PM Incremental Improvement Memo

Final
March 2023
Project 13527-002
Eastern Research Group, Inc.

Prepared by

Sargent & Lundy

55 East Monroe Street • Chicago, IL 60603 USA • 312-269-2000

LEGAL NOTICE

This analysis ("Deliverable") was prepared by Sargent & Lundy, L.L.C. ("S&L"), expressly for the sole use of Eastern Research Group, Inc. ("Client") in accordance with the agreement between S&L and Client. This Deliverable was prepared using the degree of skill and care ordinarily exercised by engineers practicing under similar circumstances. Client acknowledges: (1) S&L prepared this Deliverable subject to the particular scope limitations, budgetary and time constraints, and business objectives of the Client; (2) information and data provided by others may not have been independently verified by S&L; and (3) the information and data contained in this Deliverable are time sensitive and changes in the data, applicable codes, standards, and acceptable engineering practices may invalidate the findings of this Deliverable. Any use or reliance upon this Deliverable by third parties shall be at their sole risk.

This work was funded by U.S. Environmental Protection Agency (EPA) through Eastern Research Group, Inc. (ERG) as a contractor and reviewed by ERG and EPA personnel.

Purpose

This report summarizes potential upgrades or modifications to existing particulate control devices to incrementally improve the reduction of filterable particulate matter (PM). The following sections provide a brief background of PM emissions, description of the potential improvement options, a summary of potentially achievable performance and any performance and/or application limitations.

Background

PM composition and emission levels are a complex function of fuels fired, boiler firing configuration, unit operation, maintenance practices, and pollution control equipment utilized (including equipment designed to reduce emissions other than PM). Uncontrolled PM emissions from coal-fired boilers include the ash from combustion of the fuel, noncombustible metals present in trace quantities, and unburned carbon resulting from incomplete combustion. In pulverized coal systems, combustion is almost complete; thus, the emitted PM is primarily composed of inorganic ash residues. Other sources of PM include inorganic acid gases and organic compounds in the flue gas.

PM can be classified as either “filterable” or “condensable.” Basically, filterable PM is composed of solids that can be captured on a filter media, while condensable PM is a gas at the sampling location which condenses into a liquid or solid immediately after leaving the stack. The terms “filterable” and “condensable” describe how the particulate matter is captured in the sampling train. Filterable PM is captured in the filtering media located in the front-half of the sampling train. Condensable PM passes through the filter media and is captured in the sampling train impinger solution.

Particulate Matter Categories
Total PM (includes filterable and condensable)
PM_{10} (includes filterable < 10 microns and condensable)
$PM_{2.5}$ (includes filterable < 2.5 microns and condensable)

Current Particulate Control Devices Filterable PM Performance

All existing electric generating units (EGUs) are currently equipped with either an electrostatic precipitator (ESP) and/or a fabric filter (FF)/baghouse. Based on 2017 third quarter filterable particulate matter (PM) emissions reported to the Environmental Protection Agency (EPA), both of these control technologies have been demonstrated to be able to achieve the current Mercury and Air Toxics Standard (MATS Rule) filterable PM limit[1] of 0.030 lb/MMBtu consistently. Review of public data shows that many units are achieving emission limits well below the current MATS limit, achieving emissions at and/or below the low emitting EGU threshold (0.015 lb/MMBtu) and the new source pollution standard (NSPS) (0.010 lb/MMBtu).

When considering upgrades to existing pollution control equipment for meeting a permitted emission level, utilities will typically request vendors to guarantee an emission rate that allows for some operating margin below the permitted rate to ensure they consistently achieve compliance. Vendors in turn will

---

[1] Filterable PM emissions can be used to demonstrate compliance with the MATS rule non-mercury (Hg) hazardous air pollutant (HAP) metal requirements.

include their own design margin to ensure performance is achieved to reflect contractual make right conditions and/or liquidated damages terms and conditions with the utility as part of the supply contract. This trend is anticipated to be reflected in figure below.

Based on S&L's recent industry experience, the lowest filterable PM emission rates that an ESP supplier has been willing to guarantee is 0.030 lb/MMBtu for a new and/or completely rebuilt ESP. Baghouse suppliers have historically offered lower filterable PM emission guarantees at 0.010 lb/MMBtu for a new baghouse with some vendors considering guaranteeing even lower emissions for future applications. Therefore, to achieve emission levels equivalent to or lower than the NSPS standard, a new baghouse would likely be required to guarantee these emissions are consistently achieved.

Improvements to existing particulate control devices may allow EGUs to achieve incrementally lower emission rates. Improvements to existing particulate control devices will be dependent on a range of factors including the design and current operation of the units, which is not documented in public forums. In addition, it is not known if any of these potential improvements have already been implemented on a specific unit. As shown in the figure below, many ESPs are operating at emissions equivalent to or lower than the NSPS standard. Unfortunately, the details of how those units' ESP designs, upgrades, and operation are not publicly available; therefore, it is not possible to tie a specific performance improvement to a specific set of ESP upgrades. However, it is clear that emissions levels down to 0.010 lb/MMBtu and below are achievable in most ESP applications based on the reported emissions data.

Improvements to Particulate Control Devices Filterable PM Emissions

Installation of a new ESP or baghouse is not discussed in this report, but costs and performance for those systems are covered by stand-alone modules previously developed by S&L. Improvement options that would be characterized as major retrofits, such as replacement of an existing control device or the following upgrades or modifications, were not considered in this memo due to the extent and cost of the retrofit:

- ESP Expansion – Increasing the specific collecting area (SCA) and/or decreasing the velocity through the ESP, whether implemented by adding an ESP in parallel (i.e. piggy-back or side-wing) or adding another field in the ESP outlet nozzle, would be site specific in regards to available space in/around the ESP casing(s).

- ESP Conversion – Converting an existing ESP to a baghouse would require an extended outage, extensive modification to the ESP casing(s), and may also require fan modifications and ductwork reinforcing to accommodate the increased pressure drop. Furthermore, converted ESP performance would be limited based on the air to cloth (A/C) ratio achievable within the geometry limitations of the existing ESP casing. While this would likely be able to achieve some emission reduction it is unlikely this would achieve outlet emission rates consistent with a new stand-alone baghouse.

- Baghouse Expansion – Baghouse expansions can be achieved by reducing the A/C ratio by increasing the cloth area either by increasing the bag length (would only apply to systems not already using 10 meter bags) or adding an additional compartment(s). Most baghouses are not designed with spare height; therefore, a baghouse expansion would require significant modification to the existing control equipment.

- Baghouse Type Conversion – Only applicable to units with reverse gas baghouses to implement a pulse jet design more widely used in industry and achieve capability of online cleaning.

- Wet ESP (WESP) Addition – Only applicable to units with a WFGD system, a WESP installed downstream of a WFGD functions in a similar manner as a conventional ESP to remove particulates including micron-sized sulfuric acid aerosols and potentially other condensable particulates from the flue gas stream.

- Alternative Polishing Controls – Adding an additional particulate collection device downstream of the existing equipment, especially if using an advanced technology such as ceramic or metal filter elements would likely reduce PM emissions. However, the addition of a new control system, including the associated equipment and components would be extremely costly.

ESP Improvement Options

The following ESP improvement options have been limited to upgrades or enhancements to existing equipment. It should be noted that all costs mentioned in the following sections for the incremental improvement options are provided in 2021 dollars. Escalation is not included in the estimate because all costs are provided in 2021 dollars and are not representative of recent COVID and inflation related pricing increases.

ESP Fly Ash Resistivity Enhancement

Changes in fly ash resistivity, or a particle's resistance to transferring charge, can limit an ESP's collection efficiency. The resistivity of ash is dependent on the chemical composition of the fly ash, flue gas temperature and the sulfuric acid (SO_3) and moisture content of the flue gas. Particles with high resistivity are difficult to charge and remove charge, requiring currents/voltages to be reduced to prevent the occurrence of reverse ionization, or back corona, and thereby reduces the ESP collection efficiency. Particles with low resistivity are easily charged, but readily release charge. Although these low resistivity particles generally have no significant effect on electrical operating conditions, particles can easily re-entrain back into the flue gas increasing the PM emissions from the ESP.

Performance can be enhanced through the use of chemical conditioning agents, water injection and/or operation at lower inlet flue gas temperatures to modify the ash resistivity. In the event an existing ESP implements one of these methods, it may be possible to optimize the systems settings, its effects on resistivity and incremental improvements to current and voltages. If an existing ESP system does not utilize one of these methods, one or a combination of methods could be implemented for a potential incremental improvement in PM emissions.

Applicability and Typical Performance

It is assumed that an ESP would have been appropriately designed and/or modified for the fuels fired at a facility and to account for any other process changes, such as the addition of other pollution control systems that would impact fly ash resistivity (i.e. low NOx burners, activated carbon injection, dry sorbent injection, etc.) in order to maintain compliance with permitted PM emissions. Therefore, the applicability of this option will be unit specific and likely not applicable to most units.

ESP performance improvements through the use of a conditioning agents, water injection and/or temperature control systems can be estimated using the EPA ESP ESPVI 4.0W modeling computer program (See EPA Contract No. 68-C-99-201, Work Assignment 4-30), but require significant site-specific input to evaluate. The installation and use of one of these methods with existing ESPs are not reported and do not appear to be documented in the public domain, and as such the applicability of this option would be difficult to assess on a fleetwide basis.

Air In-Leakage Reduction

The amount of air in-leakage from a unit's economizer outlet to the stack will change based on load cycling, ambient temperatures, operating pressures (negative suction) and station maintenance practices. As such, the amount of air in-leakage can also increase over time until the next major maintenance outage. A significant amount of air in-leakage will inherently increase the flue gas volumetric flow rate, flue gas velocities and overall pressure drop through the flue gas path, but also will reduce treatment residence time through the particulate collection device and may impact its particulate removal capabilities. Typical maintenance at a power plant includes monitoring air in-leakage and maintaining and repairing equipment that may contribute to significant in-leakage, such maintenance activities including replacing seals, patching ductwork, etc.

The major source of air in-leakage typically occurs across the air preheater (APH) seals; however, this may vary based on the back-end pollution control equipment implemented on the unit and the age of the unit/equipment. Long term leakage rates would be dependent on the frequency of APH seals replacement, the APH design, and installed air in-leakage mitigation system(s). Typically, seals are replaced every three (3) years with other miscellaneous maintenance activities/adjustments completed based on outage inspections.

Assuming a facility will have already implemented these best practices to attempt to minimize APH air in-leakage, committing to a more frequent replacement of APH seals may result in slightly better and/or more consistent performance of an ESP and may result in incremental PM reductions; however, it is likely that these improvements would be negligible or difficult to measure. These reductions would be limited based on the replacement schedule, as it will likely not be economical or feasible for a facility to schedule an outage every year to replace the seals. Note that any improvements above and beyond routine maintenance, such as implementation of an advanced air-heater sealing system, leakage control system, automatic seal adjustment system, etc., would require a major overhaul of the air preheaters and are not considered.

Also, if it is found that the APH seals are not the largest contributor of air in-leakage, further analysis and likely in-duct testing by a 3rd party testing contractor would be required to determine other air in-leakage contributors both up and downstream of the APH. Once identified, additional investigation/analysis to quantify the amount of in-leakage at each source and determine if it can be minimized would be required.

Applicability and Typical Performance

The applicability of this option will be unit specific. In the event facilities do not currently replace their APH seals every three (3) years (or more frequently), doing so may result in an incremental improvement in PM reductions. This option is likely only applicable to older units that do not currently utilize modern APH designs with state-of-the-art systems to minimize air in-leakage, i.e. plants that operate with leakage rates of ≥ 20% when operating at full load conditions.

APH designs, installed air in-leakage mitigation system(s), current air in-leakage rates and maintenance practices are not documented in public forums. Overall flue gas path air in-leakage may be able to be estimated based on assumed operating conditions and stack O_2 concentrations, if publicly available (note that stack CEMS may use O_2 or CO_2 as a diluent for other emission reporting purposes). Air in-leakage rates would also not be guaranteed by APH seal vendors. As such, this would be difficult to regulate, and if implemented could potentially be prohibitive enough to significantly limit the availability of the unit or require additional costly outages.

In order to target lower outlet emissions, the APH seal replacement frequency could be increased but air in-leakage will still increase over time until the next replacement outage. Therefore, replacement every year may be required in order to have a noticeable and consistent reduction in PM emissions.

Any incremental particulate removal performance improvements that could potentially be achieved will vary significantly depending on the current air in-leakage, PM emission rates and the maintenance practices/schedule and therefore cannot be estimated on a generic fleet-wide basis.

Costs

Costs will be site specific and dependent on the APH design. Replacing just the APH seals is expected to cost up to $5/kW. In an attempt to maximize any potential reduction in APH air in-leakage, the APH baskets and seals could be replaced, which would likely cost $20-25/kW but could increase based on the APH design. It is also assumed that these costs do not consider outage costs if attempting to replace the APH seals on a more frequent basis. It would take approximately two (2) days to complete the APH seal replacement on one (1) APH but may require additional time for systems with more elaborate APH configurations.

Reduction in air in-leakage would have other co-benefits such as reduced velocity to avoid unnecessary wear an equipment internals and reduced overall flue gas path pressure drop that would potentially result in a minor reduction of auxiliary power consumption of induced draft (ID) fans.

ESP Flow Improvements

Computational fluid dynamic (CFD) modeling and/or physical flow modeling can be used to determine flow improvements required and the design of the flow correction devices. If only considering flue gas flow CFD and/or physical modeling can be completed. However, physical modeling is recommended for fly ash distribution improvements to more accurately predict the drop out and accumulation of fly ash within the flue gas path (CFD modeling can also be completed as well if desired).

Improving the flue gas flow and ash distribution to an ESP will help to enhance its PM removal performance while also reducing flue gas pressure drop. Equal distribution of the bulk of flue gas flow will reduce higher velocities through certain portions of the equipment that may be negatively impacting the equipment residence time. A more balanced distribution of ash to individual casings/compartments may also help to evenly balance the usage and performance of individual components, as well as help to mitigate areas that see accelerated wear (which may help to minimize equipment failures).

Applicability and Typical Performance

It is assumed that an ESP would have been appropriately designed for the applicable standards and recommended best practices based on the installation year of the equipment and fuels fired at a facility. Facilities that changed fuels since the original design, have a wide range of coal suppliers, have less than 1 second of residence time between the last duct transition upstream of the inlet flange, and/or have a chevron type configuration would likely be the best candidates for flow improvements; however, the applicability of this option will be unit specific and may not apply if flow has already been optimized to the greatest extent possible. All of these aspects are not documented in public forums to determine which units this option would be applicable to.

The particulate removal performance improvements that could potentially be achieved will vary significantly depending on current performance and the amount of work completed and therefore cannot be estimated at this time.

Costs

CFD modeling costs (regardless of unit size) could range from $20,000 to $45,000 and could increase depending on the complexity of the modeling, number of cases, and the degree of turning vanes/flow correction devices determined to be required.

Physical flow modeling costs will be based on the unit size and complexity of the scope to be modeled (number of fields, parallel trains, internals, etc.). Typically lines of symmetry are considered in order to save on model costs (i.e. if 2 parallel trains, only model 1). As costs of the physical model are impacted by the amount of materials needed to build the model, the cost of physical modeling cannot be directly scaled based on the unit MW rating (all case specific). For example, a small single casing ESP physical model could cost approximately $25,000 to $30,000 with larger scopes of ductwork and multiple casings costing upwards of $65,000 to $70,000. Therefore, for an average size 600 MW unit, a physical model cost could range from $35,000 to $45,000 depending on the ductwork and casing configuration.

These costs do not include detailed design, fabrication, delivery, or installation of the recommended devices in the flue gas path which would likely cost on the order of $300,000-$700,000 (or more) depending on the size of the unit, and the scope and scale of the modifications. Furthermore, to reduce the outage time required to install the flow correction devices, a more simplified design of the devices such that smaller segments of can fit through an access door may be required; however, doing so may increase the construction/assembly costs.

ESP Component Upgrades

ESP upgrades can potentially include a wide range of scope. Upgrading specific ESP components such as discharge electrodes or TR sets can potentially result in an incremental improvement to an ESP's overall performance. However, typically it is not feasible or as effective to replace or upgrade only one component without also upgrading other components to avoid potential negative side effects caused by other components limitations. For example, high-frequency TR sets can improve the overall efficiency of the ESP, but this can be hampered by the existing discharge electrode design and the plate spacing. If the existing ESP components are not conducive to this incremental retrofit, upgrading the TR sets would also require additional modifications such as increasing plate spacing and/or usage of a more robust discharge electrode type to be feasible. Therefore, upgrade of specific components may actually result in a more significant, partial- or full-rebuild of the ESP, i.e. a major modification.

There may potentially be some minor upgrades or replacements that could improve ESP performance, which could include items such as adding anti-sway systems or stabilization bars to the electrodes, replacing the TR sets, adding rappers and/or optimizing rapping that could also be implemented.

Applicability and Typical Performance

In order to evaluate the applicability of one or more of these potential improvements, information would need to be known about the existing ESPs and their respective operation which is not documented in public forums. In addition, it is possible that some or all of these improvements have already been implemented on an existing ESP. Therefore, the applicability of this option would be difficult to assess on a fleetwide basis.

The ESP performance improvements for the below listed incremental upgrades could be predicted using the EPA ESP ESPVI 4.0W modeling computer program (See EPA Contract No. 68-C-99-201, Work Assignment 4-30), but require significant site-specific input to evaluate.

- Transformer Rectifier (TR) Set Replacement: In the event a facility already has wider plate spacing (16”) and rigid discharge electrodes, high frequency transformer rectifier (HFTR) sets could be considered as an incremental upgrade. Use of HFTR sets could incrementally improve overall ESP performance by providing a more continuous supply of increased power with quicker response times to minimize the effects of sparking. Where applicable, implementation of HFTR sets could achieve as high as 20-30% reduction in filterable particulate emissions. However, the applicability and incremental performance improvement will be based on the ESP casing and components design, unit operating conditions, current performance, and current PM emissions.

- Increased Sectionalization: The reliability of the power delivery into the ESP could be improved by increasing the number of TR sets. This is typically done to either increase the number of energized electrical fields in the direction of gas flow and increase the field current density (for example, going from 3 TR sets to 4 by replacing the last field TR sets with two TR sets) or to increase equipment redundancy by adding parallel equipment to reduce the amount of untreated flue gas in the event some equipment are offline/out of service (for example, going from 3 TR sets to 6). The applicability and incremental performance improvement will be based on the ESP casing and components design, unit operating conditions, current performance, and current PM emissions.

- Discharge Electrode (DE) Upgrades: Weighted wire discharge electrodes (DEs) were used in older ESP designs that are prone to swaying (which may increase sparking) and breakage (that reduces the amount of power distributed). Newer, rigid discharge electrodes (RDEs) couple be implemented on existing ESPs that still utilize weighted wire DEs and has wider plate spacing (16”). In the event the plate spacing cannot accommodate RDEs, a solid metal frame could be implemented with wire DEs that provides a single, rigid frame that would be more easily stabilized.

- Rapping System Upgrades: Units that use tumbling hammer rapping systems to clean inlet flow distribution devices, collecting plates and DEs could implement electromagnetic impact rappers to implement a more efficient, improved cleaning cycle.

- Collecting Plate Replacement: Collecting plates can become warped or damaged over time that can reduce ESP performance. Replacement of the plates in-kind can potentially offer some incremental improvement but would only be expected to attempt to regain originally expected performance.

It is not anticipated that implementing ESP component upgrades as defined in this section could achieve more than a 15% reduction in filterable PM emissions and are not expected to be able to reduce emissions below a limit of 0.010 lb/MMBtu reliably. This would likely only be feasible by implementing a combination of the upgrades discussed in this section together. Achievable reduction and reduced filterable PM limit will be limited based on the current system design and operating conditions.

Costs

Approximate costs of the incremental ESP upgrades listed below are expected to be site specific and may not scale based on the unit kW rating. As such, costs are provided to upgrade specific components.

- TR Set Replacement & Increased Sectionalization: HFTR set pricing may vary depending on the electrical rating but are estimated to cost $25-$40/kW (including options for increased sectionalization). Costs may increase depending on the number of HFTR sets implemented.

- <u>Discharge Electrode (DE) Upgrades:</u> RDEs pricing may vary based on dimensions required but are estimated to cost approximately $20/kW to implement. However, costs may increase based on any challenging site arrangement constraints that prevent installation of modularized/pre-assembled components and/or require a longer outage.

- <u>Rapping System Upgrades:</u> Installing electromagnetic impact rappers to DE frames is estimated to cost approximately $10/kW (including control system upgrades). Retrofitting electromagnetic impact rappers to inlet flow distribution devices and collecting plate frames are estimated be higher due to the higher dust loading, costing approximately $15/kW (including control system upgrades).

- <u>Collecting Plate Replacement:</u> Replacement of 12" plate spacing are estimated to cost approximately $40-50/kW and 16" plate spacing $30-40/kW for 16" plate spacing.

ESP Improvement Options Cost Scenarios

As mentioned previously, a combination of upgrades would likely be required to achieve a measurable reduction in filterable PM emissions. Any incremental particulate removal performance improvements that could potentially be achieved will vary significantly depending on the current system design, operating conditions, current filterable PM emission rates and the combination of upgrades completed. In addition, it is possible that some or all of these improvements have already been implemented on an existing ESP (or APH), meaning that if already implemented on a unit, it would not be applicable as an incremental component upgrade. As this information is not documented in public forums, the applicability, performance improvement, and approximate cost is difficult to quantify on a generic fleet-wide basis. The following table summarizes low, average, and high-cost options that could potentially be applied to existing ESPs to achieve an incremental improvement in filterable PM emissions.

Option	**Minor Upgrades (Low Cost)**	**Typical Upgrades (Average Cost)**	**ESP Rebuild (High Cost)**
Applicability	Air in-leakage rates ≥ 20% at full load conditions <u>and</u> Residence time ≤ 1 sec, chevron design, and/or fuel change since original design	Units with original TR sets, rapping system, and discharge electrode design	Assumes system has not been installed, rebuilt and/or significantly modified in last 10 years
Summary of Improvements	In-Leakage Reduction & Flow Improvements	In-Leakage Reduction, Flow improvements, DE Upgrades, Rapping System Upgrades and TR Set Sectionalization	Complete ESP Rebuild
Estimated Cost	$6-$27 / kW	$45-$65 / kW	$75-$100 / kW
Potential Performance Improvement (Not Guaranteed Performance)	5%-10% reduction in filterable PM emissions; not applicable to units with current emission rates ≤ 0.010 lb/MMBtu	10-20% reduction in filterable PM emissions; not applicable to units with current emission rates ≤ 0.010 lb/MMBtu	Performance limited to 99.9% filterable PM removal (clean conditions)

FF Improvement Options

The following FF improvement options have been limited to upgrades or enhancements to existing equipment. It should be noted that all costs mentioned in the following sections for the incremental improvement options are provided in 2021 dollars. Escalation is not included in the estimate because all costs are provided in 2021 dollars and are not representative of recent COVID and inflation related pricing increases."

Fabric Filter Bag Replacement (Upgraded Materials)

When considering a conventional fabric filter baghouse, no physical baghouse modifications would be feasible to reduce the outlet emission rate (i.e. no change to the air to cloth (A/C) ratio, number of compartments, etc.) but the bag type and maintenance schedule could impact the achievable filterable PM emissions reduction. In general, the lowest filterable PM emissions would be achieved when using a fiberglass bag with polytetrafluoroethylene (PTFE) membrane coating. This will only improve filterable PM emissions reduction efficiency[2] and would only be applicable for units that are not currently equipped with PTFE bags.

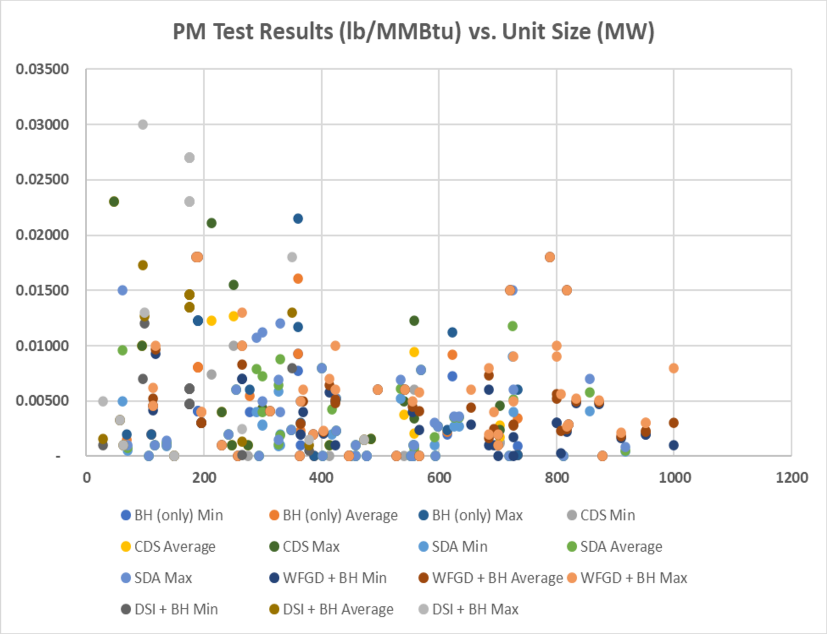
Applicability and Typical Performance

Existing Applications: With the usage of more expensive fiberglass bags with a PTFE membrane coating, it is expected that 0.00375 lb/MMBtu of filterable PM emissions could be achieved but would not be guaranteed by vendors. As such, a best-case scenario would be achieving 0.005 lb/MMBtu. Note that public information on the type of bag used within existing baghouses is not available; therefore, there is no way to know what type of bags are installed in an existing baghouse. Another important consideration for targeting extremely low outlet emissions on a consistent basis is to increase baghouse bag replacement frequency and/or limit the period of time needed to replace broken bags. However, these are maintenance practices that are not reported, would be difficult to regulate, and if implemented could potentially be prohibitive enough to significantly limit the availability of the unit.

A review of existing operation data was performed to determine if the type of bag can be interpreted from the data. Unfortunately, the variability in the operating emissions of existing baghouses fluctuates considerably across different applications and different loads, as shown in the figure below, that no trends could be observed.

---

[2] It should be noted that the degree of filterable PM emissions removal with the use of the PTFE membrane bags will still be subject to particle size and cannot be considered individually appliable to filterable PM_{10} or $PM_{2.5}$ emission incremental reductions nor can it be assumed that the resulting incremental removal attributed to the reduced total filterable PM emissions with the installation of PTFE membrane bags be equally weighted between PM_{10} and $PM_{2.5}$ emissions reductions (i.e. improvement can only be considered for total filterable PM). For example, if a unit's total filterable PM emission was made up of 50% PM_{10} and 50% $PM_{2.5}$ emissions, the total filterable PM emissions achieved with the installation of PTFE membrane bags cannot be assumed to still be made up of 50% PM_{10} and 50% $PM_{2.5}$ emissions, as realistically the improvement would be mostly contributed to by PM_{10} emission incremental reductions (e.g. potentially resulting in 10% PM_{10} and 90% $PM_{2.5}$ emissions).



New Applications: Recent discussions with some baghouse suppliers, have shown that several existing baghouses have recorded consistently low filterable PM emissions. Based on this experience, suppliers may be willing to provide a filterable PM guarantee of 0.005 lb/MMBtu for new baghouses with PTFE bags.

Costs

Recent industry pricing has indicated $125 for a standard bag, $175 for a PTFE bag and up to $250 for a PTFE bag with PTFE membrane. At the current MATS limit, the replacement schedule for a traditional bag is every 3 to 5 years for 6.0 and 4.0 A/C ratio design, respectively and the replacement schedule for PTFE bag is every 2 or 3 years for 6.0 and 4.0 A/C ratio design, respectively.

Fabric Filter Bag Replacement (Increased Frequency)

The main filtering surface in a pulse-jet fabric filter is the fabric of the bag. Once the filter cake builds up, the most effective filtering will occur until the bag becomes plugged and cleaning is required. As such, emissions have been noted to be approximately 50-70% lower in the first six (6) months of operation compared to emissions after a few years of operation.

A typical bag life on a pulse-jet fabric filter that serves as the primary PM collection device (assumed 4.0 A/C ratio) is five (5) years.[3] Bag life can be shorted due to increased bag wear caused by bag abrasion (rubbing against metal cage, high velocities hitting side or bottom of the bag, and/or aggressive cleaning

---

[3] A dry FGD pulse-jet fabric filter bag life is estimated to be three (3) or more years and polishing pulse-jet fabric filter bags are expected to have a longer lifespan assuming a lower ash loading, operating pressure and cleaning frequency required (potentially 6-8 years).

cycles); sustained operation at high pressure drops requiring more frequent pulsing; frequent excursions exceeding the thermal durability (upper temperature limit of the fabric); frequent startups/shutdowns when passing through the water and acid dew points; and/or operation with coal sulfur higher than 2.5% by mass or when SO_3 is greater than 10 ppm.

Assuming a facility will have already attempted optimizing their bag cleaning cycle to minimize bag failures and overall pressure drop through the flue gas path, committing to a more frequent changeout of the bags may achieve significant incremental PM reductions. These reductions would be limited based on the replacement schedule, as it will likely not be economical or feasible for a facility to schedule an outage every 6 months to replace all the bags.

Applicability and Typical Performance

In order to target extremely low outlet emissions on a consistent basis, the bag replacement frequency will need to be increased but will be still limited to only achieving extremely low emissions in the first few months of operation. As emissions typically increase 50-70% after the first 6 months of operation to the design emission rate of the equipment and replacement of the bags every 6 months is not practical, a blended emission rate or rolling emission rate may be required to control this on a realistic basis. As mentioned previously, these are maintenance practices that are not reported, would not be guaranteed by vendors, would be difficult to regulate, and if implemented could potentially be prohibitive enough to significantly limit the availability of the unit or require additional costly outages.

Costs

Incremental costs for this option would be based on the increased replacement frequency compared to current bag changeout schedules (i.e. purchasing more bags than over a given stretch of time). In order to estimate the costs of this option, information would need to be known about the current bag life changeout cycle and emissions after bags are initially installed which is not documented in public forums.

Recent industry pricing has indicated $125 for a standard bag, $175 for a PTFE bag and up to $250 for a PTFE bag with PTFE membrane. At the current MATS limit, the replacement schedule for a traditional bag is every 3 to 5 years for 6.0 and 4.0 A/C ratio design, respectively and the replacement schedule for PTFE bag is every 2 or 3 years for 6.0 and 4.0 A/C ratio design, respectively. Incremental costs could be calculated for increased bag frequency using the following equations, information about the current bag type, quantity, and replacement frequency needs to be known.

Equations:

Current Replacement Costs ($/year) = (# of bags) x (bag price) / (current replacement frequency per year)

New Replacement Costs ($/year) = (# of bags) x (bag price) / (new replacement frequency per year)

Incremental Replacement Costs ($/year) = New Replacement Costs – Current Replacement Costs

The required increased frequency of bag replacement would be subject to the incremental improvement in filterable PM emissions required.

With an increased frequency of bag replacement, it is likely that some bag replacements will need to occur outside of a normally scheduled maintenance outage, in which case the cost of a special outage may need to be considered. The duration of any outage required would depend on the number, size, and type of bag as well as their accessibility and connection type to the tube-sheet. Time required for the bag replacement could also be attempted to be reduced by the size of the crew and utilizing more than one (1) shift per day. Therefore, any additional special outage durations will be site specific, but would be expected to be similar to a short-term outage (i.e. less than one (1) week).

Appendix A: Other $PM_{2.5}$ Incremental Improvements

As $PM_{2.5}$ emissions are made up of particulate less than 2.5 microns in size, condensable PM is likely a larger contributor to these emissions. Contributors/sources to PM2.5 of note are summarized below:

- Sulfuric acid mist is the most widely recognized form of condensable PM emitted by combustion sources. Sulfur emissions from coal combustion consist primarily of SO_2, with much lower quantities of SO_3 and gaseous sulfates. During the combustion process up to 1% of the fuel SO_2 will oxidize to SO_3. In the event that a unit uses a Selective Catalytic Reduction (SCR) control for nitrogen oxides (NOx) control, additional SO_2 will oxidize to SO_3 across the SCR catalyst. As the gas cools, SO_3 will react with available moisture in the flue gas to form H_2SO_4 vapor. At temperatures below the acid dew point, H_2SO_4 will condense to form liquid phase sulfuric acid mist. Sulfuric acid formed in the boiler and emission control systems has a vapor pressure sufficiently low to condense at ambient conditions. Other species that can contribute to condensable PM emissions include other acid gases such as hydrochloric acid (HCl), hydrofluoric acid (HF), and condensable organic compounds.

- Ammonia (NH_3) injected for NOx control may react with SO_3 in the flue gas to form ammonium sulfate ($(NH_4)_2SO_4$) and/or ammonium bisulfate (NH_4HSO_4, also referred to as ABS). When an ammonia-based NOx control system is present, ammonium sulfate and a large portion of the ABS (depending on unit operating conditions) are expected to be present as filterable PM in the flue gas[4] and may cause a slight increase in particulate loading to the particulate collection device. In the event a unit has an ammonia-based NOx control system and a wet flue gas desulfurization (WFGD) system for SO_2 control, a significant portion of the ammonia that may be present in the flue gas can be expected to be removed from the flue gas in the WFGD system. Small quantities of unreacted NH_3 will still be present in the exhaust gas even downstream of a WFGD system. Unreacted ammonia remaining in the flue gas at the stack may be captured in the EPA Test Method 202 impingers where it can react with residual SO_2 and water to form additional $(NH_4)_2SO_4$ or NH_4HSO_4, contributing to measured $PM_{2.5}$ emissions from the unit. Ammonium sulfate compounds formed in the Method 202 impingers are commonly referred to as “pseudo-particulates” or “ammonia artifacts” but may be counted toward contributing to $PM_{2.5}$ emissions from the unit, as they are indistinguishable from true condensable particulates.

In addition to the previously listed options aimed at incremental improvement to filterable PM emissions, the following options have been summarized for consideration when targeting incremental $PM_{2.5}$ emissions improvements.

---

[4] Ammonia sulfate formed in the flue gas would be present as a filterable particulate. Depending on unit operating conditions and ammonia concentrations in the flue gas, once ABS is formed it will be in solid phase below 300°F (its melting point), liquid phase above 300°F, and gaseous phase above 914°F (its boiling point). ABS will generally condense from the gas stream and form a sticky deposit when passing through an air preheater’s heat transfer surface when temperatures range from 380 – 450°F. As majority of units’ particulate collection devices are downstream of an air preheater, ABS may be present as a liquid aerosol; however, after passing through the air preheater, it is expected that ABS would adhere to fly ash particles and be able to be captured in a particulate removal device.

Elimination of WFGD Bypass (If Present)

Some units may still operate a flue gas bypass around a WFGD system (varied percentages of the total flue gas) to re-heat the flue gas downstream of the WFGD and allow the unit to continue using an existing dry stack. WFGD systems can capture a large portion (95%+) of PM emissions with an aerodynamic diameter larger than 10 microns. Sulfuric acid mist emissions, sometimes the primary constituent of condensable $PM_{2.5}$ emissions, will be removed to some extent in the WFGD. Similarly, other acid gases remaining in the flue gas, which can contribute to increased condensable PM emissions, would be effectively removed in the WFGD. Therefore, treating 100% of the flue gas stream in the WFGD would reduce emissions of acid gases, and could result in an incremental reduction in PM emissions, including filterable and condensable emissions.

However, assuming the WFGD has the capability to treat 100% of the flue gas, eliminating the bypass would result in a saturated flue gas exhaust stream, and could require the construction of a new stack designed for saturated flue gas conditions (or alternatively, an existing dry stack could be relined/retrofitted to withstand the saturated gas). If the existing WFGD system is not capable of treating 100% of the flue gas, this would also require potentially extensive modifications.

Applicability and Performance Improvement

The applicability of this option would be limited to specific units that still operate a WFGD bypass. Eliminating the bypass would result in an incremental reduction in PM emissions but would be dependent on the amount of bypass utilized, particulate size distribution and the flue gas constituents that contribute to $PM_{2.5}$ emissions. As this would apply to only a limited number of operating units and these parameters are not documented in public forums, this option wasn't considered further.

Wet ESP

Wet electrostatic precipitator (WESP) technology has been used to reduce condensable PM emissions, primarily sulfuric acid mist from coal-fired boilers firing high sulfur coal and equipped with SCR and WFGD. A WESP functions in a similar manner as a conventional ESP. In a WESP system, the collecting electrodes are cleaned with a water wash. Particulate mass loading, particle size distribution, particulate electrical resistivity, and precipitator voltage and current will influence the WESP performance. The wet cleaning mechanism can also affect the nature of the particles that can be captured, and the performance efficiencies that can be achieved.

Applicability and Typical Performance

In a utility application, a WESP would be located downstream of the existing FGD control system to remove micron-sized sulfuric acid aerosols, and potentially other condensable particulates from the flue gas stream. WESP technology has not been widely used in a utility application and would not be used as the primary particulate matter control device at a coal-fired facility because of the wash water slurry that would be generated. However, WESP control systems could potentially be used as a secondary means of $PM_{2.5}$ control but would likely only be applicable to systems with existing WFGD systems.

The removal efficiencies achievable with WESP would also be limited based on the inlet loading to the system and each units' existing suite of control technologies. For units with a conventional baghouse and WFGD system, a WESP may be able to meet a guarantee value for total PM emission rate of 0.0015 lb/MMBtu. Applications of a WESP with an ESP upstream of the WFGD would likely also achieve reductions, but would be limited and difficult to quantify as it would be dependent on the capabilities of the existing ESP (i.e. performance may be limited to a removal efficiency with no specific emission rate guarantee).