IPM Model – Updates to Cost and Performance for APC Technologies

Particulate Control Cost Development Methodology

Final

March 2013

Project 12847-002

Systems Research and Applications Corporation

Prepared by

Sargent & Lundy LLC

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 Systems Research and Applications Corporation ("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 the U.S. Environmental Protection Agency and reviewed by William A. Stevens, Senior Advisor – Power Technologies.

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)

ESPs 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. ESPs 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. ESPs 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_3 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.

Particulate Control Cost Development Methodology

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 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:

14.7 psia/12.2 psia = 1.2 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 = Variable O&M costs for bags and cage replacement

VOMP = 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.

Particulate Control Cost Development Methodology

Table 1. Example Complete Cost Estimate for a 4.0 A/C PJFF Installation

Variable	Designation	Units	Value	Calculation
Unit Size (Gross)	A	(MW)	500	<--- User Input
Retrofit Factor	B		1	<--- User Input (An "average" retrofit has a factor = 1.0)
Gross Heat Rate	C	(Btu/kWh)	9500	<--- User Input
Type of Coal	D		Bituminous	<--- User Input
PJFF Air-to-Cloth Ratio	E		4.0 A/C Ratio	<--- User Input
Heat Input	F	(Btu/hr)	4.75E+09	= A*C*1000
Flue Gas Rate	G	(acfm)	1,719,500	Downstream of an air preheater For Bituminous Coal = A*C*0.362 For PRB Coal = A*C*0.400 For Lignite Coal = A*C*0.435
Aux Power **Include in VOM?** ☑	**H**	**(%)**	0.6	0.6 default value
Aux Power Cost	J	($/kWh)	0.06	<--- User Input
Bag Cost	K	($/bag)	100	<--- User Input
Cage Cost	L	($/cage)	30	<--- User Input
Operating Labor Rate	M	($/hr)	60	<--- User Input (Labor cost including all benefits)

Costs are all based on 2012 dollars

		Example	Comments
Capital Cost Calculation			
Includes - Equipment, installation, buildings, foundations, electrical, and retrofit difficulty			
BM ($) = if (E = 6.0 Air-to-Cloth then 530, E = 4.0 Air-to-Cloth then 600)*B*G^0.81	$	67,426,000	Base module for an additional PJFF including: Duct work modifications and reinforcement, foundations, structual steel, ID or booster fans, piping, electrical, etc…
BM ($/KW) =		135	Base module cost per kW
Total Project Cost			
A1 = 10% of BM	$	6,743,000	Engineering and Construction Management costs
A2 = 10% of BM	$	6,743,000	Labor adjustment for 6 x 10 hour shift premium, per diem, etc…
A3 = 10% of BM	$	6,743,000	Contractor profit and fees
CECC ($) = BM+A1+A2+A3	**$**	**87,655,000**	Capital, engineering and construction cost subtotal
CECC ($/kW) =		**175**	Capital, engineering and construction cost subtotal per kW
B1 = 5% of CECC	$	4,383,000	Owners costs including all "home office" costs (owners engineering, management, and procurement activities)
B2 = 6% of CECC + B1	$	5,522,000	AFUDC for PJFF: 6% for a 2 year engineering and construction cycle
TPC ($) = CECC + B1 + B2 + C1 + C2	**$**	**97,560,000**	Total project cost
TPC ($/kW) =		**195**	Total project cost per kW
Fixed O&M Cost			
FOMO ($/kW yr) = (0 additional operators)*2080*M/(A*1000)	$	-	Fixed O&M additional operating labor costs
FOMM ($/kW yr) = BM*0.005/(B*A*1000)	$	0.67	Fixed O&M additional maintenance material and labor costs
FOMA ($/kW yr) = 0.03*(FOMO+0.4*FOMM)	$	0.01	Fixed O&M additional administrative labor costs
FOM ($/kW yr) = FOMO + FOMM + FOMA	**$**	**0.68**	Total Fixed O&M costs
Variable O&M Cost			
VOMB ($/MWh) = G/(E*A*341640)*if(E = 6.0 Air-to-Cloth then (K/3+L/9) else E = 4.0 Air-to-Cloth then (K/5+L/10))	$	0.06	Variable O&M costs for bags and cages.
VOMP ($/MWh) = H*J*10	$	0.36	Variable O&M costs for additional auxiliary power required.
VOM ($/MWh) = VOMB	**$**	**0.42**	

Particulate Control Cost Development Methodology

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

Variable	Designation	Units	Value	Calculation
Unit Size (Gross)	A	(MW)	500	<--- User Input
Retrofit Factor	B		1	<--- User Input (An "average" retrofit has a factor = 1.0)
Gross Heat Rate	C	(Btu/kWh)	9500	<--- User Input
Type of Coal	D		Bituminous	<--- User Input
PJFF Air-to-Cloth Ratio	E		6.0 A/C Ratio	<--- User Input
Heat Input	F	(Btu/hr)	4.75E+09	= A*C*1000
Flue Gas Rate	G	(acfm)	1,719,500	Downstream of an air preheater For Bituminous Coal = A*C*0.362 For PRB Coal = A*C*0.400 For Lignite Coal = A*C*0.435
Aux Power **Include in VOM?** ☑	**H**	**(%)**	**0.6**	0.6 default value
Aux Power Cost	J	($/kWh)	0.06	<--- User Input
Bag Cost	K	($/bag)	100	<--- User Input
Cage Cost	L	($/cage)	30	<--- User Input
Operating Labor Rate	M	($/hr)	60	<--- User Input (Labor cost including all benefits)

Costs are all based on 2012 dollars

Capital Cost Calculation		**Example**	**Comments**
Includes - Equipment, installation, buildings, foundations, electrical, and retrofit difficulty			
BM ($) =	if (E = 6.0 Air-to-Cloth then 530, E = 4.0 Air-to-Cloth then 600)*B*G^0.81	$ 59,560,000	Base module for an additional PJFF including: Duct work modifications and reinforcement, foundations, structual steel, ID or booster fans, piping, electrical, etc…
BM ($/KW) =		119	Base module cost per kW
Total Project Cost			
A1 = 10% of BM		$ 5,956,000	Engineering and Construction Management costs
A2 = 10% of BM		$ 5,956,000	Labor adjustment for 6 x 10 hour shift premium, per diem, etc…
A3 = 10% of BM		$ 5,956,000	Contractor profit and fees
CECC ($) = BM+A1+A2+A3		**$ 77,428,000**	Capital, engineering and construction cost subtotal
CECC ($/kW) =		**155**	Capital, engineering and construction cost subtotal per kW
B1 = 5% of CECC		$ 3,871,000	Owners costs including all "home office" costs (owners engineering, management, and procurement activities)
B2 = 6% of CECC + B1		$ 4,878,000	AFUDC for PJFF: 6% for a 2 year engineering and construction cycle
TPC ($) = CECC + B1 + B2 + C1 + C2		**$ 86,177,000**	Total project cost
TPC ($/kW) =		**172**	Total project cost per kW
Fixed O&M Cost			
FOMO ($/kW yr) = (0 additional operators)*2080*M/(A*1000)		$ -	Fixed O&M additional operating labor costs
FOMM ($/kW yr) = BM*0.005/(B*A*1000)		$ 0.60	Fixed O&M additional maintenance material and labor costs
FOMA ($/kW yr) = 0.03*(FOMO+0.4*FOMM)		$ 0.01	Fixed O&M additional administrative labor costs
FOM ($/kW yr) = FOMO + FOMM + FOMA		**$ 0.60**	Total Fixed O&M costs
Variable O&M Cost			
VOMB ($/MWh) = G/(E*A*341640)*if(E = 6.0 Air-to-Cloth then (K/3+L/9) else E = 4.0 Air-to-Cloth then (K/5+L/10))		$ 0.06	Variable O&M costs for bags and cages.
VOMP ($/MWh) = H*J*10		$ 0.36	Variable O&M costs for additional auxiliary power required.
VOM ($/MWh) = VOMB		**$ 0.42**	