%. This was expected and is due to the efficiency having an upper bound of 100%. Efficiency is also bounded at 0%. Given this efficiency dependent link, it was of interest to see if S_r and S_R showed efficiency dependent trends.

Figure 18 shows the S_r and S_R for the initial efficiency results for the Type 2, 3, and 4 filters. Unlike the previous graphs in this report, this graph plots filtration efficiency on the x-axis with S_r and S_R on the y-axis. Although the scatter is high, it is interesting to note the overall trend of S_r and S_R being lowest near the efficiency bounds (i.e., near 0 and 100%) and having maximums in the mid-range (i.e., near 50% efficiency). In this plot, each data set contains 36 data points (3 filter types with 12 particle sizing channels = 36).

Going a step further, the results for the Type 2, 3, and 4 filters can be combined including the dust loading results (Figure 19). The scatter is greater, as would be expected since dust loading introduces more opportunities for laboratories to diverge. However, the overall trend remains, with S_r and S_R being lowest near the efficiency bounds (i.e., near 0 and 100%) and having maximums in the mid-range (i.e., near 50% efficiency). In this plot, each data set contains 216 data points (3 filter types tested at 6 levels of dust loading with 12 particle sizing channels = 216).

Using the quadratic fits to the repeatability and reproducibility standard deviations that are given in Figure 18, Table 21 lists the computed standard deviations and precision statistics for the initial efficiency tests results. Similarly, Table 22 lists the results for the full body of filtration efficiency results (i.e., initial efficiency and the efficiency measurements made after each level of dust loading) based on Figure 19.

By making use of the full data base of efficiency measurements, these summary results (Figures 18 and 19 and Tables 21 and 22) provide robust assessments of the precision of the ILS measurements. For example, if the Round 2 filter were removed entirely from the analysis because of the anomalies present with that filter type, the summary results remain essentially unchanged.

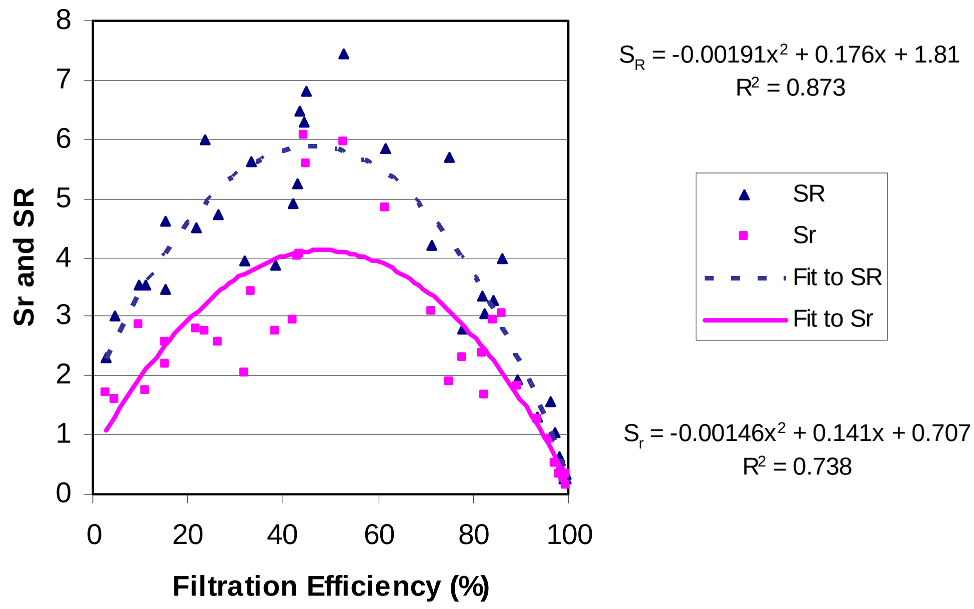


Figure 18. Pooled results for the initial efficiency tests.

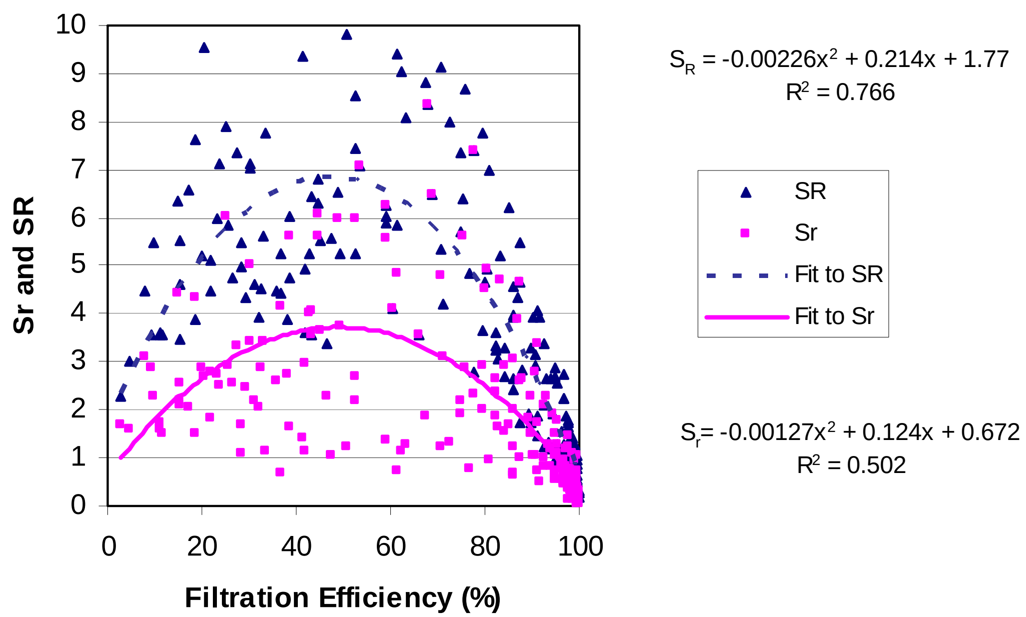


Figure 19. Pooled results for all tests (initial plus dust loading tests).

Table 21. Approximate precision statistics based on quadratic fits to S_r and S_R obtained in the Round 2 initial efficiency test results.

	Precision statistics at the indicated filtration efficiency level.										
Precision statistic	**0%**	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
S_r	0.7	2.0	2.9	3.6	4.0	4.1	3.9	3.4	2.6	1.6	0.2
S_R	1.8	3.4	4.6	5.4	5.8	5.8	5.5	4.8	3.7	2.2	0.3
“$2S_r$”	1.4	3.9	5.8	7.1	7.9	8.0	7.7	6.7	5.2	3.1	0.4
“$2S_R$”	3.5	6.6	8.9	10.5	11.4	11.4	10.8	9.4	7.2	4.3	0.6
r	2.0	5.5	8.2	10.1	11.2	11.5	11.0	9.6	7.4	4.4	0.6
R	5.1	9.5	12.8	15.0	16.2	16.3	15.4	13.4	10.3	6.1	0.9

Table 22. Approximate precision statistics based on quadratic fits to S_r and S_R for all Round 2 filtration efficiency results
(initial efficiency and the efficiency after each level of dust loading).

	Precision statistics at the indicated filtration efficiency level.										
Precision statistic	**0%**	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
S_r	0.7	1.8	2.6	3.2	3.6	3.7	3.5	3.1	2.5	1.5	0.4
S_R	1.8	3.7	5.1	6.2	6.7	6.8	6.5	5.7	4.4	2.7	0.6
“$2S_r$”	1.3	3.5	5.2	6.4	7.1	7.2	6.9	6.1	4.8	3.0	0.7
“$2S_R$”	3.5	7.2	10.1	12.1	13.2	13.4	12.7	11.1	8.7	5.3	1.1
r	1.9	5.0	7.4	9.1	10.1	10.4	9.9	8.8	6.9	4.3	1.0
R	5.0	10.3	14.4	17.2	18.8	19.1	18.1	15.9	12.4	7.6	1.6

8.2 Summary of the E1, E2, and E3 Values

Figure 20 summarizes the repeatability and reproducibility standard deviations for the E1, E2 and E3 values based on the values reported earlier in Tables 12, 14, and 16 for the three filter types. Figure 21 shows their standard deviations plotted against filtration efficiency. Because the E values often came from the initial efficiency measurements of filtration efficiency, it is not surprising that Figure 21 is similar to Figure 18.

Using the quadratic fits to the repeatability and reproducibility standard deviations presented in Figure 21, Table 23 lists the computed standard deviations and precision statistics for the E values as a function of their efficiency value.

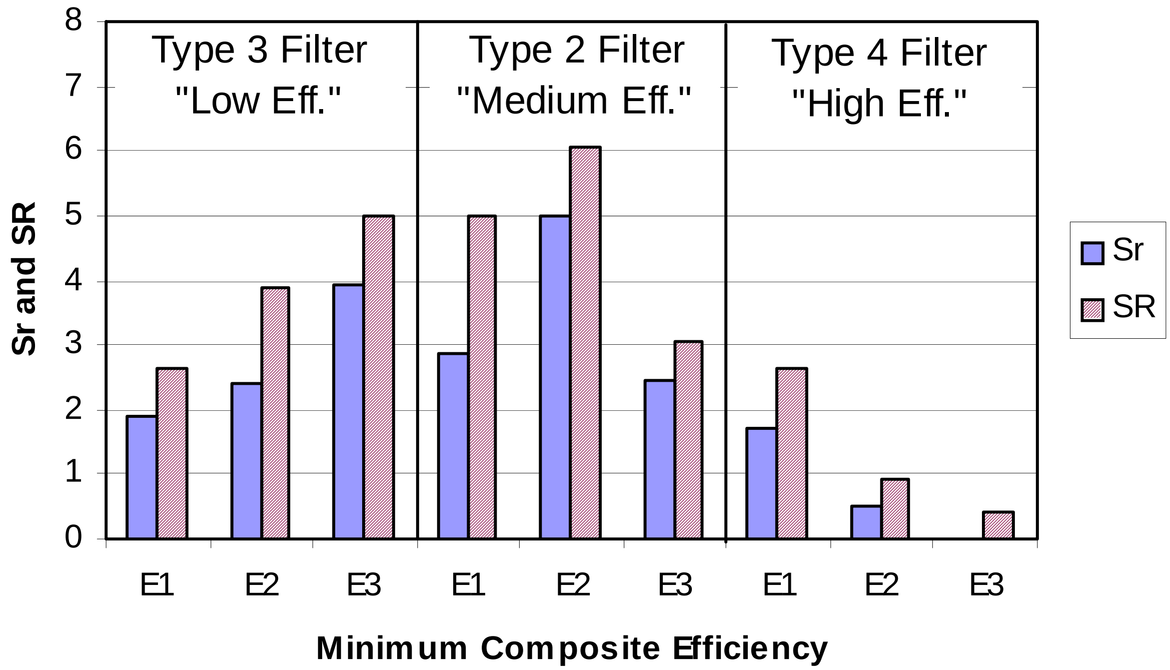


Figure 20. The repeatability and reproducibility standard deviations for the E1, E2 and E3 values for each of the three filter types.

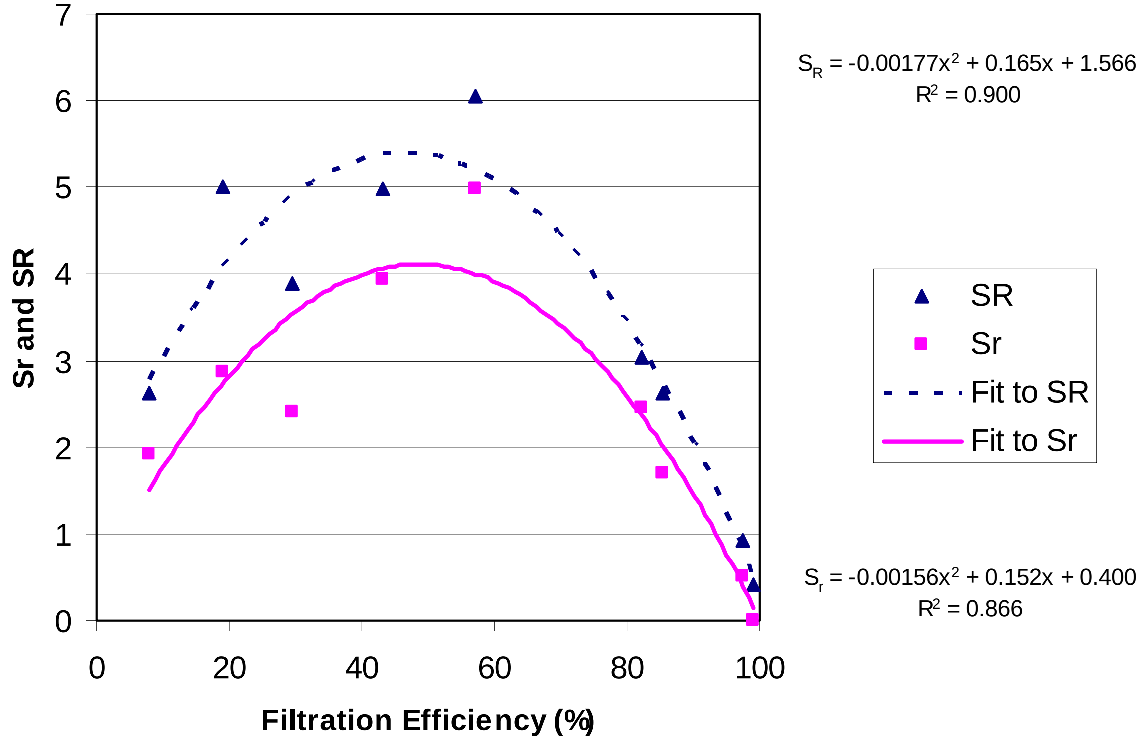


Figure 21. The repeatability and reproducibility standard deviations for the E1, E2 and E3 values plotted as a function of their efficiency value.

Table 23. Approximate precision statistics based on quadratic fits to S_r and S_R for the E values.

	Precision statistics at the indicated filtration efficiency level.										
Precision statistic	**0%**	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
S_r	0.4	1.8	2.8	3.6	4.0	4.1	3.9	3.4	2.6	1.4	0.0
S_R	1.6	3.0	4.2	4.9	5.3	5.4	5.1	4.4	3.4	2.1	0.4
"2S_r"	0.8	3.5	5.5	7.0	7.8	8.0	7.7	6.7	5.0	2.8	0.0
"2S_R"	3.1	6.0	8.1	9.6	10.5	10.6	10.0	8.7	6.7	4.1	0.7
r	1.1	4.9	7.9	10.0	11.2	11.5	10.9	9.5	7.2	4.0	0.0
R	4.4	8.5	11.6	13.8	14.9	15.1	14.3	12.4	9.6	5.8	1.0

8.3 MERV Summary

Table 24 summarizes the MERV results for the three Round 2 filters. Because MERV is a non-continuous parameter it was not subjected to statistical treatments. It is the nature of the MERV determination process that slight changes in filtration efficiency can lead to a change of one or more MERV levels. For the Type 2 filter, the jump from MERV 8 to MERV 10 and 11 is based on whether the E3 values is greater than or equal to 85%. For the Type 3 filter, the one MERV 7 determination was due to the E3 value for that test being 50%, the minimum requirement for MERV 7.

Table 24. Summary of MERV results.

Filter Type	MERV (number of occurrences in parentheses)
Type 2	MERV 8 (9) MERV 10 (1) MERV 11 (2)
Type 3	MERV 5 (1) MERV 6 (10) MERV 7 (1)
Type 4	MERV 14 (4) MERV 15 (8)

8.4 Filter Pressure Drop Summary

An important part of the ASHRAE 52.2 test is the measurement of the filter's pressure drop at the test airflow. Table 25 summarizes the repeatability and reproducibility results for these measurements. As part of RTI's pre-testing, the filter pressure drop was measured. The mean and standard deviation for these pre-test measurements are also summarized in the table.

Table 25. Precision statistics for the pressure drop measurements; in. H_2O (Pa).

	Type 2		Type 3		Type 4	
	Pre-test	**Result for the test laboratories**	**Pre-test**	**Result for the test laboratories**	**Pre-test**	**Result for the test laboratories**
S_r	0.008 (2.0)	0.018 (5.5)	0.009 (2.2)	0.005 (1.2)	0.041 (10)	0.051 (13)
S_R	na	0.023 (5.7)	na	0.015 (3.7)	na	0.055 (14)
r	0.023 (5.72)	0.049 (12.2)	0.025 (6.22)	0.014 (3.48)	0.116 (28.9)	0.143 (35.6)
R	na	0.064 (15.9)	na	0.042 (10.4)	na	0.154 (38.3)
Mean	0.32 (79.6)	0.336 (83.6)	0.289 (71.9)	0.278 (69.2)	0.768 (191)	0.763 (190)
Repeatability CV	2.6%	5.2%	3.1%	1.8%	5.4%	6.7%
Reproducibility CV	na	6.8%	na	5.3%	na	7.2%

* The pre-test pressure drop statistics are for n=12; the lab results are for n=2 with p = 6.

8.5 Weight Gain Summary
Weight gain is not part of the ASHRAE 52.2 standard. However, it is frequently determined as part of the test. It involves simply comparing the weight of the filter after testing is completed to its pre-test weight; the difference in these weights is the weight gain. It was included in the ILS as a parameter of secondary interest.

It is important to note that it was not possible to pre-test the filters for weight gain as this determination renders the filters useless for further testing. Thus, some of the within and between lab differences may be due to unaccounted for filter-to-filter product differences.

Table 26 presents the repeatability and reproducibility results for the weight gain measurements. The CV values are also shown which shows the standard deviation as a percent of the mean. For Type 2 and 3, the CVs were <10%. However, the Type 4 filter had significantly higher within- and between-lab CVs than for the Type 2 and 3 filters.

Table 26. Precision statistics for the weight gain measurements. Weight gain was reported by five of the six labs.

	Filter Type		
	Type 2	**Type 3**	**Type 4**
S_r (g)	14.7	19.6	36.4
S_R (g)	15.9	21.7	36.4
r (g)	41.1	54.9	101.9
R (g)	44.4	60.6	101.9
Mean (g)	196.7	247.6	137.6
Repeatability CV	7.5%	7.9%	26.5%
Reproducibility CV	8.1%	8.7%	26.5%

For the Type 4 filter, the weight gains exhibited a trend with the pre-tested pressure drops (Figure 23) which suggests that a portion of the scatter may be due to actual differences in the filters themselves. The Type 4 filters were obtained by RTI in two separate orders placed about 2 months apart. (After pre-testing the initial set of filters, additional Type 4 filters were needed to obtain a more-closely matched set of filters based on their initial efficiency). In Figure 22, the cluster of five pre-test pressure drops in the 0.79 – 0.82 in. H_2O range is from one order with the other five values being from the other order. Therefore, it appears that filter-to-filter differences contributed to the higher repeatability CV and reproducibility CV for the Type 4 filters.

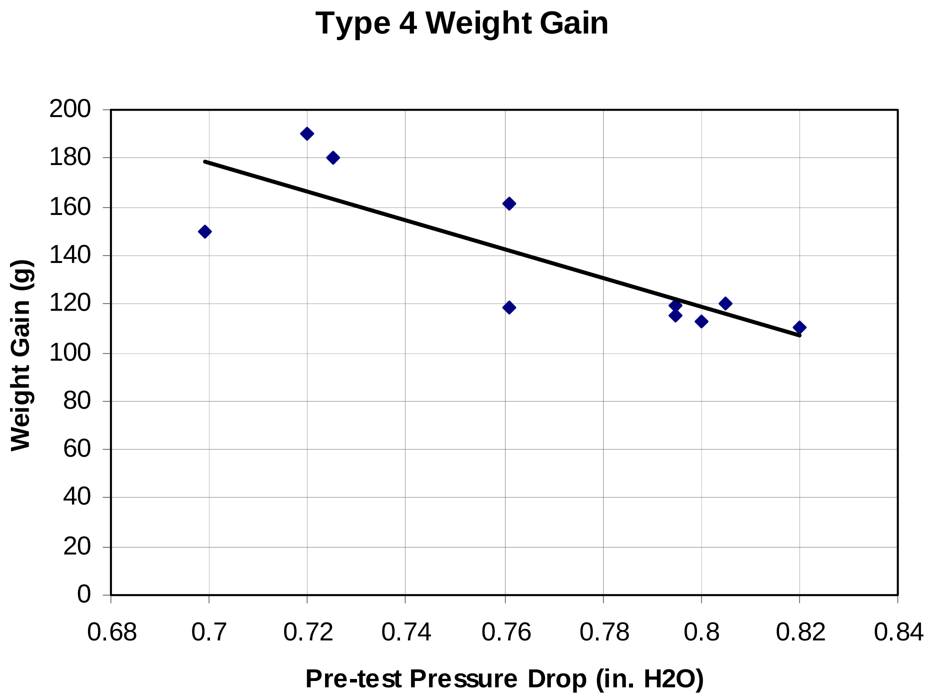


Figure 22. The weight gains for the Type 4 filter suggest a dependence upon the initial pressure drop.

9. Conclusions

Essential products of an ILS are precision statements for the tested items. Those statements were provided in Tables 11 – 16 for the Type 2, 3 and 4 filters. The results were then evaluated collectively and summarized in Tables 21, 22 and 23. Drawing from those results, the following summary conclusions are presented:

The repeatability limit r (within lab) ranged from 0.6 to 11.5 for initial efficiency tests (1.0 to 10.4 for all tests) with a maximum at mid-range efficiency (30 – 70 %) and with lower values as efficiency approaches 0% and 100%.

The reproducibility limit R (between lab) ranged from 0.9 to 16.3 for initial efficiency tests (1.6 to 19.1 for all tests) with a maximum at mid-range efficiency (30 – 70 %) and with lower values as efficiency approaches 0% and 100%.

There were four cases where anomalous results were obtained. These anomalies were not associated with any one test duct configuration (i.e., the anomalies were not isolated to a specific brand of particle counter, shape of duct or type of neutralizer).

The lack of repeatability for two labs on the initial efficiency for their duplicate filters suggests that additional criteria are needed in the standard to ensure reliable testing. Both labs believed they had properly run the test in accordance with the standard. The fact that an anomalous result can occur in one test and not on another test performed shortly thereafter (within 2 weeks) suggests the source may be associated with a procedural change rather than a change related to the qualification elements of the test duct (which should be relatively stable over time). Thus, some of the anomalies may be related to operational or procedural practices as opposed to quantitative specifications of the test duct.

The results indicate that the magnitude of the precision was often approximately the same as the step levels of the MERV table. The range of efficiency within a given MERV category is typically 15 – 20 percentage points. For example, in the MERV table, within the E3 range, MERV 5, 6, and 7 each span 15 percentage points; MERV 7 and 8 each span 20 percentage points; within E2, MERV 10 and 11 span 15 percentage points, and in E1, MERV 14 and 15 span 10 percentage points. These step levels are comparable to the repeatability and reproducibility limits for mid-range efficiencies (i.e., for efficiencies between about 20 and 80%). For higher and lower efficiencies, the repeatability and reproducibility limits are well within the span of the MERV categories. Ideally, the precision would always be substantially lower (i.e., finer resolution) than the step level of the MERV categories.

The measurements of clean filter pressure drop resulted in CV's under 8%.

The agreement on weight gain varied with filter type. For the Type 2 and 3 filters (4 inch (100 mm) pleats), the CVs on weight gain were < 10%. However, for the Type 4 filter (12 inch (300 mm) rigid cell), the CVs were 26% (due to high within-lab variability). There was some evidence that this variability may be linked to different initial pressure drops for the filters and thus be due to unaccounted for filter-to-filter product variability.

10. Recommendations

The interlaboratory study has provided a useful evaluation of the repeatability and reproducibility of tests performed in accordance with the standard. Overall, the results were free of large discrepancies in the measurements. However, the degree of scatter in the results clearly shows that there is room for improvement. In several instances, it appears that procedures may have contributed to the scatter as opposed to, or in addition to, specifications related to the apparatus qualification tests.

It is interesting to note that ASHRAE 52.2-1999 does not prescribe a periodic check on the high voltage ionizers used to neutralize the test aerosol. There is a check for the radioactive neutralizers, but no comparable check for the high voltage neutralizers.

In test duct configurations using dual particle counters, there was some confusion over how to run the correlation test. The counters are sometimes "pre-correlated" followed by performing the correlation test; in some instances, this pre-correlation was performed automatically as part of the test duct control software. This approach is not part of the standard and may allow counters that are not well-correlated to be used in testing.

A significant contributing factor to the difficulty and uncertainty of running the 52.2 test is the lack of a "standard reference material", i.e., a device or filter with known filtration efficiency at each of the 12 sizing channels. Such a device would provide labs with a known standard against which they could compare their results. While the current use of reference filters is useful, they provide only relative information on changes in efficiency. A true reference device would not only serve that purpose, but would be an absolute yardstick against which accuracy as well as precision could be established.

The following specific recommendations are presented:

Filter installation: Specifications on how filters are installed and sealed in the duct and the associated flanging and mechanisms should be added to the standard. Currently, some labs tape the filters in place, others use gasketing. While both approaches may be effective, no approach is guaranteed to be effective. Specifying one or more acceptable means of installing the filter would help minimize installation-related problems. Procedures should be added to the 52.2 standard on how to inspect the installed filter and means of checking for an effective seal (e.g., close visual inspection of the seal area). Test ducts need to be designed in a way that allows for such inspection (e.g., windows, access ports etc).

Aerosol neutralizer: ASHRAE 52.2-1999 does not contain a periodic check on high voltage ionizers used to neutralize static charge on the aerosol. High voltage ionizers need to be checked for balanced output. As the ionizing pins wear, reduced output and unbalanced conditions can occur which can lead to incomplete neutralization or actual charging of the aerosol. A monthly check for balanced output is recommended.

Correlation Test Procedures: The standard should clarify how the correlation is determined for dual counter systems. It should specifically address the use of any "pre-correlation" between the counters prior to the actual correlation test (i.e., pre-correlation is not recommended).

Test Rig: Certain aspects of the test duct need to remain fixed in place to maintain the aerosol and airflow uniformity established during qualification testing. Two critical elements are the aerosol injection tube and the mixing orifice and baffle plates. These need to be designed such that they and the test duct can be serviced without moving these critical components.

Particle Counter Design: It was not clear if all particle counters in the study met the 52.2 requirements for "wide angle collection optics or other counters demonstrating good correlation in measuring particle size efficiencies." It is recommended that this specification be clarified in the standard. The meaning of "wide angle" should be defined as well as the criteria for "demonstrating good correlation" in the measurements.

Calibration Reference Device: ASHRAE should consider a research project to develop a filter efficiency reference standard. The development of such a reference standard would allow labs to readily evaluate the accuracy and precision of their measurements against a known standard.

Precision Relative to MERV Table: It is recommended that that the precision of the test method be evaluated again after implementation of the above recommendations. If the repeatability and reproducibility limits do not improve, ASHRAE may need to consider the relationship of the precision of the test method to the step levels of the MERV table.

Future ILS: In future interlaboratory studies, it may be beneficial to focus more on quantifying agreement for initial efficiency and pressure drop only. These are non-destructive tests; the ability to retest a filter would be useful in determining the source of any variability or anomalous results. These tests can also be performed in a much shorter amount of time (roughly $1/10^{th}$ the time) and that may increase the number of participating laboratories and allow for greater replication.

Ruggedness Test: An additional evaluation tool for evaluating a test method is a "ruggedness test". Unlike an interlaboratory study, the purpose of a ruggedness test is to deliberately vary the test operating conditions to quantify the sensitivity of the measured filtration efficiency to these changes (ASTM E1169). For example, ruggedness testing would allow isolation of the operation of a high voltage ionizer to determine sensitivity to unbalanced operation, the type of particle counter, degree of aerosol and airflow uniformity mixing, and temperature and humidity conditions.

11. Acknowledgements

The authors greatly appreciate the substantial amount of time and effort each of the participating laboratories contributed to this effort. Without their commitment and willingness to share their test results and procedures, this effort would not have been possible. We acknowledge the valuable input from the ASHRAE Project Monitoring Subcommittee on filter selection, assistance with laboratory recruitment and review of results. The authors gratefully acknowledge C. Andrew Clayton, Principal Scientist at RTI, for providing guidance and insight on the statistical analyses and presentation formats.

12. References:

ANSI/ASHRAE Standard 52.2-1999 "Method of Testing Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size," American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta GA.

ASTM E456-02 Standard Terminology Relating to Quality and Statistics, ASTM International, 2002.

ASTM E 691-99 Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method, ASTM International, 1999.

ASTM E 177-04 Standard Practice for Use of the Terms Precision and Bias in ASTM Test Methods, ASTM International, 2004

ASTM E1169-02 Standard Guide for Conducting Ruggedness Tests, ASTM International, 2002.

European Standard prEN 779 Particulate Air Filters for General Ventilation; Determination of the Filtration Performance," European Committee for Standardisation, Brussels. February 2000.

Appendix A

Test Protocol and Questionnaire

Protocol for Laboratory Participation in Interlaboratory Testing of Filters Under ASHRAE Standard 52.2

Prepared by:

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Prepared under ASHRAE Project 1088-RP

November 26, 2001

1. Introduction

Under ASHRAE Project 1088, RTI is coordinating an interlaboratory evaluation (often loosely referred to as a "round robin") of ASHRAE 52.2-1999, *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size.* This is a relatively new standard, and it incorporates extensive system qualification requirements that the test rig must meet. This project will determine if those qualification criteria are adequate to yield repeatable and reproducible filtration efficiency measurements. The overseeing ASHRAE Technical Committee is TC 2.4.

The RTI Project Manager and the RTI Interlaboratory Study Coordinator are:

RTI Project Manager	**RTI Interlaboratory Study Coordinator (ILSC)**
James T. Hanley	Jenni M. Elion
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RTI	RTI
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PO Box 12194	PO Box 12194
Research Triangle Park, NC 27709	Research Triangle Park, NC 27709
tel: 919-541-5811	tel: 919-541-6253
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email: hanley@rti.org	email: jme@rti.org

2. Test Method

The specific test method being evaluated is ANSI/ASHRAE 52.2-1999, *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*. Participating laboratories may contact the ASHRAE (1792 Tullie Circle NE, Atlanta, GA, 30329) to obtain a copy of the standard. The standard details the test rig and equipment specifications, qualification testing requirements, aerosol generation and sampling requirements, and data analysis procedures. All testing will be performed in close agreement to the Standard.

3. Participating Test Laboratory Obligations

3.1. Participating laboratories should have test ducts that are in full compliance with ASHRAE 52.2. This is necessary so that the study accurately reflects the Standard.

3.2. Prior to conducting interlaboratory testing of filters, each lab will submit a data report detailing the system qualification measurements and the apparatus maintenance schedule measurements (Tables 5-1 and 5-2 of ASHRAE 52.2), along with supporting data and descriptions of the test duct and associated equipment and instrumentation (see Appendices A, B, and C). Especially important will be descriptions of the discretionary parts of 52.2 such as the particle counter used, duct configuration, and the aerosol generation and sampling systems. Throughout the study, RTI will closely guard the anonymity of information provided. Documentation may include electronic files (spreadsheets, pdf files, etc.) that can be emailed as attachments.

3.3. RTI will be available to address questions from participating labs to help them become familiar with the 52.2 test procedures, procedures for conducting qualification testing, and corrective measures that might be helpful in attaining the qualification test performance requirements.

3.4. Testing will then follow in two phases:

> **Phase I** will deal with initial efficiency (no dust loading), pressure drop and flowrate measurements. Each lab will be asked to run initial efficiency tests on two filters (each preceded by a "no filter" correlation test) and to measure the pressure drop as a function of flow rate (pressure drop at 50%, 75%, 100% and 125% of test flow). The test flow is anticipated to be 1970 cfm. The test filters will be 24 x 24 pleated filters with a depth in the range of 1 - 12 inches.
>
> **Phase II** will require the full 52.2 testing of six filters (2 each of low (MERV 5-8), medium (MERV 9-12) and high efficiency (MERV 13-16)).

3.5. Laboratory test results will include the supporting upstream and downstream particle count data.

3.6. During both Phase I and Phase II, participating labs may be contacted for further details of the test system to help reconcile any discrepancies between labs. Labs may be asked to rerun one or more tests. If the ILSC cannot determine what is causing discrepancies between labs from phone conversations, the RTI Project Manager may send some calibration equipment or request the sensor in question be sent to RTI for checking. In some rare cases, the RTI Project Manager may request to visit a lab; lab agreement to such visits would be entirely voluntary.

3.7. RTI will provide the filters and loading dust for the tests.

3.8. Laboratories will donate their testing services; there is no compensation to the labs. However, participants will benefit by knowing how their results compare to the other labs.

3.9. Although the participating laboratories will be listed in the final report, they will not be correlated to the data; the data presentations will simply use Lab A, Lab B, etc.

3.10. Because the number of ASHRAE 52.2 rigs is growing rapidly, RTI may need to limit the number of labs in the study to allow adequate time to investigate discrepancies between labs. RTI plans to include as many participants as possible within the project's budget and time constraints.

3.11. Test labs will retain the filters so that the lab if requested may retest the filters. If needed, RTI may request that the filters be returned to RTI.

3.12. Labs will exercise reasonable care in the handling and storage of the test filters. The ILSC should be notified immediately if any of the test filters appear damaged.

3.13. During testing, each lab is to keep a record or log of any special or unusual circumstances that arise during testing. Such records may be useful in interpreting any unusual measurements.

3.14. The laboratory will notify the ILSC promptly if any errors in procedure or other problems arise.

4. Schedule

Labs interested in participating should reply to Jenni Elion by November 8, 2001 with contact information (names of company and lab contact, email, telephone, fax, and shipping address for filters). The review of each lab's system qualification data report will extend through December 2001. Phase I testing is scheduled to begin in late January/February 2002 (after the ASHRAE Winter meeting). Phase II testing is scheduled to begin in July 2002 after the ASHRAE Summer meeting.

5. Test Filters and Loading Dust

RTI will provide numbered test filters and ASHRAE loading dust to each participating laboratory. RTI will conduct non-destructive testing (initial efficiency and pressure drop) on 100% of the Phase I filters that will be sent to the participating labs, and on at least 10% of the Phase II filters, selected at random, to confirm uniformity.

Upon receipt of filters from RTI, participating laboratories should store them in an appropriate location where they will be protected from damage and temperature and humidity extremes.

6. Confidentiality

RTI will maintain confidentiality of the lab-to-data link by assigning an identifier to each lab (Lab A, Lab B, …, Lab *n*) upon receipt of the system qualification documentation. Although each lab will be given the results of the entire study, they will be able to identify only their own data. Participating laboratories will be acknowledged in the final report.

RTI will communicate directly with labs one-on-one when follow-up is necessary to investigate discrepancies or scatter in the data.

7. References

ASHRAE 52.2-1999, *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*, ASHRAE, Atlanta, GA.

ASTM E691-99, *Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method*, ASTM, Philadelphia, PA.

Results and supporting data from the following qualification tests (described in ASHRAE Standard 52.2, Section 5 "Apparatus Qualification Testing") are required prior to testing the round robin filters:

- Air velocity uniformity
- Aerosol uniformity
- Downstream mixing
- 100% efficiency test
- Upper concentration limit of particle counter
- Aerosol generator response time
- Duct Leakage
- Aerosol neutralizer activity
- Dust feeder airflow rate as function of discharge pressure
- Final filter efficiency
- Measurement of dust feeder venturi dimensions (if dust feeder has exceeded 500 hours of operation)

(Correlation ratio, pressure drop across empty test section, background counts, and the particle counter zero and accuracy checks are incorporated into each 52.2 test and will be part of the data obtained when testing the filters.)

Please provide the following information for your test rig.

Lab: ____

Lab Contact: _______________________________________ Date: ______________

OVERALL DUCT CONFIGURATION:

Shape of duct: U-shaped or Straight: ___________________________________

Please attach a diagram, sketch or photograph of the overall test rig.

What ASME nozzle diameter will you use for testing at 1970 cfm? __________________

What is the elevation of your lab above sea level? ____________________________

Note: If you don't know the lab's elevation, please provide the location (either city or latitude/longitude) of the lab facility and we will determine the elevation. If your lab is in an area or city having large altitude changes, then the city's elevation may not be a good approximation of the lab's elevation; let us know if that is the case.

AEROSOL PARTICLE COUNTER:

Specific brand and model of particle counter(s): ____________________________

Particle counter serial number(s): _______________________________________

Particle counter sampling rate: ____________________

Particle counter sample time: _____________________

Do the channels correspond to the 12 channels listed in Table 4-1 of 52.2 (shown below)? ____

If not, please list (below or on an attached sheet) the size range for each channel.

1	2	3	4	5	6	7	8	9	10	11	12
0.3-0.4	0.4-0.55	0.55-0.7	0.7-1	1-1.3	1.3-1.6	1.6-2.2	2.2-3	3-4	4-5.5	5.5-7	7-10

Particle diameters in µm

For optical particle counters, does it use laser or white light? ____________________

For optical particle counters, any details on the optical scattering angles would be appreciated (or simply copy and attach sheets from owners manual if that is more convenient). We realize that this information is not always available.

____

____

FILTER PRESSURE DROP MANOMETER:

Please describe the manometer used to measure filter pressure drop:

Manufacturer: ____

Model number: ____

Is this a fluid manometer or electronic? _______________________

What is the manometer's resolution (i.e., for fluid manometers, what is the tic mark interval on the scale; for electronic manometers, how many decimal places are displayed)? _______________

How often do you check the zero: ____

For fluid manometers, is the manometer level? ____

How is this checked? ____

For fluid manometers, are you confident the correct fluid is in the manometer? _______________

For electronic manometers, when was the manometer last calibrated? _______________________

What is the full-scale range of the manometer (e.g., 10 inches H_2O)? _______________________

What is the manufacturer's stated accuracy of the manometer (e.g., x% of full scale)? ________

ASME NOZZLE PRESSURE DROP MANOMETER:

Please describe the manometer used to measure the pressure drop across the ASME nozzle:

Manufacturer: ____

Model number: ____

Is this a fluid manometer or electronic? _______________________

What is the manometer's resolution (i.e., for fluid manometers, what is the tic mark interval on the scale; for electronic manometers, how many decimal places are displayed)? _______________

How often do you check the zero: ____

For fluid manometers, is the manometer level? ____

How is this checked? ____

For fluid manometers, are you confident the correct fluid is in the manometer? _______________

For electronic manometers, when was the manometer last calibrated? _______________________

What is the full-scale range of the manometer (e.g., 10 inches H_2O)? _______________________

What is the manufacturer's stated accuracy of the manometer (e.g., x% of full scale)? ________

TEMPERATURE, HUMIDITY AND ATMOSPHERIC PRESSURE:

Do you measure the duct air temperature during testing? ________________________________

If so, what type (mercury, digital, etc) of thermometer do you use: _________________________

Do you measure the duct relative humidity during testing? _______________________________

If so, what type of humidity sensor do you use? Include manufacturer and model number:

____

How do you know the humidity sensor is working properly? (This could be a recent factory calibration, calibration with saturated salt solutions, comparison to wet bulb / dry bulb psychrometer, comparison to another humidity probe that is know to be in calibration, etc):

____

Do you measure the lab or duct atmospheric pressure? _____________________________________

If so, what type of pressure sensor do you use? ____

____

Where is the measurement taken (e.g., in the lab, in the duct, etc): _________________________

Are the pressure readings the actual pressure for the lab without correction for altitude? _______

ASME NOZZLE PRESSURE DROP and TEST FLOWRATE:

Do you determine the test flow rate using an ASME flow nozzle (required in 52.2)? __________

If not, describe in detail how you measure the duct's flowrate.

____

____

Do you determine the test flow rate using the equations presented in Section 9 of 52.2? _______

If not, please attach the equations you use to determine flowrate from the ASME nozzle pressure drop.

Do you use measured temperature, humidity and air pressures (as described above) when determining the ASME flow nozzle pressure drop for a desired flowrate (these are used to determine the humid air density)? ____

If not, do you use a set of "standard" temperature, relative humidity and air pressure conditions (which combine to define a "standard" air density) to set the ASME flow nozzle pressure drop? ________ If so, please specify this/these "standard" condition(s): ________________________

____

____

If neither of the above applies, please describe how you determine the ASME flow nozzle pressure drop for a desired airflow and whether you correct for temperature, humidity and air pressure: ____

____

____

Refer to Appendix C for two example airflow calculations.

For example 1, does your computed flow agree with the example? ____________

Your computed flow is: ________________________________

For example 2, does your computed flow agree with the example? ____________

Your computed flow is: ________________________________

AEROSOL NEUTRALIZER:

How do you neutralize the test aerosol (4.3.3 of 52.2)? (Provide details below)

___ **Radioactive neutralizer**

Date of Manufacture: ____

What is the total air flowrate through the neutralizer? _______________

What is the radioactive isotope?: __________________________________

What is its radioactive half-life? ________________________________

What is the strength of the source: _____________________________

Manufacturer: ______________________________

Model number: _____________________________

Do you wash the neutralizer at least every 100 hrs of use

(Note 5 of Table 5-2 of 52.2)?: _________________________

Do you check to ensure that the radioactive source is still active? _____________________

If so, how is this check performed and how often is it performed?

____

____

____

____

Do you perform any other routine maintenance on the neutralizer? ____________________

Is so, please describe:

____

____

____

If not indicated elsewhere, please describe exactly where in the aerosol generation system the neutralizer is located:

____

____

____

___ **High voltage bipolar ionizer**

Manufacturer: ____

Model number: ____

What is the total air flowrate through the neutralizer? ____________________

Mode of operation (e.g., AC, pulsed DC, DC, etc.): ____________________

Frequency of AC or Pulsed DC (if applicable): ____________________

Level of high voltage used: ______________________________

Do you perform any periodic maintenance on the ionizer: ________________

If so, please describe frequency and nature of the of the maintenance:

____

____

____

Do you check to ensure that the ionizer is balanced (Note 5 of Table 5-2 of 52.2)? ____

If so, how is this check performed? ______________________________

____

____

____

If not indicated elsewhere, please describe exactly where in the aerosol generation system the neutralizer is located:

____

____

____

AEROSOL GENERATION SYSTEM:

As applicable, please provide the following information. Because the specifications on the aerosol generator are discretionary, you may need to describe it in different terms than those used below.

52.2 requires use of KCl for the test aerosol. Are you using KCl? ____________________

What % salt solution are you using (e.g., 10% by weight)? ____________________

What rate is the salt solution metered to the atomizer: ____________________

Drying airflow rate: ____________________

Drying air humidity (RH or dew point): ____________________

Atomizing airflow rate: ____________________

Briefly describe your aerosol generation system; a sketch (hand-drawn is ok) or photo would be very helpful, please show all components.

____

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____

AEROSOL SAMPLING SYSTEM:

Please describe and/or attach a diagram of the aerosol sampling system. This should include all components from the sample probe within in the duct to the inlet of the particle counter.

Do you make the filtration efficiency measurements using:

___ **one** particle counter to sample from both the upstream and downstream ducts, or

___ **two** particle counters with one dedicated to upstream measurements and one dedicated to downstream measurements?

___ **Other** *(Please describe)* ____

Does the sampling system provide a particle transport of >50% for 10 micrometer particles (4.4.1 of 52.2)? ___________. How was this demonstrated? __________________________________

____

What is the diameter of the sample lines: ____

If the sampling system uses more than one sample-line diameter, please describe:

____

What is the volumetric flowrate (e.g., cfm, lpm, etc) within the sample lines: _______________

(For many systems, the sample line flowrate will equal the particle counter flowrate. However, this may not be true if diluters or primary/secondary sampling systems are used.)

Does the system use a primary and secondary sampling system (4.4.2 of 52.2)? _____________

If so please provide diagram.

Does the system use diluter(s) (4.4.3 of 52.2)? ________________

If so, please describe: ____

____

____

____

If you use one particle counter to sample from both the upstream and downstream ducts, what purge time (5.7.3 of 52.2) do you allow between samples? ______________________________

DUST FEEDER:

(Sections 4.7 and 10.7.2 of 52.2)

Manufacturer: ____

Does your dust feeder conform to that described in 52.2? ____________________

Do you use a heat lamp over the dust tray? ____________________

Do you adjust the dust feeder's gauge pressure to compensate for the duct pressure (this uses the data obtained in the dust feeder airflow qualification test)? ____________________

Do you adjust the depth of the dust in the tray to provide a dust concentration of 10 ± 7 mg/m^3 (2.0 ± 0.2 $g/1000\ ft^3$): ____________________

Do you have a method for re-entraining loading dust that falls out in the upstream duct? If so, briefly describe:

____

____

____

____

ADDITIONAL COMMENTS:

Please provide any additional information that you feel may make your test rig, equipment, or instrumentation unique from other rigs or that may influence your test results.

____

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The ASME flow nozzles provide a reliable means of airflow measurement based on the pressure drop across the nozzle. ASHRAE 52.2 (Section 9.2) lays out the equations to make this calculation. The manufacturers of ASME flow nozzles may also provide a tabulated data relating the orifice pressure drop to air flow. In both cases, corrections can be applied for non-standard air density conditions (i.e., for various temperature, humidity and absolute pressure conditions).

To reduce the likelihood of having to repeat tests solely due to flow calculation errors, please review the following two examples. Compare the computed flow to what you would compute or look up on a table. If the flowrates you would use are not in close agreement with these examples, then please review your procedures to determine where the source of the discrepancy.

Example 1 (air at "standard" density of 0.075 lb/ft^3):
ASME nozzle diameter = 8.5 inches
Temperature = 68°F
Humidity = 0% (this is a dry-air case for example purposes only)
Absolute pressure at ASME nozzle inlet = 29.92 inches mercury
ASME nozzle pressure drop = 1.578 inches H_2O
Computed flow rate = 1970 cfm

Example 2 (air at "non-standard" density):
ASME nozzle diameter = 8.5 inches
Temperature = 90°F
Humidity = 50%
Absolute pressure at ASME nozzle inlet = 25 inches mercury
ASME nozzle pressure drop = 1.239 inches H_20
Computed flow rate = 1970 cfm

NOTE: If your test system automatically computes airflow for actual input of T, RH, P and ASME pressure drop conditions, and it is not easy to manually input the above conditions, please provide two sets of actual test conditions along with your computed airflows for and we will see if we match your results

.

Appendix B

Round 1
Tabulated Test Results

	Efficiency (%) per Indicated Size Range											
OPC Channel	1	2	3	4	5	6	7	8	9	10	11	12
Channel lower bound (µm)	0.3	0.4	0.55	0.7	1	1.3	1.6	2.2	3	4	5.5	7
Channel upper bound (µm)	0.4	0.55	0.7	1	1.3	1.6	2.2	3	4	5.5	7	10
Geo. Mean Diam (µm)	0.35	0.47	0.62	0.84	1.14	1.44	1.88	2.57	3.46	4.69	6.20	8.37
Type 1, #5	15	18	26	37	50	61	69	78	86	91	94	96
Type 1, #10	17	19	26	38	51	61	71	82	90	95	97	97
Type 1, #3	26	26	31	41	55	65	75	83	89	93	94	98
Type 1, #2	6	17	26	35	50	56	66	79	88	92	95	96
Type 1, #9	19	19	26	40	55	67	73	81	88	94	97	97
Type 1, #7	14	26	36	44	52	60	71	80	88	91	95	97

	Efficiency (%) per Indicated Size Range											
OPC Channel	1	2	3	4	5	6	7	8	9	10	11	12
Channel lower bound (µm)	0.3	0.4	0.55	0.7	1	1.3	1.6	2.2	3	4	5.5	7
Channel upper bound (µm)	0.4	0.55	0.7	1	1.3	1.6	2.2	3	4	5.5	7	10
Geo. Mean Diam (µm)	0.35	0.47	0.62	0.84	1.14	1.44	1.88	2.57	3.46	4.69	6.20	8.37
Type 2, #16	11	18	24	33	45	51	63	72	77	83	83	86
Type 2, #6	17	20	25	37	49	58	67	76	83	88	87	88
Type 2, #9	22	20	27	39	54	62	71	77	82	84	87	89
Type 2, #11	6	15	23	33	46	53	64	74	82	86	86	88
Type 2, #7	13	15	23	35	48	56	66	73	81	78	86	85
Type 2, #4	16	25	34	41	55	61	69	76	81	86	88	92

Appendix C

Round 2
Test Information Sheet

Test Condition Information Sheet ASHRAE Round Robin Project

	Step 1 Your Ref. Filter	Step 2 1^{st} Type 2	Step 3 1^{st} Type 3	Step 4 1^{st} Type 4	Step 5 2^{nd} Type 3	Step 6 2^{nd} Type 4	Step 7 2^{nd} Type 2	Step 8 Your Ref. Filter
Date test begins								
Time test begins								
In-duct Temp*								
In-duct RH*								
Atm. Pressure*								
ASME Nozzle diam								
ASME Nozzle ΔP								
Filter dp @ 50%								
Filter dp @ 75%								
Filter dp @ 100%								
Filter dp @ 125%								

Dust Loading :**	wt.	ΔP	wt.	ΔP	wt.	ΔP	wt.	ΔP	wt.	ΔP	wt.	ΔP	wt.	ΔP	wt.	ΔP
Filter ΔP before dust loading***																
Wt dust fed, ΔP – 1^{st}																
Wt. dust fed, ΔP – 2^{nd}																
Wt. dust fed, ΔP – 3^{rd}																
Wt. dust fed. ΔP – 4^{th}																
Wt. dust fed, ΔP – 5^{th}																

Initial filter weight								
Final filter weight								
Filter weight gain								
Name of person conducting the test								

* enter an average value for the full 52.2 test.

** enter the weight of dust fed and the filter pressure drop (ΔP) at the end of each dust loading step.

*** should be the same as or very close to the 100% ΔP reported above.

Appendix D

Type 2 tabulated laboratory test data.

			Filtration Efficiency (%) per indicated size range											
		OPC Channel Number	*1.0*	*2.0*	*3.0*	*4.0*	*5.0*	*6.0*	*7.0*	*8.0*	*9.0*	*10.0*	*11.0*	*12.0*
		Min. Diam. (µm)	*0.3*	*0.4*	*0.6*	*0.7*	*1.0*	*1.3*	*1.6*	*2.2*	*3.0*	*4.0*	*5.5*	*7.0*
		Max. Diam. (µm)	*0.4*	*0.6*	*0.7*	*1.0*	*1.3*	*1.6*	*2.2*	*3.0*	*4.0*	*5.5*	*7.0*	*10.0*
		Geo. Mean Diam (µm)	*0.3*	*0.5*	*0.6*	*0.8*	*1.1*	*1.4*	*1.9*	*2.6*	*3.5*	*4.7*	*6.2*	*8.4*
Lab 1	Type 2, #16	*Initial*	13.7	15.5	23.0	33.1	47.5	53.8	62.4	68.7	75.9	80.9	82.7	84.9
Lab 1	Type 2, #16	*Cond.*	11.4	16.2	23.1	36.7	51.5	63.0	73.2	82.3	89.6	93.3	97.4	98.6
Lab 1	Type 2, #16	*25%*	8 . 5	17.2	33.2	44.4	60.0	70.9	81.6	88.7	93.9	97.4	99.0	100.0
Lab 1	Type 2, #16	*50%*	5 . 0	17.3	36.4	57.6	72.5	83.7	91.2	94.3	98.1	99.8	100.0	98.8
Lab 1	Type 2, #16	*75%*	5 . 6	21.6	43.0	62.8	79.5	86.5	92.8	96.2	97.7	99.8	98.5	98.0
Lab 1	Type 2, #16	*100%*	3 . 3	23.7	47.0	69.2	84.2	91.7	95.1	97.5	98.9	99.3	100.0	99.1
Lab 1	Type 2, #14	*Initial*	16.0	15.0	25.0	33.0	45.0	55.0	63.0	69.0	78.0	82.0	83.0	86.0
Lab 1	Type 2, #14	*Cond.*	17.0	18.0	24.0	34.0	50.0	62.0	74.0	81.0	89.0	93.0	98.0	99.0
Lab 1	Type 2, #14	*25%*	8 . 0	15.0	32.0	45.0	61.0	74.0	85.0	89.0	94.0	97.0	99.0	100.0
Lab 1	Type 2, #14	*50%*	9 . 0	18.0	40.0	55.0	71.0	81.0	89.0	94.0	95.0	98.0	99.0	100.0
Lab 1	Type 2, #14	*75%*	11.0	24.0	47.0	63.0	80.0	88.0	93.0	95.0	97.0	99.0	100.0	100.0
Lab 1	Type 2, #14	*100%*	9 . 0	24.0	50.0	70.0	84.0	92.0	95.0	97.0	100.0	100.0	99.0	100.0
Lab 2	Type 2, #4	*Initial*	12.5	20.5	33.4	40.5	52.5	62.0	69.1	78.5	81.4	86.3	88.0	91.6
Lab 2	Type 2, #4	*Cond.*	12.8	22.8	35.7	42.9	53.1	62.6	68.7	81.6	90.1	94.7	96.2	97.8
Lab 2	Type 2, #4	*25%*	17.0	29.0	37.0	43.6	54.2	64.7	78.4	88.6	94.9	97.4	98.7	99.4
Lab 2	Type 2, #4	*50%*	24.4	36.1	45.1	54.1	61.8	73.2	83.5	91.5	96.1	97.5	98.8	99.4
Lab 2	Type 2, #4	*75%*	25.0	40.3	52.0	60.1	67.4	78.0	88.4	94.8	97.3	97.9	98.8	99.4
Lab 2	Type 2, #4	*100%*	30.0	46.1	58.5	66.9	74.5	83.5	91.1	95.8	98.4	98.8	99.1	99.5
Lab 2	Type 2, #1	*Initial*	12.2	24.9	33.7	44.2	56.2	64.5	70.3	76.0	79.5	87.3	90.3	90.6
Lab 2	Type 2, #1	*Cond.*	15.6	25.9	35.2	44.4	57.9	64.7	75.2	82.2	88.3	91.5	94.5	95.4
Lab 2	Type 2, #1	*25%*	16.0	25.9	36.0	45.7	58.2	65.4	75.2	83.1	89.4	93.5	95.7	97.0
Lab 2	Type 2, #1	*50%*	19.6	33.0	40.1	48.4	58.2	71.6	85.1	94.7	97.0	97.4	98.8	99.3
Lab 2	Type 2, #1	*75%*	25.3	39.3	50.9	60.1	66.6	76.5	87.0	95.0	96.8	98.1	99.4	99.6
Lab 2	Type 2, #1	*100%*	32.4	42.9	52.5	64.3	76.3	84.2	88.7	93.9	96.3	98.9	99.5	99.8

			Filtration Efficiency (%) per indicated size range											
OPC Channel Number			*1.0*	*2.0*	*3.0*	*4.0*	*5.0*	*6.0*	*7.0*	*8.0*	*9.0*	*10.0*	*11.0*	*12.0*
Min. Diam. (µm)			*0.3*	*0.4*	*0.6*	*0.7*	*1.0*	*1.3*	*1.6*	*2.2*	*3.0*	*4.0*	*5.5*	*7.0*
Max. Diam. (µm)			*0.4*	*0.6*	*0.7*	*1.0*	*1.3*	*1.6*	*2.2*	*3.0*	*4.0*	*5.5*	*7.0*	*10.0*
Geo. Mean Diam (µm)			*0.3*	*0.5*	*0.6*	*0.8*	*1.1*	*1.4*	*1.9*	*2.6*	*3.5*	*4.7*	*6.2*	*8.4*
Lab 3	Type 2, #17	*Initial*	10.9	15.4	22.5	34.1	47.0	55.7	63.6	71.8	77.9	80.1	84.0	84.7
Lab 3	Type 2, #17	*Cond.*	12.3	15.3	24.4	37.7	54.0	63.8	74.3	83.1	89.3	92.6	97.2	98.0
Lab 3	Type 2, #17	*25%*	13.1	24.3	33.9	48.7	66.7	76.4	85.0	91.4	95.7	97.2	99.3	100.0
Lab 3	Type 2, #17	*50%*	22.9	38.0	51.3	68.3	83.1	89.5	93.8	96.8	98.8	99.1	99.8	100.0
Lab 3	Type 2, #17	*75%*	31.1	38.9	52.5	69.1	83.5	89.3	93.9	96.9	98.4	99.0	99.4	99.7
Lab 3	Type 2, #17	*100%*	27.8	38.1	55.3	71.1	84.4	90.0	94.5	97.4	99.2	99.8	100.0	98.9
Lab 3	Type 2, #8	*Initial*	7.2	8.4	14.2	23.0	28.3	35.3	47.7	61.8	72.3	76.1	80.6	80.4
Lab 3	Type 2, #8	*Cond.*	13.2	14.4	20.6	30.2	37.7	45.6	59.3	78.5	90.5	94.9	97.6	100.0
Lab 3	Type 2, #8	*25%*	12.1	16.5	28.3	38.5	47.7	56.5	70.2	86.8	94.7	97.8	99.7	100.0
Lab 3	Type 2, #8	*50%*	11.4	19.5	35.5	47.2	57.2	66.5	79.4	91.8	96.8	98.6	100.0	96.9
Lab 3	Type 2, #8	*75%*	19.2	28.5	42.0	56.2	65.9	74.6	85.3	94.8	98.2	99.3	99.7	100.0
Lab 3	Type 2, #8	*100%*	22.6	36.6	46.3	61.6	71.0	78.3	88.4	96.0	98.8	99.4	100.0	100.0
Lab 4	Type 2, #11	*Initial*	9.1	15.3	22.5	32.2	44.3	52.9	62.2	71.9	79.4	81.4	81.9	84.5
Lab 4	Type 2, #11	*Cond.*	8.2	13.8	22.2	34.5	53.0	62.4	75.4	88.5	95.3	98.3	99.2	99.5
Lab 4	Type 2, #11	*25%*	11.0	19.0	29.9	44.5	62.7	73.1	84.3	93.3	97.7	99.2	99.5	99.7
Lab 4	Type 2, #11	*50%*	13.1	22.7	36.0	51.9	69.0	79.3	88.5	95.6	98.4	99.4	99.6	99.6
Lab 4	Type 2, #11	*75%*	17.9	28.7	43.6	60.6	78.1	86.0	92.7	97.3	98.9	99.4	99.4	99.4
Lab 4	Type 2, #11	*100%*	20.5	32.6	50.1	67.1	83.2	89.9	95.1	98.1	99.1	99.4	99.4	99.2
Lab 4	Type 2, #2	*Initial*	10.5	16.3	25.6	33.8	45.8	53.5	63.1	74.0	80.7	85.1	86.0	86.5
Lab 4	Type 2, #2	*Cond.*	12.3	17.0	27.1	36.4	50.8	61.1	73.8	87.1	94.9	98.1	99.2	99.6
Lab 4	Type 2, #2	*25%*	15.0	21.5	33.7	45.5	62.3	72.3	83.7	93.3	97.5	99.1	99.6	99.6
Lab 4	Type 2, #2	*50%*	17.7	25.6	40.4	53.4	70.6	79.5	88.8	95.5	98.3	99.4	99.6	99.7
Lab 4	Type 2, #2	*75%*	20.6	29.7	46.0	60.3	77.4	85.8	91.9	96.8	98.9	99.4	99.6	99.6
Lab 4	Type 2, #2	*100%*	20.6	31.8	47.1	63.5	79.8	87.7	92.9	97.1	98.7	99.2	99.3	99.5

			Filtration Efficiency (%) per indicated size range											
OPC Channel Number			*1.0*	*2.0*	*3.0*	*4.0*	*5.0*	*6.0*	*7.0*	*8.0*	*9.0*	*10.0*	*11.0*	*12.0*
Min. Diam. (μm)			*0.3*	*0.4*	*0.6*	*0.7*	*1.0*	*1.3*	*1.6*	*2.2*	*3.0*	*4.0*	*5.5*	*7.0*
Max. Diam. (μm)			*0.4*	*0.6*	*0.7*	*1.0*	*1.3*	*1.6*	*2.2*	*3.0*	*4.0*	*5.5*	*7.0*	*10.0*
Geo. Mean Diam (μm)			*0.3*	*0.5*	*0.6*	*0.8*	*1.1*	*1.4*	*1.9*	*2.6*	*3.5*	*4.7*	*6.2*	*8.4*
Lab 5	Type 2, #13	*Initial*	14.2	14.6	21.8	33.4	42.5	48.7	61.4	70.3	77.4	83.3	86.6	92.8
Lab 5	Type 2, #13	*Cond.*	0.1	5.4	31.9	32.5	35.5	50.3	63.2	76.7	88.0	94.8	99.1	99.7
Lab 5	Type 2, #13	*25%*	0.1	6.8	35.1	36.7	37.4	53.1	66.6	79.8	90.1	95.3	97.8	99.2
Lab 5	Type 2, #13	*50%*	2.7	18.3	37.5	42.5	54.6	63.8	82.6	90.7	96.3	98.9	99.8	100.5
Lab 5	Type 2, #13	*75%*	5.3	28.3	52.1	61.2	74.5	82.6	92.7	96.6	99.2	100.0	100.0	101.0
Lab 5	Type 2, #13	*100%*	17.2	46.0	69.4	76.8	86.6	92.0	97.2	99.3	98.8	98.7	99.4	100.4
Lab 5	Type 2, #3	*Initial*	13.1	14.9	24.0	34.0	43.1	50.0	56.9	70.5	73.6	78.1	78.8	83.9
Lab 5	Type 2, #3	*Cond.*	1.2	10.8	24.0	35.6	47.0	56.0	65.3	79.5	85.5	91.5	94.5	97.5
Lab 5	Type 2, #3	*25%*	7.4	15.1	26.6	36.8	47.7	56.2	65.2	79.7	86.2	91.6	95.3	97.6
Lab 5	Type 2, #3	*50%*	7.6	18.6	35.0	41.9	50.9	61.8	72.9	82.6	89.2	95.2	99.4	100.2
Lab 5	Type 2, #3	*75%*	7.7	19.8	37.3	51.0	66.2	76.0	84.2	93.3	96.4	99.0	100.0	100.0
Lab 5	Type 2, #3	*100%*	8.5	20.4	37.4	54.5	70.1	79.4	86.5	94.3	96.9	99.1	100.0	100.0
Lab 6	Type 2, #6	*Initial*	8.0	12.0	19.0	29.0	43.0	49.0	59.0	70.0	77.0	81.0	82.0	81.0
Lab 6	Type 2, #6	*Cond.*	8.0	13.0	20.0	32.0	48.0	58.0	72.0	83.0	93.0	97.0	99.0	100.0
Lab 6	Type 2, #6	*25%*	8.0	15.0	24.0	37.0	56.0	66.0	79.0	91.0	97.0	99.0	100.0	100.0
Lab 6	Type 2, #6	*50%*	14.0	21.0	31.0	47.0	67.0	76.0	86.0	94.0	98.0	100.0	100.0	100.0
Lab 6	Type 2, #6	*75%*	18.0	27.0	38.0	56.0	76.0	83.0	91.0	97.0	99.0	100.0	100.0	100.0
Lab 6	Type 2, #6	*100%*	20.0	30.0	42.0	61.0	80.0	86.0	93.0	97.0	99.0	100.0	100.0	100.0
Lab 6	Type 2, #19	*Initial*	4.0	9.0	17.0	28.0	42.0	50.0	61.0	72.0	80.0	84.0	85.0	84.0
Lab 6	Type 2, #19	*Cond.*	7.0	13.0	20.0	32.0	49.0	58.0	73.0	86.0	94.0	98.0	99.0	100.0
Lab 6	Type 2, #19	*25%*	10.0	16.0	25.0	41.0	60.0	70.0	81.0	92.0	97.0	99.0	100.0	100.0
Lab 6	Type 2, #19	*50%*	12.0	21.0	33.0	50.0	70.0	78.0	88.0	95.0	98.0	100.0	100.0	100.0
Lab 6	Type 2, #19	*75%*	14.0	25.0	38.0	58.0	78.0	85.0	92.0	97.0	99.0	100.0	100.0	100.0
Lab 6	Type 2, #19	*100%*	18.0	30.0	44.0	65.0	83.0	88.0	95.0	98.0	99.0	100.0	100.0	100.0

Appendix E

Type 3 tabulated laboratory test data.

			Filtration Efficiency (%) per indicated size range											
OPC Channel Number			*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Min. Diam. (µm)			*0.30*	*0.40*	*0.55*	*0.70*	*1.00*	*1.30*	*1.60*	*2.20*	*3.00*	*4.00*	*5.50*	*7.00*
Max. Diam. (µm)			*0.40*	*0.55*	*0.70*	*1.00*	*1.30*	*1.60*	*2.20*	*3.00*	*4.00*	*5.50*	*7.00*	*10.0*
Geo. Mean Diam (µm)			*0.35*	*0.47*	*0.62*	*0.84*	*1.14*	*1.44*	*1.88*	*2.57*	*3.46*	*4.69*	*6.20*	*8.37*
Lab 1	Type 3, #11	*Initial*	4.0	6.0	6.0	16.0	20.0	28.0	32.0	32.0	35.0	34.0	28.0	34.0
Lab 1	Type 3, #11	*Cond.*	11.0	12.0	20.0	32.0	49.0	61.0	74.0	79.0	87.0	91.0	95.0	98.0
Lab 1	Type 3, #11	*25%*	21.0	24.0	30.0	43.0	58.0	71.0	80.0	86.0	90.0	95.0	96.0	100.0
Lab 1	Type 3, #11	*50%*	30.0	32.0	40.0	52.0	67.0	78.0	86.0	90.0	93.0	97.0	99.0	100.0
Lab 1	Type 3, #11	*75%*	34.0	36.0	46.0	59.0	73.0	83.0	89.0	93.0	96.0	98.0	99.0	100.0
Lab 1	Type 3, #11	*100%*	34.0	40.0	48.0	65.0	78.0	86.0	92.0	94.0	96.0	99.0	100.0	100.0
Lab 1	Type 3, #3	*Initial*	5.0	5.0	11.0	16.0	24.0	27.0	33.0	38.0	37.0	39.0	36.0	38.0
Lab 1	Type 3, #3	*Cond.*	12.0	14.0	22.0	33.0	47.0	61.0	70.0	77.0	86.0	92.0	95.0	99.0
Lab 1	Type 3, #3	*25%*	25.0	27.0	35.0	46.0	62.0	72.0	84.0	88.0	92.0	97.0	98.0	99.0
Lab 1	Type 3, #3	*50%*	30.0	31.0	42.0	54.0	68.0	79.0	88.0	93.0	94.0	98.0	99.0	100.0
Lab 1	Type 3, #3	*75%*	33.0	33.0	47.0	51.0	75.0	82.0	91.0	93.0	96.0	98.0	100.0	100.0
Lab 1	Type 3, #3	*100%*	32.0	42.0	53.0	67.0	80.0	85.0	92.0	94.0	97.0	98.0	99.0	99.0
Lab 2	Type 3, #2	*Initial*	6.0	9.3	16.0	19.6	21.0	23.3	29.6	36.2	39.8	44.0	44.2	48.7
Lab 2	Type 3, #2	*Cond.*	17.5	17.7	22.2	24.8	26.8	38.2	52.8	67.7	77.3	84.4	91.3	91.7
Lab 2	Type 3, #2	*25%*	23.9	27.0	33.5	34.1	39.9	51.2	67.9	81.4	89.2	94.2	96.0	97.8
Lab 2	Type 3, #2	*50%*	32.0	33.4	35.7	38.2	47.3	59.2	72.6	84.1	91.4	95.5	97.5	98.7
Lab 2	Type 3, #2	*75%*	39.3	39.4	40.2	44.6	57.4	68.1	78.8	87.8	93.9	96.8	98.0	99.0
Lab 2	Type 3, #2	*100%*	44.3	44.4	45.7	49.2	63.7	73.7	83.6	91.1	95.2	97.3	98.5	97.8
Lab 2	Type 3, #6	*Initial*	2.1	6.9	9.2	14.7	14.2	16.7	25.0	31.4	35.2	35.3	43.1	46.1
Lab 2	Type 3, #6	*Cond.*	7.0	15.1	19.7	25.9	29.5	36.8	52.9	69.3	78.5	85.3	90.8	93.7
Lab 2	Type 3, #6	*25%*	19.9	23.5	28.2	32.7	41.3	49.5	64.3	78.9	86.9	92.2	96.7	97.8
Lab 2	Type 3, #6	*50%*	24.4	30.8	36.1	40.6	47.0	55.6	70.4	83.6	90.2	94.7	97.3	98.8
Lab 2	Type 3, #6	*75%*	28.9	30.9	37.6	43.0	52.4	59.1	74.2	85.0	92.2	95.4	97.8	98.9
Lab 2	Type 3, #6	*100%*	29.0	31.8	42.3	50.1	61.1	64.8	78.4	88.7	93.6	96.1	97.9	99.0

			Filtration Efficiency (%) per indicated size range											
OPC Channel Number			*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Min. Diam. (µm)			*0.30*	*0.40*	*0.55*	*0.70*	*1.00*	*1.30*	*1.60*	*2.20*	*3.00*	*4.00*	*5.50*	*7.00*
Max. Diam. (µm)			*0.40*	*0.55*	*0.70*	*1.00*	*1.30*	*1.60*	*2.20*	*3.00*	*4.00*	*5.50*	*7.00*	*10.0*
Geo. Mean Diam (µm)			*0.35*	*0.47*	*0.62*	*0.84*	*1.14*	*1.44*	*1.88*	*2.57*	*3.46*	*4.69*	*6.20*	*8.37*
Lab 3	Type 3, #20	*Initial*	2.2	3.8	6.5	11.1	14.9	19.7	26.2	36.0	39.9	40.9	38.8	33.9
Lab 3	Type 3, #20	*Cond.*	8.8	11.8	16.3	24.9	32.1	40.7	54.2	73.9	85.3	91.3	94.8	96.9
Lab 3	Type 3, #20	*25%*	21.6	24.5	31.6	40.5	48.0	57.3	70.4	85.6	93.5	97.3	99.6	99.1
Lab 3	Type 3, #20	*50%*	26.4	30.5	37.6	47.6	56.3	64.8	75.8	89.1	95.5	98.0	99.1	99.8
Lab 3	Type 3, #20	*75%*	30.4	34.6	42.4	52.7	60.3	69.2	79.6	91.0	96.5	98.3	99.5	99.2
Lab 3	Type 3, #20	*100%*	35.6	41.2	48.4	59.2	67.1	74.5	83.3	93.2	97.5	99.1	100.0	98.4
Lab 3	Type 3, #4	*Initial*	6.3	8.2	10.9	16.1	17.6	23.8	30.3	41.1	47.8	49.7	49.6	53.0
Lab 3	Type 3, #4	*Cond.*	8.4	9.8	15.1	23.0	30.3	38.7	53.2	73.5	87.0	92.2	96.6	98.2
Lab 3	Type 3, #4	*25%*	19.3	22.8	29.3	38.0	45.6	54.4	66.2	84.4	92.9	96.4	98.4	99.5
Lab 3	Type 3, #4	*50%*	25.5	30.3	36.9	47.3	56.0	64.7	75.6	89.7	95.6	98.0	99.6	99.8
Lab 3	Type 3, #4	*75%*	29.0	35.1	42.8	53.8	62.5	70.6	81.2	92.4	97.5	99.1	99.8	97.3
Lab 3	Type 3, #4	*100%*	32.0	38.0	44.9	56.4	65.2	73.3	83.0	93.5	97.4	98.7	100.0	99.4
Lab 4	Type 3, #12	*Initial*	0.0	2.1	8.5	13.9	22.9	28.4	37.0	43.7	47.9	48.6	46.2	46.1
Lab 4	Type 3, #12	*Cond.*	6.6	11.7	19.0	28.4	46.0	55.6	68.3	82.1	91.6	96.2	98.3	99.2
Lab 4	Type 3, #12	*25%*	13.3	20.8	31.7	41.5	58.7	68.6	80.2	90.3	96.1	98.6	99.5	99.8
Lab 4	Type 3, #12	*50%*	23.7	30.1	40.5	52.5	68.9	76.4	85.7	93.5	97.6	99.1	99.5	99.7
Lab 4	Type 3, #12	*75%*	22.7	31.9	45.0	57.1	72.8	80.7	88.4	94.9	98.2	99.2	99.5	99.5
Lab 4	Type 3, #12	*100%*	27.1	36.0	48.5	61.5	76.6	83.7	90.2	95.6	98.6	99.4	99.4	99.5
Lab 4	Type 3, #5	*Initial*	1.3	4.2	8.8	13.4	24.9	29.0	34.6	41.6	47.1	49.1	48.0	45.1
Lab 4	Type 3, #5	*Cond.*	5.8	10.9	18.4	28.0	45.9	54.6	67.6	81.4	91.1	95.8	98.1	99.1
Lab 4	Type 3, #5	*25%*	13.8	21.8	30.4	40.9	58.4	69.0	80.1	90.3	96.5	98.8	99.6	99.8
Lab 4	Type 3, #5	*50%*	22.2	29.8	40.3	52.0	68.7	77.5	86.0	93.8	98.0	99.2	99.7	99.6
Lab 4	Type 3, #5	*75%*	23.3	32.0	42.9	55.1	71.6	80.3	88.1	94.7	98.2	99.4	99.5	99.8
Lab 4	Type 3, #5	*100%*	26.1	34.3	46.5	59.1	74.8	83.0	89.6	95.6	98.6	99.4	99.7	99.6

			Filtration Efficiency (%) per indicated size range											
OPC Channel Number			*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Min. Diam. (μm)			*0.30*	*0.40*	*0.55*	*0.70*	*1.00*	*1.30*	*1.60*	*2.20*	*3.00*	*4.00*	*5.50*	*7.00*
Max. Diam. (μm)			*0.40*	*0.55*	*0.70*	*1.00*	*1.30*	*1.60*	*2.20*	*3.00*	*4.00*	*5.50*	*7.00*	*10.0*
Geo. Mean Diam (μm)			*0.35*	*0.47*	*0.62*	*0.84*	*1.14*	*1.44*	*1.88*	*2.57*	*3.46*	*4.69*	*6.20*	*8.37*
Lab 5	Type 3, #1	*Initial*	2.5	5.3	13.4	18.4	24.5	27.0	30.9	39.1	39.6	40.9	43.5	52.2
Lab 5	Type 3, #1	*Cond.*	9.3	12.3	24.1	38.3	50.0	58.8	67.3	77.7	86.1	92.0	93.2	95.8
Lab 5	Type 3, #1	*25%*	10.1	19.0	22.6	39.7	51.3	59.3	67.7	79.8	87.4	92.4	96.7	98.5
Lab 5	Type 3, #1	*50%*	14.9	17.6	24.0	46.5	57.3	64.9	72.4	83.3	90.5	95.2	96.9	99.7
Lab 5	Type 3, #1	*75%*	12.8	16.9	32.1	44.4	53.8	65.2	75.1	86.4	92.1	96.9	99.0	99.8
Lab 5	Type 3, #1	*100%*	24.8	25.6	40.7	54.9	64.8	74.0	81.8	90.4	94.7	97.7	99.0	100.0
Lab 5	Type 3, #18	*Initial*	1.8	4.5	13.1	21.2	28.8	30.6	32.1	40.0	43.7	44.4	46.2	45.6
Lab 5	Type 3, #18	*Cond.*	7.4	8.3	20.2	33.0	50.4	56.0	66.3	77.2	85.4	92.1	92.3	93.7
Lab 5	Type 3, #18	*25%*	10.5	12.5	20.0	34.5	51.7	58.0	68.8	80.5	88.0	92.7	94.2	98.7
Lab 5	Type 3, #18	*50%*	11.1	13.4	20.1	37.3	55.7	61.8	72.9	83.3	91.0	95.5	97.8	100.4
Lab 5	Type 3, #18	*75%*	11.9	13.1	27.7	45.3	62.1	67.9	78.0	87.3	91.5	96.3	98.9	100.4
Lab 5	Type 3, #18	*100%*	11.9	15.9	36.7	56.8	70.8	75.9	84.4	92.4	96.4	99.1	99.9	100.0
Lab 6	Type 3, #15	*Initial*	0.1	0.1	7.0	11.0	24.0	32.0	35.0	40.0	45.0	44.0	47.0	48.0
Lab 6	Type 3, #15	*Cond.*	2.0	6.0	13.0	24.0	43.0	53.0	67.0	80.0	89.0	95.0	97.0	99.0
Lab 6	Type 3, #15	*25%*	7.0	12.0	22.0	33.0	54.0	66.0	77.0	87.0	95.0	98.0	99.0	100.0
Lab 6	Type 3, #15	*50%*	13.0	18.0	30.0	45.0	66.0	75.0	85.0	92.0	97.0	99.0	100.0	100.0
Lab 6	Type 3, #15	*75%*	18.0	25.0	38.0	53.0	74.0	81.0	89.0	95.0	98.0	100.0	100.0	100.0
Lab 6	Type 3, #15	*100%*	22.0	30.0	43.0	60.0	80.0	85.0	92.0	96.0	99.0	100.0	100.0	100.0
Lab 6	Type 3, #19	*Initial*	0.1	0.1	4.0	11.0	24.0	30.0	37.0	41.0	45.0	46.0	49.0	45.0
Lab 6	Type 3, #19	*Cond.*	1.0	6.0	12.0	24.0	46.0	55.0	66.0	80.0	89.0	95.0	97.0	99.0
Lab 6	Type 3, #19	*25%*	9.0	15.0	23.0	36.0	59.0	66.0	78.0	89.0	95.0	98.0	99.0	100.0
Lab 6	Type 3, #19	*50%*	12.0	20.0	30.0	46.0	68.0	75.0	85.0	93.0	97.0	99.0	100.0	100.0
Lab 6	Type 3, #19	*75%*	18.0	26.0	38.0	54.0	74.0	82.0	90.0	95.0	99.0	99.0	100.0	100.0
Lab 6	Type 3, #19	*100%*	21.0	30.0	43.0	61.0	80.0	86.0	92.0	97.0	99.0	100.0	100.0	100.0

Appendix F

Type 4 tabulated laboratory test data.

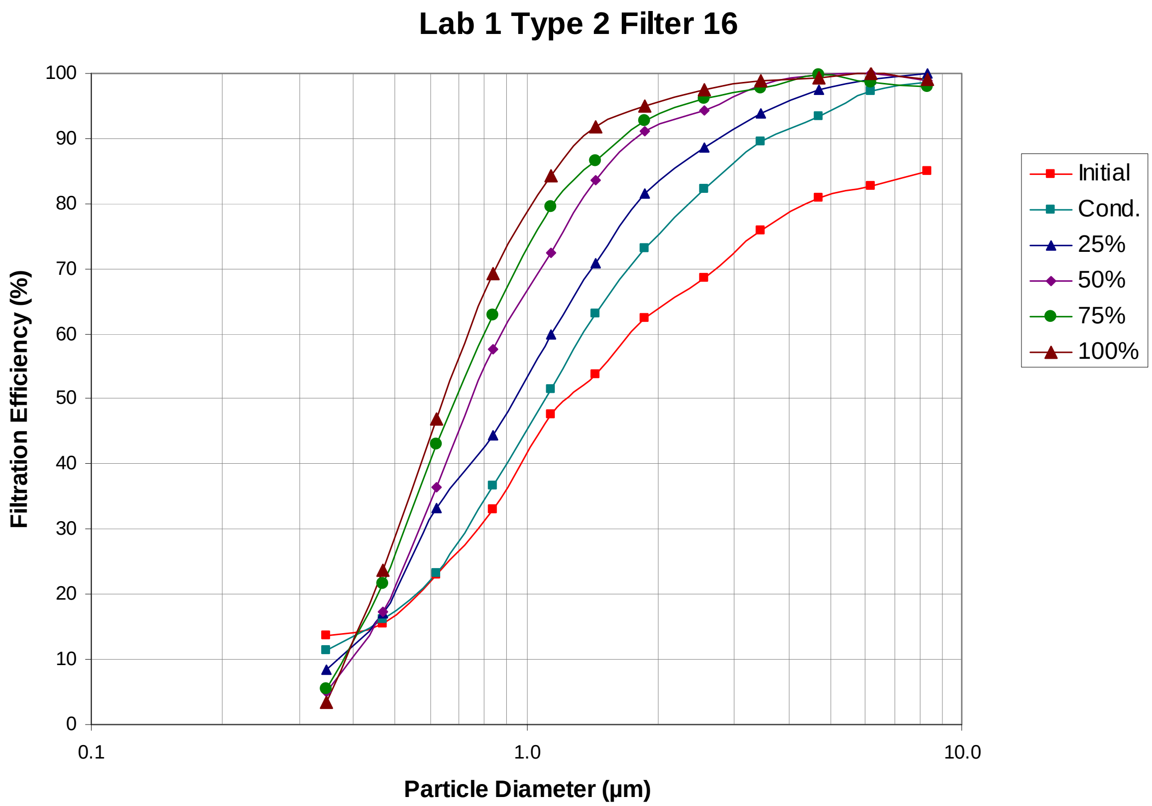
			Filtration Efficiency (%) per indicated size range											
OPC Channel Number			*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Min. Diam. (µm)			*0.30*	*0.40*	*0.55*	*0.70*	*1.00*	*1.30*	*1.60*	*2.20*	*3.00*	*4.00*	*5.50*	*7.00*
Max. Diam. (µm)			*0.40*	*0.55*	*0.70*	*1.00*	*1.30*	*1.60*	*2.20*	*3.00*	*4.00*	*5.50*	*7.00*	*10.0*
Geo. Mean Diam (µm)			*0.35*	*0.47*	*0.62*	*0.84*	*1.14*	*1.44*	*1.88*	*2.57*	*3.46*	*4.69*	*6.20*	*8.37*
Lab 1	Type 4, #13	*Initial*	81.0	86.0	92.0	96.0	98.0	98.0	99.0	99.0	99.0	100.0	99.0	100.0
Lab 1	Type 4, #13	*Cond.*	83.0	88.0	93.0	96.0	98.0	99.0	99.0	99.0	99.0	100.0	100.0	100.0
Lab 1	Type 4, #13	*25%*	86.0	89.0	95.0	97.0	99.0	99.0	99.0	100.0	99.0	100.0	100.0	100.0
Lab 1	Type 4, #13	*50%*	87.0	92.0	96.0	98.0	99.0	99.0	99.0	100.0	99.0	100.0	100.0	100.0
Lab 1	Type 4, #13	*75%*	88.0	93.0	96.0	98.0	99.0	99.0	99.0	99.0	100.0	100.0	100.0	99.0
Lab 1	Type 4, #13	*100%*	90.0	94.0	97.0	98.0	99.0	99.0	100.0	100.0	99.0	100.0	100.0	100.0
Lab 1	Type 4, #24	*Initial*	77.0	82.0	88.0	93.0	97.0	98.0	99.0	99.0	99.0	99.0	100.0	100.0
Lab 1	Type 4, #24	*Cond.*	78.0	82.0	89.0	94.0	97.0	98.0	99.0	99.0	100.0	100.0	100.0	100.0
Lab 1	Type 4, #24	*25%*	78.0	81.0	89.0	94.0	97.0	98.0	99.0	99.0	100.0	100.0	100.0	100.0
Lab 1	Type 4, #24	*50%*	85.0	89.0	94.0	97.0	98.0	99.0	99.0	99.0	99.0	99.0	99.0	100.0
Lab 1	Type 4, #24	*75%*	88.0	91.0	95.0	97.0	98.0	99.0	99.0	99.0	99.0	99.0	99.0	100.0
Lab 1	Type 4, #24	*100%*	88.0	92.0	95.0	97.0	98.0	98.0	99.0	99.0	99.0	99.0	99.0	100.0
Lab 2	Type 4, #11	*Initial*	78.8	84.5	88.5	91.3	92.6	94.8	97.1	98.2	98.9	98.9	99.4	99.5
Lab 2	Type 4, #11	*Cond.*	82.4	87.9	90.6	93.1	94.4	95.9	97.6	98.5	98.8	99.3	99.3	99.8
Lab 2	Type 4, #11	*25%*	82.7	88.4	91.9	94.5	95.2	96.5	97.6	98.5	98.8	99.2	99.3	99.5
Lab 2	Type 4, #11	*50%*	84.2	90.3	93.3	95.2	95.9	96.9	97.7	98.1	98.8	99.2	99.1	99.4
Lab 2	Type 4, #11	*75%*	86.5	92.3	94.5	95.4	96.0	96.7	97.3	98.0	98.1	98.6	99.0	99.1
Lab 2	Type 4, #11	*100%*	87.4	92.9	94.8	95.3	95.7	96.2	97.0	97.6	98.6	98.8	99.1	99.3
Lab 2	Type 4, #16	*Initial*	78.7	85.5	89.9	92.6	94.2	95.6	97.2	98.5	98.6	99.1	99.0	99.6
Lab 2	Type 4, #16	*Cond.*	83.7	88.6	91.9	93.8	95.2	96.5	97.7	98.5	98.9	99.4	99.6	99.9
Lab 2	Type 4, #16	*25%*	83.7	89.2	92.8	94.4	95.8	96.9	97.8	98.5	98.8	99.3	99.6	99.6
Lab 2	Type 4, #16	*50%*	84.2	90.6	93.8	95.1	96.5	97.1	97.7	98.5	98.7	99.3	99.3	99.4
Lab 2	Type 4, #16	*75%*	87.7	92.4	94.6	95.8	96.8	96.8	97.5	98.1	98.4	99.2	99.4	99.5
Lab 2	Type 4, #16	*100%*	87.3	92.7	97.8	95.3	96.0	96.5	96.9	98.0	98.3	99.0	99.1	99.4

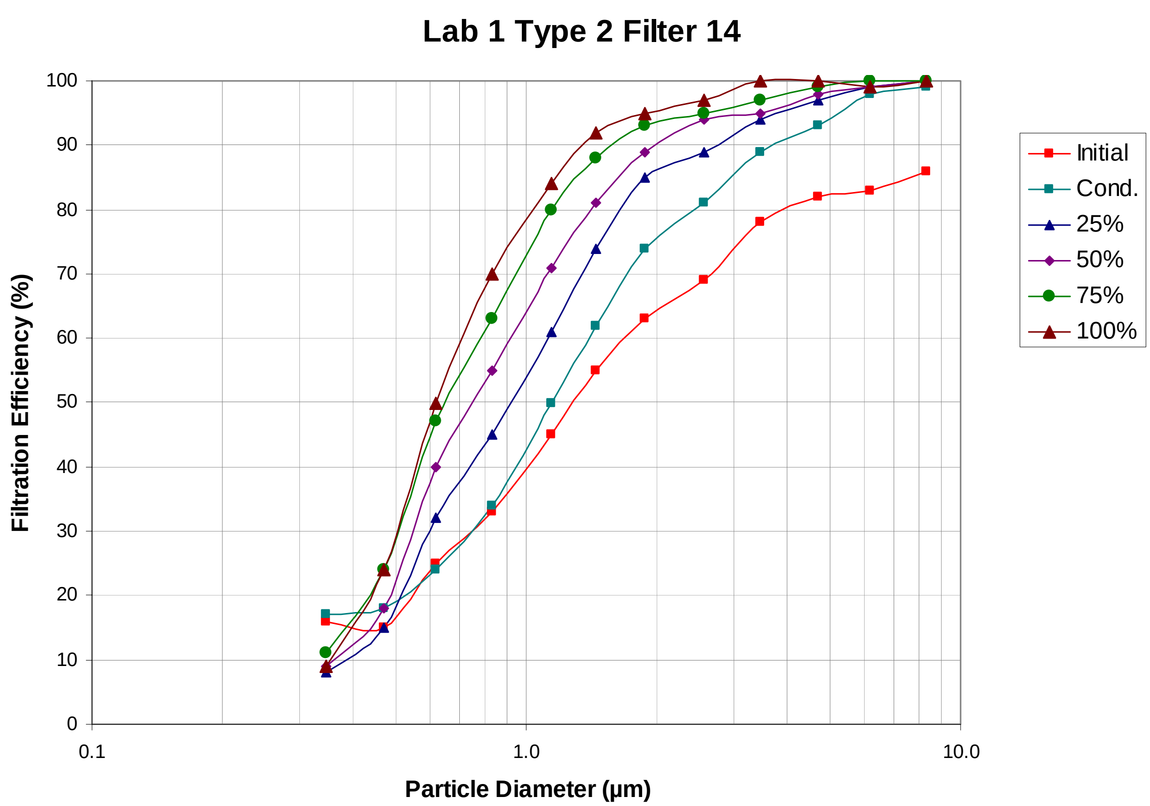
			Filtration Efficiency (%) per indicated size range											
OPC Channel Number			*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Min. Diam. (µm)			*0.30*	*0.40*	*0.55*	*0.70*	*1.00*	*1.30*	*1.60*	*2.20*	*3.00*	*4.00*	*5.50*	*7.00*
Max. Diam. (µm)			*0.40*	*0.55*	*0.70*	*1.00*	*1.30*	*1.60*	*2.20*	*3.00*	*4.00*	*5.50*	*7.00*	*10.0*
Geo. Mean Diam (µm)			*0.35*	*0.47*	*0.62*	*0.84*	*1.14*	*1.44*	*1.88*	*2.57*	*3.46*	*4.69*	*6.20*	*8.37*
Lab 3	Type 4, #22	*Initial*	76.9	82.6	87.7	92.4	94.9	96.3	97.5	98.4	98.9	99.1	99.5	99.7
Lab 3	Type 4, #22	*Cond.*	79.2	84.5	88.9	93.1	95.3	96.6	97.9	98.8	99.2	99.4	99.5	99.5
Lab 3	Type 4, #22	*25%*	84.1	88.1	91.8	95.0	96.3	97.2	98.1	98.6	98.7	99.1	100.0	99.0
Lab 3	Type 4, #22	*50%*	84.4	89.2	92.8	95.6	97.0	97.4	98.0	98.8	99.3	99.2	100.0	99.4
Lab 3	Type 4, #22	*75%*	87.0	91.1	94.0	96.4	97.2	97.6	98.1	98.6	98.7	99.4	99.9	100.0
Lab 3	Type 4, #22	*100%*	88.3	92.2	94.7	96.6	97.4	97.7	98.2	98.6	99.3	99.3	100.0	98.4
Lab 3	Type 4, #6	*Initial*	80.5	86.1	92.0	95.3	97.2	97.8	98.3	98.7	99.1	99.3	99.5	99.3
Lab 3	Type 4, #6	*Cond.*	83.2	88.0	93.0	96.0	97.6	98.1	98.6	98.8	99.2	99.5	99.2	99.6
Lab 3	Type 4, #6	*25%*	84.2	89.3	94.0	96.4	97.5	98.1	98.5	98.7	99.1	99.5	99.7	100.0
Lab 3	Type 4, #6	*50%*	86.5	91.3	95.1	96.9	97.7	98.2	98.4	98.6	98.9	99.1	99.3	99.5
Lab 3	Type 4, #6	*75%*	85.5	91.8	95.5	97.0	97.7	97.9	98.4	98.7	98.9	99.2	99.3	100.0
Lab 3	Type 4, #6	*100%*	87.1	92.7	95.9	97.1	97.6	97.9	98.4	98.5	98.8	98.9	99.4	99.7
Lab 4	Type 4, #20	*Initial*	76.0	83.3	89.7	93.9	96.7	97.5	98.2	98.4	98.9	99.3	99.3	99.5
Lab 4	Type 4, #20	*Cond.*	82.1	87.6	92.1	95.3	97.3	97.8	98.5	98.6	99.2	99.4	99.8	99.7
Lab 4	Type 4, #20	*25%*	84.0	89.4	93.5	96.0	97.3	97.7	98.2	98.5	99.0	99.5	99.7	99.7
Lab 4	Type 4, #20	*50%*	85.5	90.5	94.1	96.4	97.5	97.8	97.9	98.4	98.8	99.3	99.7	99.6
Lab 4	Type 4, #20	*75%*	86.8	91.7	94.8	96.5	97.3	97.5	98.0	98.3	98.7	99.3	99.6	99.6
Lab 4	Type 4, #20	*100%*	88.3	92.6	95.2	96.6	97.3	97.3	97.6	98.2	98.7	99.2	99.4	99.4
Lab 4	Type 4, #7	*Initial*	77.4	84.6	91.1	94.7	97.2	97.8	98.2	98.6	99.1	99.3	99.6	99.7
Lab 4	Type 4, #7	*Cond.*	81.6	87.6	93.0	95.8	97.7	98.4	98.7	99.0	99.4	99.7	99.9	99.8
Lab 4	Type 4, #7	*25%*	85.2	90.5	94.8	96.7	97.8	98.3	98.7	99.0	99.5	99.7	99.9	99.9
Lab 4	Type 4, #7	*50%*	85.5	91.2	95.1	96.8	98.0	98.4	98.5	98.9	99.3	99.7	99.7	99.7
Lab 4	Type 4, #7	*75%*	87.4	92.7	95.9	97.2	97.8	97.8	98.4	98.8	99.3	99.4	99.6	99.9
Lab 4	Type 4, #7	*100%*	89.1	93.7	96.2	97.2	97.5	97.8	98.3	98.7	99.2	99.5	99.8	99.7

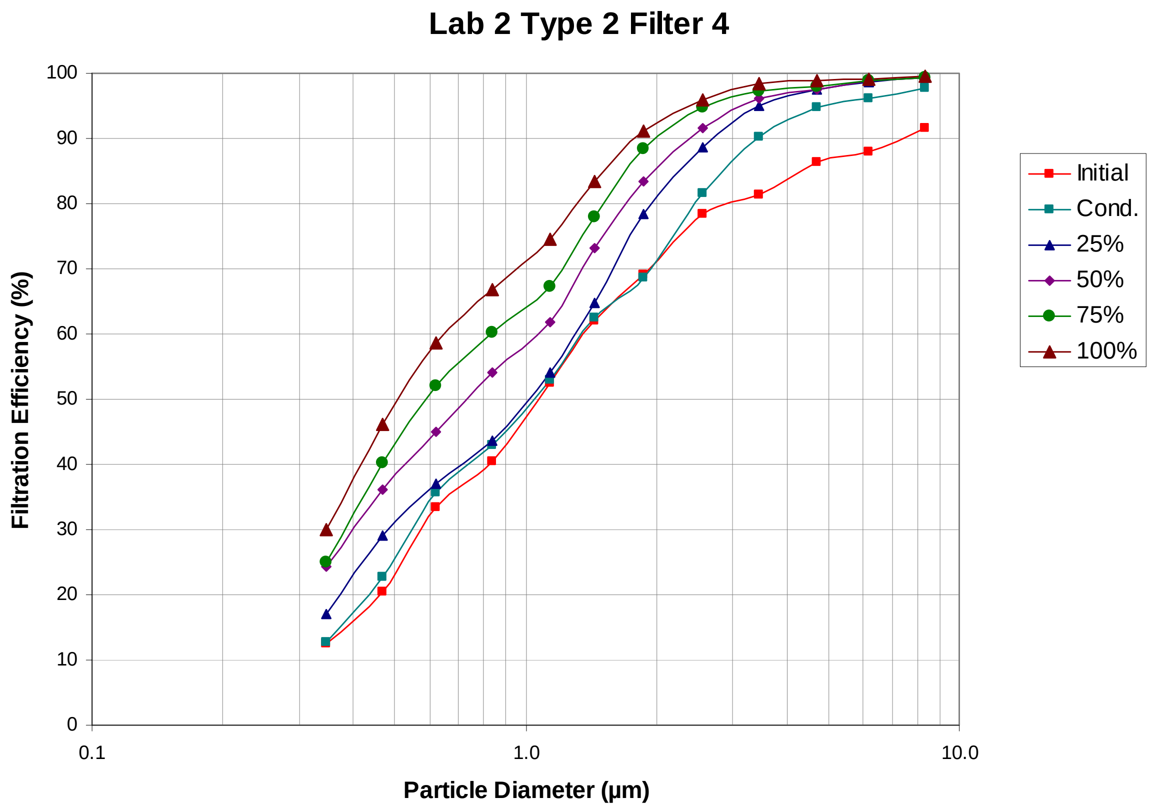
			Filtration Efficiency (%) per indicated size range											
		OPC Channel Number	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
		Min. Diam. (μm)	*0.30*	*0.40*	*0.55*	*0.70*	*1.00*	*1.30*	*1.60*	*2.20*	*3.00*	*4.00*	*5.50*	*7.00*
		Max. Diam. (μm)	*0.40*	*0.55*	*0.70*	*1.00*	*1.30*	*1.60*	*2.20*	*3.00*	*4.00*	*5.50*	*7.00*	*10.0*
		Geo. Mean Diam (μm)	*0.35*	*0.47*	*0.62*	*0.84*	*1.14*	*1.44*	*1.88*	*2.57*	*3.46*	*4.69*	*6.20*	*8.37*
Lab 5	Type 4, #21	*Initial*	68.3	80.9	90.3	93.5	96.4	97.6	98.3	98.7	99.1	99.2	99.7	99.8
Lab 5	Type 4, #21	*Cond.*	76.2	86.2	93.0	95.5	97.5	98.3	98.6	98.6	99.2	99.5	99.9	99.9
Lab 5	Type 4, #21	*25%*	76.9	86.4	93.4	95.6	97.4	98.3	98.7	98.9	99.2	99.5	99.6	99.9
Lab 5	Type 4, #21	*50%*	78.5	87.9	94.3	96.4	98.0	98.7	99.2	99.5	100.0	100.0	100.0	100.0
Lab 5	Type 4, #21	*75%*	82.4	90.8	95.5	96.9	97.9	98.4	98.6	98.9	99.5	100.0	100.0	100.0
Lab 5	Type 4, #21	*100%*	85.9	93.2	96.5	97.4	98.0	98.3	98.5	100.0	100.0	100.0	100.0	100.0
Lab 5	Type 4, #8	*Initial*	64.8	79.4	89.6	93.4	95.7	96.9	97.4	98.1	98.3	98.6	99.6	100.0
Lab 5	Type 4, #8	*Cond.*	78.5	86.7	92.9	95.5	97.1	97.7	98.1	98.6	98.7	99.4	100.0	100.0
Lab 5	Type 4, #8	*25%*	76.6	86.0	92.9	95.7	97.1	97.7	98.0	98.5	98.6	99.5	99.9	100.1
Lab 5	Type 4, #8	*50%*	78.3	86.5	92.3	96.0	97.0	97.7	98.3	98.5	98.8	99.4	99.7	99.9
Lab 5	Type 4, #8	*75%*	83.5	91.0	95.5	96.9	97.4	97.7	98.1	98.6	99.1	99.5	99.8	100.0
Lab 5	Type 4, #8	*100%*	87.1	93.2	96.1	96.9	97.3	97.7	98.0	98.7	99.0	99.4	99.8	100.1
Lab 6	Type 4, #17	*Initial*	69.0	78.0	86.0	93.0	96.0	97.0	98.0	99.0	99.0	99.0	100.0	100.0
Lab 6	Type 4, #17	*Cond.*	74.0	82.0	89.0	94.0	97.0	98.0	98.0	99.0	99.0	100.0	100.0	100.0
Lab 6	Type 4, #17	*25%*	77.0	85.0	91.0	95.0	97.0	98.0	98.0	99.0	99.0	100.0	100.0	100.0
Lab 6	Type 4, #17	*50%*	78.0	86.0	92.0	96.0	98.0	98.0	98.0	99.0	99.0	100.0	100.0	100.0
Lab 6	Type 4, #17	*75%*	82.0	89.0	93.0	96.0	97.0	98.0	98.0	99.0	99.0	100.0	100.0	100.0
Lab 6	Type 4, #17	*100%*	84.0	90.0	94.0	96.0	98.0	98.0	98.0	99.0	99.0	100.0	100.0	100.0
Lab 6	Type 4, #4	*Initial*	69.0	78.0	87.0	93.0	97.0	97.0	98.0	98.0	99.0	99.0	100.0	100.0
Lab 6	Type 4, #4	*Cond.*	74.0	82.0	89.0	94.0	97.0	98.0	99.0	99.0	100.0	100.0	100.0	100.0
Lab 6	Type 4, #4	*25%*	79.0	87.0	92.0	96.0	98.0	98.0	99.0	99.0	100.0	100.0	100.0	100.0
Lab 6	Type 4, #4	*50%*	82.0	89.0	94.0	96.0	98.0	98.0	99.0	99.0	100.0	100.0	100.0	100.0
Lab 6	Type 4, #4	*75%*	82.0	89.0	94.0	96.0	97.0	98.0	99.0	99.0	100.0	100.0	100.0	100.0
Lab 6	Type 4, #4	*100%*	86.0	91.0	95.0	97.0	97.0	98.0	98.0	99.0	100.0	100.0	100.0	100.0

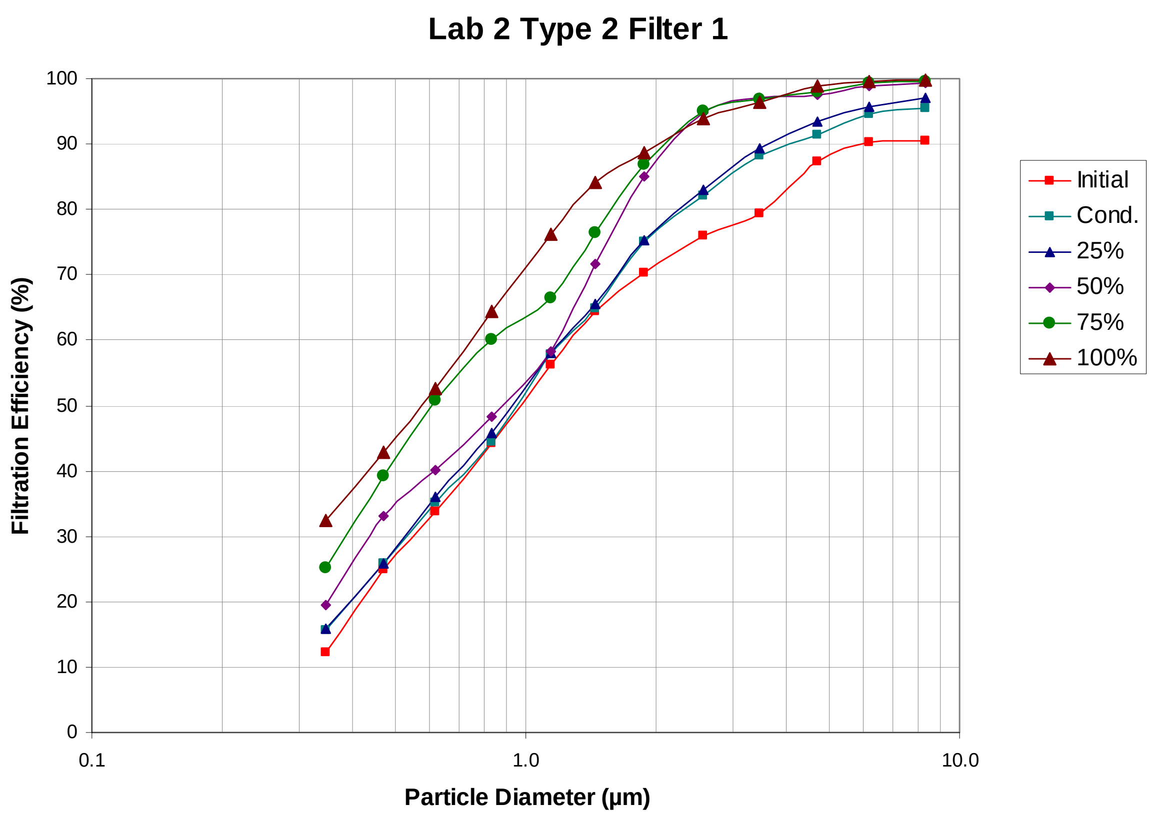
Appendix G

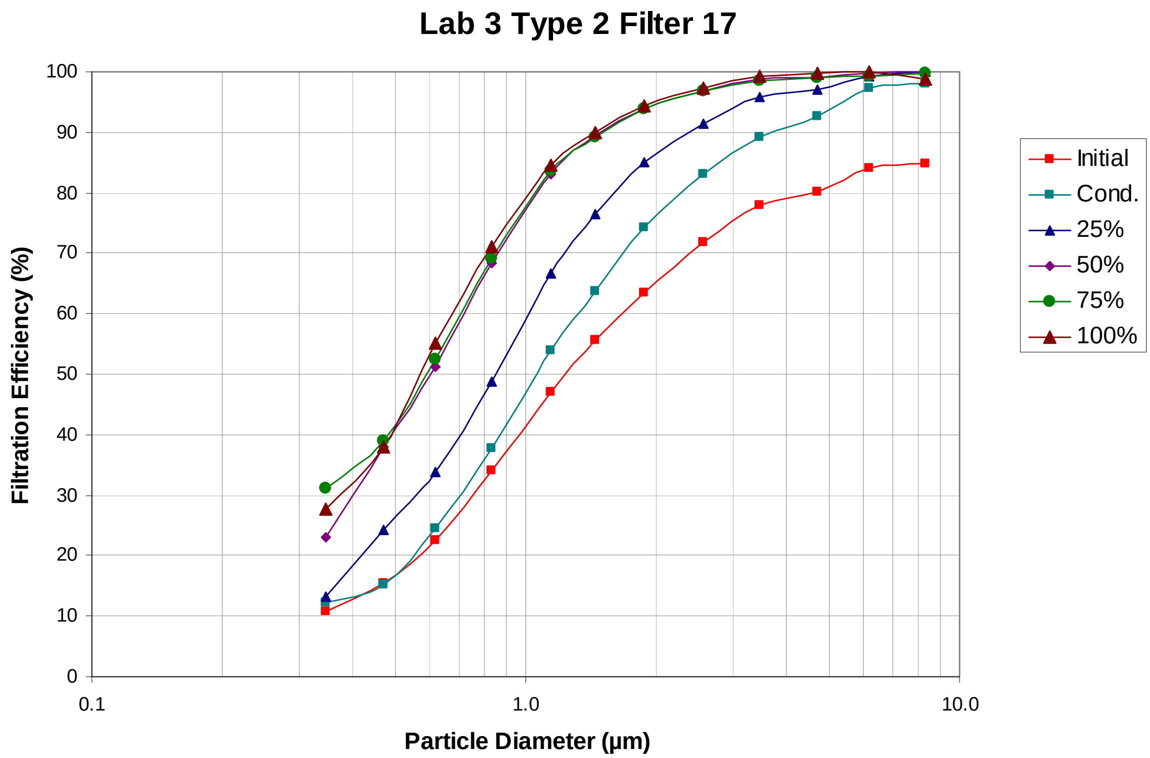
Round 2 graphical summaries for each lab and filter

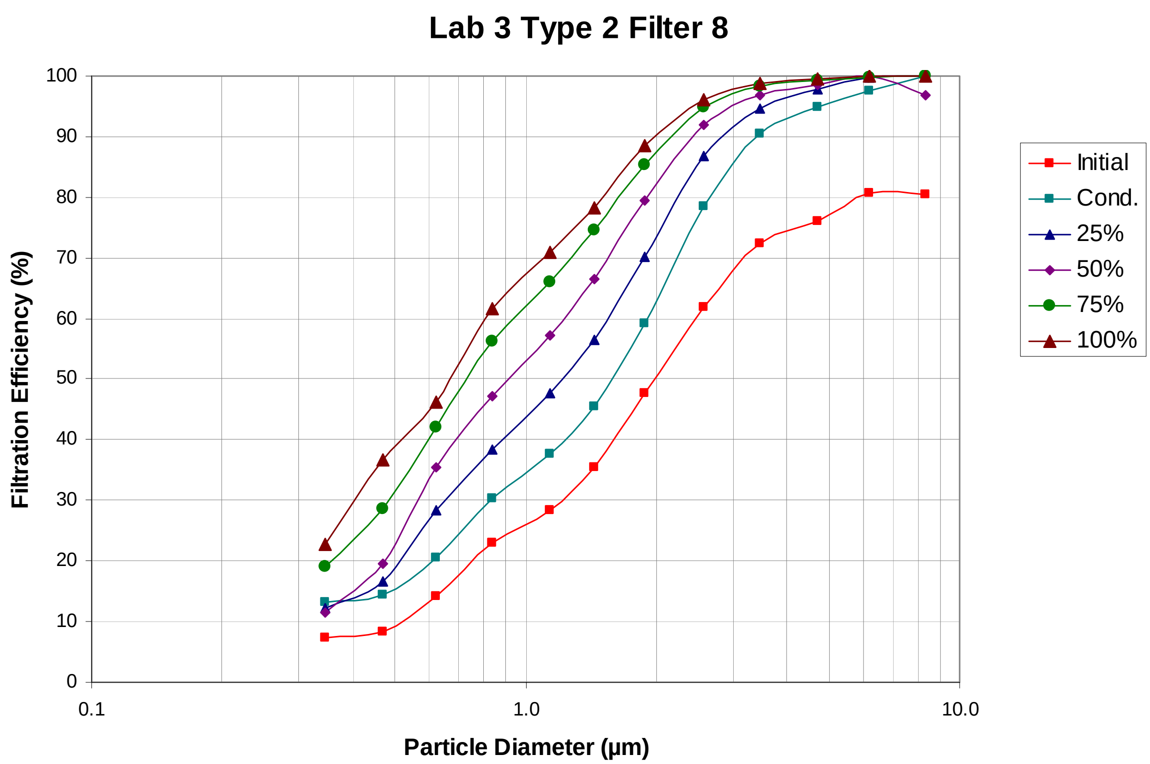

Lab 1 Type 2 Filter 16
Filtration Efficiency (%)
Particle Diameter (µm)
0
10
20
30
40
50
60
70
80
90
100
0.1
1.0
10.0
Initial
Cond.
25%
50%
75%
100%

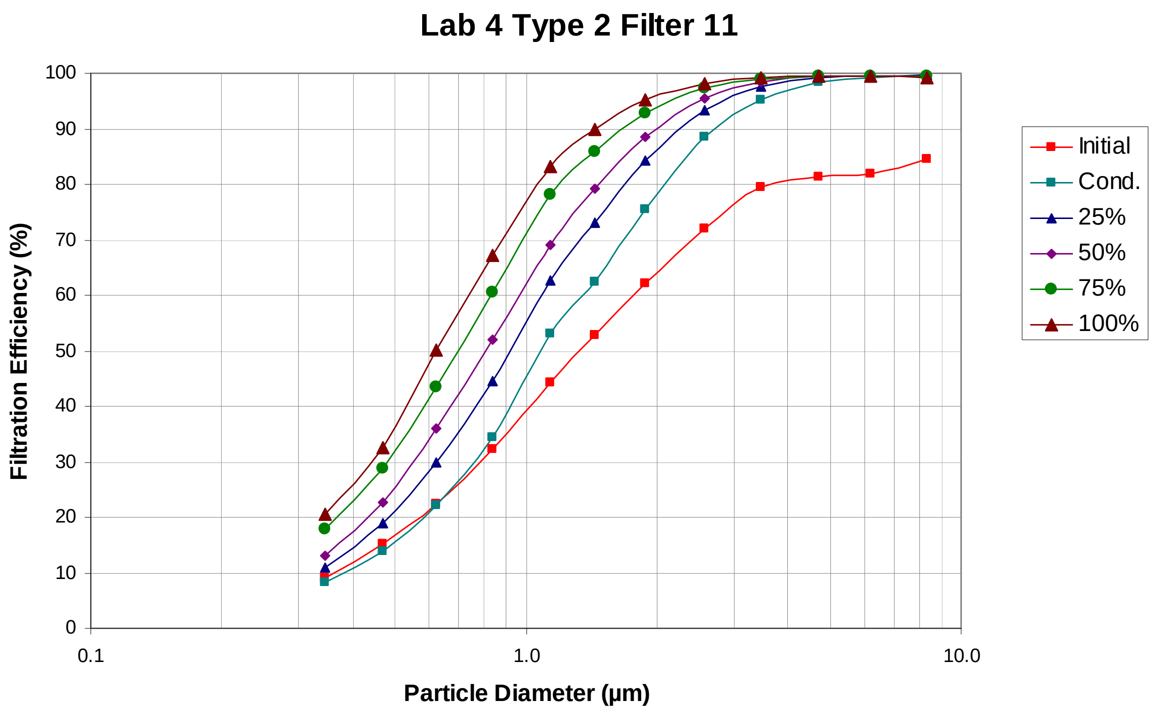

Lab 1 Type 2 Filter 14
Filtration Efficiency (%)
Particle Diameter (µm)
0
10
20
30
40
50
60
70
80
90
100
0.1
1.0
10.0
Initial
Cond.
25%
50%
75%
100%

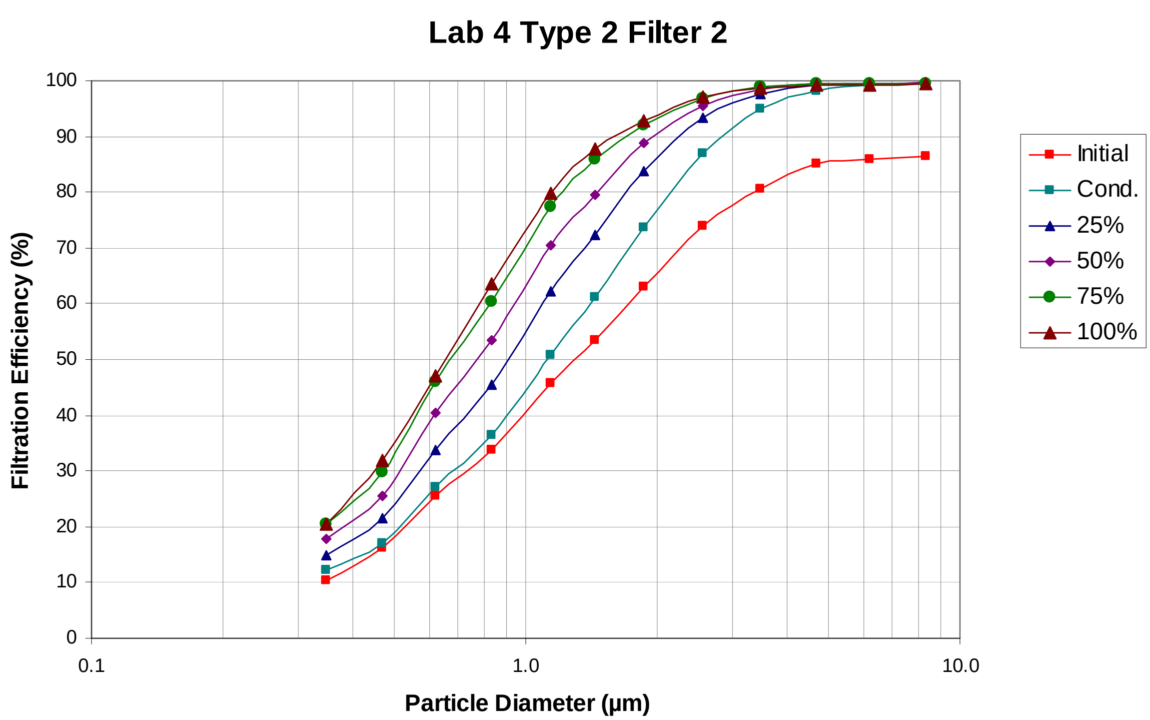

Lab 2 Type 2 Filter 4
Filtration Efficiency (%)
Particle Diameter (µm)
0
10
20
30
40
50
60
70
80
90
100
0.1
1.0
10.0
Initial
Cond.
25%
50%
75%
100%

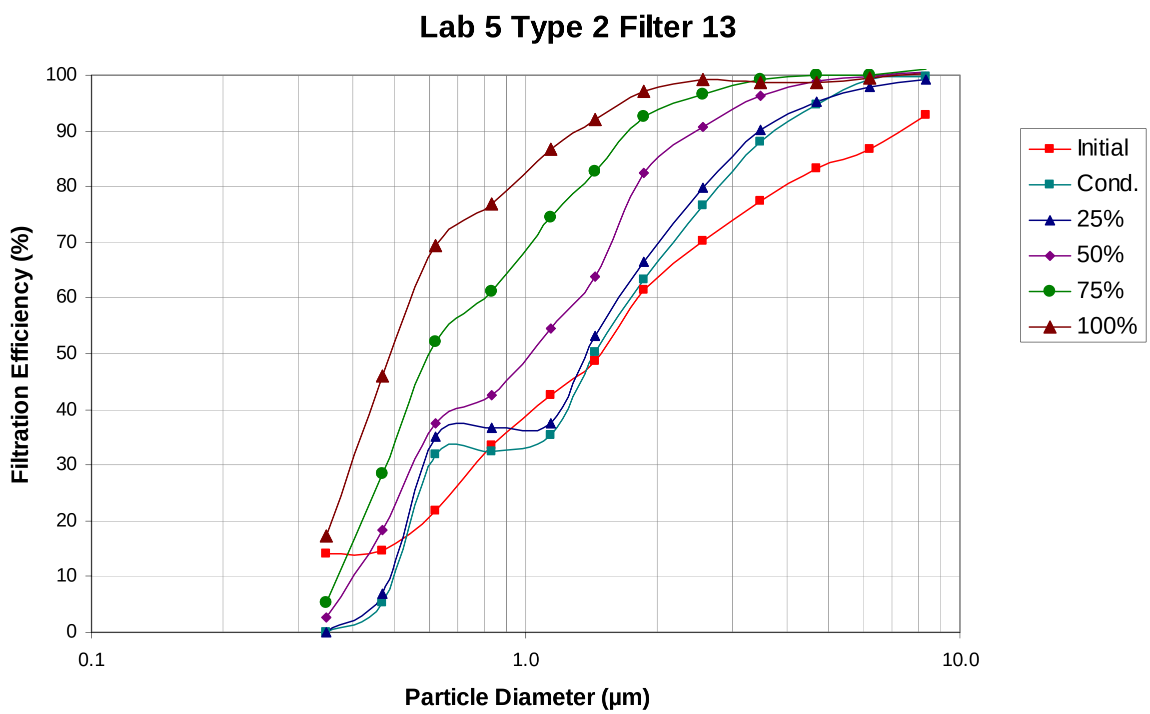

Lab 2 Type 2 Filter 1
Filtration Efficiency (%)
Particle Diameter (µm)
0
10
20
30
40
50
60
70
80
90
100
0.1
1.0
10.0
Initial
Cond.
25%
50%
75%
100%

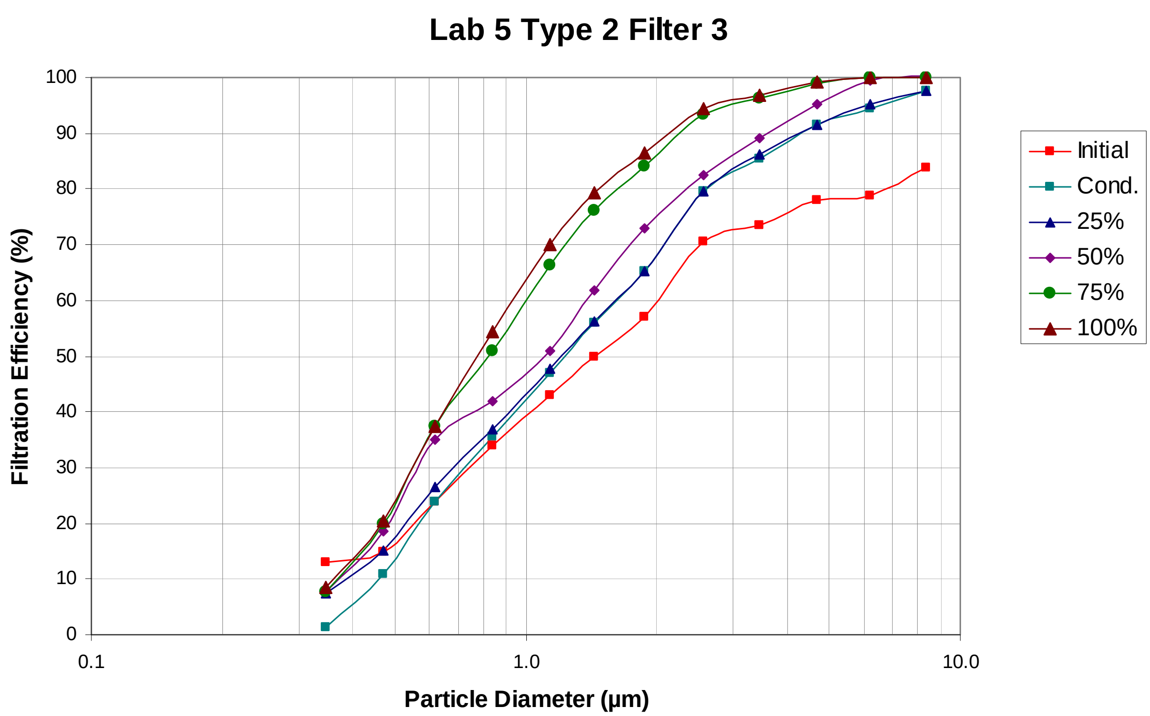

Lab 3 Type 2 Filter 17
Filtration Efficiency (%)
Particle Diameter (µm)
0
10
20
30
40
50
60
70
80
90
100
0.1
1.0
10.0
Initial
Cond.
25%
50%
75%
100%

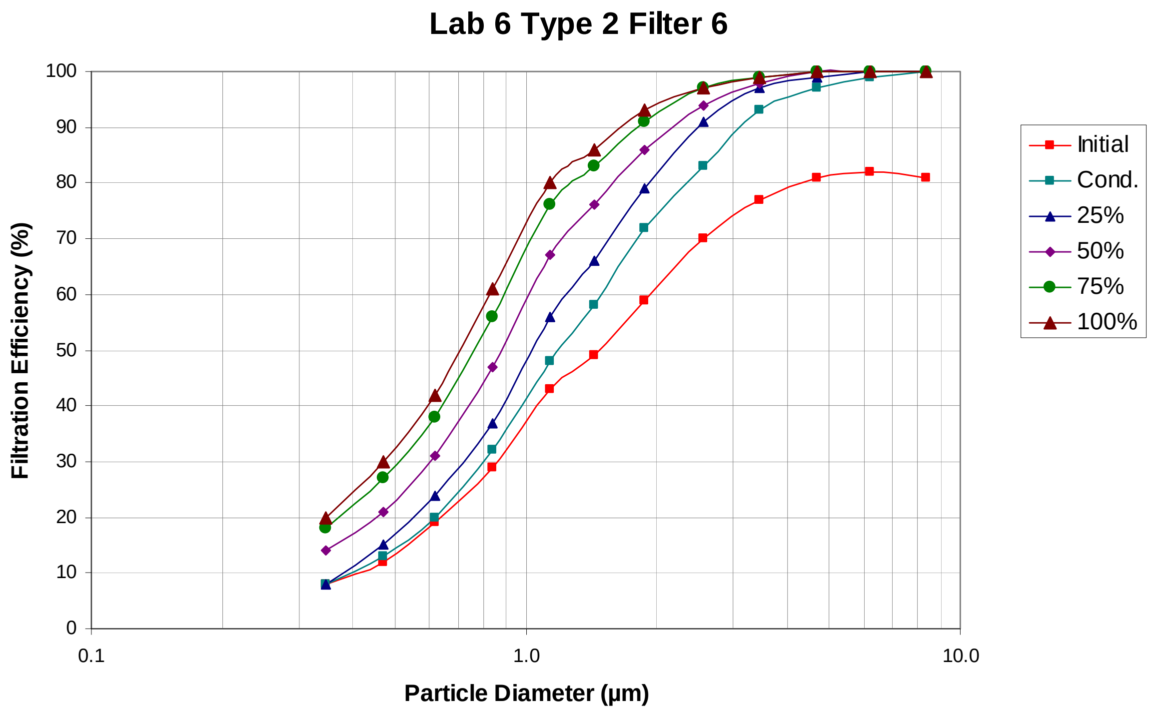

Lab 3 Type 2 Filter 8
Filtration Efficiency (%)
Particle Diameter (µm)
0
10
20
30
40
50
60
70
80
90
100
0.1
1.0
10.0
Initial
Cond.
25%
50%
75%
100%

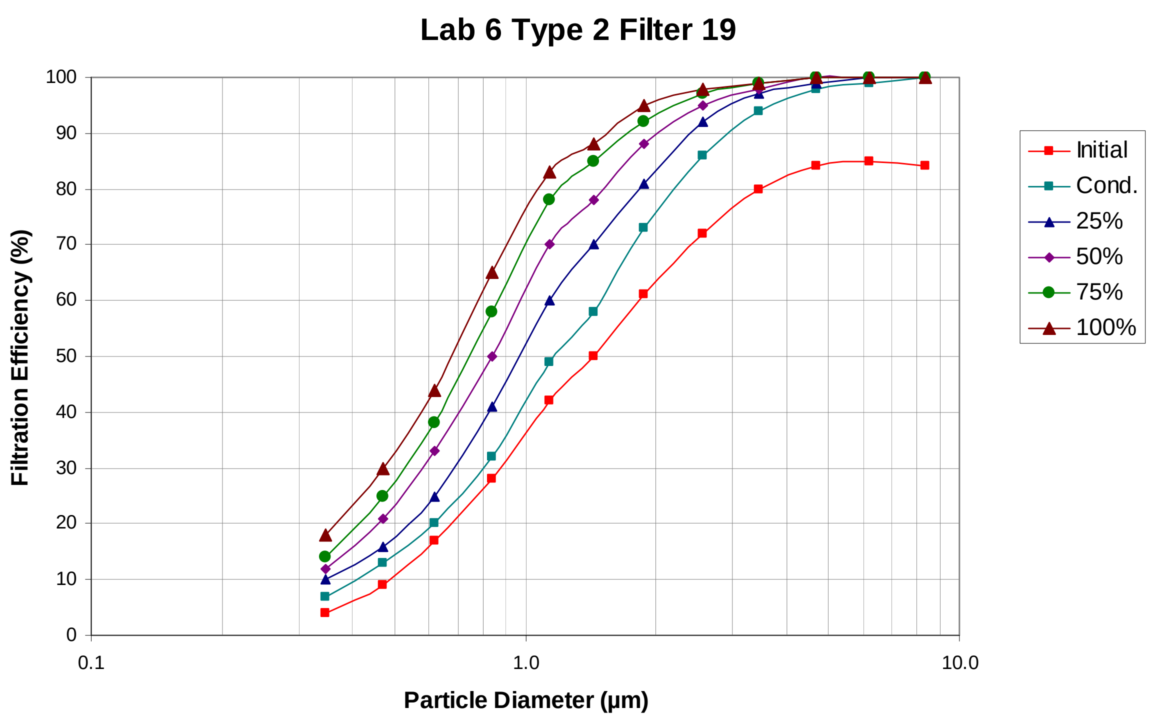

Lab 4 Type 2 Filter 11
100
90
80
70
60
50
40
30
20
10
0
0.1
1.0
10.0
Filtration Efficiency (%)
Particle Diameter (µm)
Initial
Cond.
25%
50%
75%
100%

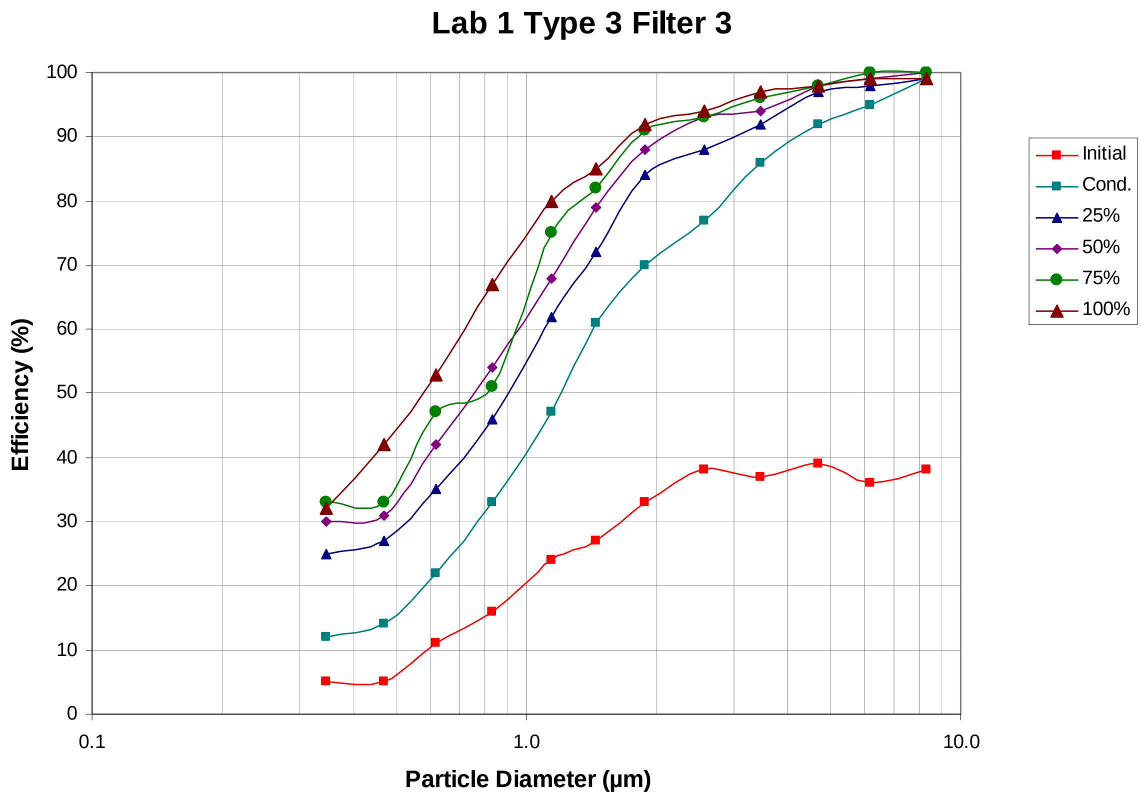

Lab 4 Type 2 Filter 2
100
90
80
70
60
50
40
30
20
10
0
0.1
1.0
10.0
Filtration Efficiency (%)
Particle Diameter (µm)
Initial
Cond.
25%
50%
75%
100%

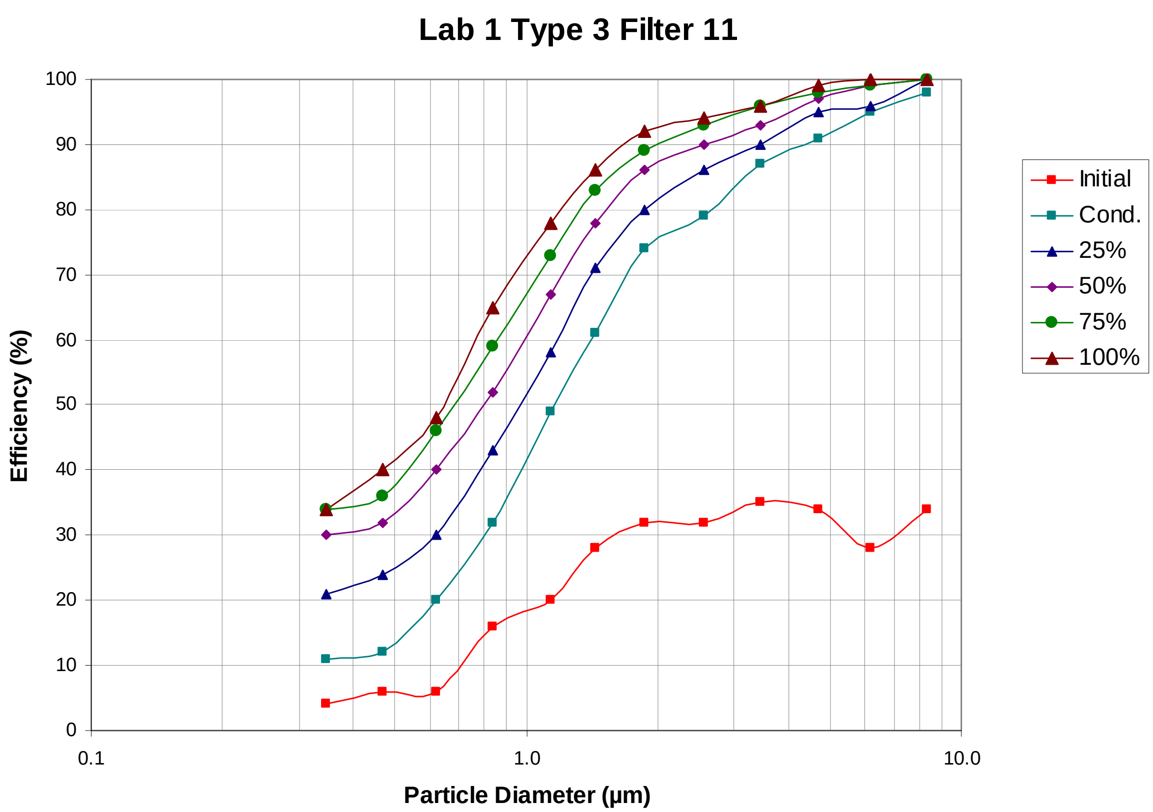

Lab 5 Type 2 Filter 13
Filtration Efficiency (%)
0
10
20
30
40
50
60
70
80
90
100
0.1
1.0
10.0
Particle Diameter (µm)
Initial
Cond.
25%
50%
75%
100%

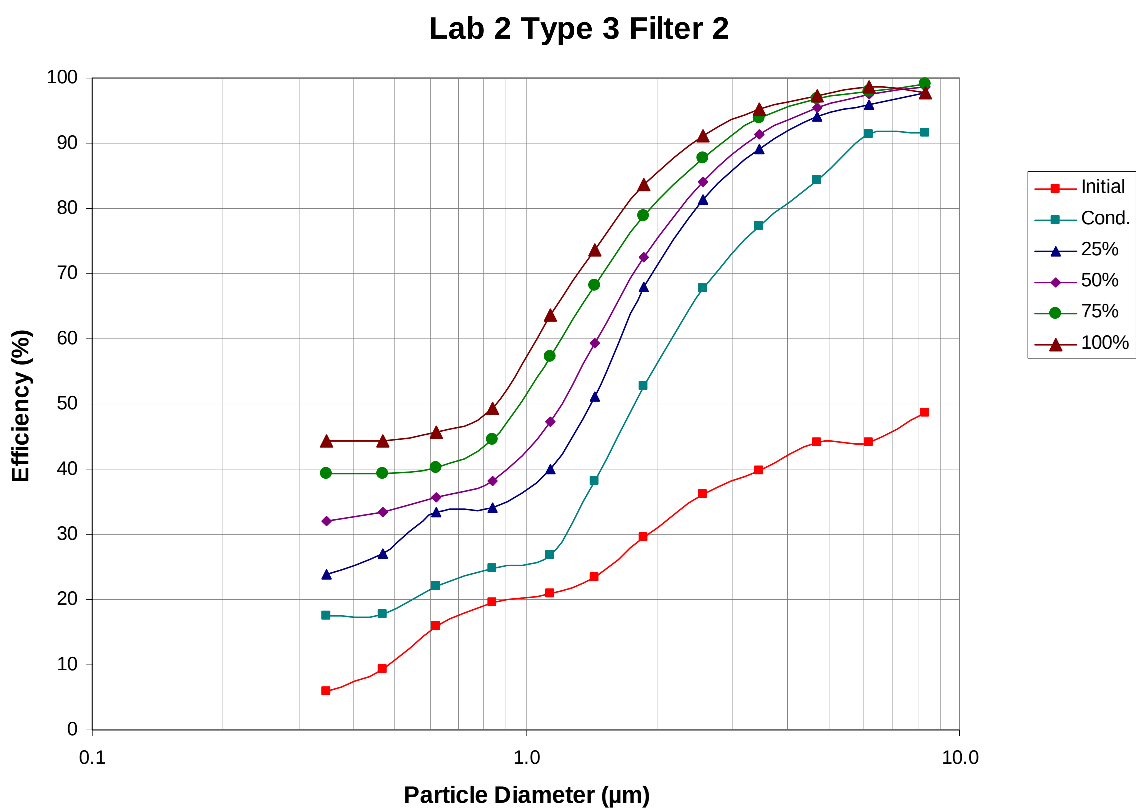

Lab 5 Type 2 Filter 3
Filtration Efficiency (%)
0
10
20
30
40
50
60
70
80
90
100
0.1
1.0
10.0
Particle Diameter (µm)
Initial
Cond.
25%
50%
75%
100%


Lab 6 Type 2 Filter 6
Filtration Efficiency (%)
Particle Diameter (µm)
0.1
1.0
10.0
0
10
20
30
40
50
60
70
80
90
100
Initial
Cond.
25%
50%
75%
100%

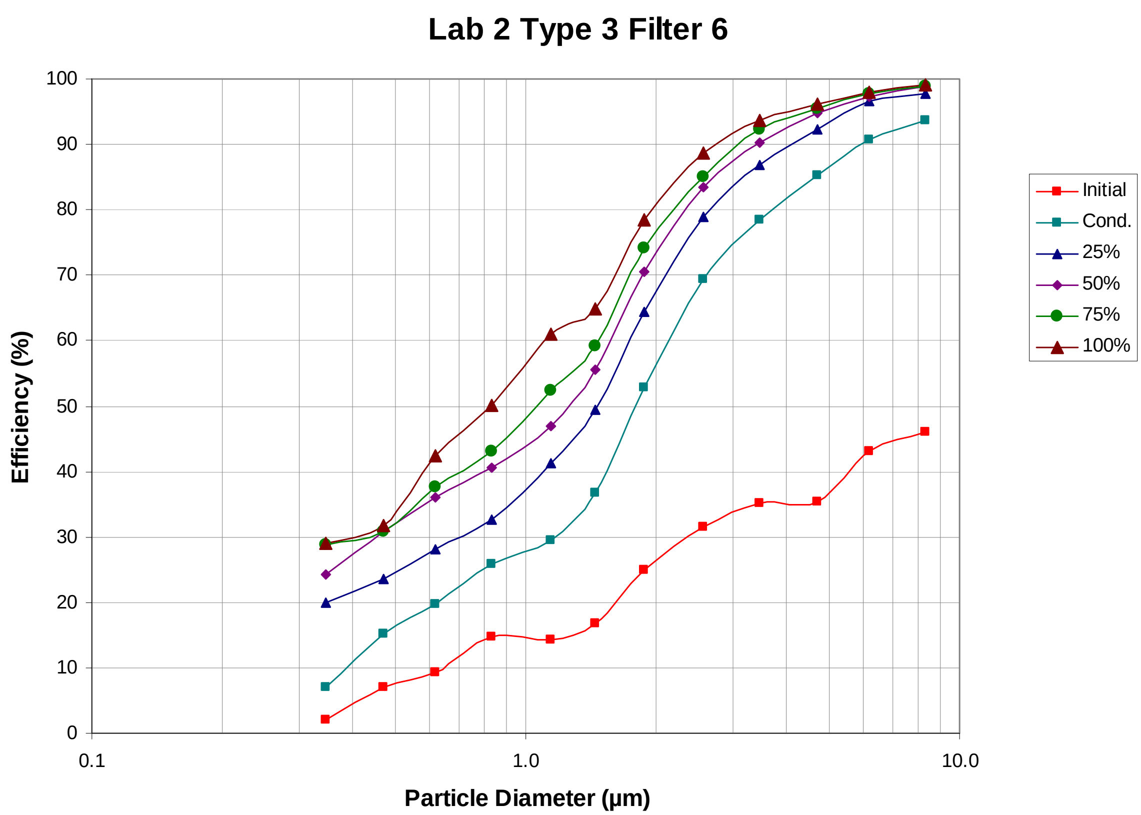

Lab 6 Type 2 Filter 19
Filtration Efficiency (%)
Particle Diameter (µm)
0.1
1.0
10.0
0
10
20
30
40
50
60
70
80
90
100
Initial
Cond.
25%
50%
75%
100%


Lab 1 Type 3 Filter 3
Efficiency (%)
Particle Diameter (µm)
0.1
1.0
10.0
0
10
20
30
40
50
60
70
80
90
100
Initial
Cond.
25%
50%
75%
100%

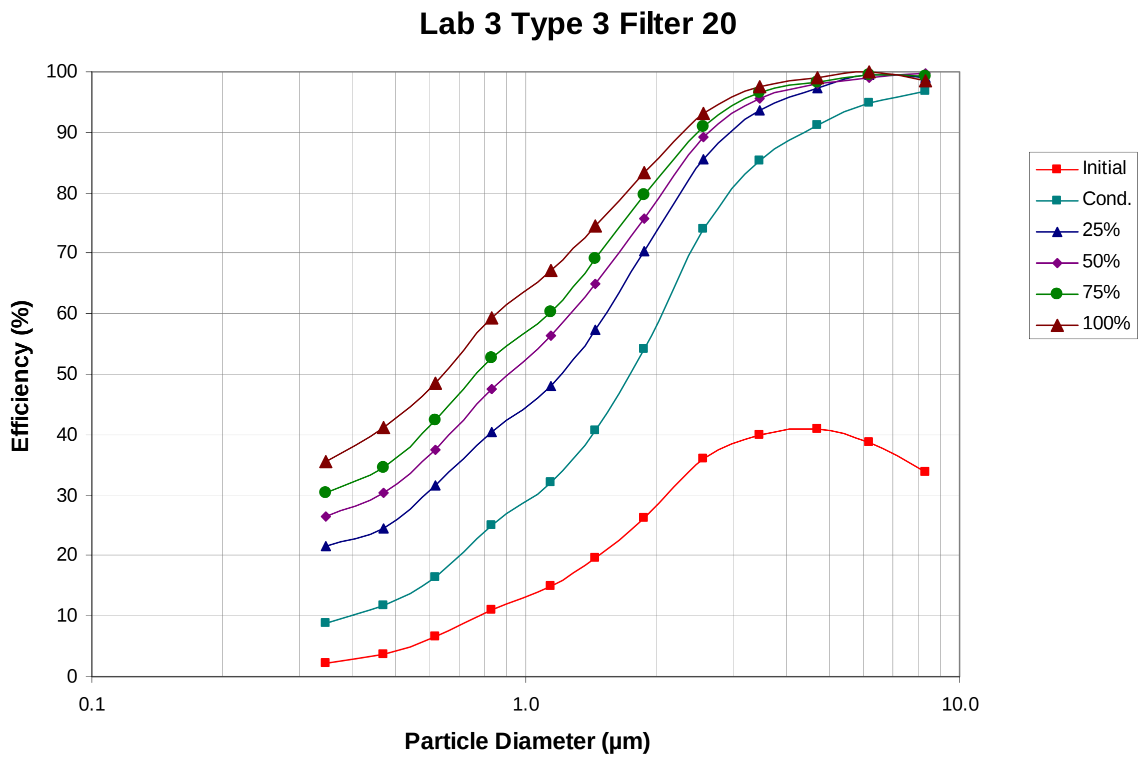

Lab 1 Type 3 Filter 11
Efficiency (%)
Particle Diameter (µm)
0.1
1.0
10.0
0
10
20
30
40
50
60
70
80
90
100
Initial
Cond.
25%
50%
75%
100%

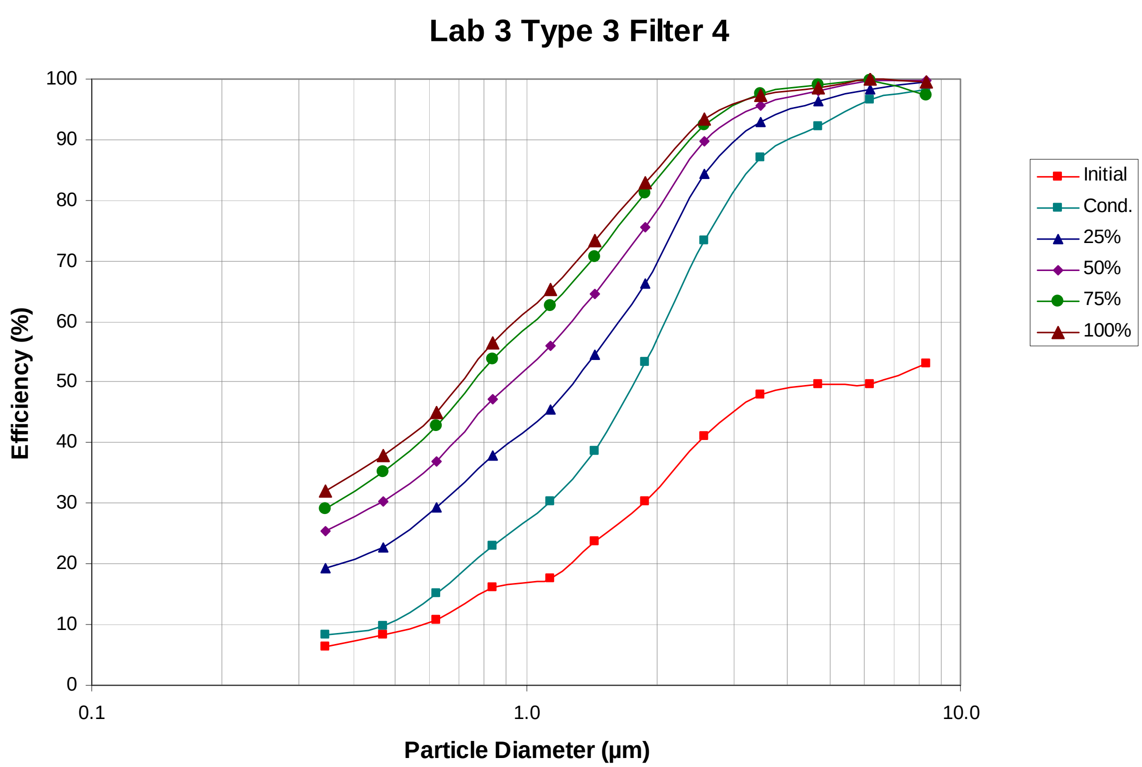


Lab 2 Type 3 Filter 2
100
90
80
70
60
50
40
30
20
10
0
Efficiency (%)
0.1
1.0
10.0
Particle Diameter (µm)
Initial
Cond.
25%
50%
75%
100%

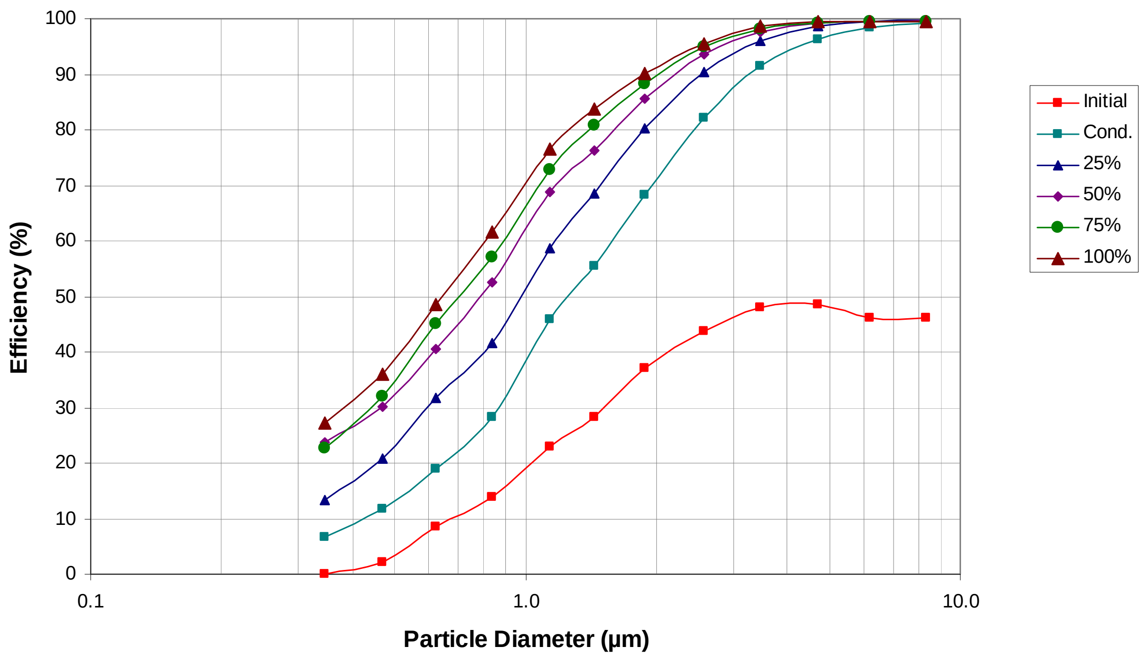


Lab 2 Type 3 Filter 6
100
90
80
70
60
50
40
30
20
10
0
Efficiency (%)
0.1
1.0
10.0
Particle Diameter (µm)
Initial
Cond.
25%
50%
75%
100%

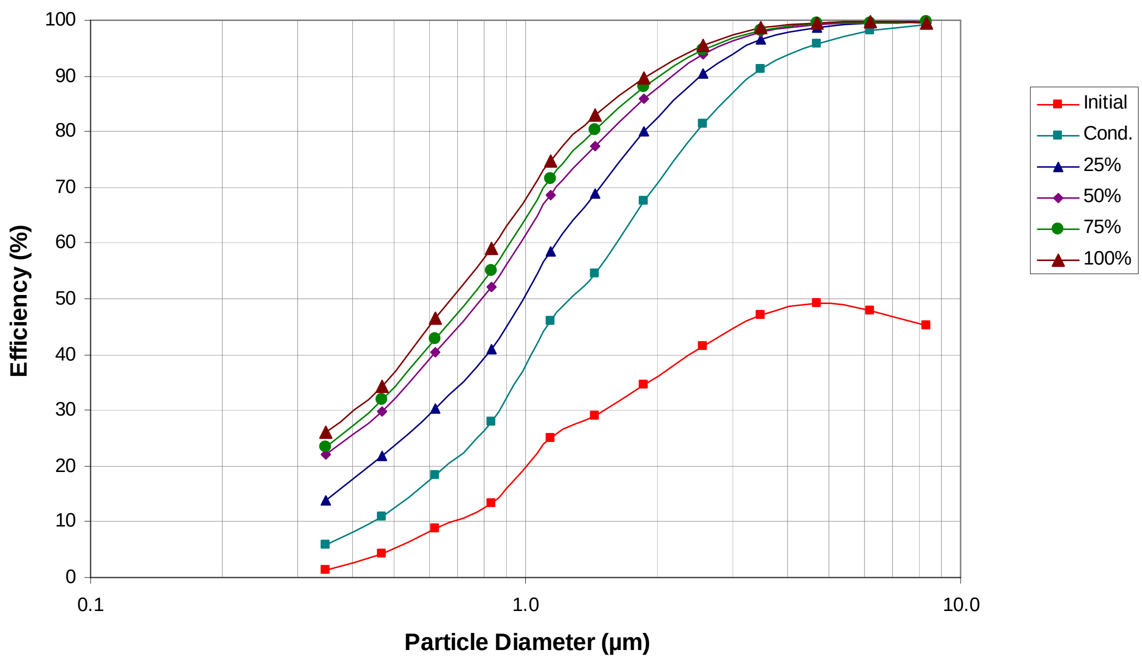

Lab 3 Type 3 Filter 20
Efficiency (%)
100
90
80
70
60
50
40
30
20
10
0
0.1
1.0
10.0
Particle Diameter (µm)
Initial
Cond.
25%
50%
75%
100%


Lab 3 Type 3 Filter 4
Efficiency (%)
100
90
80
70
60
50
40
30
20
10
0
0.1
1.0
10.0
Particle Diameter (µm)
Initial
Cond.
25%
50%
75%
100%

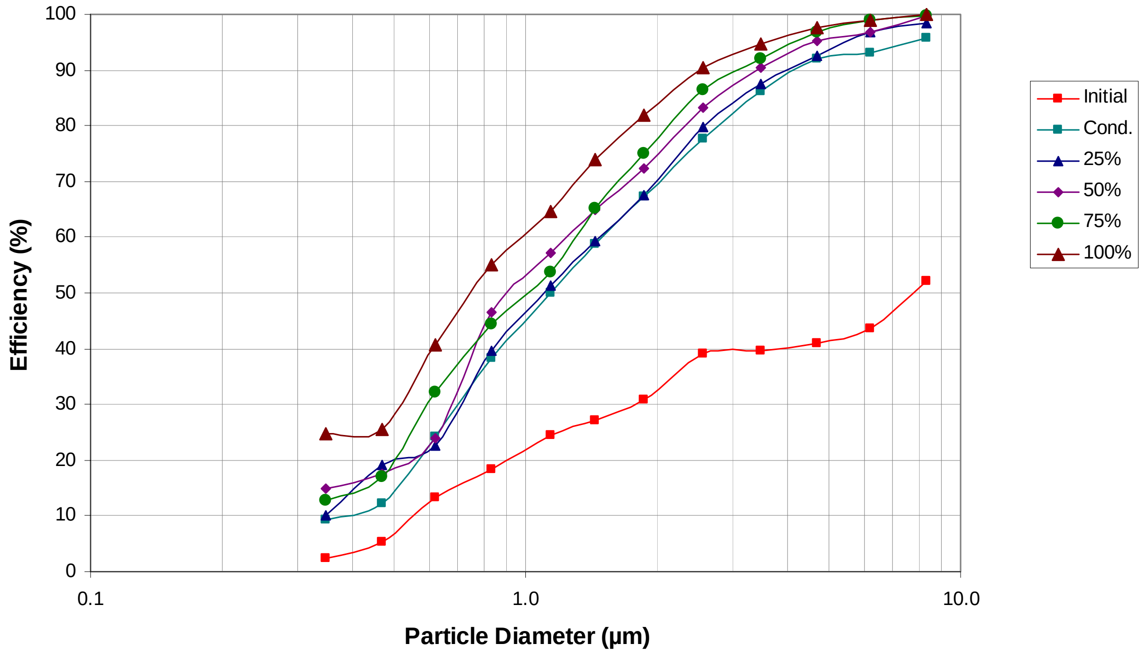
Lab 4 Type 3 Filter 12



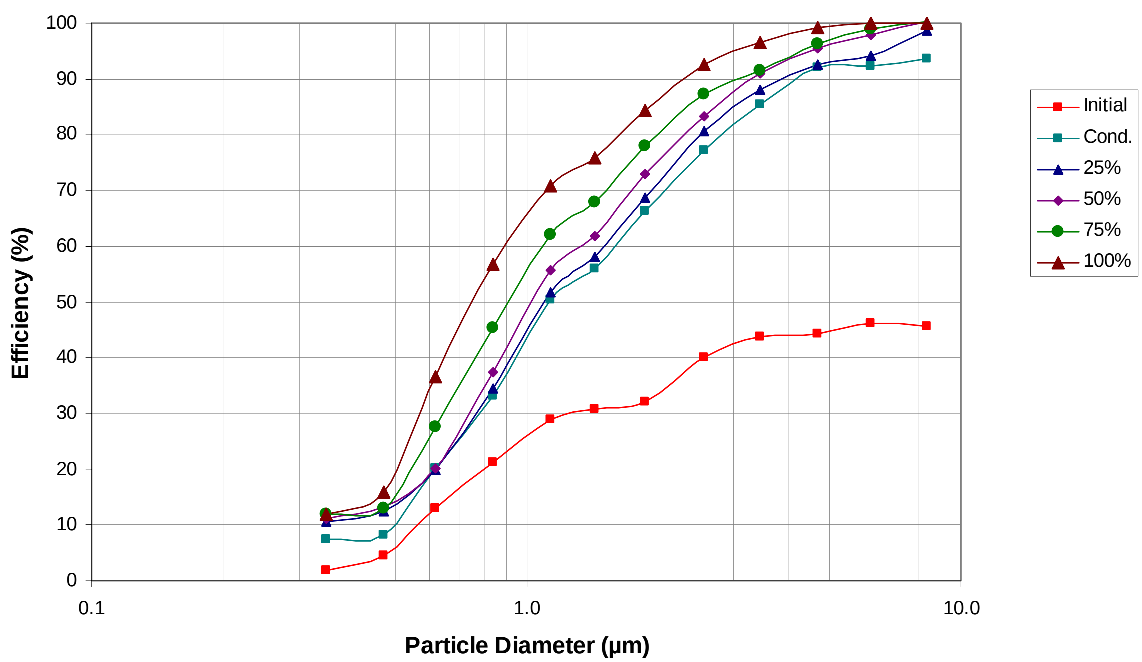
Lab 4 Type 3 Filter 5

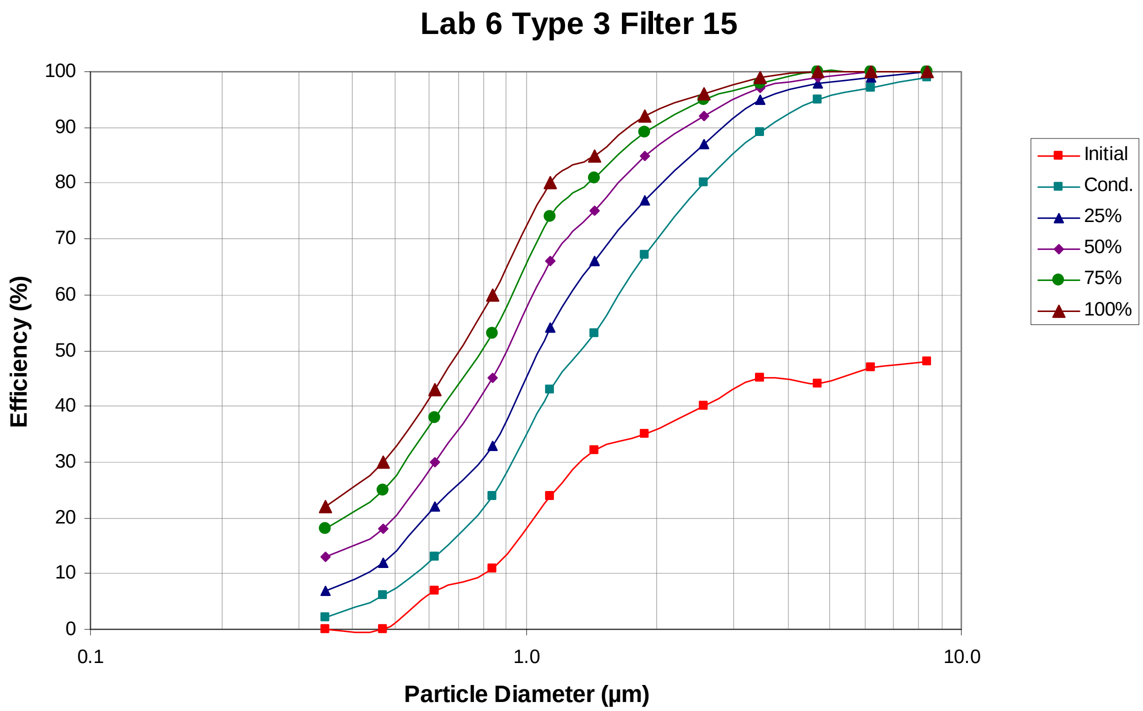


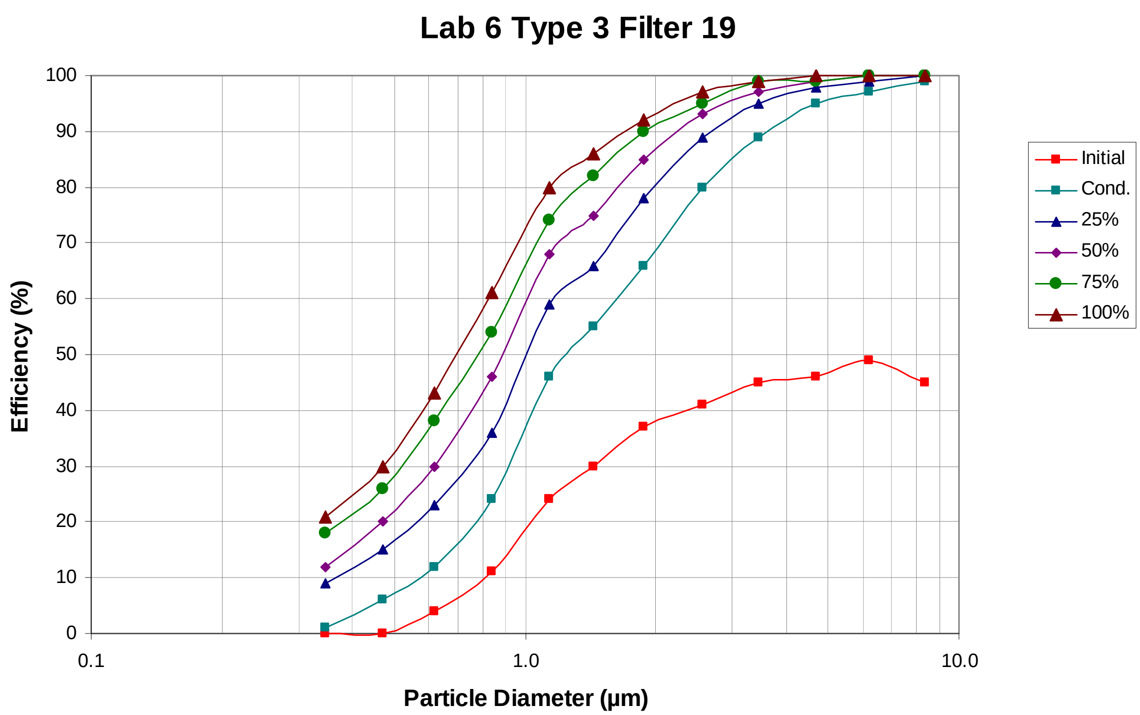
Lab 5 Type 3 Filter 1

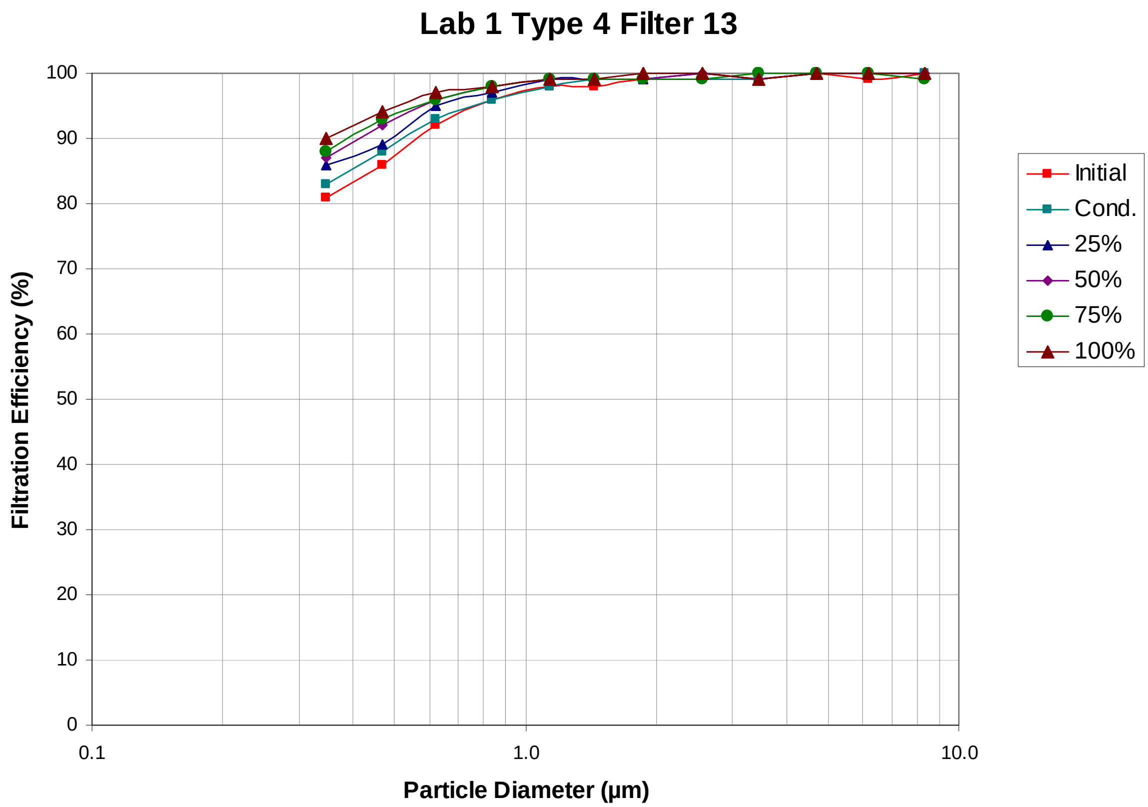


Lab 5 Type 3 Filter 18

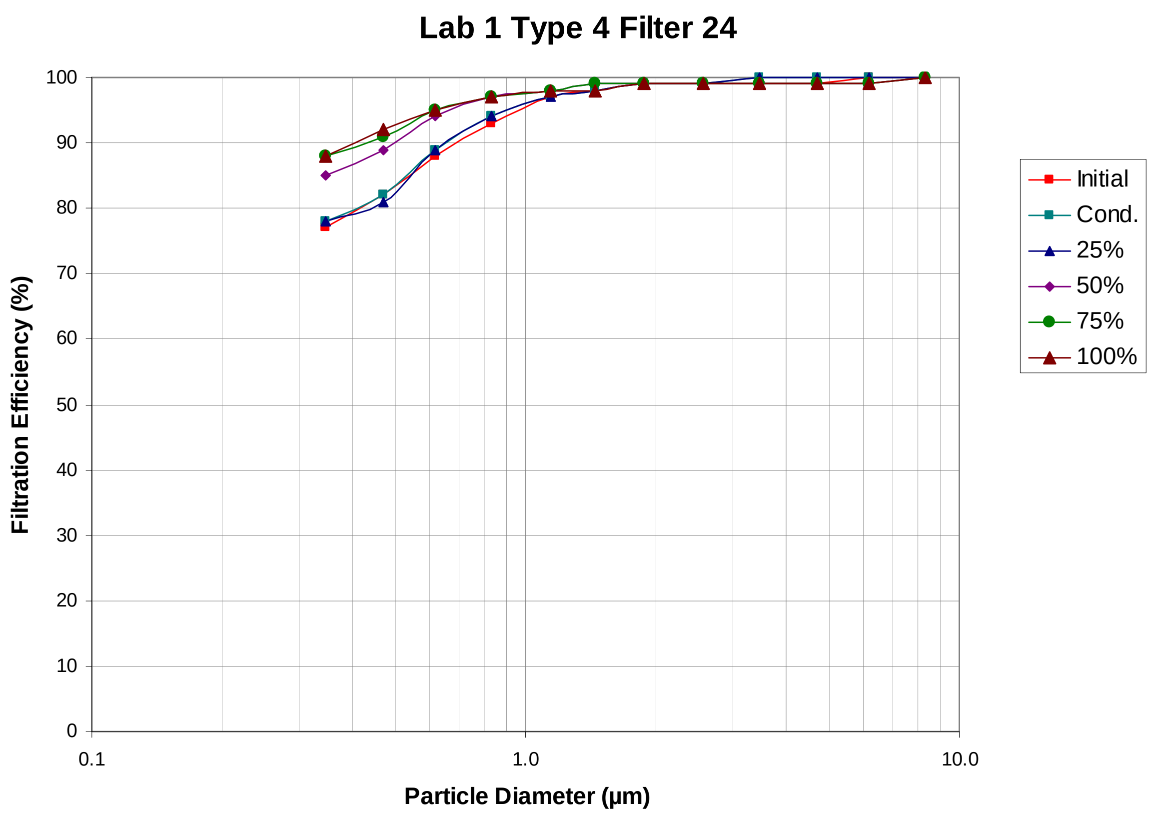



Lab 6 Type 3 Filter 15
Efficiency (%)
0
10
20
30
40
50
60
70
80
90
100
0.1
1.0
10.0
Particle Diameter (µm)
Initial
Cond.
25%
50%
75%
100%

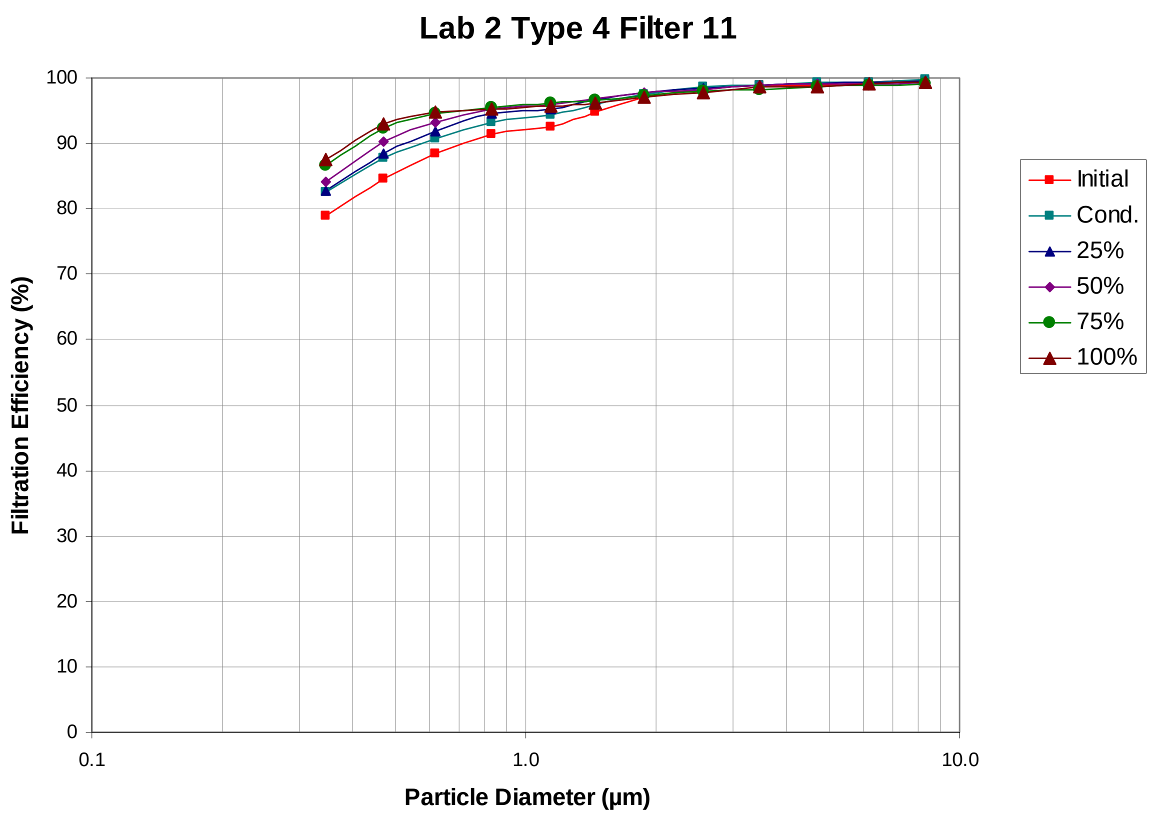

Lab 6 Type 3 Filter 19
Efficiency (%)
0
10
20
30
40
50
60
70
80
90
100
0.1
1.0
10.0
Particle Diameter (µm)
Initial
Cond.
25%
50%
75%
100%

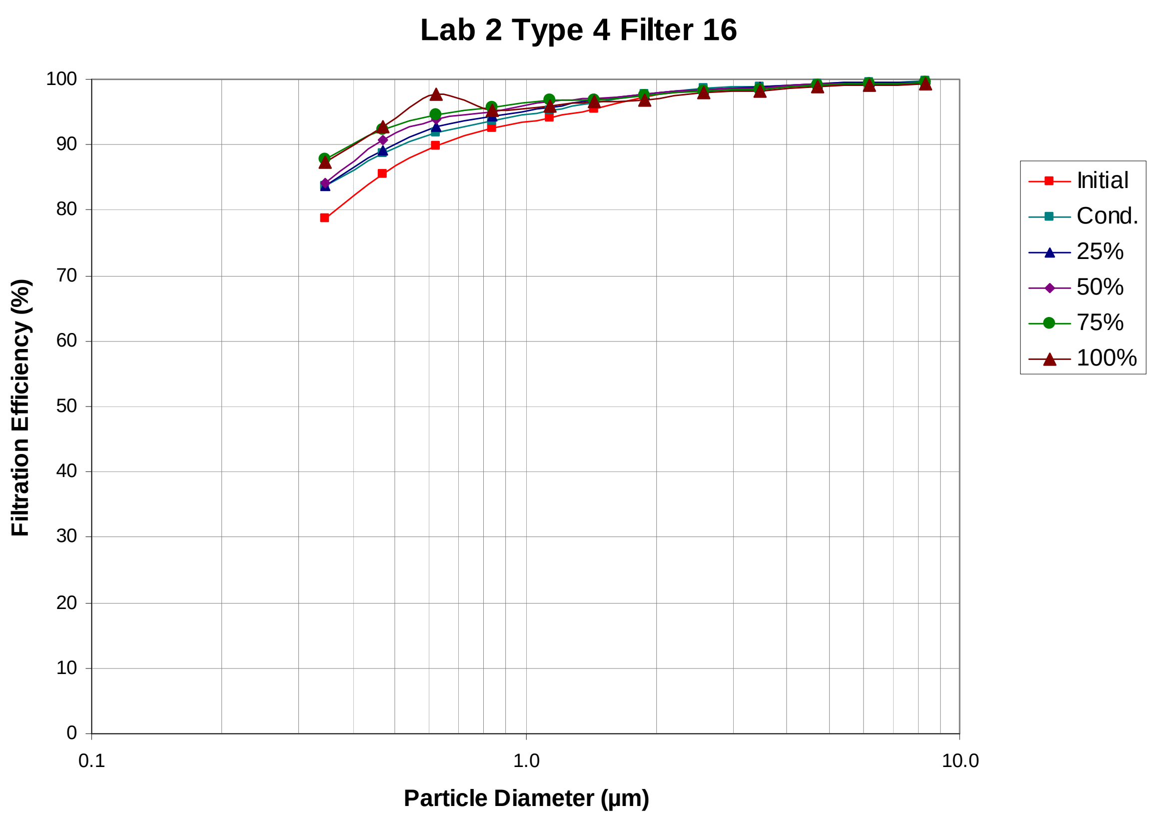


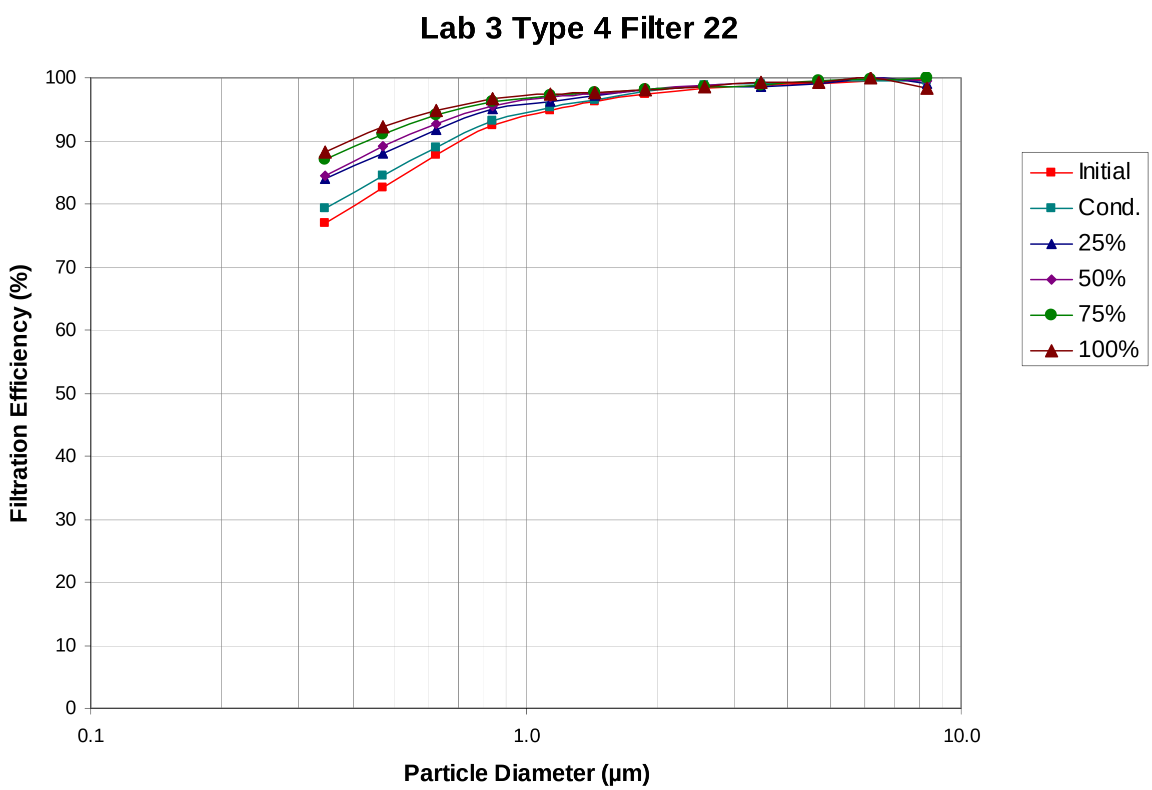
Lab 1 Type 4 Filter 13
Filtration Efficiency (%)
100
90
80
70
60
50
40
30
20
10
0
0.1
1.0
10.0
Particle Diameter (µm)
Initial
Cond.
25%
50%
75%
100%

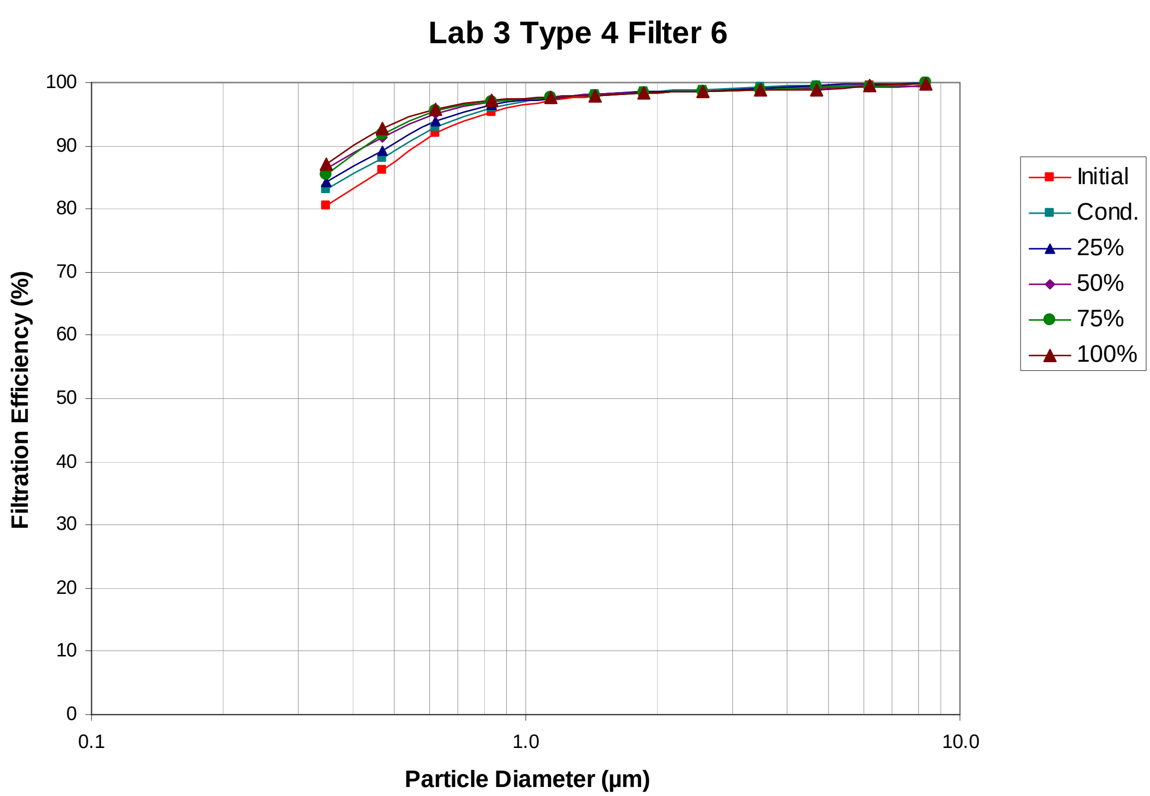


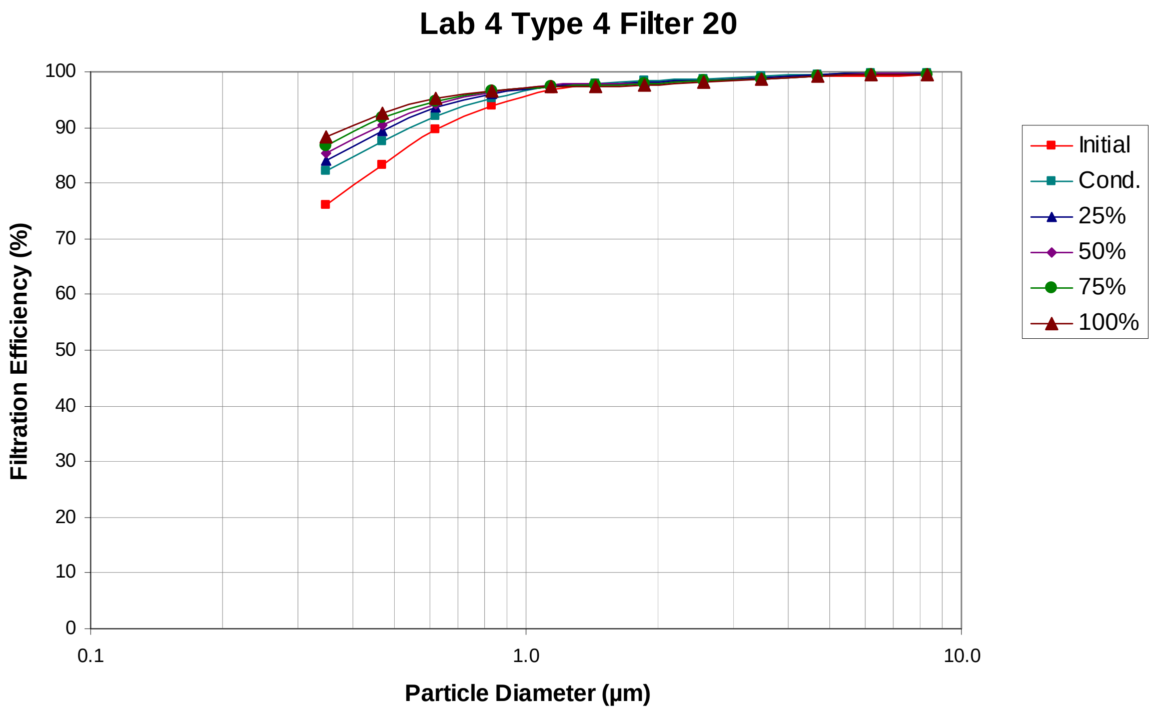
Lab 1 Type 4 Filter 24
Filtration Efficiency (%)
100
90
80
70
60
50
40
30
20
10
0
0.1
1.0
10.0
Particle Diameter (µm)
Initial
Cond.
25%
50%
75%
100%

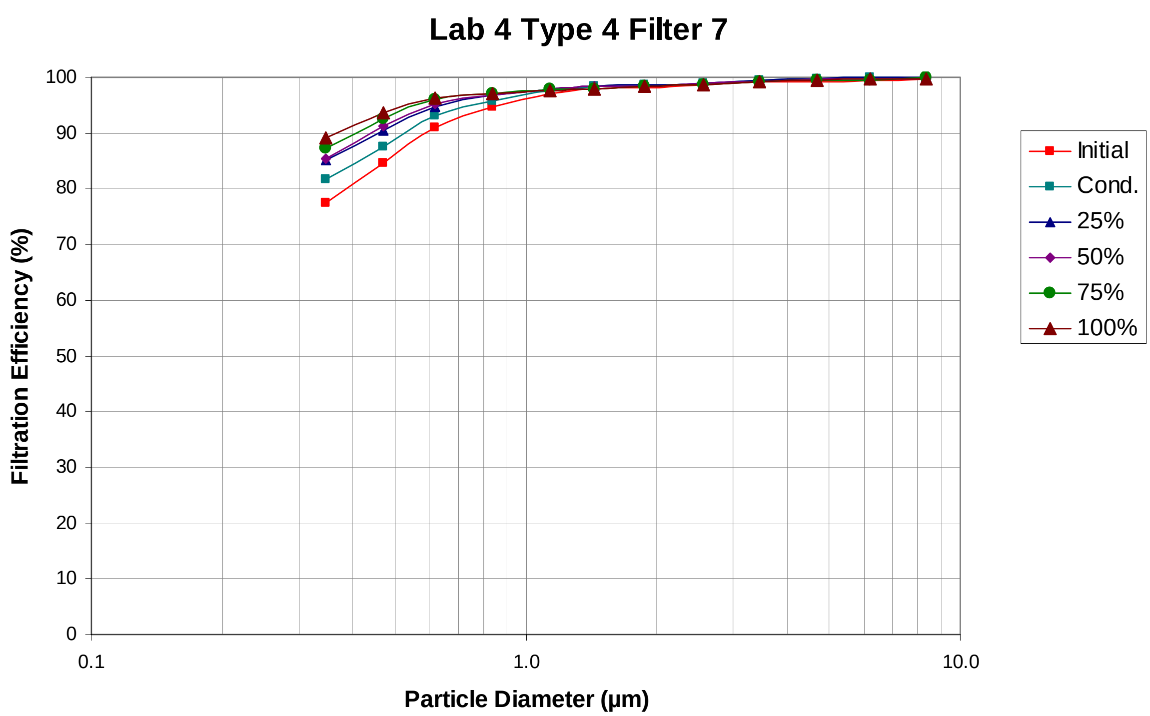

Lab 2 Type 4 Filter 11
Filtration Efficiency (%)
Particle Diameter (µm)
0
10
20
30
40
50
60
70
80
90
100
0.1
1.0
10.0
Initial
Cond.
25%
50%
75%
100%

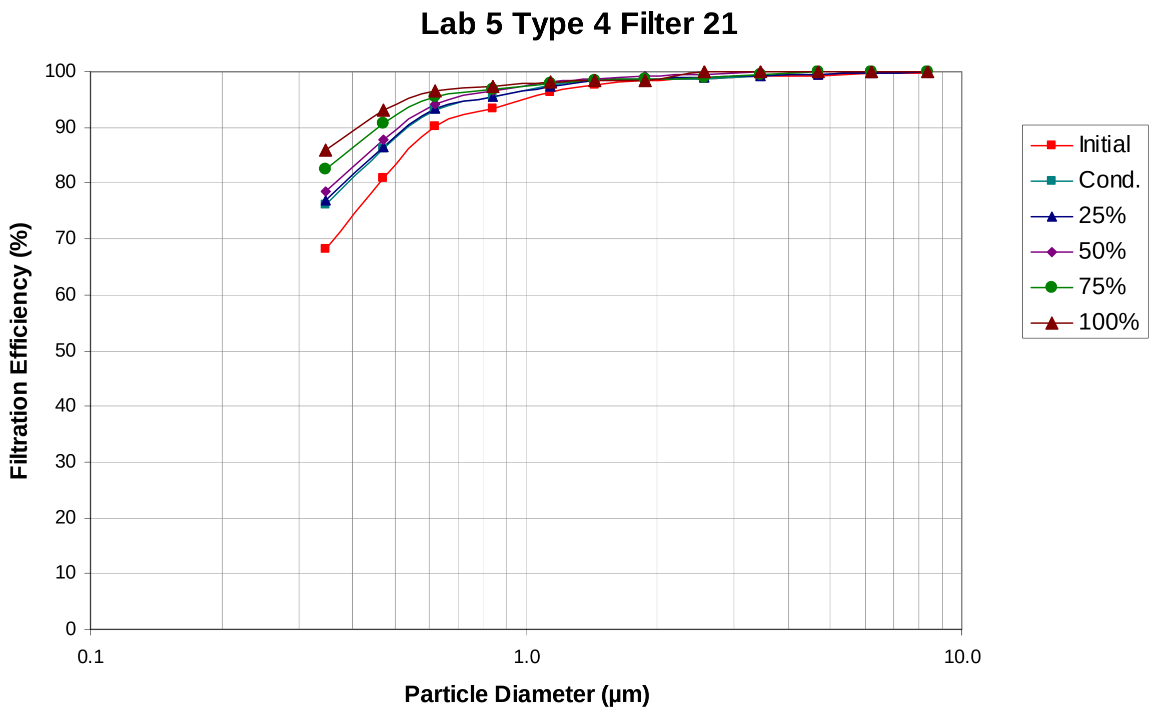

Lab 2 Type 4 Filter 16
Filtration Efficiency (%)
Particle Diameter (µm)
0
10
20
30
40
50
60
70
80
90
100
0.1
1.0
10.0
Initial
Cond.
25%
50%
75%
100%

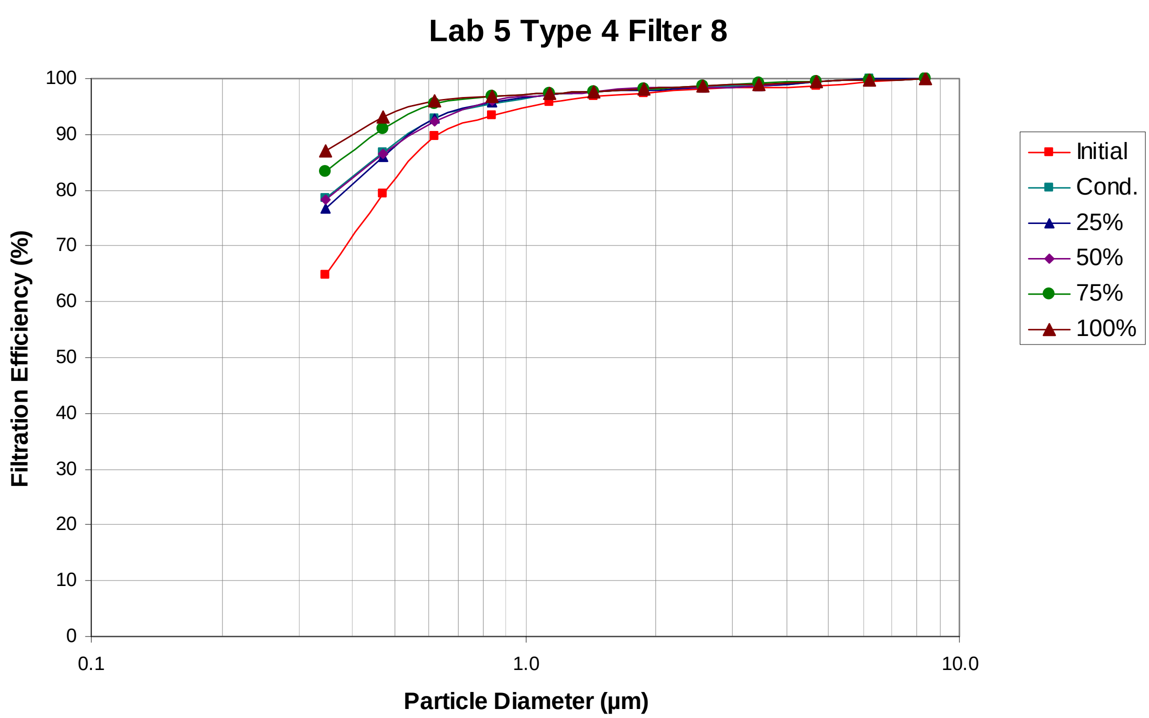

Lab 3 Type 4 Filter 22
Filtration Efficiency (%)
Particle Diameter (µm)
0
10
20
30
40
50
60
70
80
90
100
0.1
1.0
10.0
Initial
Cond.
25%
50%
75%
100%

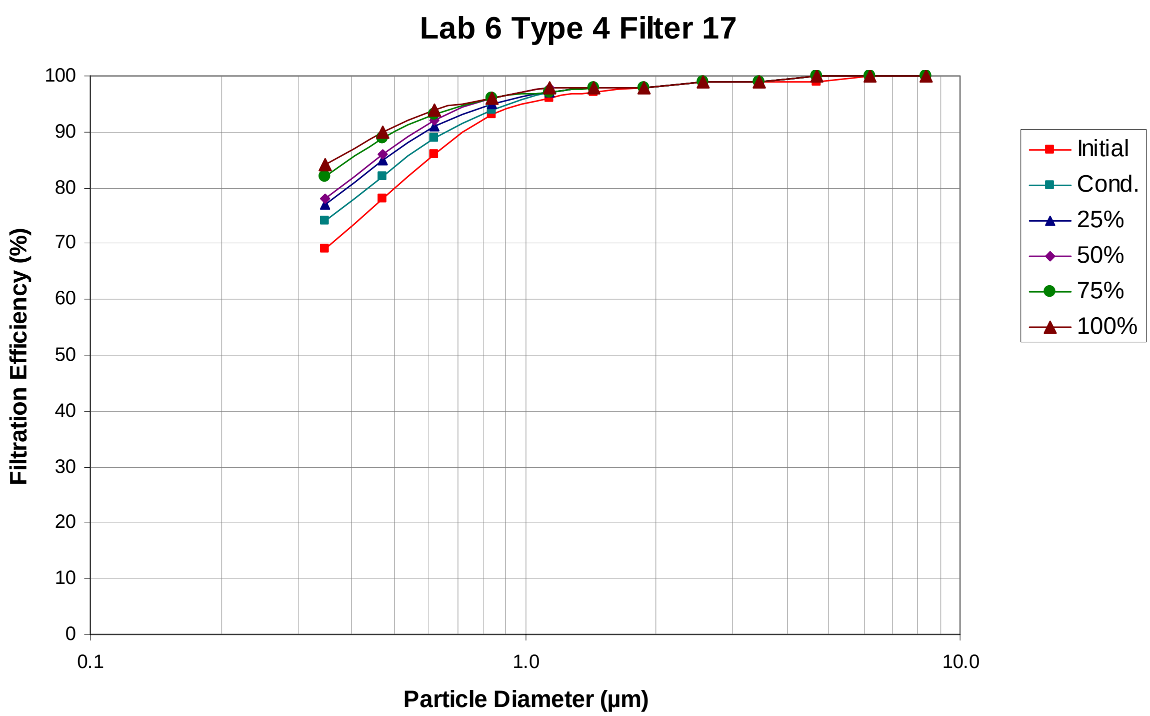

Lab 3 Type 4 Filter 6
Filtration Efficiency (%)
Particle Diameter (µm)
0
10
20
30
40
50
60
70
80
90
100
0.1
1.0
10.0
Initial
Cond.
25%
50%
75%
100%

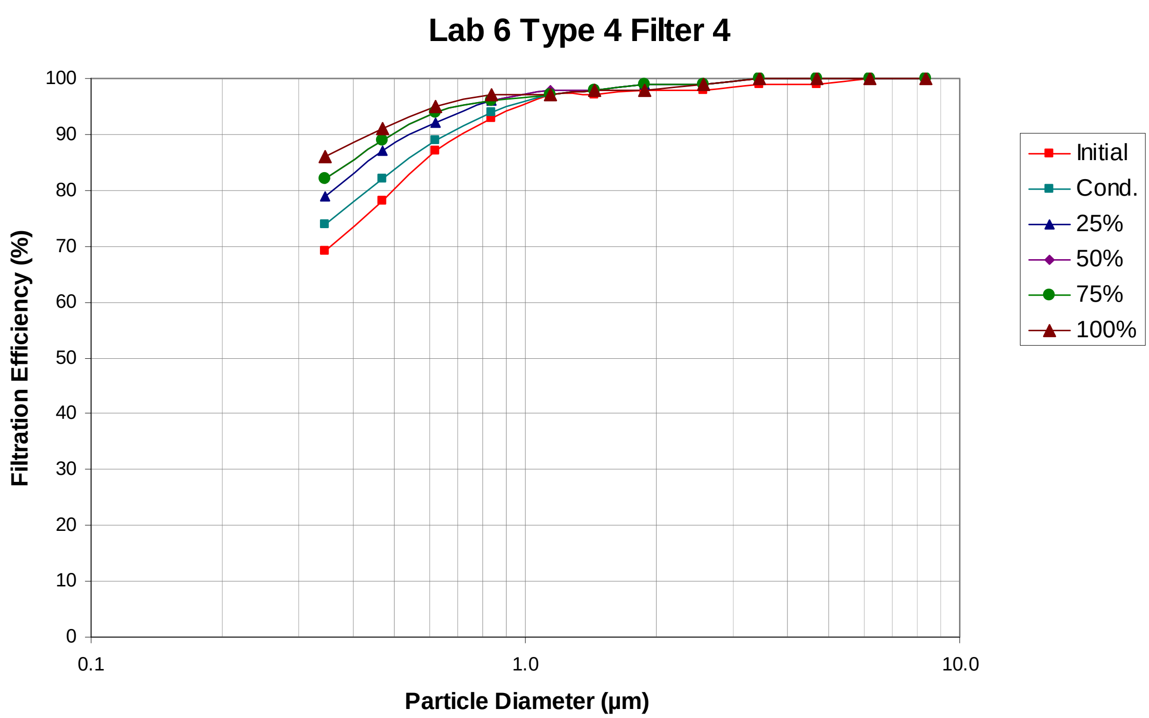

Lab 4 Type 4 Filter 20
Filtration Efficiency (%)
100
90
80
70
60
50
40
30
20
10
0
0.1
1.0
10.0
Particle Diameter (µm)
Initial
Cond.
25%
50%
75%
100%


Lab 4 Type 4 Filter 7
Filtration Efficiency (%)
100
90
80
70
60
50
40
30
20
10
0
0.1
1.0
10.0
Particle Diameter (µm)
Initial
Cond.
25%
50%
75%
100%


Lab 5 Type 4 Filter 21
Filtration Efficiency (%)
Particle Diameter (µm)
0.1
1.0
10.0
0
10
20
30
40
50
60
70
80
90
100
Initial
Cond.
25%
50%
75%
100%


Lab 5 Type 4 Filter 8
Filtration Efficiency (%)
Particle Diameter (µm)
0.1
1.0
10.0
0
10
20
30
40
50
60
70
80
90
100
Initial
Cond.
25%
50%
75%
100%


Lab 6 Type 4 Filter 17
Filtration Efficiency (%)
Particle Diameter (µm)
0
10
20
30
40
50
60
70
80
90
100
0.1
1.0
10.0
Initial
Cond.
25%
50%
75%
100%


Lab 6 Type 4 Filter 4
Filtration Efficiency (%)
Particle Diameter (µm)
0
10
20
30
40
50
60
70
80
90
100
0.1
1.0
10.0
Initial
Cond.
25%
50%
75%
100%

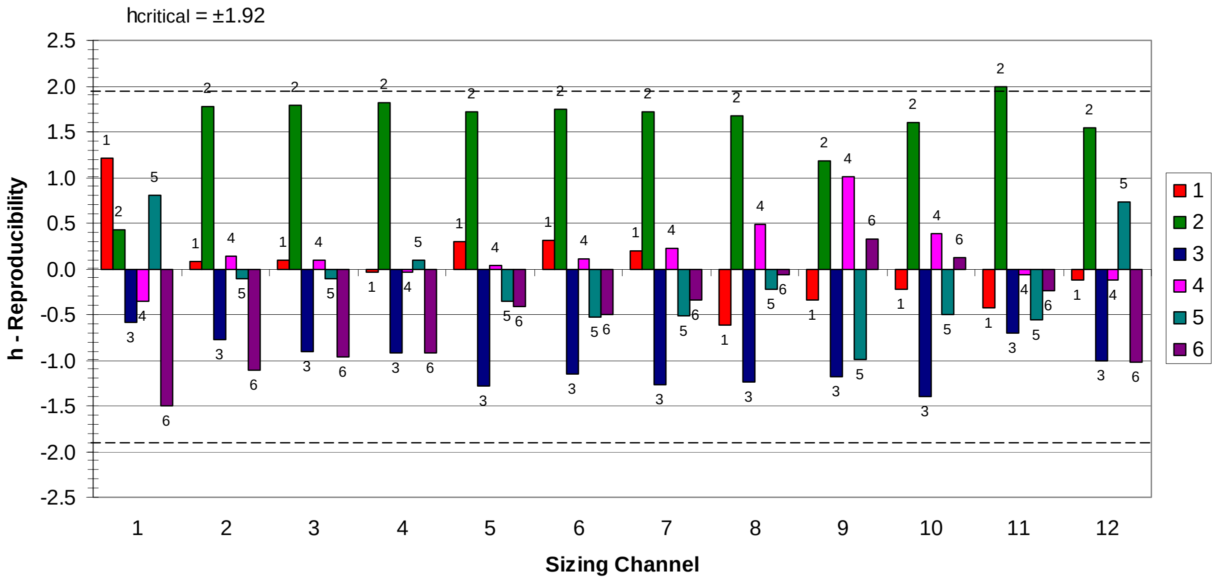
Appendix H

Plots of the reproducibility consistency statistic, h

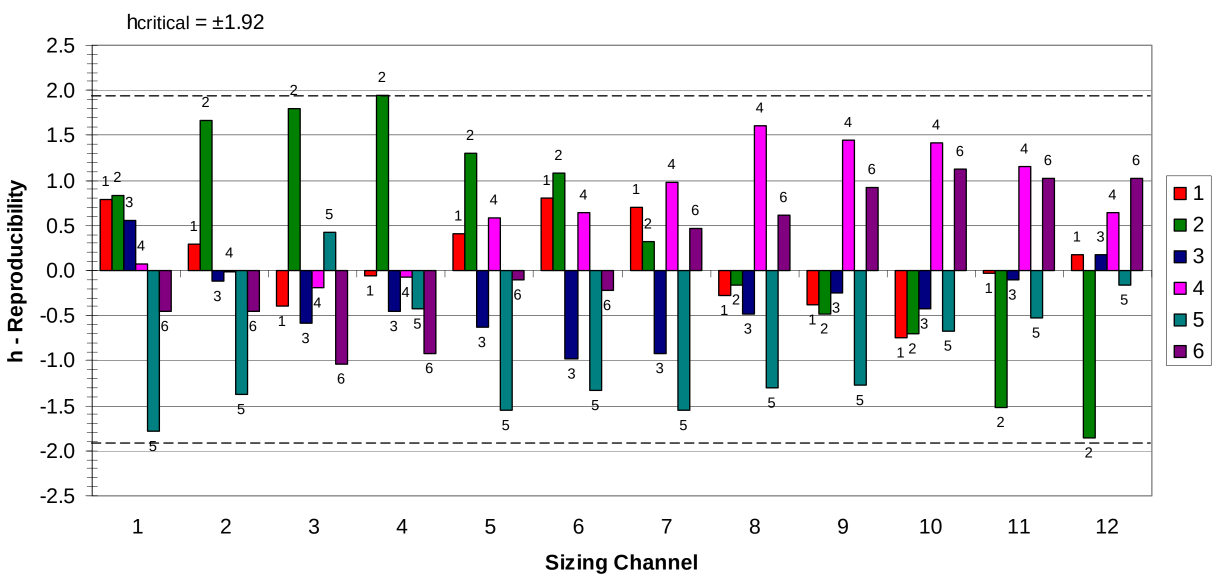
Values of h are plotted for each filter type, sizing channel and laboratory. For clarity, the lab number is shown above each bar in addition to the color codes presented in the legend.

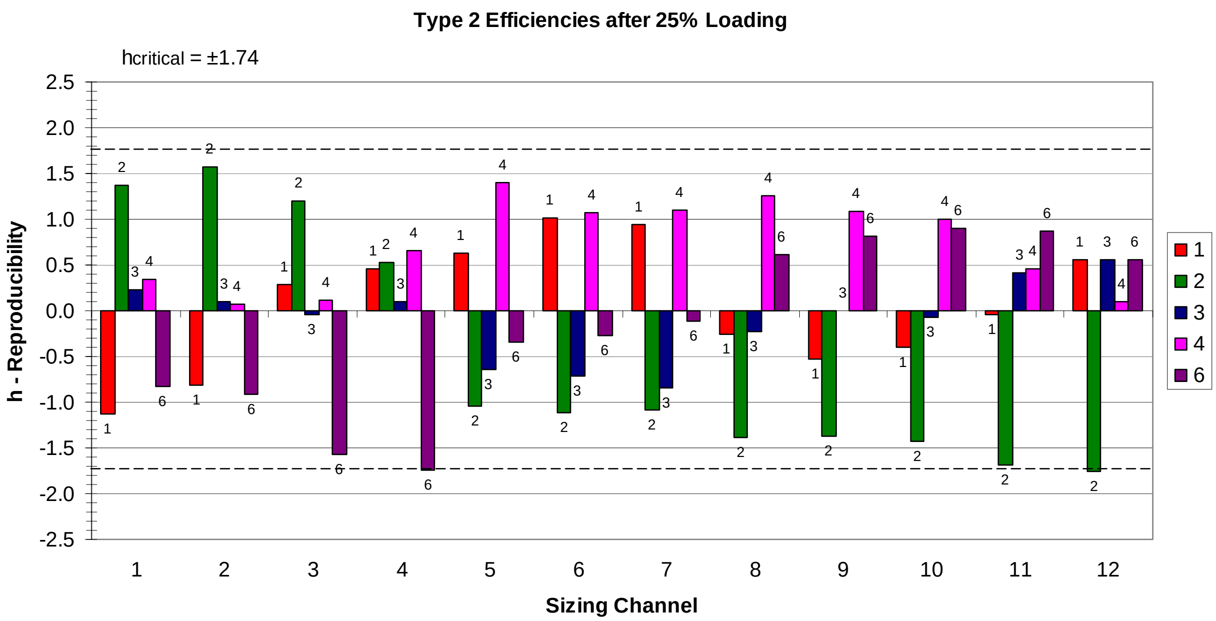
As a tool for flagging possible outliers, the "critical value" of h was established per ASTM 691 based on the number of laboratories in the study. At the 0.5% significance level, the critical value for h was 1.92 for six laboratories and 1.74 for five laboratories (used where Laboratory 5 data was not applicable). Data for which h is near or exceeds the critical value may indicate an outlier. In this study, while some data exceeded these critical values, all data were included in the statistical analyses.

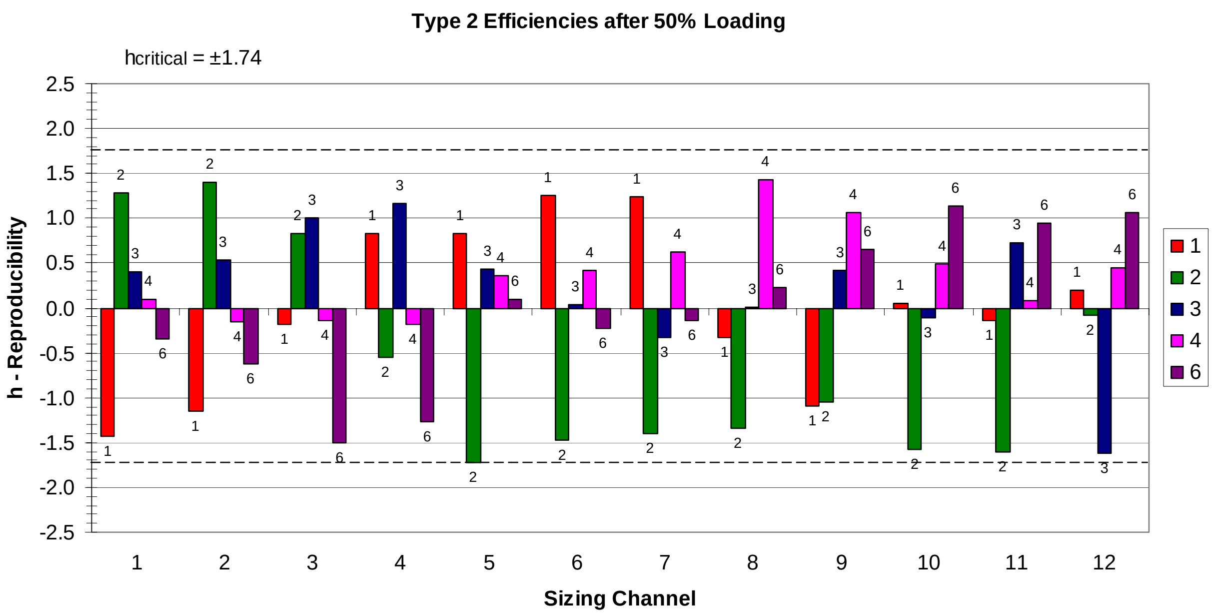
Type 2 Initial Efficiencies

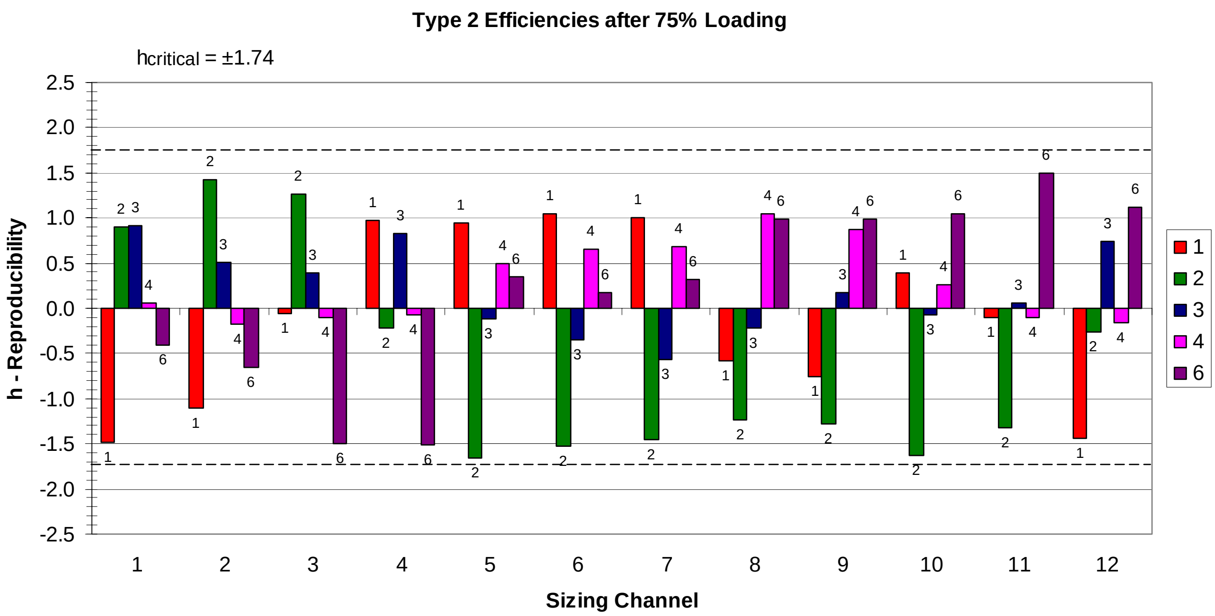


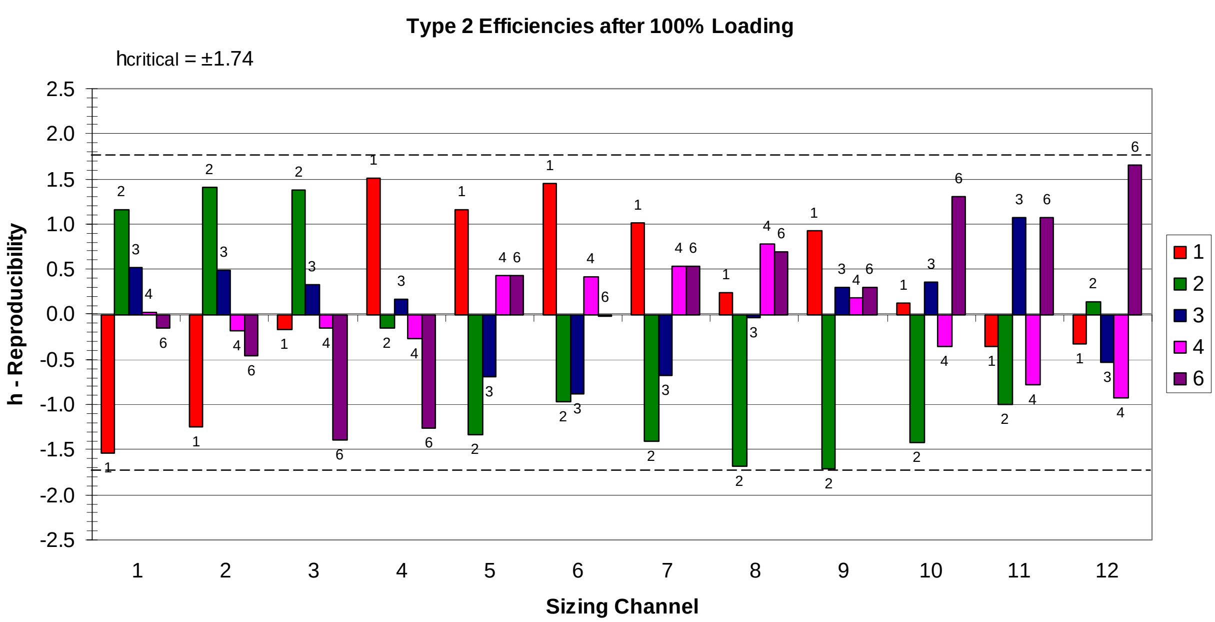
Type 2 Efficiencies after Conditioning



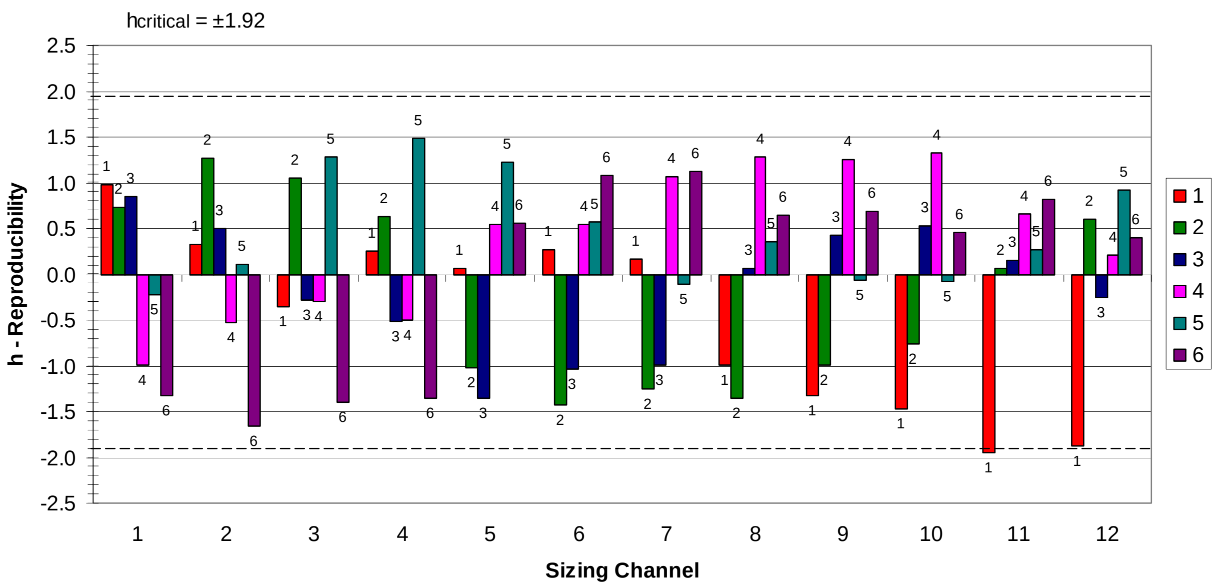

Type 2 Efficiencies after 25% Loading
hcritical = ±1.74
h - Reproducibility
Sizing Channel


Type 2 Efficiencies after 50% Loading
hcritical = ±1.74
h - Reproducibility
Sizing Channel

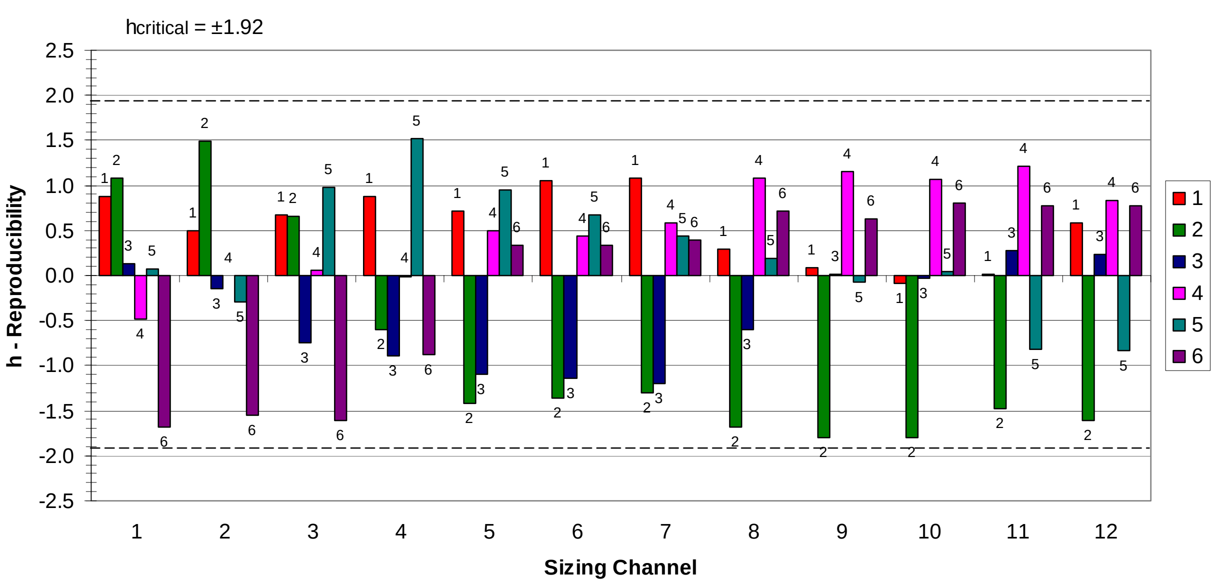

Type 2 Efficiencies after 75% Loading
hcritical = ±1.74
h - Reproducibility
Sizing Channel
1
2
3
4
6


Type 2 Efficiencies after 100% Loading
hcritical = ±1.74
h - Reproducibility
Sizing Channel
1
2
3
4
6

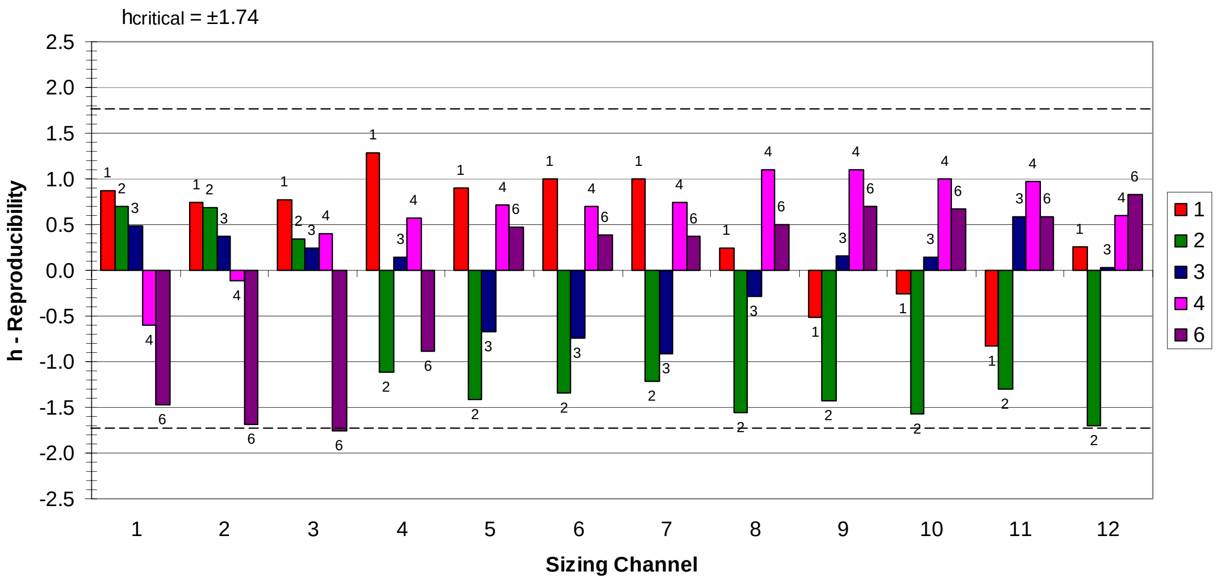
Type 3 Initial Efficiencies



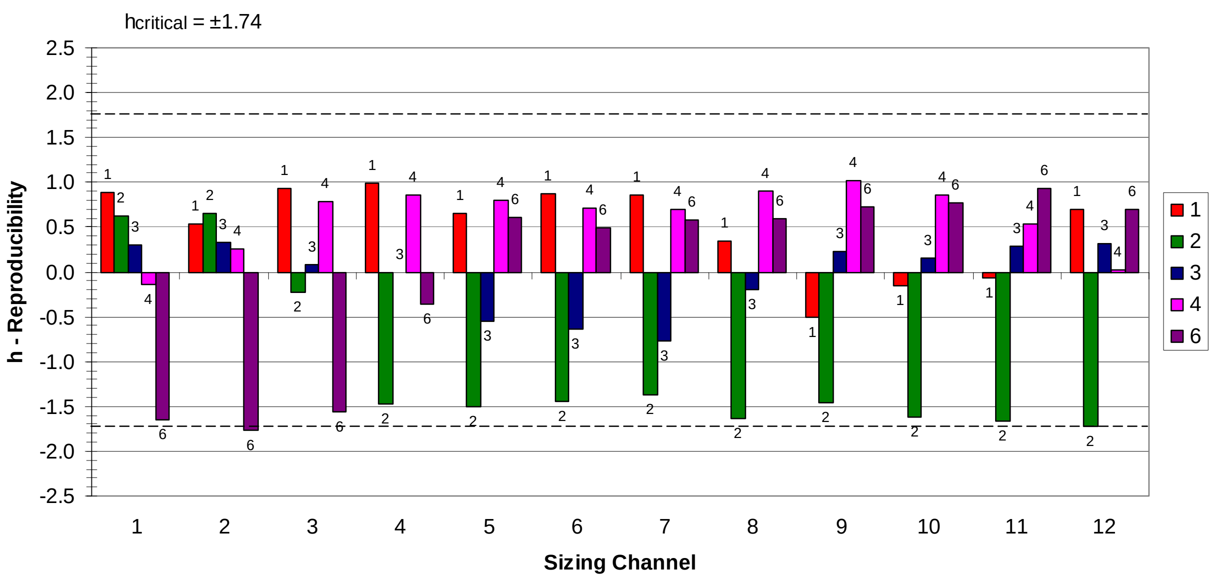
Type 3 Efficiencies after Conditioning

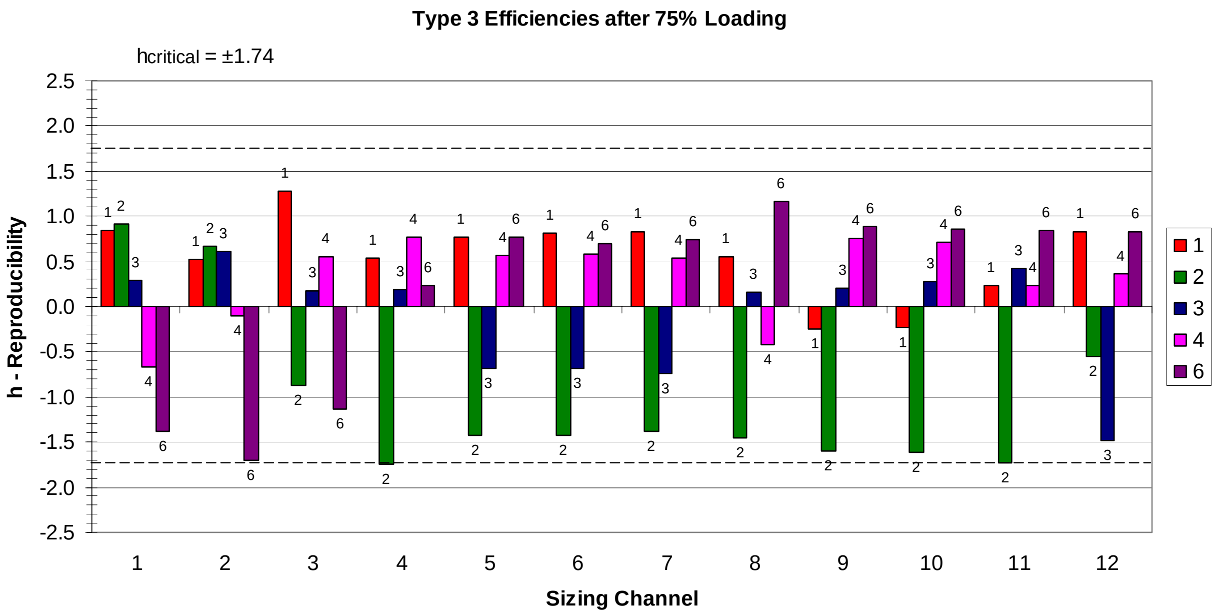


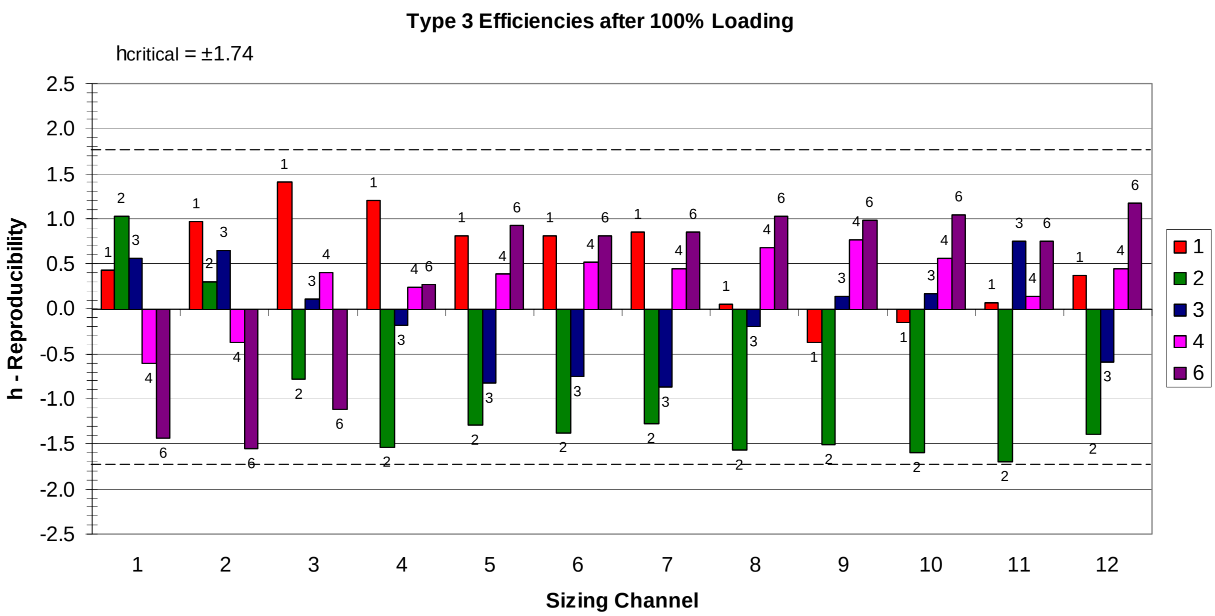
Type 3 Efficiencies after 25% Loading

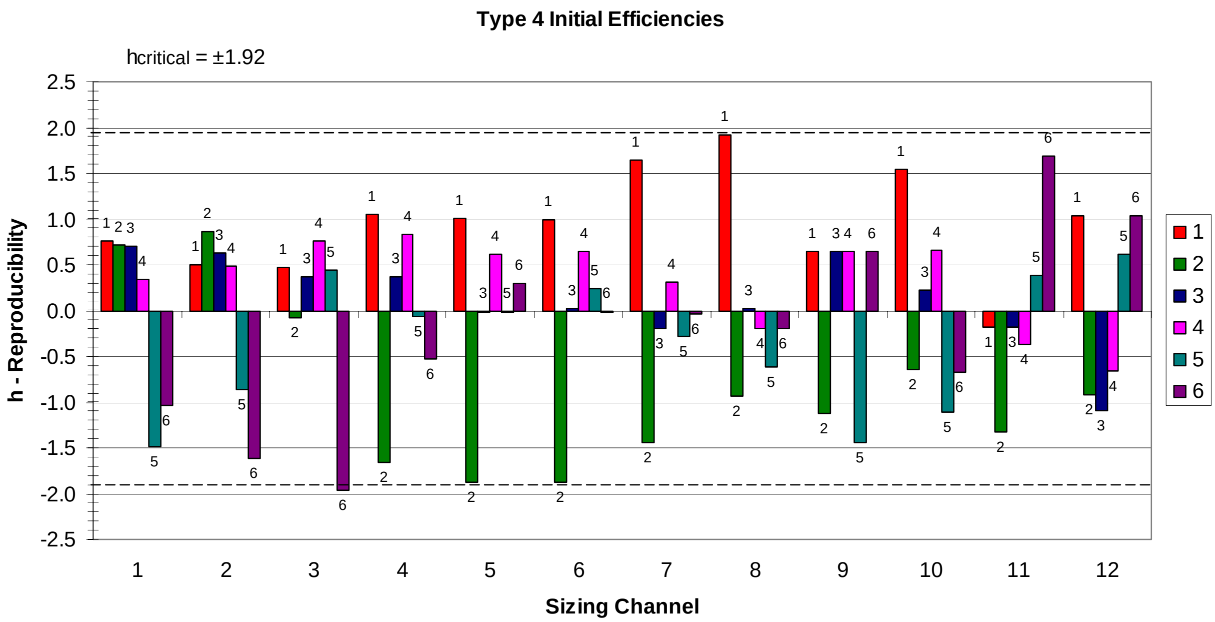


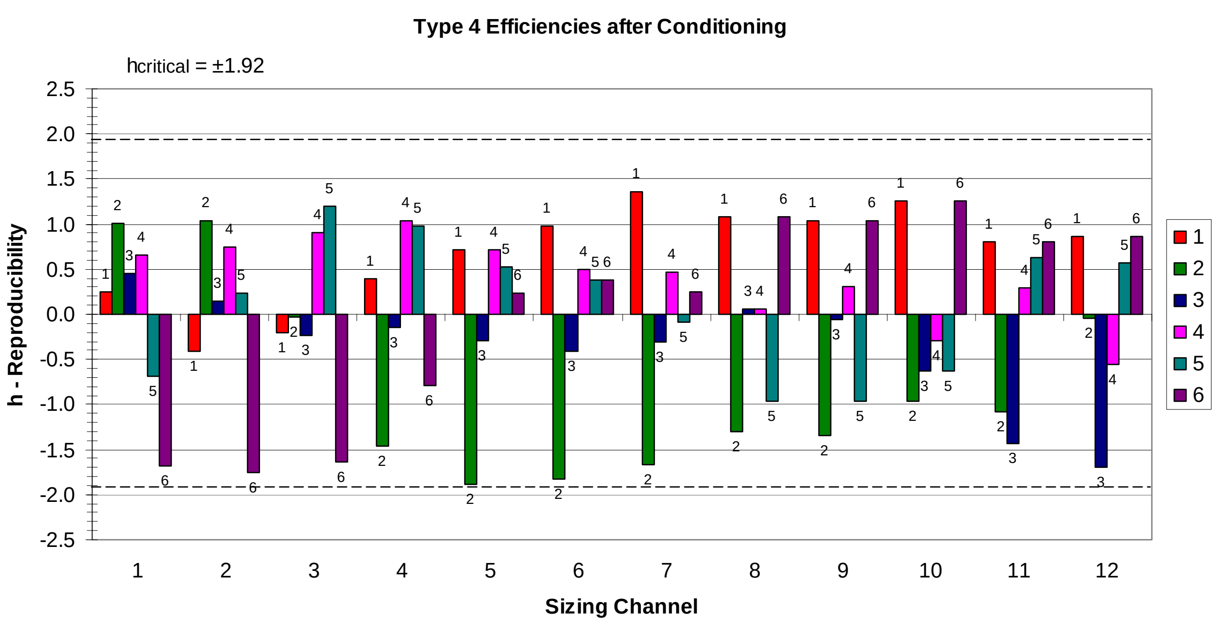
Type 3 Efficiencies after 50% Loading

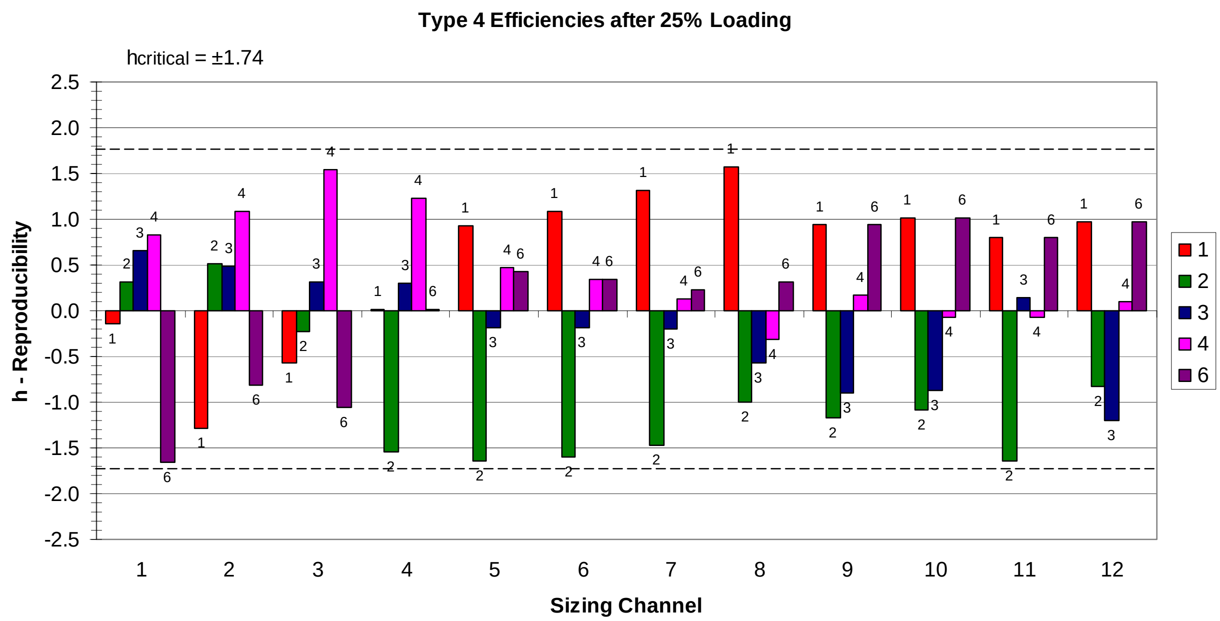


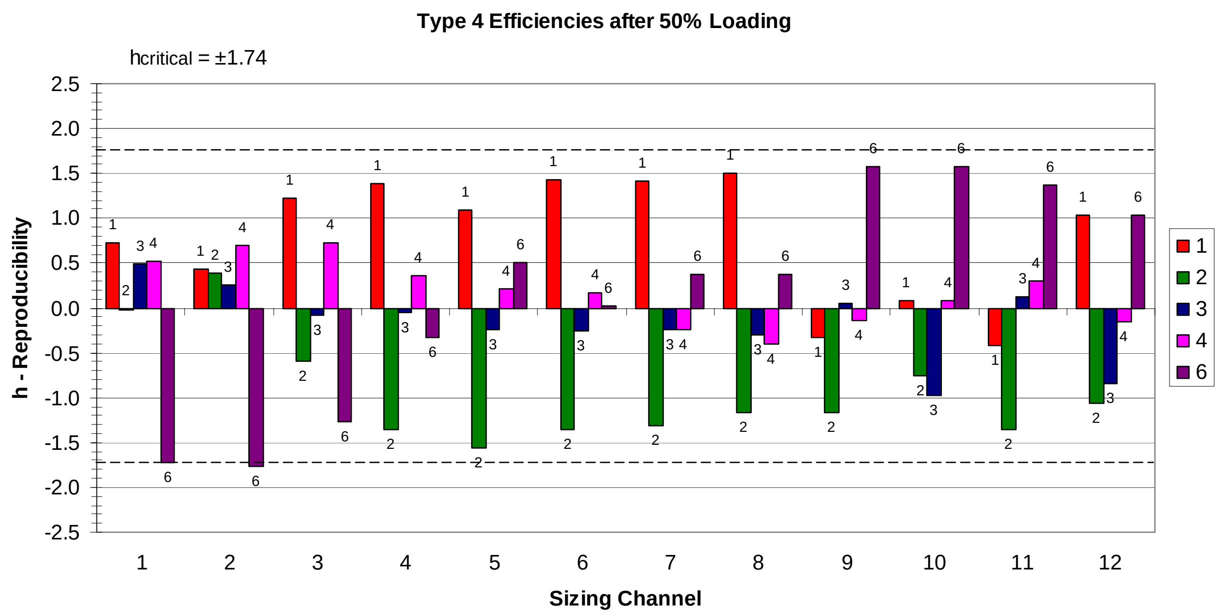

Type 3 Efficiencies after 75% Loading
hcritical = ±1.74
h - Reproducibility
Sizing Channel
1
2
3
4
6

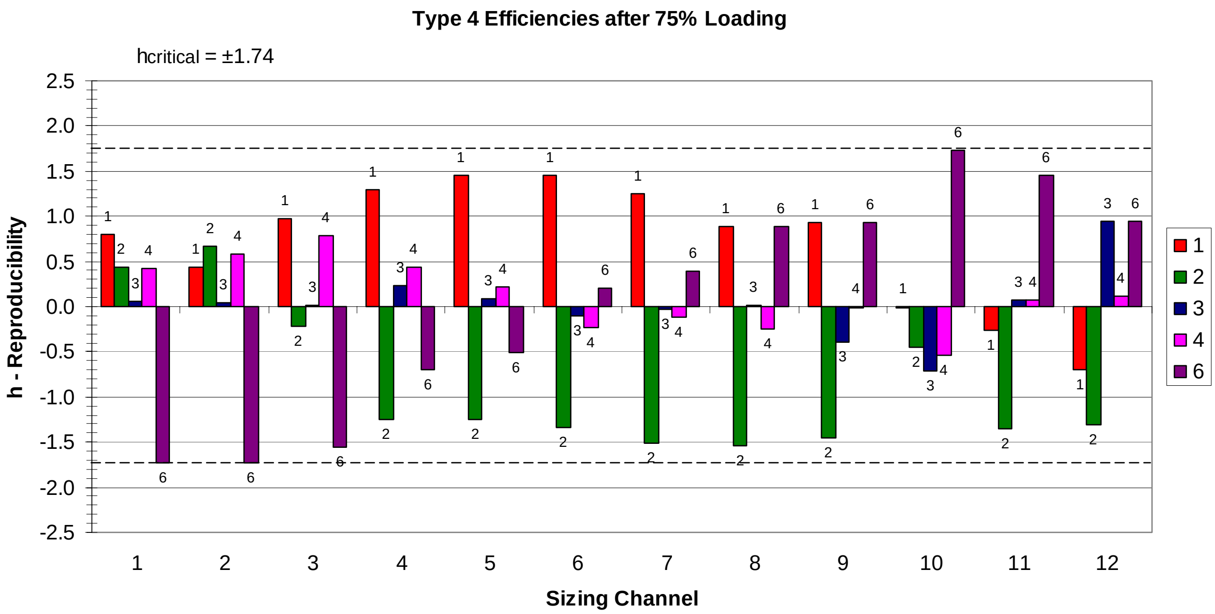

Type 3 Efficiencies after 100% Loading
hcritical = ±1.74
h - Reproducibility
Sizing Channel
1
2
3
4
6


Type 4 Initial Efficiencies
hcritical = ±1.92
h - Reproducibility
Sizing Channel
1
2
3
4
5
6

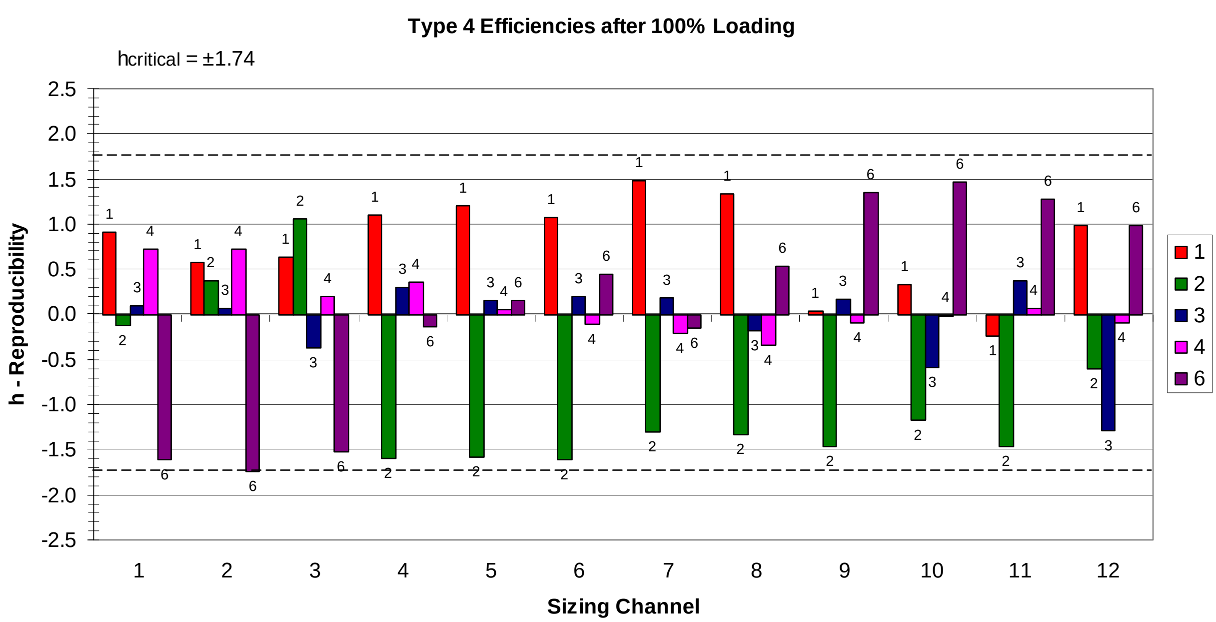

Type 4 Efficiencies after Conditioning
hcritical = ±1.92
h - Reproducibility
Sizing Channel
1
2
3
4
5
6


Type 4 Efficiencies after 25% Loading
hcritical = ±1.74
h - Reproducibility
Sizing Channel
1
2
3
4
6


Type 4 Efficiencies after 50% Loading
hcritical = ±1.74
h - Reproducibility
Sizing Channel
1
2
3
4
6



Type 4 Efficiencies after 75% Loading
hcritical = ±1.74
h - Reproducibility
Sizing Channel
1
2
3
4
6



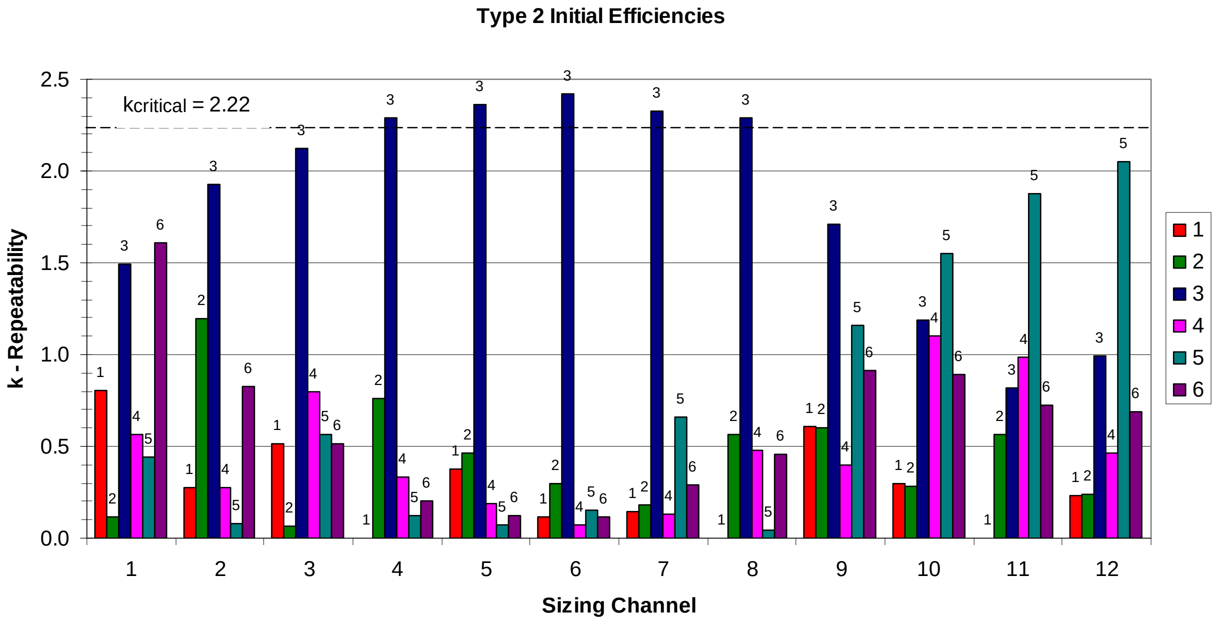
Type 4 Efficiencies after 100% Loading
hcritical = ±1.74
h - Reproducibility
Sizing Channel
1
2
3
4
6

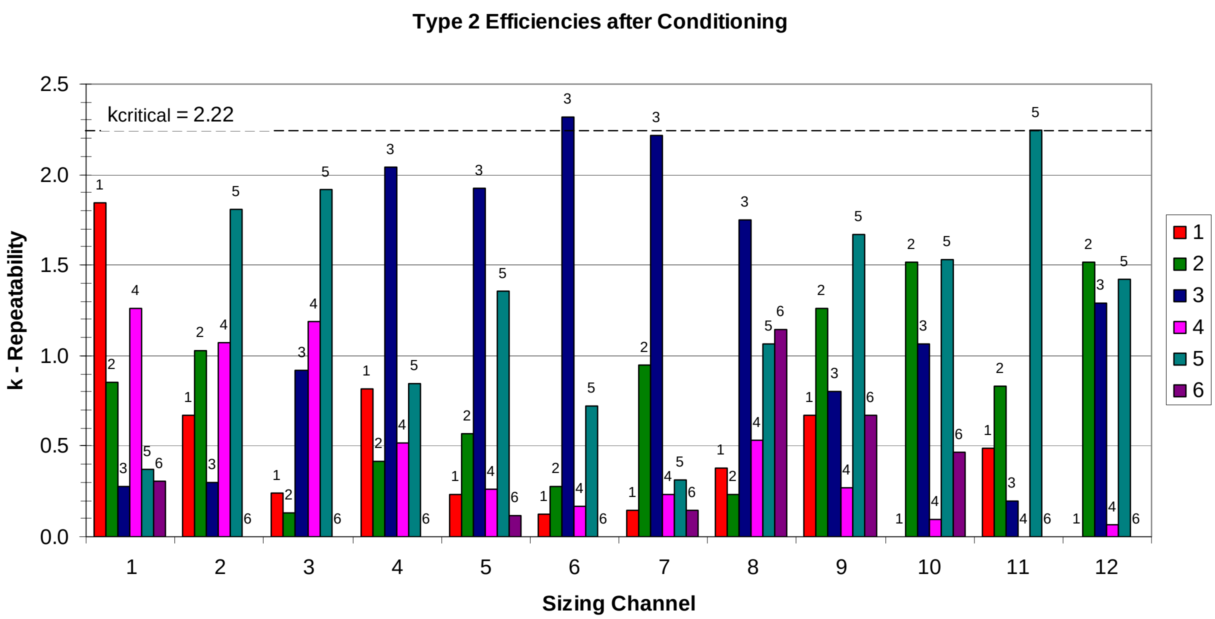
APPENDIX I

Plots of the repeatability consistency statistic, k

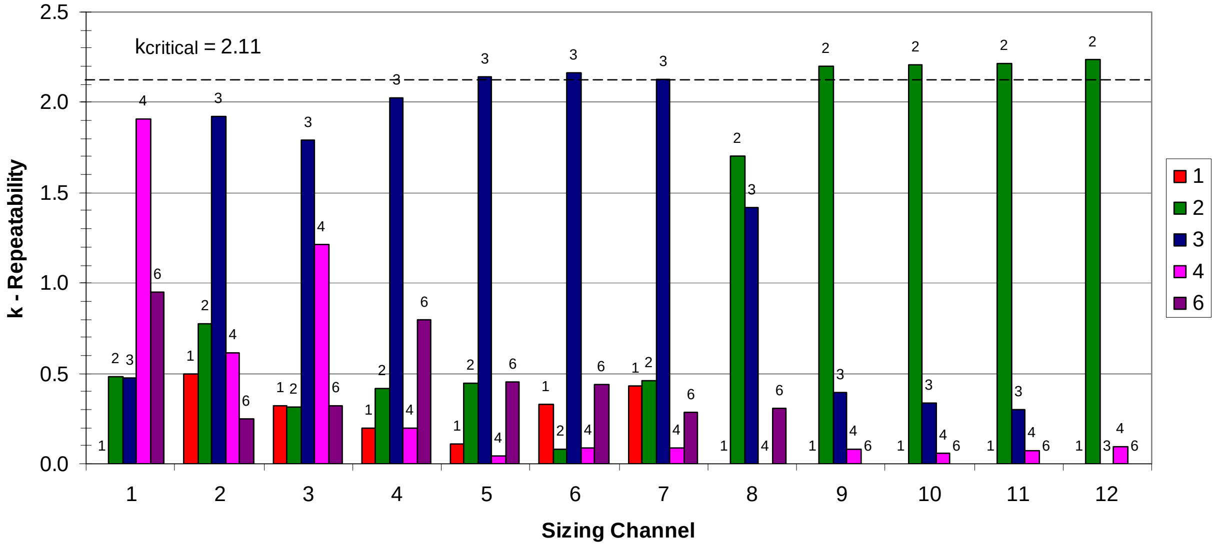
Values of k are plotted for each filter type, sizing channel and laboratory. For clarity, the lab number is shown above each bar in addition to the color codes presented in the legend.

As a tool for flagging possible outliers, the "critical value" of k was established per ASTM 691 based on the number of laboratories in the study and the number of replicates. At the 0.5% significance level, the critical value for k was 2.22 for six laboratories and 2.11 for five laboratories (used where Laboratory 5 data was not applicable). Data for which h is near or exceeds the critical value may indicate an outlier. In this study, while some data exceeded these critical values, all data were included in the statistical analyses.

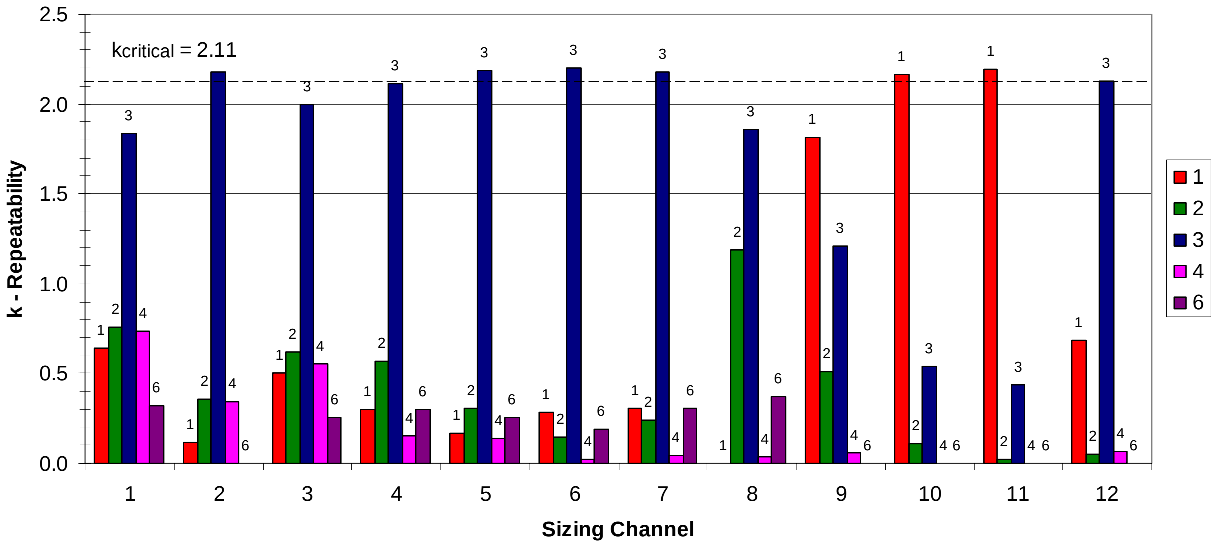

Type 2 Initial Efficiencies
kcritical = 2.22
k - Repeatability
Sizing Channel
0.0
0.5
1.0
1.5
2.0
2.5
1
2
3
4
5
6
7
8
9
10
11
12


Type 2 Efficiencies after Conditioning
kcritical = 2.22
k - Repeatability
Sizing Channel
0.0
0.5
1.0
1.5
2.0
2.5
1
2
3
4
5
6
7
8
9
10
11
12

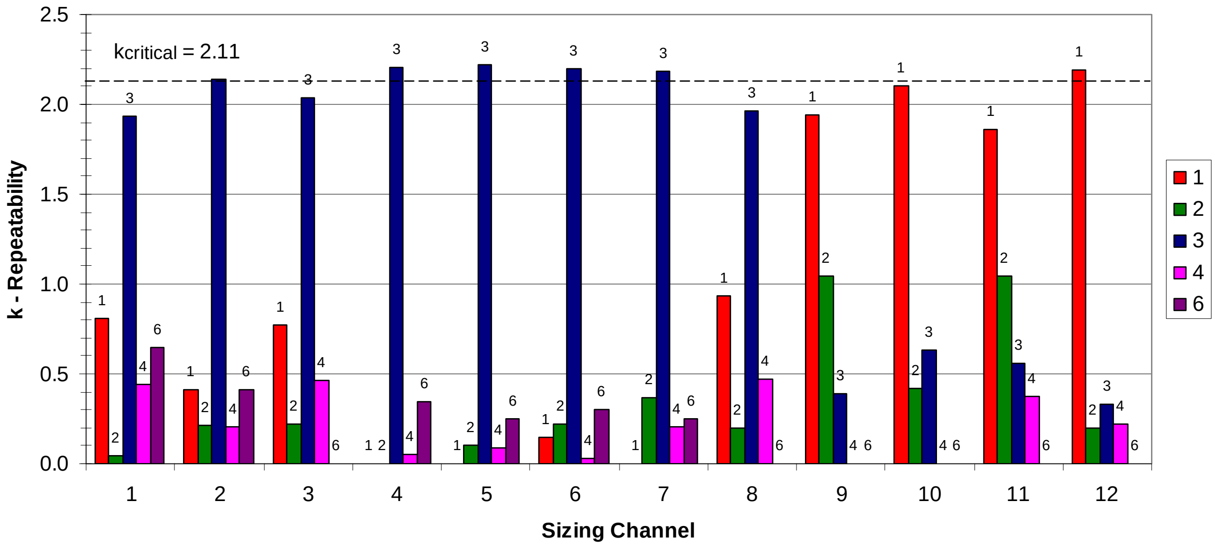
Type 2 Efficiencies after 25% Loading



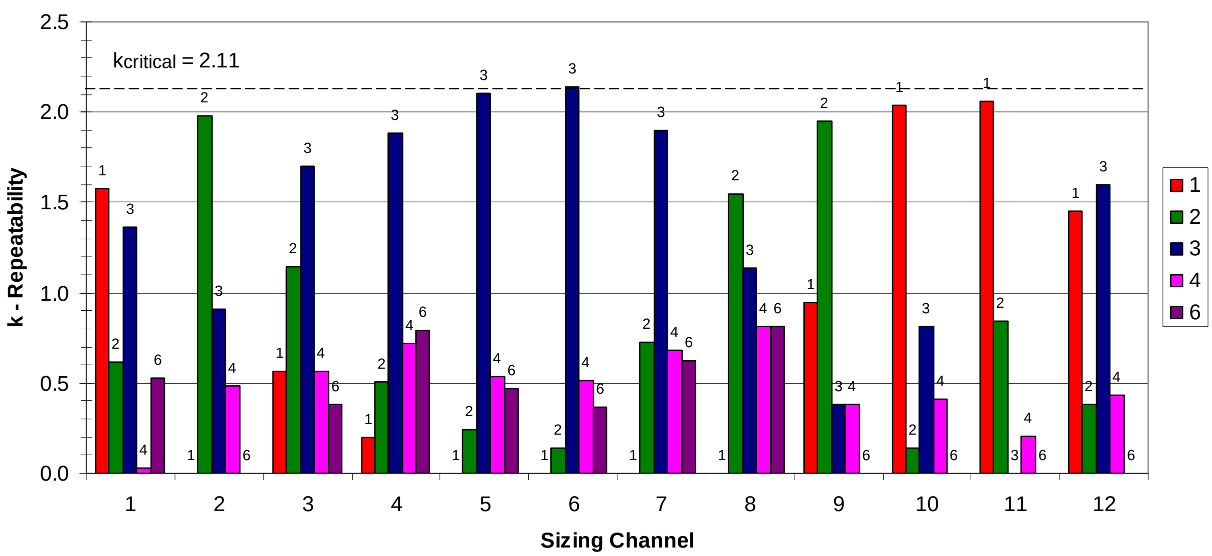
Type 2 Efficiencies after 50% Loading

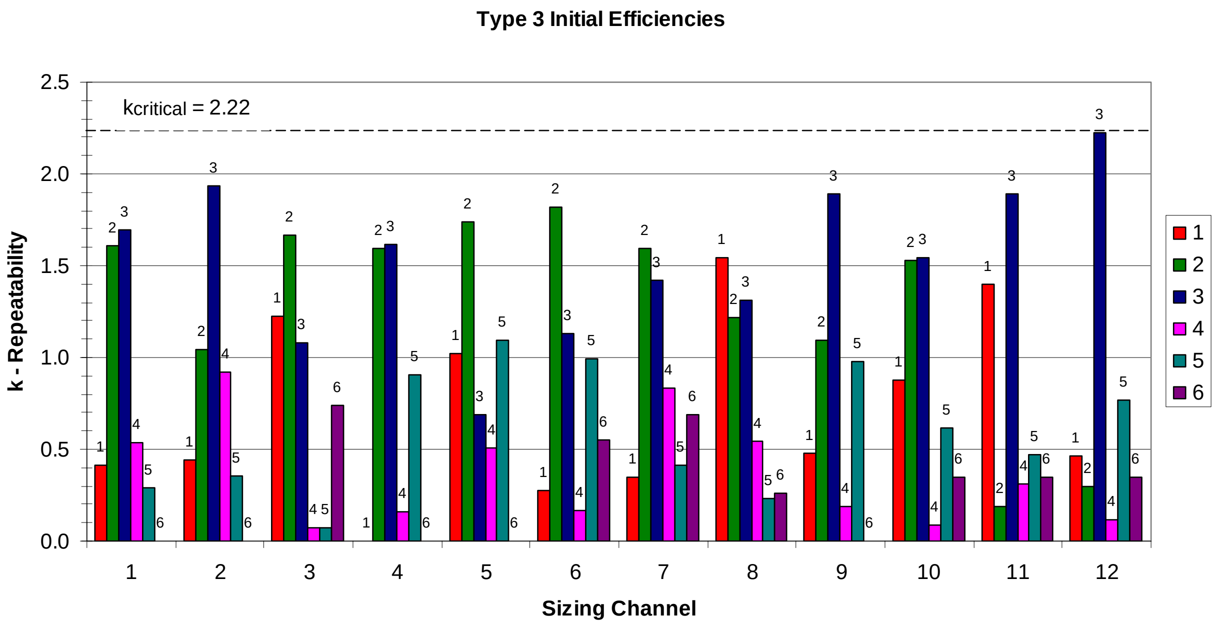


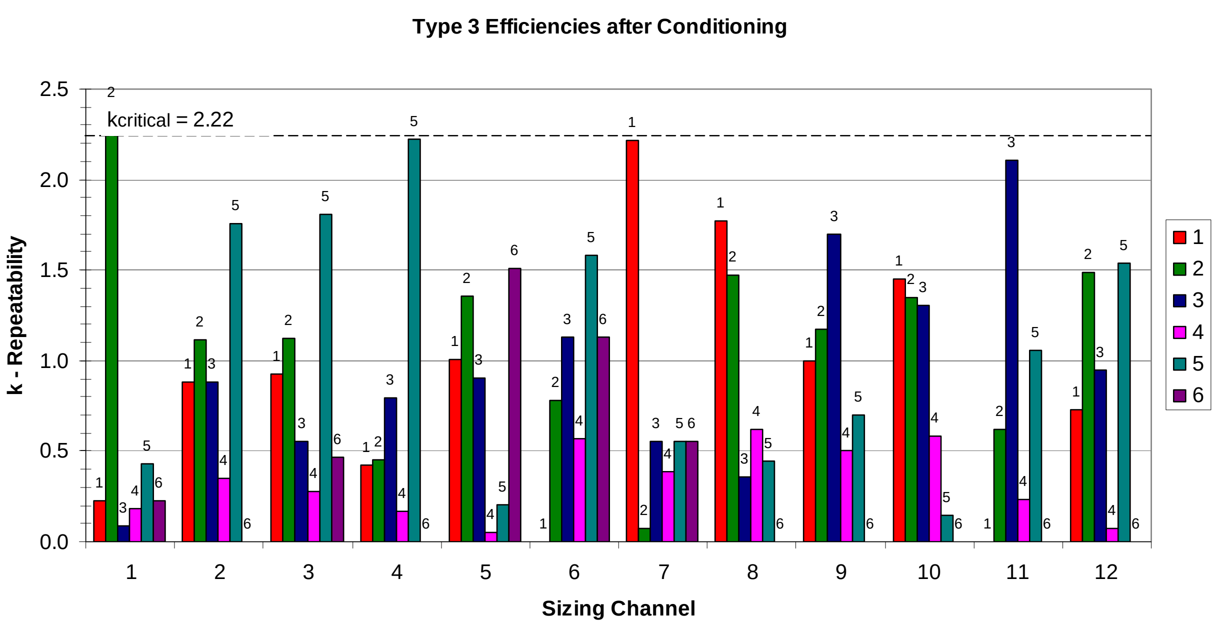
Type 2 Efficiencies after 75% Loading

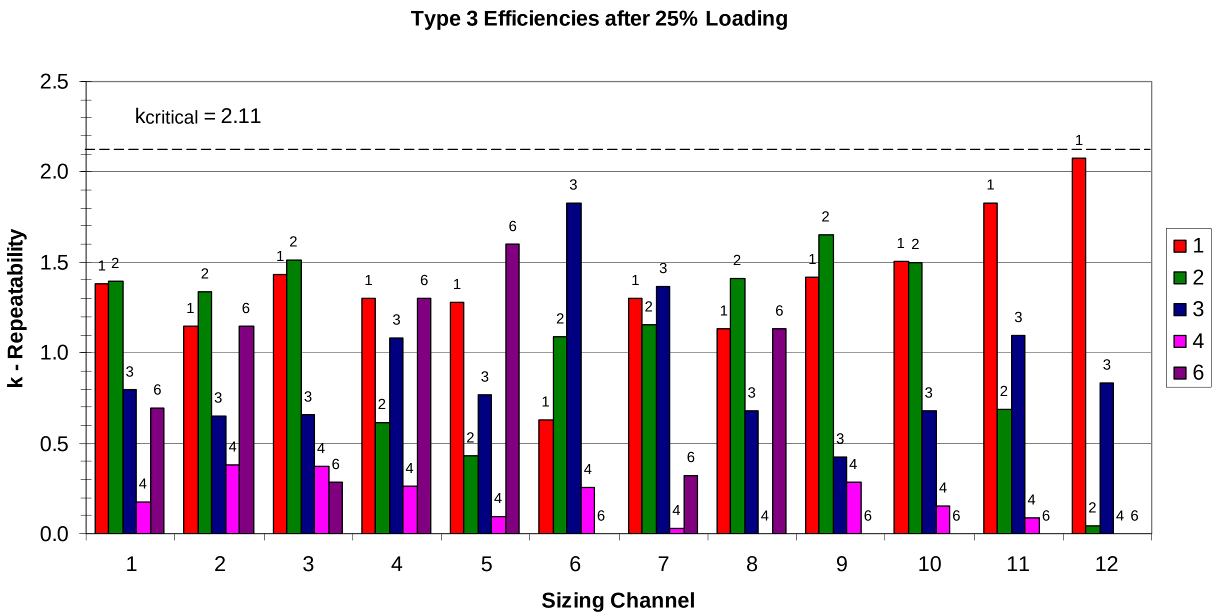


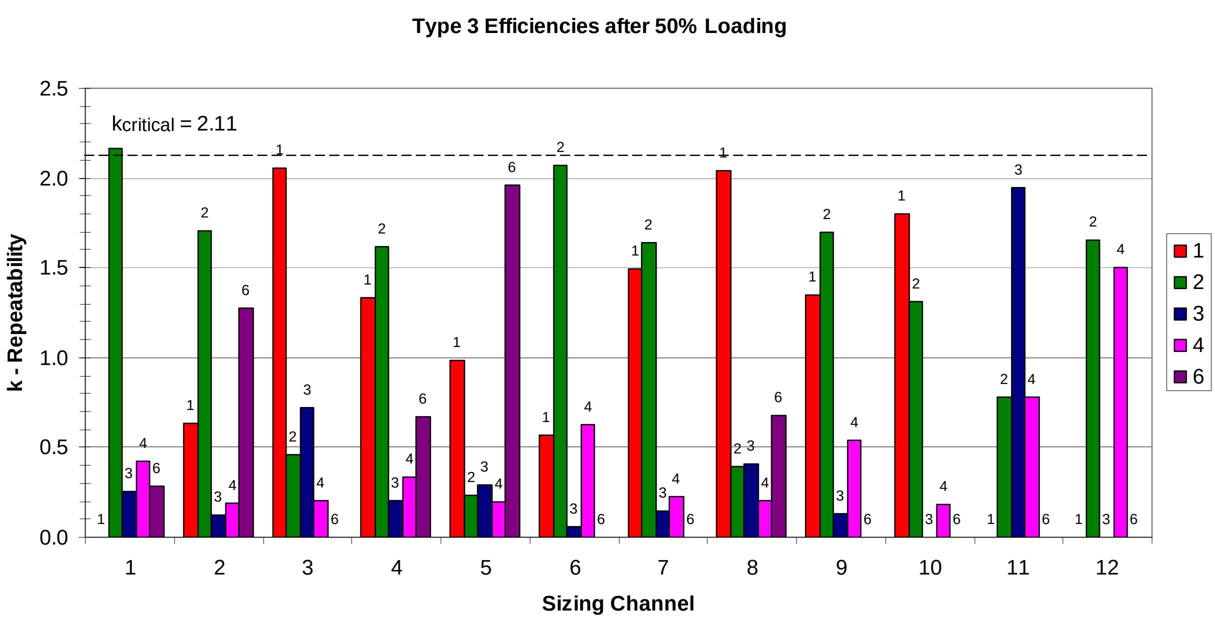
Type 2 Efficiencies after 100% Loading

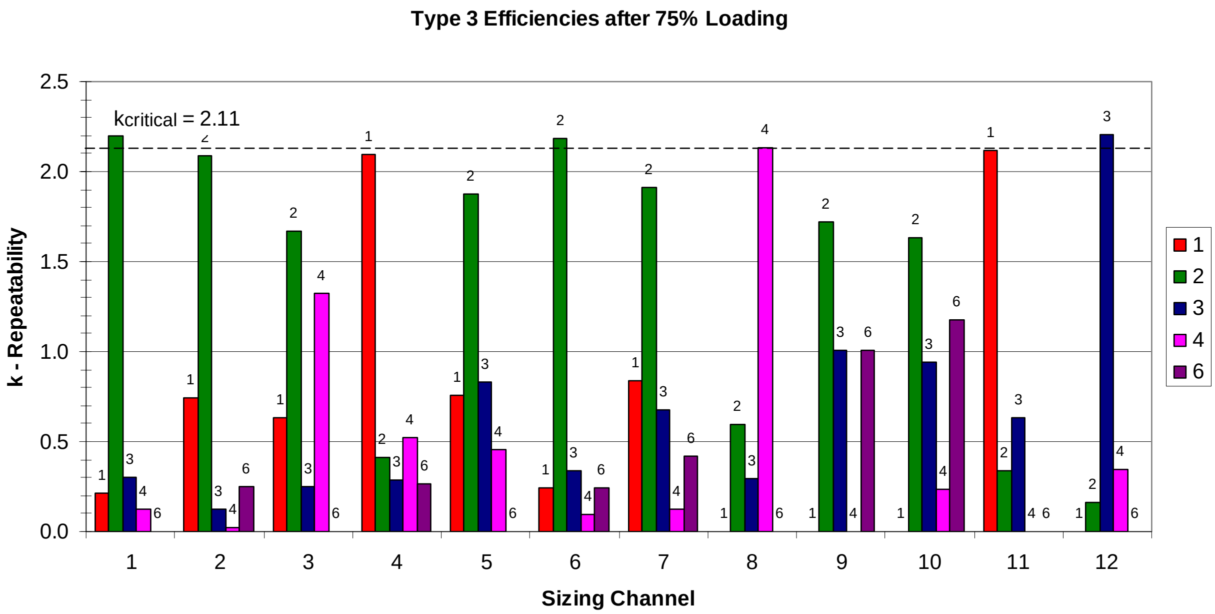


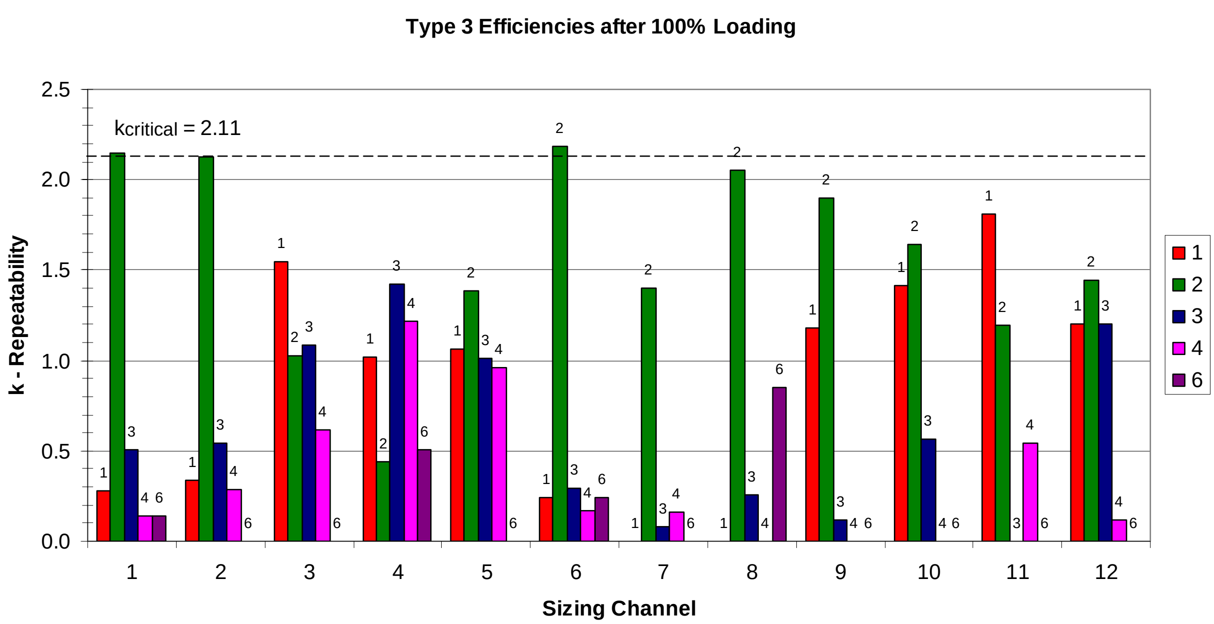

Type 3 Initial Efficiencies
kcritical = 2.22
k - Repeatability
Sizing Channel
1
2
3
4
5
6

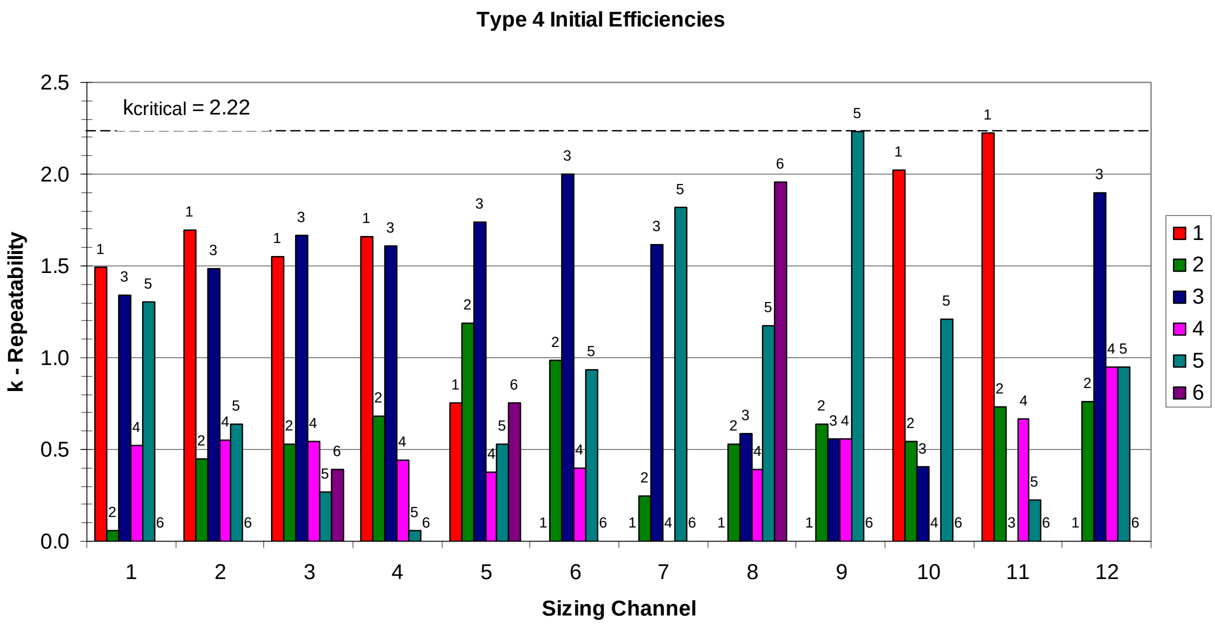

Type 3 Efficiencies after Conditioning
kcritical = 2.22
k - Repeatability
Sizing Channel
1
2
3
4
5
6

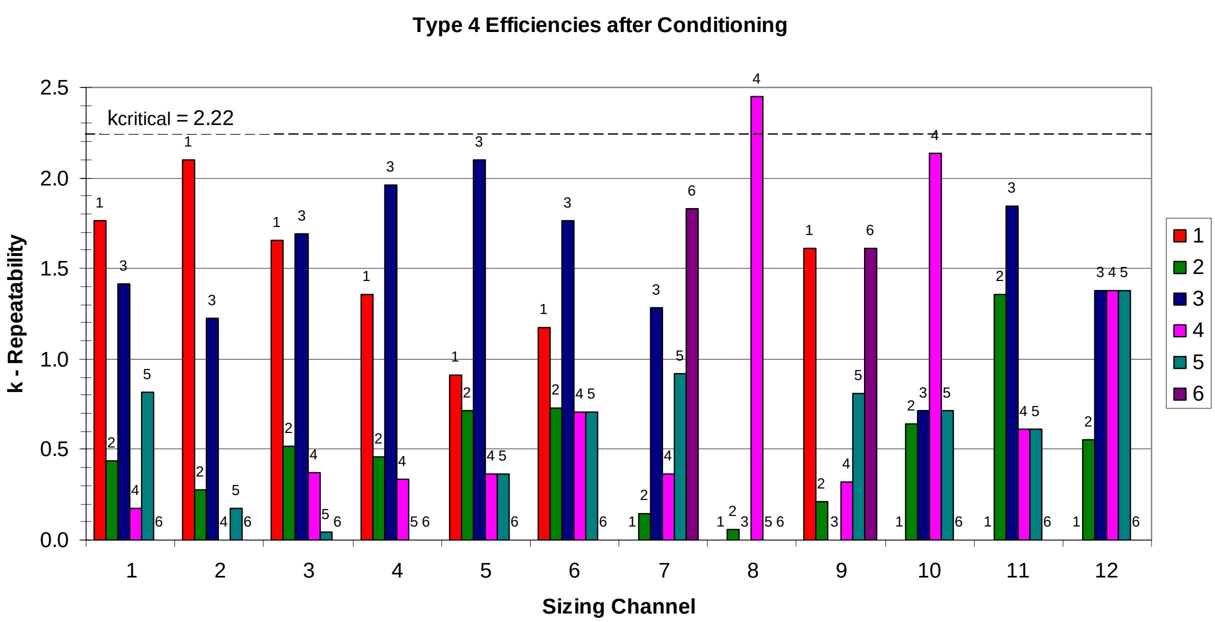

Type 3 Efficiencies after 25% Loading
kcritical = 2.11
k - Repeatability
Sizing Channel
1
2
3
4
6


Type 3 Efficiencies after 50% Loading
kcritical = 2.11
k - Repeatability
Sizing Channel
1
2
3
4
6

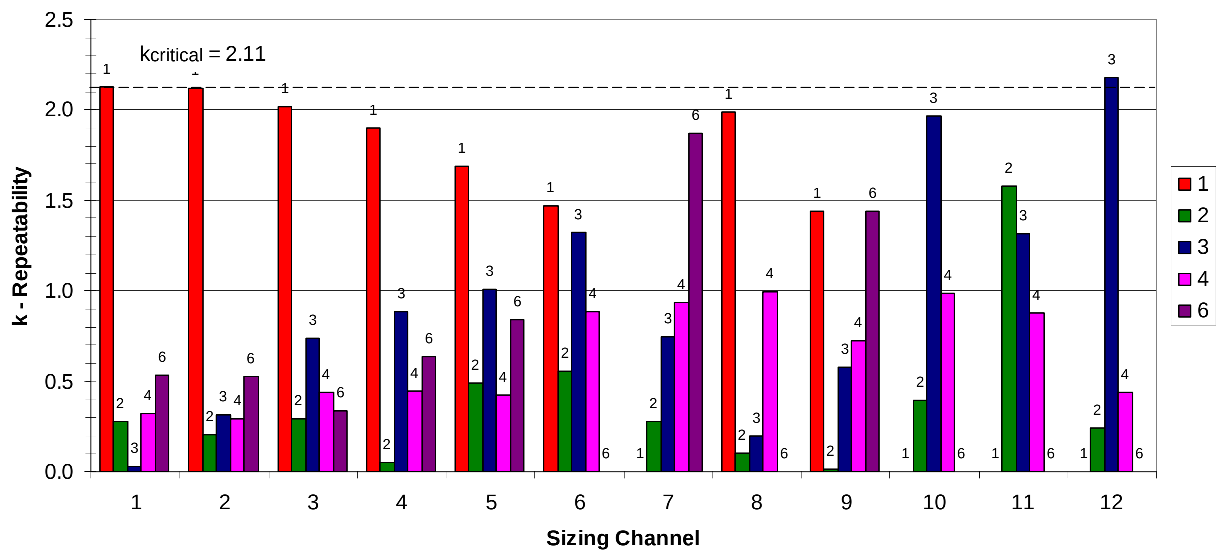

Type 3 Efficiencies after 75% Loading
kcritical = 2.11
k - Repeatability
Sizing Channel
1
2
3
4
6


Type 3 Efficiencies after 100% Loading
kcritical = 2.11
k - Repeatability
Sizing Channel
1
2
3
4
6

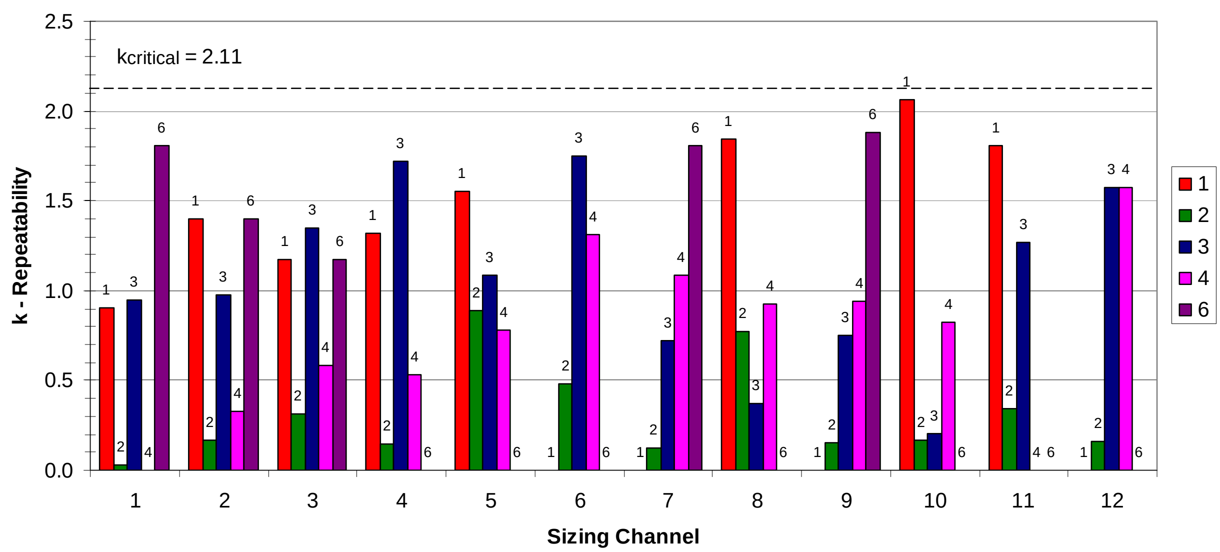

Type 4 Initial Efficiencies
kcritical = 2.22
k - Repeatability
Sizing Channel


Type 4 Efficiencies after Conditioning
kcritical = 2.22
k - Repeatability
Sizing Channel

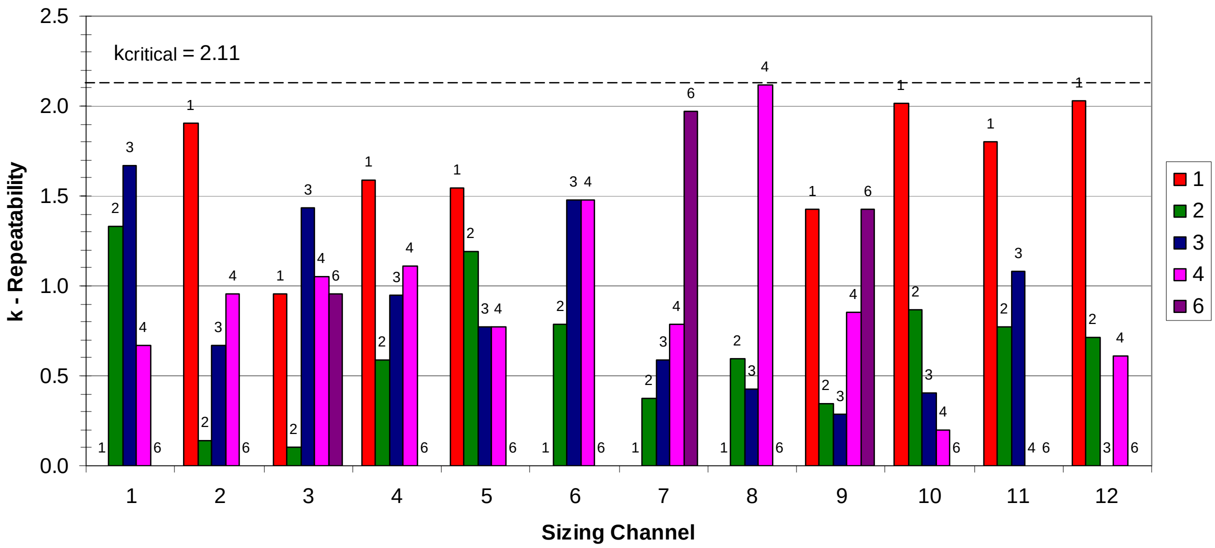
Type 4 Efficiencies after 25% Loading



Type 4 Efficiencies after 50% Loading



Type 4 Efficiencies after 75% Loading



Type 4 Efficiencies after 100% Loading