Future Boiler MATS Regulations & Baghouse Emission Concerns

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ABSTRACT

Ever since the 1970 Clean Air Act was made law, the particulate emission requirements have become more and more stringent. Currently, most coal fired utility boilers and industrial boilers have particulate emission code limits in the range of 0.01 to 0.03 pounds per million Btu (lb/mmBtu). The Mercury and Air Toxics Rule (MATS) specifies that as of 2015, any "new" boiler (constructed after May, 2011) will have limits of 0.001 lb/mmBtu. As particulate control has moved towards fine particle control, the baghouse has become the control device of choice for both industrial and utility coal fired boilers. The possibility of an emission limit of 0.001 lb/mmBtu raises two questions:

1) Is the current baghouse capable of emission control at this lower level?
2) If it is capable at this level, how many bags can fail before the baghouse is no longer in compliance?

This paper will explore potential answers to the above two questions. The following two issues will be reviewed and addressed:

1) The current fabric emission control capability both in terms of lab and field data will be addressed. This will be complemented with a discussion of the need for more conservative baghouse designs and greater preventive maintenance programs.
2) A mathematical model developed from first principles, which determines the baghouse outlet emission level as a function of the sudden rupture of one or more filter bags will be reviewed. Illustrative examples are provided for a number of different bag failure assumptions. This exercise is then used to provide some general guidance as to the need for immediate response when one or more bags fail.

INTRODUCTION

Ever since the 1970 Clean Air Act was made law, the particulate emission requirements have become more and more stringent. In 2006 the U.S. Environmental Protection Agency (EPA) promulgated a revised $PM_{2.5}$ particulate standard (see Table 1).[1] In 2011 the EPA considered revising particulate matter standards on the basis of the most current assessment of the scientific information. The EPA's Clean Air Interstate Rule (CAIR) for 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.[2,3]

The EPA issued the final Mercury and Air Toxics Standards (MATS) on 12/16/2011. This standard could possibly require 40% of all coal fired power plants to add air pollution control systems to control mercury and other air toxics. The MATS (also known as the Utility MACT Rule) are the first ever national standards to reduce mercury and air toxics from approximately 1400 coal and oil fired electric utility plants in the USA. Compliance within 3 to 4 years is required. It is noted that the limit for particulate includes a limit for discrete particulate only and thus does not include condensables.[4] The fine PM is seen as a surrogate for the metal toxics, most of which are discrete particles. Publication of the final MATS in February of 2012 brought about a firestorm of legal challenges. This has left the impression that the final details on timing and even levels of control are an open question. In any case, fabric filters will be one of the more important technologies utilized to achieve the reductions in primary fine particulate emissions.

Table 1. EPA Particulate Matter Standards from 1997 and 2006[1]

	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

Currently, most coal fired utility boilers and industrial boilers have particulate emission code limits in the range of 0.01 to 0.03 lb/mmBtu. Proposed codes indicate that new coal fired boilers in about 2015 could have limits of 0.001 lb/mmBtu. As particulate control has moved towards fine particle control, the baghouse has become the control device of choice for both industrial and utility coal fired boilers.

CURRENT BAGHOUSE CAPABILITY

Filter Media testing of filtration performance has shown that “current test method non-detect” particulate emission levels are achievable. Fabric filter baghouses have been utilized for more than a century to control particulate emissions, and typically the current selection criteria have focused first on cost, operating cost and bag life. The key criteria may well change; and the emission control performance, especially fine particle control at very high levels, may become a dominant consideration.[2,3]

In the early 1990s the 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 (17 percent) in direct $PM_{2.5}$ from man-made sources was made between 1993 and 2002. 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.[2,3]

Research and development activities centered in the following three areas:

1) 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.[2,3]

2) 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. 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.[2,3]

3) 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 the EPA's National Risk Management Research Laboratory, has, as of 2012, verified the performance of 30 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.[5]

ASTM International (formerly known as the American Society for Testing and Materials) and International Organization for Standardization (ISO) test methods have also been established. These methods have evolved from the Verein Deutscher Ingenieure (VDI) and EPA test methods (see Table 2).[2,3]

Table 2. Summary of the Evolution of Standard Test Methods[2,3]

	EPA/ETV	**ASTM International**	**ISO**
YEAR	2000	2002	2011
I.D.	BFP	Method D6830	Method 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	2 m/min.(120 m/h)

DUST (Concentration)	Pural NF 18.4 g/dscm	Pural NF 18.4 g/dscm	Pural NF 5.0 g/m^3
CLEANING	Pulse-jet	Pulse-jet	Pulse-jet

The results of the ETV/BFP Program have shown that an outlet loading of < 0.0001 grains/actual cubic feet per minute (gr/acfm) is achievable with "cutting edge" commercially ready baghouse filtration products.[5,6] The field results of baghouse performance falls far short of the ETV and ASTM International lab results.[7] If the two were to be brought closer together, it would seem that much more rigorous baghouse preventive maintenance programs would be called for as well as quick corrective action programs enforced when slight emission leaks are detected. Keeping the dust from contaminating the "clean side" of the baghouse is essential.

OUTLET EMISSIONS AS A FUNCTION OF BAG RUPTURE

Baghouse design, performance and use can be significantly impacted by bag failure(s) in the unit. More stringent air pollution regulations and the environmental risks associated with emissions from baghouses have increased concern with the effect of bag failures on baghouse outlet loading. This section addresses this issue.

The highest source of maintenance and maintenance cost in baghouses are generally the filter bags. All bag sets have a finite lifetime which will vary by application, installation, operating parameters, fabric type, and so on. Typical causes of bag failure are:

- High A/C abrasion
- Metal-to-cloth abrasion
- Bag-to-bag abrasion
- Inlet velocity abrasion (on inside-outside cleaning)
- Chemical attack
- Accidents
- Upset conditions (e.g., temperature)
- Thread mismatch
- Cuff mismatch

In addition, each bag in a set may have a different life as a result of fabric quality, bag manufacturing tolerances, location in the collector and variation in the bag cleaning mechanism. Any one or a combination of these factors can cause bags to fail. This means that a baghouse will experience a series of intermittent bag failures until the failure rate requires either failed bag replacement or total bag replacement. Typically, a few bags will fail initially or after a short period of operation due to installation damage or manufacturing defects. The failure rate should then remain very low until the operating life of the bags is reached, unless a unique failure mode is present within the system. The failure then increases, normally at a near exponential rate. Industry often describes this type of failure rate behavior as that similar to a "bathtub" curve.[8, 9]

The importance of when to correct/replace a broken bag will depend on the type of collector and the resultant effect on outlet emissions. In "inside bag collection" types of collectors, it is very important that dust leaks be stopped as quickly as possible to prevent adjacent bags from being abraded by jet streams of dust emitting from the broken bag. This is called the "domino effect" of bag failure. "Outside bag collection" systems do not have this problem, and the speed of repair is determined by whether the outlet opacity has exceeded its limits. Often, it will take several broken bags to create an opacity problem and a convenient maintenance schedule can be employed instead of emergency maintenance.

In either type of collector, the location of the broken bag or bags has to be determined and corrective action taken. In a non-compartmentalized unit, this requires system shutdown and visual inspection. In inside collectors, bags often fail close to the bottoms, near the tube sheet. Accumulation of dust on the tube sheets, the holes themselves, or unusual dust patterns on the outside of the bags often occurs. Other probable bag failure locations in reverse-air bags are near anti-collapse rings or below the top cuff. In shaker bags, one should inspect the area below the top attachment. Improper tensioning can also cause early failure. In outside collectors, which are normally top-access systems, inspection of the bag itself is difficult; however, location of the broken bag or bags can normally be found by looking for dust accumulation on top of the tube sheet, on the underside of the top access door, or on a blow pipe.

If the system is compartmentalized, the search for broken bags can be narrowed by monitoring the stack while isolating one known compartment at a time. Through an opacity monitor, and sometimes visual observation of the stack, the compartment containing broken bags can be identified, since the emission will be reduced when a compartment containing broken bags is isolated from the system. One of the techniques for locating failed bags is the use of fluorescent or phosphorescent powder and an ultraviolent light. The powder is injected into the inlet gas stream and the ultraviolet light used to scan the clean-air side of the collector. Very small leaks can be detected from the glow of the powder under the ultraviolet light where it has penetrated the clean air plenum.

Individual bags within a compartment should not be replaced with clean bags, as they will filter a much higher volume of air than the older dust-laden bags, due to their lower resistance. This higher filtering velocity could cause permanent "blinding" and high pressure drop or early failure through dust abrasion. Instead, the broken bag should be tied off or plugged up. In inside collection bags where the failure has not occurred too close to the tube sheet, the bag should be cut, tied, and stuffed into its hole. For outside collection bags and inside collection bags with holes too close to tie, a hole plug should be used. The collector manufacturer can probably supply hold plugs or they can be made from steel plate with proper gasketing or heavy sand bags made from the same material as the filter bags. US Patent 4,297,113 deals exclusively with the bag failure problem; and, if properly utilized, can eliminate the bag failure problem in baghouses over the lifetime of the unit.[10]

Further action will be dictated by increased pressure drop. As the number of bags taken out of service rises, so will the pressure drop. At some point there will be a need to replace the broken bags. When this occurs, it is sometimes recommended that one replace all broken bags with used bags from one designated compartment. One should also replace all bags in the designated compartment with new bags and damper the flow into that compartment until a sufficient dust cake has been developed. Extra “used” bags for future replacement should be stored.

Care should also be taken not to damage adjacent bags and to properly reinstall the new bag. This operation should not be rushed and as a good working environment as possible should be provided. Errors here will only create more problems later.

It should be noted that a mechanism and design procedure is available to automatically “cap” broken bags, thus reducing the need for bag replacement during operation in many applications.[10] Applying this can in many situations eliminate the need for any bag replacement over the lifetime of the baghouse.

Bag Failure Model

The effect of bag failure on baghouse efficiency can be described by the following equations:[11, 12, 13]

$$E = \frac{QI-QO}{QI} = \frac{I-O}{I} \quad \textbf{(Eq. 1)}$$

$$P^{*} = 1 - E \quad \textbf{(Eq. 2)}$$

$$P^{*} = P + P_c \quad \textbf{(Eq. 3)}$$

$$P_c = \frac{0.582}{\Phi} * \sqrt{\Delta P} \quad \textbf{(Eq. 4)}$$

$$\Phi = \frac{Q}{Ld^2\sqrt{t+460}} \quad \textbf{(Eq. 5)}$$

where:

d = Bag (or thimble) diameter, inches
E = Mass collection efficiency
I = Inlet dust loading
L = Number of broken bags
O = Outlet dust loading before bag breakage
P^* = Penetration after bag failure
P = Penetration before bag failure
P_c = Contribution of broken bags to P^*; penetration correction term
ΔP = Pressure drop, inches of H_2O
Φ = Dimensional parameter
Q = Volumetric flow rate of contaminated gas, acfm
t = temperature, °F

The above equations will be referred to as the Theodore and McKenna (TAM) model in the development to follow.

An illustrative example is provided below which demonstrates the applicability of the TAM model in describing the effect of bag failure on baghouse outlet loading and/or overall particulate collection efficiency.

Illustration Example

A baghouse has been used to clean a particulate gas stream. There are 11,648 bags that are 5 inches in diameter in the unit and 1,500,000 acfm of dirty gas at 300°F enters the baghouse with a loading of 2.0 gr/acfm. Current local EPA regulations state that the outlet particulate loading should not exceed 0.012 gr/acfm. If the system operates at a pressure drop of 6.0 inches H_2O, how many bags can fail before the unit is out of compliance? The TAM model applies and all contaminated gas emitted through the broken bags may be assumed the same as that passing through the tube sheet thimble.

The efficiency E and penetration P^* based on regulatory conditions from Eq. 1 and Eq. 2 are:

$$\mathrm{E} = \frac{2.0 - 0.12}{2.0} = 0.994 = 99.4\%$$

$$\mathrm{P}^* = 1 - 0.994 = 0.006 = 0.6\%$$

The penetration term P_c associated with the failed bags from Eq. 3, assuming that the current outlet loading is zero, is then:

$$\mathrm{P_c} = 0.006 - 0 = 0.006$$

Writing Eq. 5 in terms of the number of broken bags, L, that can fail before the unit is out of compliance gives the following:

$$\mathrm{L} = \frac{\mathrm{Q}}{\Phi \mathrm{d}^2\sqrt{\mathrm{t}+460}} \qquad \textbf{(Eq. 6)}$$

Solving Eq. 4 for Φ and inserting into Eq. 6 above gives:

$$\mathrm{L} = \frac{\mathrm{Q}^*\,\mathrm{P_c}}{(0.582)\mathrm{d}^2\sqrt{\Delta \mathrm{P}}\sqrt{\mathrm{t}+460}} \qquad \textbf{(Eq. 7)}$$

The number of bag failures that the system can tolerate and still remain in compliance is calculated as:

$$\mathrm{L} = \frac{(1{,}500{,}000)(0.006)}{(0.582)(5)^2\sqrt{6}\,\sqrt{300+460}}$$

$$L = 9.2 \text{ broken bags}$$

Thus, if 9 bags fail, the baghouse is out of compliance.

More stringent regulatory requirements in the future may not allow for many broken bags before causing the baghouse to be out of compliance as shown in Table 3. As can be seen in Table 3 if the emission code is tightened to an overall baghouse outlet of 0.0012 grains/acfm, a single broken bag will result in the unit being out of compliance. This being the case, the importance of a rigorous implementation of QA/QC, bag monitoring, and preventative maintenance programs will become all the more critical.

Table 3. Number of Broken Bags for Code Allowable Emissions

Code	**Allowable Emissions (grains/acfm)**	**Number of Broken Bags Before Out of Compliance**
Current	0.012	9.2
Possible Future	0.0012	0.92
Possible Future	0.0005	0.38

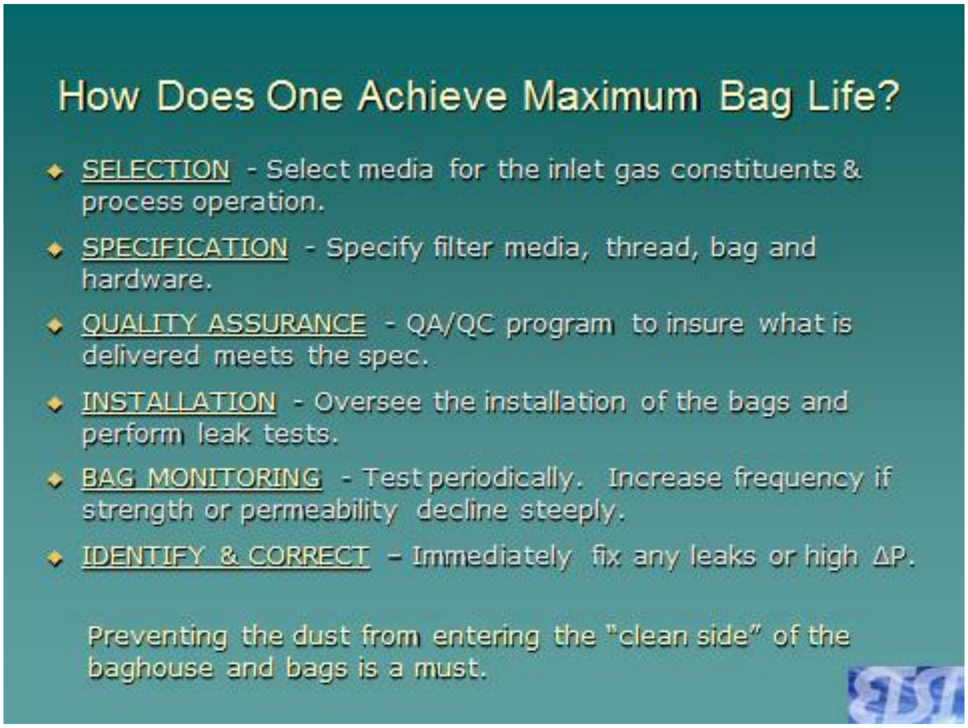
CONCLUSIONS

Assuming that the particulate emission codes will continue to become ever more stringent, two of the questions raised regarding baghouse operation and design are:

1) How do I achieve and maintain compliance?
2) How do I achieve maximum bag life?

The initial baghouse design detail is critical and key in the choice of a conservative bag-to-cloth ratio. The bag is the heart of the baghouse and there are six activities which are vital to high level emission control and long lasting bags. These six are Bag Selection, Specification, Quality Assurance, Installation, Monitoring, and Maintenance. These activities are shown in Figure 1. While many if not all of these may seem obvious, it is the depth of detail, breathe, rigor and consistent application that is the difference between success and failure. Preventing the dust from entering the clean side of the baghouse is the critical output of the six activities. Especially in the case of the pulse jet, dust on the clean side is a guarantee of greatly shortened bag life and loss of compliance.

Figure 1. How Does One Achieve Maximum Bag Life?



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KEYWORDS

Baghouse, Particulate Emissions, Mercury and Air Toxics Standards (MATS)