The Evolution & Impact of Baghouse Filter Performance Testing

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ABSTRACT

In 1995 the U.S. EPA initiated the Environmental Technology Verification (ETV) program for the purpose of generating independent and credible performance verification of innovative technologies and helping to accelerate acceptance of these products into the marketplace to further benefit the environment and protect public health. Technology vendor participation is voluntary, and technologies are not approved. Quality data, responsive to customer need, are the product of verification testing. The results are publicly available at www.epa.gov/etv.

In 1998 the Air Pollution Control Technology Center (APCT Center) instituted a Baghouse Filtration Products (BFP) Program as part of EPA's ETV program. Essentially, the BFP program uses a testing protocol approved by the U.S. EPA to verify the performance of commercially available filtration products for pulse-jet baghouses in removing fine particulate matter ($PM_{2.5}$). The BFP program is one of the more successful ETV programs. The vast majority of filtration fabric suppliers to the domestic bag market have participated in this program. This verification testing protocol was later used as a basis for the development of the American Society for Testing and Materials (ASTM) Method D6830 in 2002, and a Final Draft International Standards Organization (ISO) method with a possible publication date of October 2011.

In 2005 the South Coast Air Quality Management District (SCAQMD) in California adopted Rule 1156 which in part encourages the use of ETV/ASTM-verified filtration media by allowing the facilities that use these products to reduce the frequency of compliance testing from annually to every 5 years. Subsequently, the EPA's Office of Air Quality Planning and Standards (OAQPS) issued a memorandum to the Regional Air Division Directors highly encouraging the regional offices to facilitate the use of ETV/ASTM-verified filtration media. This paper highlights the expansion of the SCAQMD's regulatory activity, details of the ISO approval process, future consideration of baghouse permitting, baghouse O&M plans, fabric/bag QA/QC, and bag monitoring plans.

INTRODUCTION

In 1995 the U.S. EPA initiated the Environmental Technology Verification (ETV) program for the purpose of generating independent and credible performance verification of innovative

technologies and helping to accelerate acceptance of these products into the marketplace to further benefit the environment and protect public health. Technology vendor participation is voluntary, and technologies are not approved. Quality data, responsive to customer need, are the product of verification testing.[1]

In 1998 the Air Pollution Control Technology Center (APCT Center) instituted a Baghouse Filtration Products (BFP) Program as part of EPA's ETV program. Essentially, the BFP verification program uses a testing protocol approved by the U.S. EPA to verify the performance of commercially available filtration products for pulse-jet baghouses in removing fine particulate matter ($PM_{2.5}$). 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.[1] This verification testing protocol was later used as a basis for the development of the ASTM Method D6830[2] in 2002, and a Final Draft ISO method ISO/FDIS 11057[3] with a possible publication date of October 2011.

Fast-forward to the year 2006. In 2006 the U.S. Environmental Protection Agency (EPA) promulgated a revised $PM_{2.5}$ particulate standard (see Table 1).[4] In 2011 EPA will consider again revising particulate matter standards on the basis of the most current assessment of the scientific information. In the USA the Clean Air Interstate Replacement (CAIR) Rule (SO_2 and NO_x), Regional Haze (SO_2, NO_x, PM), and National Ambient Air Quality Standard (NAAQS) Revisions ($PM_{2.5}$, Ozone, SO_2, NO_2) will probably act to drive total particulate emissions limits to near detection levels. Fabric filters will be one of the more important technologies utilized to achieve the reductions in primary fine particulate emissions. Filter Media testing of filtration performance has shown that "current test method non-detect" particulate emission levels are achievable.

Table 1. EPA 1997 and 2006 National Ambient Air Quality Standards for Particulate Matter[4]

	1997 Standards		**2006 Standards**	
	Annual	24-hour	Annual	24-hour
$PM_{2.5}$ (Fine)	15 μg/m^3	65 μg/m^3	15 μg/m^3	35 μg/m^3
	Annual arithmetic mean, averaged over 3 years	98th percentile, averaged over 3 years	Annual arithmetic mean, averaged over 3 years	98th percentile, averaged over 3 years
PM_{10} (Coarse)	50 μg/m^3	150 μg/m^3	Revoked	150 μg/m^3
	Annual arithmetic mean, averaged over 3 years	Not to be exceeded more than once per year on average over a 3-year period		Not to be exceeded more than once per year on average over a 3-year period

Fabric filter baghouses have been utilized for more than a century to control particulate emissions, and typically the current selection criteria have focused on first cost, operating cost and bag life. The key criteria may well change. The emission control performance, especially fine particle control at very high levels, may become a dominant consideration.

In the early 1990s EPA was persuaded that $PM_{2.5}$ particles posed sufficient harm to humans and the environment and that more in-depth research & development and health studies were needed. Goals and objectives were formulated for obtaining the information and using it to show effects and trends of $PM_{2.5}$. A significant nationwide reduction in direct $PM_{2.5}$ from man-made sources was made between 1993 and 2002 (17 percent). This reduction does not account for secondary particles, which typically account for a large percentage of total ambient $PM_{2.5}$. The secondary particles are principally sulfates, nitrates, and organic carbon.[5]

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Environmental Technology Verification (ETV)

EPA's ETV program, which was initiated in October 1995, develops testing protocols and verifies the performance of innovative technologies that have the potential to improve protection of human health and the environment. ETV was created to accelerate the entrance of new environmental technologies into the domestic and international marketplace. ETV achieves this goal by generating independent and credible data on the performance of innovative technologies that have the potential to improve protection of public health and the environment.

Air Pollution Control Technology (APCT)

The air pollution control area is a focus of the ETV program because it assists vendors and users in demonstrating technologies for air pollution control. Baghouse Filtration Products was proposed as a verification technical area of emphasis within the APCT Center and verifications were initiated in 2000. New fabrics have been developed that offer the combination of highly effective particle removal and low operational pressure drop. Selecting the best fabric for each application requires having reliable and credible performance data.

Baghouse Filtration Products (BFP)

The BFP program effort is intended to verify the performance of industrial air filtration control technologies. The ETV APCT Center, operated by RTI International under a cooperative agreement with EPA's National Risk Management Research Laboratory, has, as of April 2010, verified the performance of 24 technologies for reducing emissions of fine particulate matter ($PM_{2.5}$). All of the verified products are commercial fabrics used in baghouse emission control devices.[6]

South Coast Air Quality Management District Regulatory Activity

The California Legislature created the District in 1977 as the agency responsible for developing and enforcing air pollution rules and regulations in the South Coast Air Basin (Basin), and the Riverside County portions of the Salton Sea Air Basin (SSAB) and Mojave Desert Air Basin (MDAB). The District has jurisdiction over an area of approximately 10,743 square miles, consisting of Orange County, and the non-desert portions of Los Angeles, Riverside, and San Bernardino counties, with a total population of approximately 17 million people. The Basin is

classified by the U.S. EPA as a nonattainment area for fine particulate matter ($PM_{2.5}$) with an attainment date of 2010. The District has requested the U.S. EPA a five-year extension to 2015 to demonstrate attainment with the annual $PM_{2.5}$ standard.[7] With respect to coarse particulate matter (PM_{10}), the District is classified as "serious" nonattainment. Currently, the American Lung Association has classified the Basin as the third most polluted city with respect to long term exposures to particulate pollution, and the fourth most polluted city with respect to short term exposures to particulate pollution.[8] Particle pollution leads to increased hospital admissions and emergency room visits. Short term exposures cause irritation of the airways, coughing, difficulty breathing, asthma attacks and acute bronchitis. Long-term exposures are linked to reduced lung and brain function, development of chronic bronchitis, and even death from heart or lung diseases or premature death. Children, older adults and people with heart or lung diseases are the most likely to be affected by particle exposures. It was reported that attainment with the federal $PM_{2.5}$ standards would avoid more than 3,000 premature deaths annually, 1.7 million respiratory symptoms and bronchitis, 3,000 non-fatal heart attack, 1,400 respiratory and cardio hospital admissions, 2,000 children's asthma emergency room visits, and 400,000 work lost days due to illness in the South Coast air basin.[5, 9-11]

The District implements all necessarily feasible and cost-effective control measures in order to help the Basin attain the ozone and $PM_{2.5}$ standard as expeditiously as possible. On November 4, 2006, the District developed and adopted Rule 1156 – Further Reductions of Particulate Emissions from Cement Manufacturing Facilities[12], and subsequently, on December 4, 2009, the District developed and adopted Rule 1155 – Particulate Matter (PM) Control Devices.[13] The main purpose of Rule 1155 and Rule 1156 is to reduce particulate matter (PM) emissions from the affected facilities by ensuring good maintenance and housekeeping practices, visible emissions monitoring, baghouse upgrades, installation of bag leak detection system (BLDS), and promoting the use of filtration product that has been verified under the U.S. EPA Environmental Technology Verification (ETV). Rule 1156 estimated a 50% additional reduction from the baseline emissions for cement manufacturing facilities while Rule 1155 did not quantify any additional reductions. Specific requirements pertaining to emission standards and operational requirements for baghouses are summarized below and shown in Table 2.

Rule 1156 is applicable to cement manufacturing facilities. The rule specifies an outlet concentration standard of 0.01 grain/dscf measured at stack for existing baghouses installed before November 4, 2005; and 0.005 grain/dscf for new baghouses installed after November 4, 2005. Pulse-jet baghouses are required to comply with the emission standard by December 31, 2006, and other types of baghouses are required to comply by December 31, 2010. The baghouse's ventilation and hood system must meet a minimum capture velocity requirement specified in the U.S. Industrial Ventilation Handbook, American Conference of Governmental Industrial Hygienists. In addition, the rule requires the operator to monitor record and report (MRR) several pertinent operating parameters of the air pollution control device such as flue gas flow rates and pressure drop across the control device to ensure compliance. The rule also requires the operator to use Continuous Opacity Monitor Systems (COMS) or Bag Leak Detection Systems (BLDS) for top process particulate emitters; and develop and implement Operational & Maintenance (O&M) Procedures for all operations at the facility. To ensure that the baghouses for the kilns and clinker coolers meet the emission standard, the rule requires the operator to conduct a source test on an annual basis. The frequency of source testing is reduced to every 5 years if the baghouses are equipped with the U.S. EPA verified filtration products.

Table 2. Emission Standards and Operational Requirements for Baghouses

AQMD Rule	Type	Emission Standards/Operational Requirements	Compliance Date
Rule 1156	Baghouses at cement manufacturing facilities	— 0.01 grains/dry standard cubic feet for existing baghouses installed prior to 11/4/2005 — 0.005 gr/dscf for new baghouses on or after 11/4/2005 — Bag Leak Detection System (BLDS) or Continuous Opacity Monitoring System (COMS) — Monitor flue gas flow rates and pressure drops for kilns/clinker coolers' baghouses — 10% opacity with weekly (or monthly) observation — Source test every year (or every five years)	12/31/2006
Rule 1155	Baghouses with filter surface area greater than 7,500 ft2 (Tier 3 baghouses)	— 0.01 grains/dry standard cubic feet. If the emission standard is exceeded, the operator shall file a permit application to use verified filtration products (or other technologies) to achieve the 0.01 gr/dscf, unless the problem is resolved within 24 hours of discovery. — No visible emissions, and operated and maintained according to manufacturers' operation and maintenance manual, or written manual. — Equipped with BLDS — Source test once every 5 years	1/1/2011 4/1/2010 5/1/2010 1/1/2011
	Tier 1/Tier 2 Baghouses	No visible emissions, and operated and maintained according to manufacturers' operation and maintenance manual, or written manual.	4/1/2010

While Rule 1156 is only applicable to two cement manufacturing facilities in the Basin, Rule 1155 affects approximately 1,500 remaining facilities in nearly all sectors of the South Coast's regional economy with nearly 5,000 particulate matter control devices. Because of its vast application, Rule 1155 emphasizes in good operational practices and maintenance. The rule requires that all permitted particulate matter air pollution control devices should have no visible emissions by April 1, 2010. The facility operator must have at a minimum of one person trained in reading of visible emissions pursuant to EPA Method 22 to conduct a once a week, five-minute visible emissions observation to detect early leakage from all baghouses at the facility. Similar to Rule 1156, the rule requires that all air pollution control devices must be operated and maintained pursuant to either manufacturer's or distributor's O&M manual, or a written O&M manual. The rule sets an emission standard of 0.01 grain/dscf limit for large baghouses with a filter area greater than 7,500 square feet (Tier 3 baghouses). Tier 3 baghouses at Title V facilities are required to be source tested as of January 1, 2011, and again every five years thereafter. Baghouses in the hot mix asphalt production facilities shall comply with this requirement by January 1, 2013, and in the event that new bags have been installed within 12 months prior to December 4, 2009, the compliance date would be January 1, 2014 or at the end of the bag's useful life, whichever occurs sooner. In addition, the operator is required to install BLDS to Tier 3 baghouses to continuously monitor bag leakage and failure by detecting the increases of particulate matter concentration in the exhaust stack. Smaller sizes of baghouses (Tier 2 baghouses with filter surface area greater than 500 ft^2 but less than or equal to 7,500 ft^2, and Tier 1 baghouses with filter surfaces less than or equal to 500 ft^2) must be operated with no

visible emissions and maintained according to manufacturers' operation and maintenance manual.
Rule 1155 and Rule 1156 strongly encourage the use of the U.S. verification products in baghouses. In Rule 1156, the affected facility is required to conduct source tests for kiln/clinker cooler's baghouses every year to demonstrate compliance with the emission limit. However, if the facility elects to use verified filtration products in their baghouses, the rule allows the facility to conduct source testing once every five years as shown in paragraph (e)(7) of Rule 1156. Under Rule 1155 requirements, the facility must conduct visible emissions observation once a week. However, as shown in paragraph (e)(2) of Rule 1155, if the facility elects to use verified filtration products in their baghouses, they can conduct visible emissions observation once a month. In addition, Rule 1155 requires Tier 3 baghouses to meet the 0.01 grain/dscf emission standard, and if the 0.01 grain/dscf is exceeded, paragraph (d)(6) of Rule 1155 requires the facility to file a permit application to use the U.S. EPA verified filtration products, or other technologies or methods, to meet the required standard expeditiously.

In addition to Rule 1155 and 1156, the U.S. EPA's Office of Air Quality Planning and Standards (OAQPS) issued a memorandum to the Regional Air Division Directors highly encouraging the regional offices to facilitate the use of ETV/ASTM-verified filtration media on September 26, 2007.[14] It is anticipated that the interest of using the EPA ETV verified products will increase with the implementation of Rule 1155, Rule 1156, and the U.S. EPA's OAQPS memorandum.

It should be noted that the verification test protocol used under the EPA's ETV program is limited to a set of controlled lab environment conditions and mainly applicable for pulse-jet baghouses. Some of the emission levels reported through the ETV program are listed in Table 3 in comparison to the test results collected through actual source testing in the South Coast Basin listed in Table 4. The actual test results were mostly under the limit of 0.01 grain/dscf, but were many times greater than the ETV's verified levels. It seems that the EPA's ETV verification testing protocol can be expanded to include a broader range of baghouse filtration products and testing conditions that match the typical actual operating conditions of the baghouses. If that can be done, the benefit of the ETV verification testing protocol will increase substantially to users, regulators, as well as the public. This future expansion for the ETV testing protocol will need a strong support and collaboration from the U.S. EPA, SCAQMD, ETS, stakeholders, and the manufacturers of the filtration products.

Table 3. Emission Levels Reported Through the ETV Program*

Type	PM (grain/dscf)	Description
Donalson Company, Inc.	0.000009	Woven fiberglass with Tetratex membrane
Donalson Company, Inc.	<0.0000073	Woven fiberglass with Tetratex expanded polytetrafluoroethylene (ePTFE) membrane
Donalson Company, Inc.	<0.0000073	Polyester spunbond with Tetratex PTFE membrane
Donalson Company, Inc.	<0.0000073	Pleatable PPS with Tetratex ePTFE
GE Energy	<0.0000073	Woven glass with expanded microporous membrane, thermally laminated
Southern Filter Media, LLC	0.000025	Micro-denier polyester felt
TDC Filter Manufacturing, Inc.	0.0000675	Non-woven spun polyester
WL Gore & Associates, Inc.	<0.0000073	Membrane/fiberglass laminate

* As shown Table III-1 of PR1155 Staff Report.

Table 4. Emission Levels Reported Through Source Testing in the South Coast Air Basin*

Industry	Test Date	Source	PM (grain/dscf)
Cement	2005	Kiln with waste heat boiler	0.0036, 0.0049
	2005	Kiln w/o waste heat boiler	0.0065, 0.0074
	2005	Kiln/Clinker cooler	0.00327, 0.0063
	2005	Finishing mill	0.0027
	2006	Kiln	0.0024
	2007	Finishing mill	0.0002
	2008	Finishing mill	0.0015
	2009	Raw mill & precalcining kiln	<0.002
Metal	2003	Aluminum melting furnace	0.0004
	2005	Metal grinding operations	0.0004
Aggregate	2007	Aggregate conveying storage bin	0.0015
Asphalt	2007	Hot asphalt batch	0.0094
	2008	Rotary kiln asphalt dryer	0.0064
	2000	Asphalt batch (rotary dryer)	0.0168
	2008	Asphalt concrete rotary dryer	0.013
	2008	Asphalt dryer	0.021
	2008	Asphalt concrete rotary dryer	0.015

* As shown in Table 3-4 and 3-5 of Staff Report of Rule 1156; and Table II-1, Appendix II, Staff Report of Rule 1155.

American Society for Testing and Materials (ASTM)

ASTM International has adopted the ETV baghouse filtration testing protocol as its standard (ASTM D6830-02 Methods for Characterizing the Pressure Drop and Filtration Performance of Cleanable Filters), promoting standardization and consistency in performance evaluation of these technologies. Since 2002, there have been approximately 350 runs performed at ETS, Inc.

International Standards Organization (ISO)

The ISO, a worldwide voluntary standards organization, has also proposed the ETV testing protocol as their standard and it is progressing through the ISO adoption and approval process.

A summary of the evolution of the standard test methods may be found in Table 5.[15] The goal of the ETV BFP project, which started in 2000, was to produce, for the public, credible test reports and verification statements regarding $PM_{2.5}$ removal by tested baghouse filtration media based on a modified VDI Method 3926, Part 2, *"Testing of Filter Media for Cleanable Filters Under Operational Conditions."*[16] The idea here was to accelerate market entry of commercial ready filter media by verifying product developer's filtration performance claims. The ETV protocol was then used as a basis for the development of the ASTM Method D6830 in 2002. ASTM D6830 quickly took hold for two reasons. Firstly, it is used as a 2.5 performance test prior to submitting for an EPA ETV verification to assure that the ETV test submission has a high probability of success. Secondly, ASTM D6830 has been widely applied as a performance test for screening and guidance of new filter media development. Since 2002 ISO has been working

on a similar method with a possible publication date of October 2011. The main purpose of the ISO method is to gain information about both the operational performance and the particle emission of cleanable filter media.

Table 5. Summary of the Evolution of Standard Test Methods[15]

	EPA/ETV	ASTM	ISO
YEAR	2000	2002	2011
I.D.	BFP	D6830	"11057"
GOAL	Verification of BFP Vendor Claims 2.5 Efficiency ΔP	Product Development End User Suitability 2.5 Efficiency ΔP	Comparison of Operational Performance & Particle Emission
PROTOCOL	EPA	EPA/Modified	ISO
SAMPLE	Vertical Round Disc	Vertical Round Disc	Vertical Round Disc
FILTER FACE VELOCITY	120 m/h	120 m/h[1]	2 m/min.(120 m/h)
DUST (Concentration)	Pural NF 18.4 g/dscm	Pural NF[1] 18.4 g/dscm	Pural NF 5.0 g/m^3
CLEANING	Pulse-jet	Pulse-jet[1]	Pulse-jet

Note:
1) ETS, Inc. can modify test conditions such as filter face velocity, user-supplied dust, dust feed rate, reverse air cleaning, etc. to suit the end user's requirements.

The three test methods are very similar in that the filter samples are all vertically mounted round discs with an exposed diameter of 140 mm located at the entrance to a horizontal duct (clean-gas channel), the filtration velocities (G/C) are set at 120 m/h, the test dust is specified as aluminum oxide (calcined alumina) dust (Pural NF or equivalent), and they all specify pulse-jet cleaning mechanisms. One notable difference in the methods is the specification for the inlet dust concentrations. Both the ETV and ASTM methods specify a value of 18.4 g/dscm and are measured continuously with a dust load cell and mass flow controller and can be adjusted throughout the runs. The ISO method, however, specifies a dust concentration presented to the filter of 5 g/m^3 and is to be determined gravimetrically prior to each test.[15] A photo of the typical test rig used in each method is shown below in Figure 1.

Figure 1. ETS Chemical Engineer utilizing the filtration performance apparatus to measure filter media performance under defined conditions to simulate actual baghouse conditions.

QA/QC Programs

Ironically for decades QA/QC Programs for air pollution control (APC) filter media have not included a filtration performance test. Typically earlier programs have included permeability and strength tests such as ASTM D737 Permeability[17], ASTM D3786 Mullen Burst[18] and ASTM D5035 Tensile Strength.[19] Today as a consequence of the higher particulate removal and size specific legislation, it is becoming more common to have a much more rigorous QA/QC program including filtration performance testing as shown in Table 6. The value of a fabric and bag QA/QC program, bag installation oversight and bag monitoring program increases as the code requirements become tighter and tighter. The intrinsic value of the QA/QC program is driven by the fact that the failure of even one bag can cause dust contamination of the clean side of the baghouse. This in turn leads to widespread premature bag failure and/or pressure drop increases. Recent new fabric and bag QA/QC programs have detected membrane failures, out of spec strength and permeability, fabric shrinkage concerns, bag punctures and significant dimensional issues.

Table 6. Typical Bag Quality Control Program

Fabric	**Bags**
• Construction • Tensile • Permeability • Mullen Burst • MIT Flex Endurance • Finish • Fabric Thermal Stability (% Shrinkage) • Organic Matter (% LOI) • **Filtration Performance**	• Inspect for general quality of workmanship • Length as fabricated • Length under tension • Cuff to thimble & cap mate • Cage Fit
Thread	**Hardware**
• Material • Strength	• Caps • Rings • Compression Bands

Bag Monitoring

Once the bag set is installed and operating, a bag monitoring program is undertaken. Bag monitoring has as its purpose: 1) To determine the retention of strength and flow characteristics of a bag set with on-stream time, 2) Aid in determining the useful life and scheduling the replacement of a bag set and 3) Provide a tool in assisting the client or his agent in troubleshooting a baghouse.

The monitoring program normally includes permeability and strength. Early on the MIT Flex Test (ASTM D2176)[20] proved to be the leading indicator of bag failure for woven glass bags; more recently it has also proven to be a valuable early warning tool for P-84 and PPS felts as well. Each program is custom designed in terms of tests conducted as well as frequency and location of bag "pulls". The Bag Monitoring Program is a crucial element and cost saver when it comes to bag replacement timing.

SUMMARY

ETV/ASTM/ISO Filtration performance testing is a new tool which provides a major step forward in assuring the ability to achieve fine particle emission control. Implementation of Rule 1155 and Rule 1156 in the SCAQMD in California and the U.S. EPA's OAQPS memorandum to the Regional Air Division Directors should increase the usage of ETV/ASTM-verified filtration media in the United States, while the ISO test should provide filter/fabric suppliers with a level international playing field. A comprehensive fabric and bag QA/QC program including filtration performance can greatly reduce the risk of premature emissions, failure to meet emission performance guarantees as well as code compliance issues and fines. A well planned and executed Bag Monitoring Program can identify when the bag set is approaching "end of life" and exposure to high risk of bag failure. It may not predict the exact timing of the bag set end of life, but it can provide the time frame between premature costly bag replacement and even more costly catastrophic bag set failure.

REFERENCES

1) Trenholm, A.; Mycock, J.; McKenna, J.; Kosusko, M. The Evolution of Improved Baghouse Filter Media as Observed in the Environmental Technology Verification Program, Paper # 176. *Proceedings of the 101st A&WMA Annual Conference & Exhibition*, Portland, OR, June 24-27, 2008.

2) ASTM 6830-02 (2008). Standard Test Method for Characterizing the Pressure Drop and Filtration Performance of Cleanable Filter Media. *ASTM Standards on Disc,* Volume 11.07; ASTM International, 2009.

3) ISO/FDIS 11057. Air quality – Test method for filtration characterization of cleanable filter media, Status: Under Development. International Organization for Standards Web Site. http://www.iso.org/iso/catalogue_detail.htm?csnumber=50020 (accessed Mar. 2011).

4) *Integrated Review Plan for the National Ambient Air Quality Standards for Particulate Matter;* EPA 452/R-08-004; U.S. Environmental Protection Agency, National Center for Environmental Assessment, Office of Research and Development: Research Triangle Park, North Carolina, March 2008. EPA Web site. http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_2007_pd.html (accessed Nov. 2010).

5) McKenna, J. D.; Turner, J. H.; McKenna, J. P., Jr. *Fine Particle (2.5 microns) Emissions Regulations, Measurement, and Control*; John Wiley & Sons, Inc., Hoboken, New Jersey, 2008; pp 10-11.

6) U.S. Environmental Protection Agency. Environmental Technology Verification Program, ETV website: www.epa.gov./nrmrl/std/etv/vt-apc.html#bfp (accessed November 2010).

7) Final 2007 Air Quality Management Plan, http://aqmd.gov/aqmp/07aqmp/index.html

8) American Lung Association, Most Polluted Cities. http://www.stateoftheair.org/2010/city-rankings/most-polluted-cities.html

9) The Benefits of Meeting Federal Clean Air Standards in the South Coast and San Joaquin Valley Air Basins. Jane V. Hall, Ph.D., Victor Brajer, Ph.D., California State University Fullerton, CA & Frederick W. Lurmann, M.S., Sonoma Technology, Inc., Nov. 2008.

10) Health and Environment – Particulate Matter http://www.epa.gov/pm/health.html

11) Particle Pollution and Your Health, http://www.epa.gov/pm/pdfs/pm-color.pdf

12) South Coast Air Quality Management District Rule 1156 – Further Reductions of Particulate Emissions from Cement Manufacturing Facilities, Adopted November 4, 2005; and Staff Report of Rule 1156, M. Pham, P.E., November 4, 2005.

13) South Coast Air Quality Management District Rule 1155 – Particulate Matter (PM) Control Devices, Adopted December 4, 2009; and Staff Report of Rule 1155, J.H. Lee, Ph.D., December 2009.

14) Page, S. D. Office of Air Quality Planning and Standards: Memorandum: Use of New ASTM Performance Verifications for Baghouse Media, Sept. 26, 2007.

15) McKenna, J. D.; Clark, C.; Williamson, T. The Impact of PM Legislation on Baghouse Technology. *Filtration News* **2010**, 29, 20-24.

16) VDI 3926, Part 2. Testing of Filter Media for Cleanable Filters under Operational Conditions; Verein Deutscher Ingenierure, December 1994. Available from beuth Verlag GmbH, 10772 Berlin, Germany.

17) ASTM Method D737-04 (2008). Standard Test Method for Air Permeability of Textile Fabrics. *ASTM Standards on Disc*, Volume 7.01; ASTM International, 2009.

18) ASTM Method D3786/D3786M-09. Standard Test Method for Bursting Strength of Textile Fabrics-Diaphragm Bursting Strength Tester Method. *ASTM Standards on Disc*, Volume 7.01; ASTM International, 2009.

19) ASTM Method D5035-06 (2008): Standard Test Method for Breaking Force and Elongation of Textile Fabrics (Strip Method). *ASTM Standards on Disc*, Volume 7.02; ASTM International, 2009.

20) ASTM Method D2176-97 (2007): Standard Test Method for Folding Endurance of Paper by the M.I.T. Tester.

KEYWORDS

Baghouse, Particulate Emissions, Verification