The Evolution of Improved Baghouse Filter Media as Observed in the Environmental Technology Verification Program

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ABSTRACT

The U.S. Environmental Protection Agency (EPA) implemented the Environmental Technology Verification (ETV) Program in 1995 to generate independent and credible data on the performance of innovative technologies that have the potential to improve protection of public health and the environment. The purpose of this program is to help organizations, industries, business, states, communities, and individuals make better informed decisions when selecting new environmental technologies. Technology vendor participation is voluntary, and technologies are not approved. Quality data, responsive to customer need, are the product of verification testing. ETV success depends on obtaining and communicating information about the performance of technologies to those who decide on the selection and implementation of environmental solutions. The results are publicly available on ETV's web site at www.epa.gov/etv.

In 1998, the Air Pollution Control Technology Verification Center (APCT Center) instituted a Baghouse Filtration Products (BFP) Program as part of EPA's ETV program. The purpose of the BFP program was to verify the performance of baghouse filtration media on removing fine particles ($PM_{2.5}$), along with a limited number of other parameters, including pressure drop and cleaning requirements of commercial-ready products. The expectation was that BFP verifications would accelerate the market entry of verified fabrics and would thereby help improve the environment as the new federal fine particle code was implemented at the state level. The BFP program has been one of the more successful ETV programs, and the vast majority of filtration fabric suppliers to the domestic bag market have participated in the program. In many cases, the suppliers have continuously submitted newly developed fabrics for verification. A review of the data from the program initiation to date is provided in this paper. In general, this review indicates continuous improvement in the performance of the verified fabrics. A discussion of the implications of this conclusion is also provided.

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) implemented the Environmental Technology Verification (ETV) program in 1995 to generate independent and credible data on the performance of innovative technologies that have the potential to improve protection of public health and the environment. The purpose of the ETV program is to help organizations, industries, business, states, communities, and individuals make better informed decisions when selecting new environmental technologies. Technology vendor participation is voluntary. Technologies are not approved or certified for use and no guarantees or recommendations are made. Quality data, responsive to customer need, are ETV's product. The success of the ETV program depends on obtaining and communicating information about the performance of technologies to those who decide on the selection and implementation of environmental solutions.

Information about the ETV program is available at www.epa.gov/etv.[1] ETV does not conduct technology development research. Instead, its function is to test, evaluate, and publish information about the performance of fully commercial-ready innovative technologies. This occurs through the development of test protocols, Test and Quality Assurance (test/QA) Plan, the testing of volunteered technology, and the release of verification reports and statements that document results. Activities of ETV centers are communicated by media-specific stakeholder groups, which consist of technical experts in the field; buyers and sellers of technologies; state, federal, and local permit writers; and others with interest in the area. These groups set priorities and help develop test protocols and operating procedures.

One focus of ETV is the air pollution control area. The Air Pollution Control Technology Verification Center (APCT Center) serves as the organizational unit in this area. RTI International (RTI) is the cooperating partner and verification organization for the APCT Center. Several other organizations support RTI in various aspects of the work.

Because innovative industrial filters control fine particles, and thus meet an important environmental need, they have been identified by APCT Center stakeholders as a high-priority technology group. Baghouse filtration products (BFP) were proposed as a verification technical area of emphasis within the APCT Center and verifications were initiated there in 2000. Forecasts indicate that there is a large market for new and retrofit fabric filters. New fabrics have been developed that offer the combination of highly effective particulate removal and low operational pressure drop. Improving performance of the fabrics can be observed in verification test data trends.

VERIFICATION APPROACH FOR BAGHOUSE FILTRATION PRODUCTS

The verification effort for BFP is intended to verify the performance of industrial air filtration control technologies. After this technology area was selected, a technical panel (TP) was assembled to develop the verification protocol. The TP included experts in baghouse filtration and associated test methods. A balance among permitters, developers or vendors, and users is sought for TP members. With assistance from the APCT Center staff, the TP develops the generic verification protocol by first determining performance factors. Second, an evaluation is made of existing test methods and protocols that may be applicable. To the extent possible, the protocol includes elements that are universal to similar technologies. The TP considered many factors, including efficiency, emission rates, by-products, operating costs, reliability, and operating limitations. Factors specific to the verification protocol for filtration products included removal performance by particle size and power consumption caused by pressure drop and cleaning requirements for the media. The parameters to be tested and the reporting format are specified in formats useful to vendors, users, and regulators. The TP decided that testing of filtration products was best accomplished in a laboratory setting.

Drafts of the protocol are reviewed by the APCT Center's director and quality assurance (QA) manager and by EPA's technical and QA staff. Before any testing begins, the protocol is supplemented by a detailed test and QA plan. The plan addresses all emission and process data to be gathered, including project description, project organization and responsibilities, QA objectives, site selection, sampling and monitoring procedures, analytical procedures and calibration, data reduction and reporting, and quality control (QC) checks, audits, and calculations. This plan is reviewed and accepted by the APCT Center and EPA. The BFP protocol[2] and test and QA plan[3] are published on the ETV web site.

QA is vital in ensuring credible data in ETV, and its implementation is directed and guided by the Program's Quality Management Plan (QMP),[4] which describes how QA is implemented in the ETV Program. All ETV Centers have their own EPA-approved QMP, which also complies with ANSI/ASQC E4-1994, *Specifications and Guidelines for Quality Systems for Environmental Data Collection and Environmental Technology Programs*.[5]

Upon completion of verification testing, the data from the test are compiled, checked, and presented in a form that is consistent with the objectives of the test. All data are assessed as part of the verification process, and a report is prepared by the ETV center that thoroughly documents the test results. Any necessary deviations from the plan are explained and documented, raw data are documented, and QC results are presented. The report provides all necessary information to support the resulting verification statement.

In addition to the detailed test report, a concise verification statement is prepared for each vendor's technology and is reviewed and approved by EPA staff. To the extent possible, the format is consistent with the data requirements of permitting agencies. The verification statement includes a concise summary of the test report with descriptive information about the system tested, test methods used and their selection, operating parameters and conditions, statistical analysis, QA and QC audit results, and any limitations on the collection and use of the test data. Organizations conducting the testing and providing QA oversight are identified.

VERIFICATION APPARATUS AND PROCEDURES

Under subcontract to RTI, ETS, Inc. (ETS) conducts the verification tests for BFP with the test apparatus that it built based on the German VDI method 3926 (VDI 1994).[6] This equipment allows the user to measure filter performance under defined conditions with regard to the filtration velocity, particle size distribution, and cleaning requirements. Filtration and cleaning conditions can be varied to simulate conditions that prevail in actual baghouse operations.

The test apparatus shown in Figure 1 consists of a brush-type dust feeder that disperses test dust into a vertical rectangular duct (raw-gas channel). The dust feed rate is continuously measured and recorded on an electronic scale beneath the dust feed mechanism. The scale has a continuous readout with a resolution of 10 grams (g). A radioactive Polonium-210 alpha source is used to electrically neutralize the dust before its entry into the raw-gas channel. An optical photo sensor monitors the opacity of the dust and air and verifies that the opacity is stable for the duration of the test. A portion of the gas flow is extracted from the raw-gas channel through the test filter, which is mounted vertically at the entrance to a horizontal duct (clean-gas channel).

Figure 1: Diagram of Test Apparatus for Baghouse Filtration Products

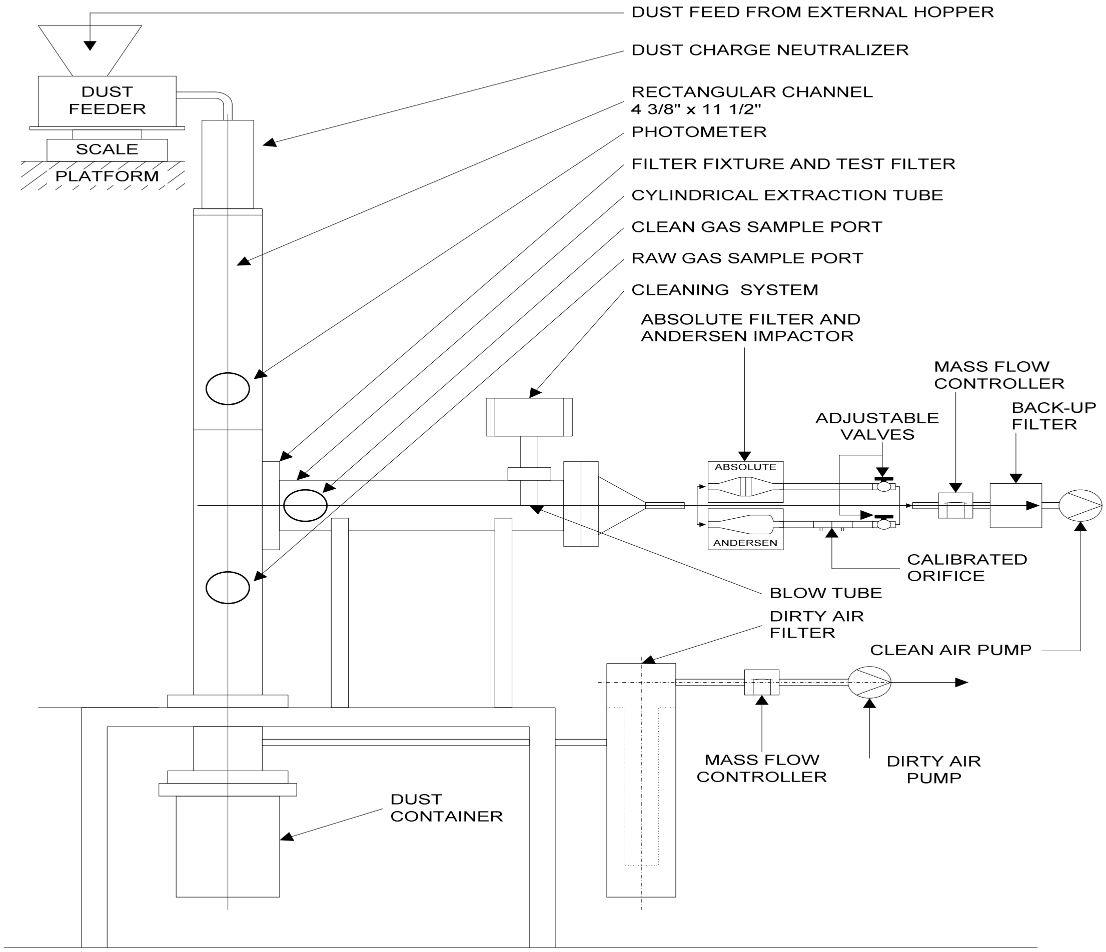


Figure 2 shows a filter sample being installed. Two vacuum pumps maintain airflow through the raw-gas and clean-gas channels. The flow rates, and thus the filtration velocity through the test filter, are kept constant using mass flow controllers. High-efficiency filters and pumps to prevent contamination or damage caused by the dust are installed upstream of the flow controllers. The cleaning system consists of a compressed-air tank set at 0.52 megapascals above ambient pressure (75 pounds per square inch gauge), a quick-action diaphragm valve, and a blow tube 25.4 millimeter (mm) diameter (0.1 inch) with a nozzle 3 mm diameter (0.01 inch) facing the downstream side of the test filter.

Figure 2: Installing a Fabric Sample in the Test Apparatus for the Baghouse Filtration Products

Each verification test consists of three test runs, and each test run consists of three sequential phases or test periods: a conditioning period, a recovery period, and a performance test period. The gas-to-cloth ratio (filtration velocity) and inlet dust concentrations are maintained at 120 ±6.0 meter/hour (6.6 ±0.3 feet per minute) and 18.4 ±3.6 grams per dry standard cubic meter (g/dscm) (8.0 ±1.6 grains per dry standard cubic foot), respectively, throughout all phases of the test.

To simulate long-term operation, the test filter is first subjected to a conditioning period that consists of 10,000 rapid-pulse cleaning cycles under continuous dust loading. During this period, the time between cleaning pulses is maintained at 3 seconds (s). No filter performance parameters are measured during this period.

The conditioning period is immediately followed by a recovery period, which allows the test filter to recover from rapid pulsing. The recovery period consists of 30 normal filtration cycles under continuous dust loading. During a normal filtration cycle, the dust cake is allowed to form on the test filter until a differential pressure of 1,000 pascals (Pa) (4.0 inches of water gauge is reached). At this point, the test filter is cleaned by a pulse of compressed air from the clean-gas side. Immediately after pulse cleaning, the pressure fluctuates rapidly inside the test duct. Some of the released dust immediately redeposits onto the test filter. The pressure then stabilizes and returns to normal. Thus, the residual pressure drop across the test filter is measured 3 s after the conclusion of the cleaning pulse. It is monitored and recorded continuously throughout the filter medium recovery and performance test periods of each test run.

Performance testing occurs for a 6-hour period immediately following the recovery period (a cumulative total of 10,030 filtration cycles after the test filter has been installed in the test apparatus). During the performance test period, normal filtration cycles are maintained and, as in the case of the conditioning and recovery periods, the test filter is subjected to continuous dust loading. Outlet mass and particulate matter 2.5 µm in aerodynamic diameter or smaller ($PM_{2.5}$) dust concentrations are measured using an inertial impactor located downstream of the test filter at the end of the horizontal (clean-gas) duct. The impactor consists of impaction stages needed to quantify total PM and $PM_{2.5}$ concentrations. The weight gain of each stage's substrate is measured with a high-resolution analytical balance that is capable of measurements to within 10 µg.

VERIFICATIONS COMPLETED

The ETV Program has verified the performance of 20 BFPs designed primarily to reduce $PM_{2.5}$ emissions and has one additional verification in progress. All of the verified products are commercial fabrics used in baghouse emission control devices. The reports on all verifications can be found at http://www.epa.gov/etv/verifications. Due to the evolving nature of these products and their markets, the BFPs' verification statements are valid for 3 years from the date of verification. Table 1 identifies the verified technologies.

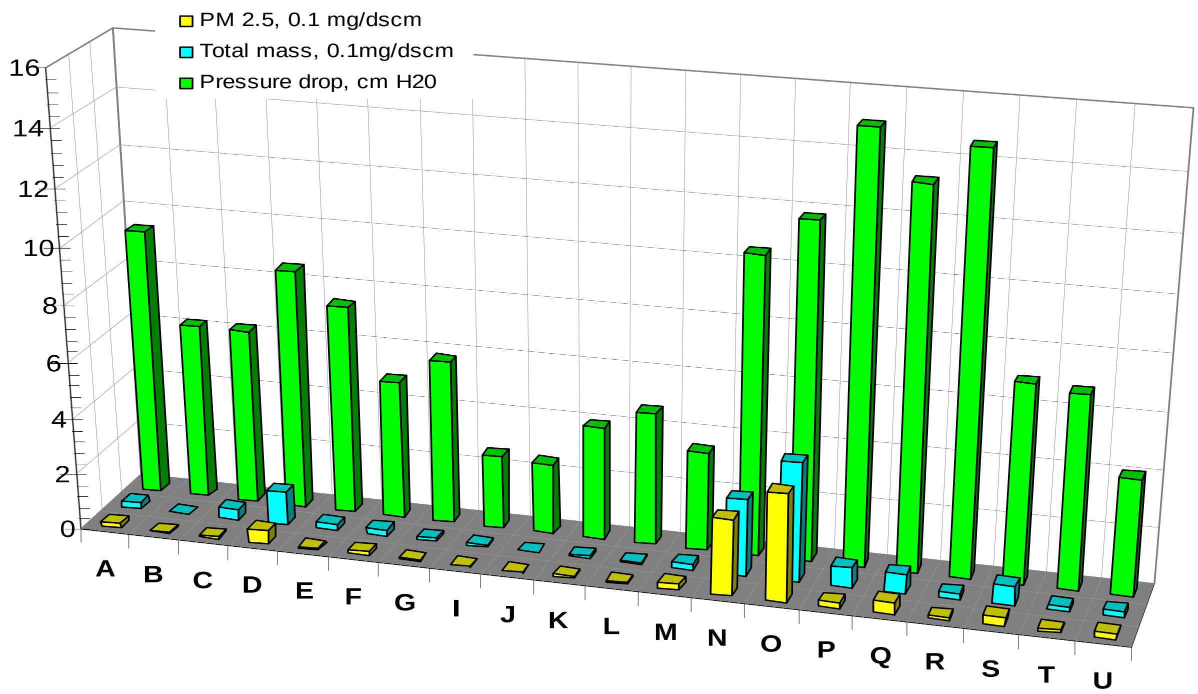
Table 1. ETV-verified baghouse filtration products.

Technology Name	Verification Date	Description
BWF America, Inc. Grade 700 MPS Polyester Felt	September 2005	A micro-pore-size, high-efficiency, scrim-supported felt fabric
W.L. Gore & Associates, Inc. L3560	July 2006	A membrane and fiberglass fabric laminate
Southern Filter Media. PE-16/M-SPES	February 2007	A singed micro-denier polyester felt
Donaldson Company, Inc. 6277 filtration media	May 2007	An 8 ounces per square yard (opsy) polyester spun-bond with Tetratex polytetrafluoroethylene (PTFE) membrane
Donaldson Company, Inc. 6282 filtration media	July 2007	A 10 opsy pleatable polyphenylene sulfide with Tetratex PTFE membrane
Donaldson Company, Inc. 6255 filtration media	September 2007	A woven fiberglass with Tetratex PTFE membrane
GE Energy. QG061 filtration media	In progress	A woven glass substrate with an expanded, microporous membrane
TDC Filter Manufacturing	In progress	An 8 opsy non-woven, spun-bond polyester
Donaldson Company, Inc. 6255-3 filtration media	In progress	A woven fiberglass with Tetratex PTFE membrane
Expired Verifications		
Air Purator Corporation Huyglas 1405M	September 2000	An expanded PTFE film applied to a glass felt for use in hot-gas filtration
Albany International Corporation Primatex Plus I	September 2000	A polyethylene terephthalate filtration fabric with a fine fibrous surface layer
BASF Corporation AX/BA-14/9-SAXP 1405M	September 2000	A Basofil filter media
BHA Group, Inc. QG061	September 2000	A woven-glass-base fabric with an expanded, microporous PTFE membrane, thermally laminated to the filtration or dust cake surface
BHA Group, Inc. QP131	September 2001	A polyester needlefelt substrate with an expanded, microporous PTFE membrane, thermally laminated to the filtration or dust cake surface
BWF America, Inc. Grade 700 MPS Polyester	June 2002	A micro-pore-size, high-efficiency, scrim-supported felt fabric
Inspec Fibres 5512BRF	September 2000	A scrim-supported needlefelt fabric
Menardi-Criswell 50-504	September 2000	A singed micro-denier polyester felt
Polymer Group, Inc. DURAPEX PET	September 2001	A non-scrim-supported 100% polyester, non-woven fabric
Standard Filter Corporation Capture PE16ZU	September 2000	A stratified micro-denier polyester non-woven product
Tetratec PTFE Technologies. Tetratex 8005	September 2000	A polyester scrim-supported needlefelt fabric with an expanded PTFE membrane

Technology Name	Verification Date	Description
Tetratec PTFE Technologies Tetratex 6212	September 2001	A polyester needlefelt fabric with an expanded PTFE membrane
W.L. Gore & Associates, Inc. L4347	September 2000	An expanded PTFE membrane and polyester felt laminate
W.L. Gore & Associates, Inc. L4427	September 2001	A membrane and polyester felt laminate

Figure 3 summarizes the performance data for the 20 BFPs, which have completed verification to date. Because the ETV program does not compare technologies, the performance results shown in Figure 3 do not identify the vendor associated with each result and are not in the same order as the list of technologies in Table 1. The verified results for outlet $PM_{2.5}$ concentrations ranged from $2x10^{-6}$ to $3.8x10^{-4}$ g/dscm and total particulate concentrations of $2x10^{-6}$ to $4.2x10^{-4}$ g/dscm. The residual pressure drop ranged from 2.5 to 15.0 centimeters water gauge. The membrane fabrics tested generally yielded lower $PM_{2.5}$ (first row) and total PM mass (middle row) concentrations downstream of the filter and lower pressure drop (third row) across it than did the non-membrane filters.

Figure 3: Results for Verification Tests of 20 Baghouse Filtration Products



A-J: Membrane Fabrics. K-S: Non-membrane Fabrics

SCIENTIFIC AND TECHNOLOGY ADVANCEMENT OUTCOMES

The APCT Center's BFP Program has resulted in advancements in science and baghouse media in addition to the increased knowledge on performance of BFP. The development of the ETV protocol for BFP has promoted standardization and consistency in evaluating the performance of baghouse media. The ETV protocol has been adopted by the American Society for Testing and

Materials (ASTM) as ASTM D6830, Characterizing the Pressure Drop and Filtration Performance of Cleanable Filter Media. The International Organization for Standardization (ISO), which is a worldwide voluntary standards organization, has also proposed the ETV testing protocol as its standard, and it is progressing through the ISO adoption and approval process. In addition, the development of the protocol and publication of verification results has provided and will continue to provide valuable scientific information to facilities, vendors, and state and local agencies. For example, the ASTM method has been used for more than 100 tests over the past 3 years. These tests have been used to screen media during early stage development of new media and as a QC test for commercial lots of fabric.

The BFP Program has also prompted advancement in the performance of baghouse media. A review of all of the ETV/BFP test results provides the basis for some interesting observations in the media performance over time. The trends can be observed in Figure 3, where the performance of fabrics, which incorporate membranes, are separated from those that do not contain membranes. Within each type of fabric, the results are presented in chronological order, relative to the date of the testing. As expected, the PM penetration for the membrane fabrics is lower. The overall trend for both the membrane and the non-membrane fabrics indicates that the filtration performance of both types of fabric improves the more current the testing.

This trend of improving performance over time can be observed more clearly if the data are grouped by time period. Table 2 presents the data as average results for three time periods: initial verifications conducted in 2000, a second round of verifications conducted in 2001, and the most recent verifications conducted in 2005 through 2007.

Table 2. Baghouse filtration products performance by time periods.

Time Period	Number of Verifications	Percent of Media with Membranes	$PM_{2.5}$, mg/dscm	Total Mass, mg/dscm	Average Delta P, cm w.g.
2000	10	50	0.0911	0.1164	10.18
2001	6	67	0.0120	0.0279	7.00
2005–2007	7	71	0.0164	0.0173	3.82
cm w.g. = centimeters water gauge; mg/dscm = milligrams per dry standard cubic meter					

Figures 4 and 5 graphically show the PM penetration data and delta P data, respectively. Grouping the data in this manner shows the trends more clearly. For instance, both $PM_{2.5}$ and total PM penetration decrease over time. Total PM continued to decrease over the time period observed, whereas the performance of the media for $PM_{2.5}$ may be reaching a plateau. The data in Table 2 also show the increase in use of membrane fabrics, whereas Figure 5 shows the clear progress in decreasing the residual delta P without sacrificing PM control. Lower residual delta P results in energy savings, longer bag life, and lower life-cycle costs.

Figure 4: Particulate Matter Results by Time Period

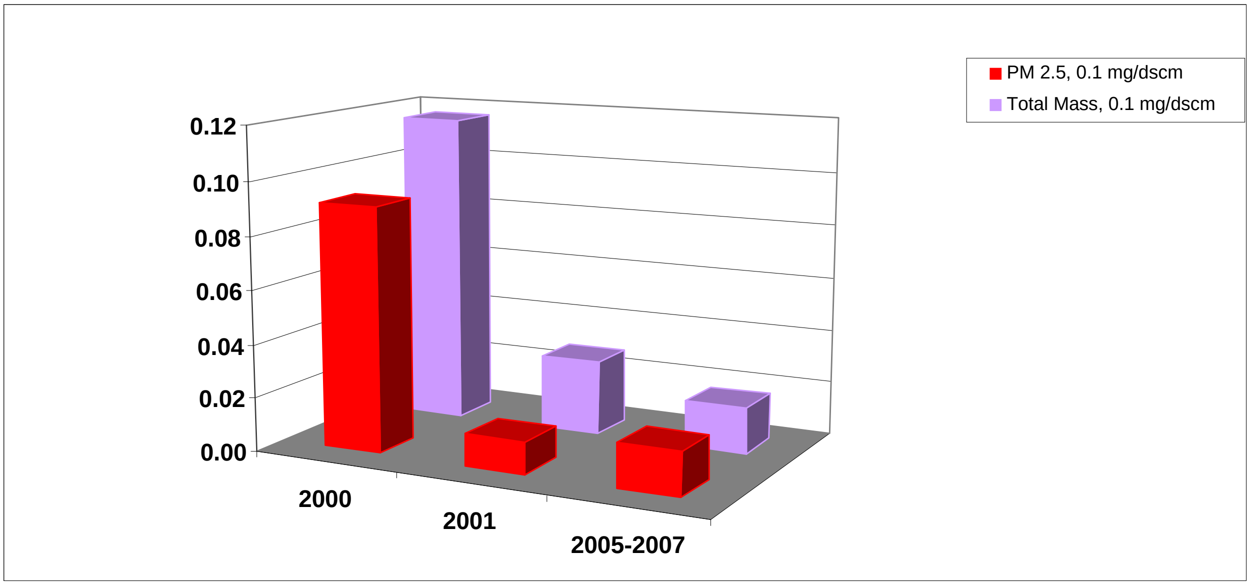
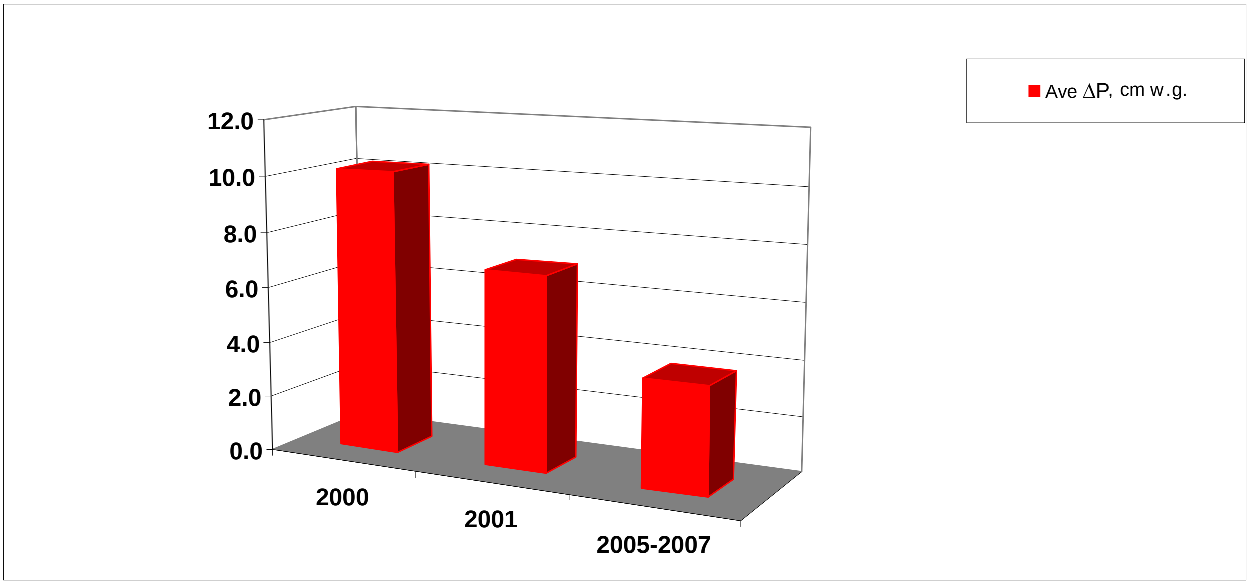


Figure 5: Residual Pressure Drop Results by Time Period



One conclusion that may be drawn from these data is that the establishment of the ETV/BFP program has influenced the development of the filtration fabrics towards better filtration performance. In essence, because the data are public and the test method is both accepted and transparent, the fabric developers have a published target performance. The developers use this information to compete with other developers to create the best performing fabric, which has led to a continuous improvement in the filtration performance and the increased potential for environmental improvement.

REGULATORY COMPLIANCE OUTCOMES

EPA has identified 39 areas of the United States with a total population of 90 million that exceed the National Ambient Air Quality Standards for $PM_{2.5}$. Although controls on other pollutants, such as those required under the 2005 Clean Air Interstate Rule, will help some areas meet the $PM_{2.5}$ standards, EPA anticipates that many states will require emissions controls on large stationary sources of $PM_{2.5}$. ETV-verified BFPs can be used to meet these requirements. In addition, the verification data can assist facilities and state and local agencies in evaluating the technologies' effectiveness for meeting these requirements. The availability of ETV data has also facilitated the permitting process for users. A vendor of a verified fabric was quoted as saying, "At least one customer… made his work with permitting easier by running our materials through the ETV testing process…"

The ETV program also supports vendors and users in compliance with state and local air pollution rules. On November 4, 2005, the California South Coast Air Quality Management District adopted Rule 1156, which encourages the use of ETV-verified baghouse fabrics to control PM emissions from cement manufacturing facilities. Paragraph (e)(7) of the rule allows facilities that use ETV-verified products in their baghouses to reduce the frequency of compliance testing from annually to every 5 years. EPA's Office of Air Quality Planning and Standards issued a memorandum to "EPA Regional offices and State Directors, which endorses the use of verified baghouse filter media and encourages its future use in both permits and in new or revised regulations wherever appropriate."

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KEY WORDS

Baghouse, Particulate Emissions, Verification