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Particulate Control Cost Development Methodology

Technology Description

There are two main particulate capture unit operations employed in the utility industry:

- Electrostatic Precipitator (ESP)
- Fabric Filter (FF)

ESP's have been implemented in the utility industry since the 1960’s; there have been a great number of installations in the U.S. and around the world. The ESP collects PM in a three step process: charging, collecting, and cleaning the collected ash off the electrodes. The ESP relies on fly ash resistivity to charge and collect the particles. ESP's can reduce PM emissions to below 0.015 lb/MMBtu and opacity below 10%. However, it is difficult to collect fly ash when burning low sulfur coal because of high fly ash resistivity. ESP's are not well suited for processes that are highly variable because the collection efficiency is sensitive to fluctuations in gas stream conditions.

Recently fabric filters (specifically pulse-jet fabric filters abbreviated as PJFF) have become the preferred choice for new and retrofit utility particulate capture. PJFFs have been utilized commercially for over 25 years and are considered a mature technology. Modern PJFFs are reliable, versatile and cost effective. In a PJFF, particulate matter is collected on a fabric bag; then the particles are cleaned off the bag surfaces with a pulse of air. During cleaning, the collected particulate falls into hoppers and is removed via an ash handling system to a fly ash storage silo. PJFF suppliers provide guarantees as low as 0.010 lb/MMBtu depending on the application.

Co-Benefits

Due to the filter cake inherent in PJFFs, PJFF units have additional benefits that are not available in ESPs:

- Mercury removal is enhanced by a PJFF by contacting the flue gas with the unburned carbon in the fly ash;
- High capture of SO$_2$ and HCl for alkaline ashes;
- Collection of injected activated carbon with a PJFF can dramatically increase the mercury removal from the flue gas versus an ESP particulate collector;
- With in-duct dry sorbent injection, the SO$_2$ removal can be greatly increased when an PJFF is used versus an ESP for the sorbent capture; and
- Acid gases are removed when the flue gas is passed through the filter cake in a PJFF.
Establishment of Cost Basis
The major cost driver for a fabric filter is the required gross air-to-cloth (A/C) ratio. When the fabric filter is installed in a retrofit situation following another collection device, such as an ESP, then an A/C of 6.0 or lower would be appropriate if activated carbon injection is applied for mercury removal.

If the fabric filter will be used as the sole particulate capture unit operation, an A/C of 4.0 or lower should be specified. The lower A/C ratio will provide better bag life with the high inlet particulate loading expected for the single particulate capture device in the process.

Cost data from the S&L current database of projects, for several different PJFF installations, was reviewed and a relationship was developed for the capital costs of the system on a flue gas rate basis. The capital costs include:

- Duct work modifications and reinforcement,
- Foundations,
- Structural steel,
- Interconnecting piping, etc… to existing fly ash handling system,
- ID fan modifications or new booster fans, and
- Electrical modifications.

Boiler reinforcement is not included. It is likely that boiler pressure control will be done with controls and not with structural reinforcement.

Methodology
Inputs
Several input variables are required in order to predict the total future retrofit costs:

- Type of coal,
- Unit size,
- Unit heat rate, and
- PJFF required size.

A retrofit factor that equates to difficulty in construction of the system must be defined.

The cost methodology is based on a unit located within 500 feet of sea level. The actual elevation of the site should be considered separately and factored into the flue gas rate as the rate is directly impacted by the site elevation. The flue gas rate should be increased based on the ratio of the atmospheric pressure between sea level and the unit location. As
Particulate Control Cost Development Methodology

an example, a unit located 1 mile above sea level would have an approximate atmospheric pressure of 12.2 psia. Therefore, the flue gas rate should be increased by:

\[
\frac{14.7 \text{ psia}}{12.2 \text{ psia}} = 1.2 \text{ multiplier to the flue gas rate}
\]

**Outputs**

**Total Project Costs (TPC)**

An installed cost for the fabric filter base module is calculated (BM). The base module installed cost includes:

- All equipment;
- Duct work modifications;
- Duct work reinforcement;
- New ID or booster fans;
- Modifications to the fly ash handling system;
- Installation;
- Buildings;
- Foundations;
- Electrical;
- Retrofit difficulty.

The base module cost is then increased by:

- Engineering and construction management costs at 10% of the BM cost;
- Labor adjustment for 6 x 10 hour shift premium, per diem, etc., at 10% of the BM cost; and
- Contractor profit and fees at 10% of the BM cost.

A capital, engineering, and construction cost subtotal (CECC) is established as the sum of the BM and the additional engineering and construction fees.

Additional costs and financing expenditures for the project are computed based on the CECC. Financing and additional project costs include:

- Owner’s home office costs (owner’s engineering, management, and procurement) at 5% of the CECC; and
- Allowance for Funds Used During Construction (AFUDC) at 6% of the CECC is added to account for AFUDC based on a complete project duration of 2 years.
Particulate Control Cost Development Methodology

The total project cost is based on a multiple lump sum contract approach. Should a turnkey engineering procurement construction (EPC) contract be executed, the total project cost would be 10 to 15% higher than what is currently estimated.

Escalation is not included in the estimate. The total project cost (TPC) is the sum of the CECC and the additional costs and financing expenditures.

**Fixed O&M (FOM)**
The fixed operating and maintenance (O&M) cost is a function of the additional operations staff (FOMO), maintenance labor and materials (FOMM), and administrative labor (FOMA) associated with the fabric filter installation. The FOM is the sum of the FOMO, FOMM, and FOMA.

The following factors and assumptions underlie calculations of the FOM:

- All of the FOM costs were tabulated on a per kilowatt-year (kW yr) basis.
- In general, 0 additional operators are required for a PJFF.
- The fixed maintenance materials and labor is a direct function of the process capital cost at 0.5% of the BM.
- The administrative labor is a function of the FOMO and FOMM at 3% of (FOMO + 0.4FOMM).

**Variable O&M (VOM)**
Variable O&M is a function of:

- Bag and cage replacement and unit costs, and
- Additional power required and unit power cost.

The following factors and assumptions underlie calculations of the VOM:

- All of the VOM costs were tabulated on a per megawatt-hour (MWh) basis.
- Bag and cage replacement every 3 and 9 years respectively for unit operations with 6.0 A/C.
- Bag and cage replacement every 5 and 10 years respectively for unit operations with 4.0 A/C.
Particulate Control Cost Development Methodology

- The additional power required includes increased fan power to account for the added fabric filter pressure drop.

- The additional power is reported as a percent of the total unit gross production. In addition, a cost associated with the additional power requirements can be included in the total variable costs.

Input options are provided for the user to adjust the variable O&M costs per unit. Average default values are included in the base estimate. The variable O&M costs per unit options are:

- Auxiliary power cost in $/kWh, and
- Bag and cage costs in $/item.

The variables that contribute to the overall VOM are:

\[
VOMB = \text{Variable O&M costs for bags and cage replacement}
\]
\[
VOMP = \text{Variable O&M costs for additional auxiliary power}
\]

The total VOM is the sum of the $VOMB$ and $VOMP$. Table 1 contains an example of the complete capital and O&M cost estimate worksheet for a fabric filter installation at an air-to-cloth ratio of 4.0. Table 2 contains an example of the complete capital and O&M cost estimate worksheet for a fabric filter installation at an air-to-cloth ratio of 6.0.
Table 1. Example Complete Cost Estimate for a 4.0 A/C PJFF Installation

<table>
<thead>
<tr>
<th>Variable</th>
<th>Designation</th>
<th>Units</th>
<th>Value</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit Size (gross)</td>
<td>A</td>
<td>(MW)</td>
<td>500</td>
<td>User Input</td>
</tr>
<tr>
<td>Retrofit Factor</td>
<td>B</td>
<td></td>
<td>1</td>
<td>User Input (An “average” retrofit has a factor = 1.0)</td>
</tr>
<tr>
<td>Gross Heat Rate</td>
<td>C</td>
<td>(Btu/Wh)</td>
<td>9500</td>
<td>User Input</td>
</tr>
<tr>
<td>Type of Coal</td>
<td>D</td>
<td></td>
<td>Blufomine</td>
<td>User Input</td>
</tr>
<tr>
<td>PJFF Air-to-Cloth Ratio</td>
<td>E</td>
<td></td>
<td>4.9 A/C Ratio</td>
<td>User Input</td>
</tr>
<tr>
<td>Heat Input</td>
<td>F</td>
<td>(Btu/hr)</td>
<td>4.75E+09</td>
<td>A<em>C</em>1000</td>
</tr>
<tr>
<td>Fuel Gas Rate</td>
<td>G</td>
<td>(acfm)</td>
<td>1,719,500</td>
<td>Downstream of an air preheater; For Bituminous Coal = A<em>C</em>0.382 For PRB Coal = A<em>C</em>0.400 For Lignite Coal = A<em>C</em>0.430</td>
</tr>
<tr>
<td>Aux Power Inclusive in VOM?</td>
<td>H</td>
<td>(%)</td>
<td>0.6</td>
<td>0.6 default value</td>
</tr>
<tr>
<td>Aux Power Cost</td>
<td>J</td>
<td>(S/Wh)</td>
<td>0.00</td>
<td>User Input</td>
</tr>
<tr>
<td>Bag Cost</td>
<td>K</td>
<td>(S/Bag)</td>
<td>100</td>
<td>User Input</td>
</tr>
<tr>
<td>Cage Cost</td>
<td>L</td>
<td>(S/Bag)</td>
<td>30</td>
<td>User Input</td>
</tr>
<tr>
<td>Operating Labor Rate</td>
<td>M</td>
<td>(S/hr)</td>
<td>60</td>
<td>User Input (Labor cost including all benefits)</td>
</tr>
</tbody>
</table>

Costs are all based on 2012 dollars

Example: $67,426,000

Example: Base module for an additional PJFF including: Dust work modifications and reinforcement, foundations, structural steel, ID or booster fans, piping, electrical, etc...

Example: $6,743,000

Example: Engineering and Construction Management costs

Example: $6,743,000

Example: Labor adjustment for 0 x 10 hour shift premium, per diem, etc...

Example: $6,743,000

Example: Contractor profit and fees

Example: $87,655,000

Example: Capital, engineering and construction cost subtotal

Example: $176

Example: Capital, engineering and construction cost subtotal per kW

Example: $4,383,000

Example: Owners costs including all "home office" costs (owners engineering, management, and procurement activities)

Example: $5,522,000

Example: AFUDC for PJFF 6% for a 2 year engineering and construction cycle

Example: $97,560,000

Example: Total project cost

Example: $196

Example: Total project cost per kW

Example: $6,743,000

Example: Fixed O&M additional operating labor costs

Example: $0.07

Example: Fixed O&M additional material and labor costs

Example: $0.01

Example: Fixed O&M additional administrative labor costs

Example: $0.68

Example: Total Fixed O&M costs

Example: $0.06

Example: Variable O&M costs for bags and cages.

Example: $0.36

Example: Variable O&M costs for additional auxiliary power required.

Example: $0.42
# Particulate Control Cost Development Methodology

## Table 2. Example Complete Cost Estimate for a 6.0 A/C PJFF Installation

<table>
<thead>
<tr>
<th>Variable</th>
<th>Designation</th>
<th>Units</th>
<th>Value</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit Size (Gross)</td>
<td>A</td>
<td>(MW)</td>
<td>500</td>
<td>&lt;--- User Input</td>
</tr>
<tr>
<td>Retrofit Factor</td>
<td>B</td>
<td></td>
<td>1</td>
<td>&lt;--- User Input (An &quot;average&quot; retrofit has a factor = 1.0)</td>
</tr>
<tr>
<td>Gross Heat Rate</td>
<td>C</td>
<td>(Btu/kWh)</td>
<td>9,500</td>
<td>&lt;--- User Input</td>
</tr>
<tr>
<td>Type of Coal</td>
<td>D</td>
<td></td>
<td>Bituminous</td>
<td>&lt;--- User Input</td>
</tr>
<tr>
<td>PJFF Air-to-Cloth Ratio</td>
<td>E</td>
<td></td>
<td>6.0 A/C Ratio</td>
<td>&lt;--- User Input</td>
</tr>
<tr>
<td>Heat Input</td>
<td>F</td>
<td></td>
<td>4.75E+09</td>
<td>= A<em>C</em>1000</td>
</tr>
<tr>
<td>Flue Gas Rate</td>
<td>G</td>
<td>(acfm)</td>
<td>1,719,500</td>
<td>Downstream of an air preheater</td>
</tr>
<tr>
<td>Aux Power Include in VOM?</td>
<td>H</td>
<td>(%)</td>
<td>0.6</td>
<td>0.6 default value</td>
</tr>
<tr>
<td>Aux Power Cost</td>
<td>J</td>
<td>($/kWh)</td>
<td>0.06</td>
<td>&lt;--- User Input</td>
</tr>
<tr>
<td>Cages Cost</td>
<td>K</td>
<td>($/cage)</td>
<td>100</td>
<td>&lt;--- User Input</td>
</tr>
<tr>
<td>Operating Labor Rate</td>
<td>M</td>
<td>($/hr)</td>
<td>60</td>
<td>&lt;--- User Input (Labor cost including all benefits)</td>
</tr>
</tbody>
</table>

### Capital Cost Calculation

- Includes - Equipment, installation, buildings, foundations, electrical, and retrofit difficulty

\[
BM ($) = \begin{cases} 
if (E = 6.0 \text{ Air-to-Cloth then} 530, E = 4.0 \text{ Air-to-Cloth then} 600) \cdot B \cdot G^{0.81} \end{cases} 
\]

\[
BM ($/kW) = 119 
\]

### Total Project Cost

- A1 = 10% of BM
- A2 = 10% of BM
- A3 = 10% of BM
- CECC ($) = BM + A1 + A2 + A3
- CECC ($/kW) = 155
- B1 = 5% of CECC
- B2 = 6% of CECC + B1
- TPC ($) = CECC + B1 + B2 + C1 + C2
- TPC ($/kW) = 172

### Fixed O&M Cost

- FOMO ($/kW yr) = (0 additional operators) * 2080 M$/M(A*1000)
- FOMM ($/kW yr) = BM*0.005/(B*A*1000)
- FOMA ($/kW yr) = 0.03*(FOMO+0.4*FOMM)
- FOM ($/kW yr) = FOMO + FOMM + FOMA

### Variable O&M Cost

- VOMB ($/MWh) = G/(E*A*341640) if (E = 6.0 Air-to-Cloth then (K3+L9) else E = 4.0 Air-to-Cloth then (K5+L10))
- VOMP ($/MWh) = H*J*10
- VOM ($/MWh) = VOMB

### Costs are all based on 2012 dollars

<table>
<thead>
<tr>
<th>Example</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>BM ($)</td>
<td>$ 59,560,000 Base module for an additional PJFF including: Duct work modifications and reinforcement, foundations, structural steel, ID or booster fans, piping, electrical, etc...</td>
</tr>
<tr>
<td>BM ($/kW)</td>
<td>$ 119 Base module cost per kW</td>
</tr>
<tr>
<td>A1 = 10% of BM</td>
<td>$ 5,956,000 Engineering and Construction Management costs</td>
</tr>
<tr>
<td>A2 = 10% of BM</td>
<td>$ 5,956,000 Labor adjustment for 6 x 10 hour shift premium, per diem, etc...</td>
</tr>
<tr>
<td>A3 = 10% of BM</td>
<td>$ 5,956,000 Contractor profit and fees</td>
</tr>
<tr>
<td>CECC ($) = BM + A1 + A2 + A3</td>
<td>$ 77,428,000 Capital, engineering and construction cost subtotal</td>
</tr>
<tr>
<td>CECC ($/kW) = 155</td>
<td></td>
</tr>
<tr>
<td>B1 = 5% of CECC</td>
<td>$ 3,871,000 Owners costs including all &quot;home office&quot; costs (owners engineering, management, and procurement activities)</td>
</tr>
<tr>
<td>B2 = 6% of CECC + B1</td>
<td>$ 4,878,000 AFUDC for PJFF: 6% for a 2 year engineering and construction cycle</td>
</tr>
<tr>
<td>TPC ($) = CECC + B1 + B2 + C1 + C2</td>
<td>$ 86,177,000 Total project cost</td>
</tr>
<tr>
<td>TPC ($/kW) = 172</td>
<td></td>
</tr>
<tr>
<td>Fixed O&amp;M Cost</td>
<td></td>
</tr>
<tr>
<td>FOMO ($/kW yr) = (0 additional operators) * 2080 M$/M(A*1000)</td>
<td>$ - Fixed O&amp;M additional operating labor costs</td>
</tr>
<tr>
<td>FOMM ($/kW yr) = BM<em>0.005/(B</em>A*1000)</td>
<td>$ 0.60 Fixed O&amp;M additional maintenance material and labor costs</td>
</tr>
<tr>
<td>FOMA ($/kW yr) = 0.03*(FOMO+0.4*FOMM)</td>
<td>$ 0.01 Fixed O&amp;M additional administrative labor costs</td>
</tr>
<tr>
<td>FOM ($/kW yr) = FOMO + FOMM + FOMA</td>
<td>$ 0.60 Total Fixed O&amp;M costs</td>
</tr>
<tr>
<td>Variable O&amp;M Cost</td>
<td></td>
</tr>
<tr>
<td>VOMB ($/MWh) = G/(E<em>A</em>341640) if (E = 6.0 Air-to-Cloth then (K3+L9) else E = 4.0 Air-to-Cloth then (K5+L10))</td>
<td>$ 0.06 Variable O&amp;M costs for bags and cages.</td>
</tr>
<tr>
<td>VOMP ($/MWh) = H<em>J</em>10</td>
<td>$ 0.36 Variable O&amp;M costs for additional auxiliary power required.</td>
</tr>
<tr>
<td>VOM ($/MWh) = VOMB</td>
<td>$ 0.42</td>
</tr>
</tbody>
</table>