ESP and Fabric Filter Considerations for Meeting Environmental Regulations: IED, LCP and WI BREF

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ABSTRACT

Regulations for emission control in Europe continue to pose challenges for utilities and industrial plants. To achieve compliance, plant owners and operators must consider a multi-component strategy for removing particulate matter (PM), acid gases, mercury and other hazardous air pollutants.

Air quality control systems (AQCS) are delivering maximum operating efficiency for emission control by combining different technologies such as dry sorbent injection (DSI), wet and dry electrostatic precipitators (ESPs), fabric filters, spray dryer absorbers (SDAs), fluidized bed scrubbers, and wet flue gas desulphurization (FGD). A thorough assessment of the plant’s current flue gas pollutant concentration is critical to selecting the optimum combination of technologies. This informative paper will examine how ESPs and fabric filters can effectively be integrated into a multi-component air quality control system. Co-benefits of each technology will be addressed including:

- ESP & fabric filter design considerations for compliance strategies
- Choosing the best combination of technologies based on the plant’s flue gas pollutants
- Options for upgrading or retrofitting ESPs or fabric filters
- Impact of DSI / activated carbon injection (ACI) & additional PM loading on ESPs & fabric filters
- Factors driving the selection of wet ESPs (PM2.5, sulfuric acid mist, plume/opacity control, etc.)
- Considerations when converting from ESP to fabric filter
This paper will also cover lessons learned from emission control technologies and strategies implemented in the U.S. and their applicability to meeting future European emissions requirements. In addition, a recent reference project covering a coal-fired boiler installation will be discussed.

**INTRODUCTION**

Current and pending environmental regulations in Europe are expected to drive many plant owners to upgrade existing air pollution control equipment, or install new equipment in order to meet the required emission limits. Major regulations include:

- Industrial Emissions Directive (IED)
- BAT (Best Available Techniques) Reference Document (BREF) for Large Combustion Plants (LCP)
- BAT (Best Available Techniques) Reference Document (BREF) for Waste Incineration (WI)

In many instances, power plant owners and operators can achieve environmental compliance by combining different air pollution control products and technologies with their existing equipment. The equipment designers must conduct a thorough assessment of the flue gas pollutant mix in order to select the optimum combination of technologies and achieve the lowest possible life cycle costs. Technology selection varies from unit to unit based on differences in fuels, capacity factors, existing equipment configuration, and operating practices.

**ELECTROSTATIC PRECIPITATOR DESIGN CONSIDERATIONS**

ESPs can operate at high temperatures and are better suited for sticky fly ash, which can be problematic for fabric filters. ESPs are relatively low maintenance and exhibit low pressure drops. Major ESP disadvantages include a dependence on fly ash resistivity, which is affected by the addition of DSI sorbents, and the overall ESP power consumption. As a general rule, ESP economics become unfavorable when emission levels fall below 10 mg/Nm$^3$ as the physical size is much larger than a comparable fabric filter for the application.

Major design considerations when assessing existing ESPs include specific collection area (SCA), flue gas velocity, physical geometry, current and future fuel selection (i.e. ash resistivity), and site-specific construction restraints to implement upgrades or replacement. The two main types of ESPs: tumbling hammer designs and top-rapped / magnetic-impulse designs are often selected based on customer preference. Amec Foster Wheeler offers both types of ESPs.

**FABRIC FILTER (FF) DESIGN CONSIDERATIONS**

A large number of power plants are adding or upgrading existing fabric filters to address PM emissions requirements. FFs provide a greater PM reduction than ESPs and are less dependent
on consistent operating parameters. FFs can handle a wide fuel mix and emissions stay relatively constant. Additionally, a FF with upstream DSI or ACI injection significantly improves sorbent utilization due to the increased residence time on the filter bags. The major disadvantage of a FF lies with operating costs attributable to consumable filter bags and the comparatively high pressure drop.

The air-to-cloth ratio ($m^3/min / m^2$, typically expressed as m/min) of the FF determines the overall size and performance of the unit. In general, lowering the air-to-cloth ratio increases FF costs and improves performance, while increasing the air-to-cloth ratio lowers costs and worsens performance. Experienced FF suppliers with knowledge of similar applications should be relied upon to provide the optimal air-to-cloth ratio.

The filter bag material is the heart of any FF design and key material selection parameters include: flue gas temperature and chemistry, emissions performance, filter material longevity, and costs. In order to comply with the most stringent regulatory requirements, filter media with an expanded polytetrafluoroethylene (ePTFE) membrane typically provides the lowest PM emissions (typically <5 mg/Nm$^3$).

FF cleaning cycle frequency is another key design factor that affects overall emissions performance. Most utility FFs operate in an on-line cleaning mode, which means that the filter bags remain on-line processing flue gas while they are simultaneously cleaned. There is bleed-through of PM during pulsing, and excessive pulsing leads to high emissions. For this reason, a robust and efficient pulse cleaning system coupled with a low “can velocity” gas flow distribution design, such as the Amec Foster Wheeler Jet VIP, will result in the lowest PM emissions possible.

**CHOOSING THE BEST COMBINATION OF TECHNOLOGIES**

Particulate matter (PM) control is central to any multi-component AQCS. Both electrostatic precipitators (ESPs) and fabric filters (FFs) provide effective PM removal and must be integrated into the overall emissions compliance strategy. The PM control technology selection will affect the approach to mercury and other acid gases. ESPs and FFs are relied upon to provide additional co-benefits, such as mercury capture in particulate form, mercury absorbed and collected with powdered activated carbon, and acid gas control by collecting dry flue gas desulfurization (FGD) sorbents.

The primary technologies for acid gas (SO$_x$ and HCl) removal are spray dryer absorbers (SDAs), circulating fluidized bed scrubbers (CFBS), dry sorbent injection (DSI), and wet flue gas desulfurization (WFGD). Powdered activated carbon (PAC) injection systems provides a low capital cost technology for controlling mercury emissions, and ESPs or FFs are widely applied for PM control. As shown in Figure 1, combining these technologies has marked impacts on project costs and schedule, depending on the specific complexity adopted by each plant.
### Options for Upgrading

There are a number of upgrade options available for improving existing ESP PM collecting efficiency and overall performance. Amec Foster Wheeler has an extensive portfolio of rebuilds on many different types and models of ESPs. As shown in Figure 2, some ESP upgrades can be completed during minor outages while more extensive, higher cost upgrades require a major outage. A thorough condition assessment of a plant’s ESP equipment will help to determine if an upgrade is feasible and economical.

### ESP Upgrades

<table>
<thead>
<tr>
<th>Minor Upgrades (Requires Minor Outage)</th>
<th>Major Upgrades (Requires Major Outage)</th>
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</thead>
<tbody>
<tr>
<td>Low-Ripple Power Supplies</td>
<td>Modernize Internals (Wide Plate Spacing, Wires to RDE’s)</td>
</tr>
<tr>
<td>Modernization of Control Scheme</td>
<td>Optimize Field Length / Additional Field</td>
</tr>
<tr>
<td>Increased Sectionalization (Depending Upon ESP Type)</td>
<td>Increase Field Height</td>
</tr>
<tr>
<td>CFD Modeling / Flow Distribution</td>
<td>New ESP in Parallel / Series</td>
</tr>
<tr>
<td>Pre-Conditioning</td>
<td>New FF in Series or ESP-to-FF Conversion</td>
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Figure 2. ESP Upgrades During Minor or Major Outages

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**DSI & ACI with Existing PM Control**
- Low Capital Investment
- Minimal Footprint Impact

**Add-On / Upgrade PM Control Device + DSI & ACI**
- Upgrade or Replace Aging ESP
- Polishing FF Downstream of ESP
- Improved PM Collection & Sorbent Consumption with FF

**Add-On Dry FGD System**
- Improved Acid Gas Control
- Decreased Sorbent Consumption
- Dry Disposal

**Add-On Wet FGD System**
- Typically Multi-Product AQCS Train
- High Acid Gas Control
- Gypsum Byproduct

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Figure 1. Complexity of Technologies Increases Costs and Schedule
In cases where upgrading an existing ESP cannot sufficiently improve PM removal efficiency, or where space and economic constraints do not allow for full replacement of the ESP, plant owners and operators can install a small polishing FF downstream of the existing ESP. This configuration, which has gained a large U.S. experience base and which Amec Foster Wheeler helped pioneer, provides improved PM emission reductions and lower DSI and ACI sorbent costs. If the sorbents are added at a point between the ESP and FF, ash recovered from the ESP hoppers is not contaminated with the sorbents, thus maintaining its marketability. However, high air-to-cloth ratio pulse-jet fabric filters are more sensitive to high dust and sorbent loadings, and must be designed with additional considerations for reliable performance.

Retrofits and upgrades of existing FFs are typically designed to lower the air-to-cloth ratio, improve the bag material selection, and/or reduce the pulse cleaning frequency. Refer to Figure 3.

<table>
<thead>
<tr>
<th>Minor Upgrades (Requires Minor Outage)</th>
<th>Major Upgrades (Requires Major Outage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change Filter Media</td>
<td>Change to Jet VIP Cleaning System to Reduce Pulse Cleaning Frequency</td>
</tr>
<tr>
<td>CFD Modeling / Flow Distribution</td>
<td>Increase Cloth Area (Increase Bag Length, Add Compartments, etc.)</td>
</tr>
<tr>
<td>Reduce Air In-Leakage</td>
<td>New Polishing FF in Series</td>
</tr>
</tbody>
</table>

Figure 3. PJFF Upgrades During Minor or Major Outages

CONVERTING ESP TO FABRIC FILTER

Another option is direct conversion of the existing ESP to a Pulse Jet Fabric Filter (PJFF), assuming the ESP casing and hoppers are structurally sound. For the ESP-to-PJFF conversion option, key design considerations include ESP casing size and geometry, induced draft fan capacity, ductwork layout and design, and PJFF compartmentalization requirements.

ESP-to-PJFF conversions are more labor intensive than typical capital equipment projects. A successful project will maximize pre-assembly in order to reduce the total amount of work that must be conducted during the tie-in outage. Refer to Figure 4 for a typical ESP-to-PJFF configuration:
IMPACT OF DRY SORBENT INJECTION (DSI) & ACTIVATED CARBON INJECTION (ACI) ON EXISTING EQUIPMENT

Since DSI and ACI with existing PM control equipment is generally the most preferential retrofit solution if feasible, the impact of the sorbents on existing equipment and overall balance-of-plant must be analyzed.

If the sorbent(s) are collected along with the boiler fly ash, then the sorbent properties may affect the sale, beneficial use, and/or disposal of the fly ash. In the U.S., many plants have opted to install polishing baghouses downstream of existing ESPs in order to maintain the marketability of their fly ash.

The other major consideration for sorbent injection into existing equipment is performance, particularly with existing ESPs. Dry sorbent injection systems do provide some pollutant removal “in-flight”, however the majority of the removal is accomplished on the surface of the fabric filter bags. As the sorbent builds up on the surface of the filter bags, the mass transfer between the pollutant and sorbent maximizes the removal of the pollutant and helps to minimize the sorbent consumption.

The capture mechanism for electrostatic precipitators is limited to “in-flight” capture. Since ESPs do not build-up a filter cake, the mass-transfer between the sorbent and pollutant does not
occur, limiting the sorbent’s ability to capture the pollutant based on the dispersion of the sorbent into the ductwork. ESPs can provide high pollutant removal rates however at a feed rate higher than fabric filters. Upstream ductwork configuration and residence time becomes more important with ESPs in order to maximize the distribution of the sorbent into the flue gas prior to entering the ESP. As a general rule, sorbent consumption rates would be expected to be 3 to 5 times higher for a ESP as the primary PM control device compared to a fabric filter. This high operating cost must be properly evaluated to determine the optimal long-term solution.

**FACTORS DRIVING THE SELECTION OF WET ELECTROSTATIC PRECIPITATORS (WESP)**

Wet electrostatic precipitators have been utilized in multiple industries as an essential process device as well as an emissions control device. Wet ESPs have been installed on many different industrial applications and even on power boilers in the utility industry. Some of the main reasons that plant owners select wet electrostatic precipitator technology are as follows;

1. **Multi-pollutant control; sub-micron particulate, metals and condensed acids**

   As the particulate matter size decreases, it becomes harder to capture this particulate in upstream dust collectors. Wet ESPs are highly efficient collection devices for particulate matter less than 1 micron. The mechanics of this collection are based upon the generation of a very high voltage field at relatively low particulate concentration in order to capture this sub-micron particulate. Wet ESPs will remove any pollutant that is in the particulate form, regardless of the process. Often times Wet ESPs are installed downstream of air pollution control such as scrubbers and oxidizers. In the flue gas stream, acid gases such as sulfur dioxide can be oxidized into sulfur trioxide which, after being subjected to scrubbers / cooling chambers, will condense into sulfuric acid mist. Sulfuric acid mist is a sub-micron particulate which can greatly contribute to the overall particulate matter concentration exiting the stack as well as play a significant role into the opacity (i.e. cause a “blue plume”). Wet ESPs can remove sulfuric acid mist at a high rate. With electrostatic precipitators and fabric filters, alkali injection is required to capture acid gases, with varying success depending upon many process factors.

2. **Final polishing device and opacity reduction device**

   In most applications, wet ESPs are installed as the last air pollution control device in the flue gas train. Wet ESPs remove any remaining particulate from the process and are often dubbed the “final polishing device”. Consequently, wet ESPs have often been used as an opacity reduction device or for “good neighbor” policies. Whether it is removal of water vapor or removal of fine particulate and sulfuric acid mist, wet ESPs are often installed to minimize the opacity of the plant.

3. **Add-on to back end equipment**
When retrofitting other air pollution control devices, extensive work can be required such as device replacement, complex ductwork system, revamping of ash handling system as well as modifications to system fans. Wet ESPs have a relatively small footprint and can be added in the area immediately upstream of the stack. Wet ESPs have very little pressure drop which most often does not require any changes to the fan. Additionally, wet ESPs can be worked into the water supply and effluent system with very little impact to the existing system.

LESSONS LEARNED FROM RECENT U.S. COMPLIANCE STRATEGIES

The United States utility and industrial boiler markets have recently undergone significant upgrades for environmental compliance. The primary U.S. regulations are:

- Mercury and Air Toxics Standards (MATS) for Power Plants; Compliance April 2015 (or later per granted extensions)
- Industrial Boiler Maximum Achievable Control Technology (MACT); Compliance January 2016

The pollutants and allowable emission levels for the recent U.S. regulations are similar to the pending environmental regulations in Europe, particularly regulations pertaining to mercury control.

CASE STUDY

The City of Fremont, Nebraska’s Lon D. Wright Unit 8 is a 90 MW (gross) pulverized coal (PC) unit (1800 psig, 1005 °F) fired by Powder River Basin coal. Considering the only component of the unit’s AQCS was a hot-side ESP, emissions from the unit exceeded the mercury, PM, and acid gas MATS limits. Based on an analysis by HDR Engineering, the city elected to install a PAC system for mercury control, a SDA for acid gas control, and a PJFF to remove PM. In 2013, the city awarded a contract to Fagen Inc. for execution of the project. Fagen subcontracted the complete AQCS equipment scope to Siemens Environmental (now Amec Foster Wheeler).

The Unit 8 flue gas pollutant mix, as shown in Figure 5, required additional AQCS equipment to meet the MATS emission limits.
<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Unit 8 Emissions (Pre 2013 Project)</th>
<th>MATS Limits&lt;sup&gt;1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>1.2 lb/MMBtu ~1900 mg/Nm&lt;sup&gt;3&lt;/sup&gt;</td>
<td>0.2 lb/MMBtu ~300 mg/Nm&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>HCl</td>
<td>0.008 lb/MMBtu ~12.4 mg/Nm&lt;sup&gt;3&lt;/sup&gt;</td>
<td>0.002 lb/MMBtu ~3.1 mg/Nm&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>PM</td>
<td>0.16 lb/MMBtu ~250 mg/Nm&lt;sup&gt;3&lt;/sup&gt;</td>
<td>0.03 lb/MMBtu ~47 mg/Nm&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>Hg</td>
<td>10.3 lb/TBtu ~16 μg/Nm&lt;sup&gt;3&lt;/sup&gt;</td>
<td>1.2 lb/TBtu ~1.9 μg/Nm&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1</sup> MATS Limits for Existing Electric Generating Units Burning Coal > 8,300 Btu/lb

**Figure 5. Unit 8 Flue Gas Pollutants**

The PAC system scope provided by Amec Foster Wheeler consisted of a storage silo and redundant blower/feeder systems. For acid gas control, Amec Foster Wheeler provided one (1) 100% SDA and a lime preparation system. Two-fluid nozzle SDA technology was selected for its superior reliability and operational flexibility.

For controlling PM emissions, it was determined that the existing hot-side ESP would remain in service to capture the majority of the fly ash, and a new PJFF would be installed to collect the SDA byproducts and any remaining fly ash from the existing ESP. Amec Foster Wheeler designed and supplied a modular PJFF in order to minimize the field labor and construction. The PJFF is capable of operating and meeting emissions requirements with one (1) module off-line for maintenance. Each module is fully shop-assembled including the walls, hopper, roof, and tubesheet.

Amec Foster Wheeler selected an intermediate pressure intermediate volume (IPIV) Jet VIP pulse cleaning system. The Jet VIP pulse cleaning system utilizes 3 inch double diaphragm pulse valves, large capacity pulse air headers, and variable-hole manifold pipes for equal and efficient cleaning, which is critical for optimal performance.
Figure 6. Unit 8 AQCS Equipment (left to right showing Pebble Lime Storage Silo, PJFF Housing, PAC storage Silo, Spray Dryer Absorber, and associated SDA inlet ductwork)

Figure 7. Unit 8 AQCS Equipment (showing SDA Penthouse and PJFF Housing)
Initial performance of the SDA and PJFF system has been according to Amec Foster Wheeler predictions with no major issues to report. Emissions are within all MATS limits. Depending on operating conditions of the upstream ESP, the PJFF cleaning system has cleaned at a rate of approximately 7 – 24 pulses / bag / day, which is less than most typical dry FGD applications. The low cleaning rate of the Jet VIP system should help extend the filter bag life for the City of Fremont.

CONCLUSIONS

ESP’s and fabric filters are both proven and reliable technologies for controlling particulate emissions from utility and industrial boilers. The PM control device is an important and integral part of any modern air quality control system. Each technology has a wide range of considerations that must be taken into account when determining the proper solution for complying with new and challenging environmental regulations, such as mercury and low-level particulate.

In order to address the current and pending environmental regulations in Europe, recent MATS and Boiler MACT project experience and lessons learned in the U.S. will provide a roadmap for success.