# IPM Model – Updates to Cost and Performance for APC Technologies

## Mercury Control Incremental Operating Cost Methodology

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# Mercury Control Incremental Operating Cost Methodology

## IPM Model Overview

Cost algorithms in the IPM model are based primarily on a statistical evaluation of cost data available from various industry publications, and do not take into consideration site-specific cost issues. The primary purpose of the IPM cost modules is to provide generic order-of-magnitude costs for various air quality control technologies that can be applied to the electric power generating industry on a system-wide basis, not on an individual unit basis. By necessity, the cost algorithms were designed to require minimal site-specific information. The IPM cost equations can provide order-of-magnitude capital costs for various air quality control systems based only on a limited number of inputs such as unit size, gross heat rate, inlet NOx level, fuel sulfur level, % removal efficiency, fuel type, and a subjective retrofit factor. The outputs from these equations represent the “average” costs associated with the “average” project scope for the subset of data utilized in preparing the equations. The IPM cost equations do not account for site-specific factors that can significantly impact costs, such as flue gas volume, temperature and do not address regional labor productivity, local workforce characteristics, local unemployment and labor availability, project complexity, local climate, and working conditions. Finally, the indirect capital costs included in the IPM cost equations do not account for all project-related indirect costs a facility would incur to install a retrofit control such as project contingency.

EPA requested that S&L develop new cost algorithms for mercury controls, specifically focusing on the incremental capture that may be achieved with an existing control system, which is summarized in this report. The cost algorithms in this report build on the previously developed Mercury Control IPM cost algorithms developed by S&L including updated industry information for injection rates and reagent costs to reflect changes since the previous IPM model. As the focus of these cost algorithms are incremental improvements, these cost algorithms calculate the incremental operating costs only. For the purposes of this evaluation, it is assumed that no capital improvements will be made to the existing system, therefore no capital costs are estimated.

## Mercury Speciation

Mercury is contained in varying concentrations in different coal supplies. During combustion, mercury is released in the form of elemental mercury. As the combustion gases cool, a portion of the mercury transforms to ionic mercury. Ultimately, there are three possible forms of mercury:

- Elemental ($Hg^0$),
- Ionic or Oxidized ($Hg^{++}$), or
- Particulate-bound.

The proportion of the various mercury forms is called its speciation. The conversion of elemental mercury to the other forms depends upon several factors: cooling rate of the gas, presence of halogens or sulfur trioxide ($SO_3$) in the flue gas, amount and composition of fly ash, presence of unburned carbon, and the installed air pollution control equipment. Particulate-bound mercury typically is bound to fly ash or unburned carbon.

Considering the interaction of the various parameters, ionic mercury can vary between 10%-90% of the total mercury in the flue gas. Particulate mercury generally ranges from about 5-15% of the total mercury. The remainder is elemental mercury that typically makes up 10-90% of the total mercury.

## Activated Carbon Injection Technology

Activated carbon injection (ACI) involves the adsorption of mercury on activated carbon by injection of powdered activated carbon (PAC) in the flue gas. Commercial experience has shown that ACI can

# Mercury Control Incremental Operating Cost Methodology

achieve up to a 95% reduction in total Hg in some cases. The speciation of the mercury plays a significant role in the ease of its capture. ACI can remove both oxidized and elemental mercury; however, the choice of carbon sorbent is highly dependent on the speciation. In addition, some flue gas constituents, especially $SO_3$, reduce the effectiveness of ACI.

## Mercury Capture

Particulate-bound mercury is removed very efficiently from the flue gas by the particulate control device (i.e. baghouse or electrostatic precipitator) and therefore it is desirable to convert as much mercury as possible to particulate-bound mercury. Activated carbon and/or the addition of halogens increase the conversion of elemental and ionic mercury to particulate-bound mercury.

## Establishment of Incremental Operating Cost Basis

Bituminous coals will have relatively high halogen concentrations in the flue gas while sub-bituminous, i.e., Powder River Basin (PRB), and lignite coals have relatively low halogen concentrations. Halogens contribute to the conversion of elemental to ionic mercury for more efficient capture rates. For fuels with low halogen concentrations, halogenated sorbents can be used to help increase the conversion of elemental mercury and thus increase the rate of mercury capture. The type of PAC selected is dependent on the fuel type and the required outlet mercury emission rate.

The PAC feed rate is a function of the fuel type, PAC type, required Hg emission rate, and particulate collection device. The PAC rate was based on the use of either Standard PAC or Premium PAC. Further, for PRB and Lignite fuels, a halogenated version of these PACs was assumed to be required to meet specified Hg emission rates due to the low halogen content of the fuel. To summarize:

| Fuel Type | PAC Type | |
|---|---|---|
| | Hg Emission Rate <1.2 lb/TBtu | Hg Emission Rate ≥1.2 lb/TBtu |
| PRB | Halogenated Premium PAC | Halogenated Standard PAC |
| Bituminous | Premium PAC | Standard PAC |
| | Hg Emission Rate <4.0 lb/TBtu | Hg Emission Rate ≥4.0 lb/TBtu |
| Lignite | Halogenated Premium PAC | Halogenated Standard PAC |

Injection curves were generated based on industry values for Standard and Premium PAC dependent on the fuel type and controlled outlet emission rate requirement, which can be applied directly to the halogenated versions (i.e. halogenation does not vary the injection rate). The cut-off for selection of Premium PAC is based on current MATS rule Hg emission limits, assuming the industry Standard PAC can achieve current limits in most cases. PRB and bituminous fuels will have similar injection curves while Lignite will require additional PAC due to higher levels of fuel mercury.

The injection curves were used to develop equations below to estimate the incremental changes to the injection rates and outlet mercury emissions based on the current system operation. These calculations are also based on the following design considerations:

- Flue gas rate established downstream of the air preheater consistent with previous ACI model,
- Existing system is assumed to have sufficient residence time needed to meet model specified emission rates,

# Mercury Control Incremental Operating Cost Methodology

- The existing ACI injection system and particulate control device are assumed to have sufficient capacity to handle a 20% increase in the injection rate relative to current operating rates,
- No co-benefit or other unit operations considered, and
- Minimum Hg emission rates by fuel:
  - PRB & Bituminous Fuel: 0.25 lb/TBtu
  - Lignite: 1.1 lb/TBtu

## Injection Rate / Emission Rate Calculations

Current Injection Rate:

$$x = \frac{\ln\left(\frac{y}{a}\right)}{b}$$

Where,

x is the **current** injection rate (lb/MMacf),
y is the **current** emission rate (lb/TBtu), and
a and b are coefficients dependent on the fuel, particulate collection device, and PAC type (see table below).

Option 1 – Achievable Emission Rate based on New Injection Rate (Recommended Maximum 20% Increase):

$$y = a * e^{b*x}$$

Option 2 – New Injection Rate based on New Emission Rate (Per Minimum Limits Above):

$$x = \frac{\ln\left(\frac{y}{a}\right)}{b}$$

Where,

x is the **new** injection rate (lb/MMacf),
y is the **new** emission rate (lb/TBtu), and
a and b are coefficients dependent on the fuel, particulate collection device, and PAC type (see table below).

| Fuel Type | PRB or Bituminous | | Lignite | |
|---|---|---|---|---|
| Particulate Control Type | Baghouse | ESP | Baghouse | ESP |
| **Coefficient 'a'** | | | | |
| Premium PAC | 4.3552 | 4.3552 | 21.567 | 21.567 |
| Standard PAC | 3.7609 | 3.7609 | 25.886 | 25.886 |
| **Coefficient 'b'** | | | | |
| Premium PAC | -0.988 | -0.593 | -1.647 | -1.086 |
| Standard PAC | -0.636 | -0.381 | -0.987 | -0.69 |

Note that in order to account for the existing system efficiencies, the new injection rate should be considered as the existing injection rate plus the difference in injection rates to go from the current emission rate to the new achievable emission rate. Additionally, the new injection must be limited to no more than 20% increase above the existing injection rate.

# Methodology

## Inputs

Several input variables are required in order to estimate the incremental ACI operating costs:

- Unit size,
- Unit heat rate,
- Uncontrolled Hg emission rate,
- Current controlled Hg emission rate,
- Additional system capacity remaining,
- Model estimated or user entered new controlled emission rate,
- Type of coal,
- Existing PM control,
- Current PAC type,
- Future PAC type,
- Model estimated or user entered current PAC injection rate, and
- Unit costs for current sorbent, future sorbent and waste disposal.

Flue gas flowrate is calculated by the model and used to determine the hourly injection rate along with the design PAC loading (lb/MMacf) and is based on typical flue gas conditions downstream of air preheater. 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

Note that the purpose of this estimate is to determine incremental costs of achieving stricter mercury emission limits on units with existing ACI systems. As such, the model restricts operating modifications to updates that would not require capital improvements.

### *Fixed O&M (FOM)*

All modifications to existing ACI systems are based on operating changes only and include no capital improvements. Change in existing FOM rates related to increasing the injection rate of an existing system or upgrading the PAC are expected to be negligible and therefore excluded from the model.

### *Variable O&M (VOM)*

Variable O&M is a function of:

- Current & incremental PAC use and unit costs;
- Incremental waste production and unit disposal costs; and

The following factors and assumptions underlie calculations of the VOM:

# Mercury Control Incremental Operating Cost Methodology

- All of the VOM costs were tabulated on a per megawatt-hour (MWh) basis.

- Increased Injection Rate:

  - Existing ACI systems are assumed to be built with some design margin that can be utilized to increase PAC injection rates without capital improvement. The remaining design margin is assumed to be 20% and therefore, the increased injection rate is assumed to be 20% higher than the current injection rate of the existing system as long as it meets the following conditions:
    - The new controlled mercury rate does not drop below 1.1 lb/TBtu for Lignite or 0.25 lb/TBtu for PRB or Bituminous fuels.
    - The overall control rate does not exceed 95% from the uncontrolled rate.

    *In either of these cases, the model will reduce the increased injection rate in order to satisfy both conditions.*
  - User can enter a site-specific remaining design margin value, however, it is recommended not to use more than 20% without obtaining site-specific information on remaining ACI system capacity.

- PAC Usage:
  - The total PAC usage is calculated from the total flue gas flow rate and the expected design injection rate to achieve the new Hg emission rate.
  - The incremental sorbent usage is calculated from the flue gas flow rate and the difference between the new expected injection rate and the current injection rate.

- Since the model was developed for units with an existing ACI system, it is assumed that no additional flyash will be captured as a result of increased PAC injection. Therefore, the PAC waste generation rate is equal to the PAC feed rate for the total and incremental rates.

- There is not expected to be an appreciable change in the power consumption of the existing system, therefore, no increase in power VOM is included in the model.

Due to the variability in PAC costs depending on the selected sorbent type, sorbent unit costs ($/ton) can be entered by the user, otherwise the user can choose to use estimated sorbent costs which are based on current industry values as of 2021.

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:

- Current and Future PAC costs in $/ton
- Waste disposal costs in $/ton

The variables that contribute to the overall VOM are:

VOMR = Variable O&M costs for incremental PAC

VOMW = Variable O&M costs for incremental waste disposal

VOMP = Variable O&M costs for additional auxiliary power (set to zero)

The total VOM is the sum of VOMR, VOMW and VOMP.

# Mercury Control Incremental Operating Cost Methodology

Table 1 contains an example of the complete O&M cost estimate worksheet when firing Lignite coal with an ESP using an existing Hg emission rate of 4.0 lb/TBtu (existing MATS limit) and upgrading PAC from standard to premium type. Table 1 contains an example of the complete O&M cost estimate worksheet when firing Lignite coal with a baghouse using an existing Hg emission rate of 4.0 lb/TBtu (existing MATS limit) and upgrading PAC from standard to premium type. Table 3 contains an example of the complete O&M cost estimate worksheet when firing PRB coal with a baghouse using an existing Hg emission rate of 1.2 lb/TBtu (existing MATS limit) and upgrading PAC from standard to premium type. Table 4 contains an example of the complete O&M cost estimate worksheet when firing PRB coal with an ESP using an existing Hg emission rate of 1.2 lb/TBtu (existing MATS limit) and upgrading PAC from standard to premium type.

# Mercury Control Incremental Operating Cost Methodology

## Table 1. Example Complete O&M Estimate for Increased ACI Rate on Lignite-fired Boiler w/ ESP

Fill in the yellow cells with the known data inputs. The resulting costs are tabulated below. Variable names are defined as outlined in the table.

| Variable | Designation | Units | Value | Calculation |
|---|---|---|---|---|
| Unit Size (Gross) | A | MW | **500** | <--- User Input |
| Gross Heat Rate | B | Btu/kWh | **9500** | <--- User Input |
| Uncontrolled Hg Rate | C | lb/TBtu | **6** | <--- User Input. Enter Hg emission rate with no controls. |
| Current Controlled Hg Rate | D | lb/TBtu | **4.00** | <--- User Input. Enter the current control rate when injecting the design rate. |
| Additional System Capacity Remaining | E | | **20%** | <--- User Input. S&L recommends not exceeding 20%. Note this will be applied as additional capacity (i.e. current injection rate plus X%). |
| New Controlled Hg Rate Basis | | | Model Estima | <--- User Input. Select basis for controlled emission rate. |
| | | | 1.20 | |
| Estimated Best Hg Controlled Rate | | lb/TBtu | 1.10 | Calculated based on specified remaining capacity (Line E) with minimum values set at 1.1 lb/TBtu for Lignite, or 0.25 lb/TBtu for PRB or bituminous fuel. |
| New Controlled Hg Rate | F | lb/TBtu | 1.10 | |
| Type of Coal | G | | Lignite | <--- User Input |
| Existing PM Control | H | | ESP | <--- User Input |
| Current Sorbent | J | | Standard PAC | <--- User Input |
| New Selected Sorbent | K | | Premium P<br>1 | Lignite requires standard PAC for control rates >=4 lb/TBtu. PRB and Bituminous require standard PAC for control rates >=1.2 lb/Tbtu. Lignite requires Halogenated Premium PAC to achieve 1.1-4 lb/TBtu. PRB and Biminous fuels require Premium PAC for 0.25-1.2 lb/Tbtu. Additionally, PRB and Lignite fuels require halogenated PAC in any case in order to convert Hg from elemental to ionic for more efficient capture. Although both standard and premium PAC can in some cases achieve the same emission rate with different injection rates, it is assumed the most efficient selection is relative to current MATS limit (4.0 lb/TBtu for Lignite and 1.2 lb/TBtu for PRB and Bituminous). |
| Existing Injection Rate | L | | Model Estimated<br>2 | If current injection rate (lb/Mmacf) is known, select User Entered. If not, enter Model Estimated. |
| | | | | |
| Estimated Injection Rate | | lb/MMacf | 2.7 | Injection rate calculated based on the current outlet emission rate, fuel type and PM removal type. |
| New Injection Rate | M1 | lb/MMacf | 2.7 | New injection rate calculated based on the new outlet emission rate, fuel type and PM removal type. Limited to remaining system capacity increase, applied to current injection rate, based on no modifications to existing equipment. |
| New Estimated Emission Rate | M2 | lb/TBtu | 1.1 | |
| Addtitional Control | N | % | 72.5 | = (D-E)/D*100 |
| Heat Input | P | Btu/hr | 4.75E+09 | = A*B*1000 |
| Flue Gas Rate | Q | acfm | 2,066,250 | Downstream of an air preheater<br>For Bituminous Coal = A*B*0.362<br>For PRB Coal = A*B*0.400<br>For Lignite Coal = A*B*0.435 |
| Total Sorbent Feed | R1 | lb/hr | 340 | = Q*60*M1/1000000 |
| Estimated Current | R2 | lb/hr | 336 | = Q*60*L/1000000 |
| Total Sorbent Waste | S | lb/hr | 340 | = R1 |
| Incremental Sorbent Feed Rate | T | lb/hr | 4 | = Q*60*(M1-L)/1000000 |
| Incremental Sorbent Waste Rate | U | lb/hr | 4 | = T |
| Current Sorbent Cost - Delivered | V | $/ton | **880** | <--- User input cost (Standard PAC = $880, Halogenated PAC = $1040, Premium PAC = $1080 and Halogenated Premium PAC = $1280) |
| Sorbent Cost - Delivered | W | $/ton | **1080** | <--- User input cost (Standard PAC = $880, Halogenated PAC = $1040, Premium PAC = $1080 and Halogenated Premium PAC = $1280) |
| Waste Disposal Cost | X | $/ton | **30** | <--- User Input |

### Costs are all based on 2021 dollars

**Estimated Existing Variable O&M Cost**

| | | | |
|---|---|---|---|
| VOMR ($/MWh) = (R2*V)/(2000*A) | $ | 0.30 | Estimated current variable O&M costs for sorbent. |
| VOMW ($/MWh) = R2/2000*X/A | $ | 0.01 | Estimated current variable O&M costs for waste disposal. |
| VOMP ($/MWh) = 0 | | | Not estimated |
| **VOM ($/MWh) = VOMR + VOMW + VOMP** | **$** | **0.31** | |

**Incremental Variable O&M Cost**

| | | | |
|---|---|---|---|
| VOMR ($/MWh) = [(T*W+(R2)*(W-V)]/(2000*A) | $ | 0.07 | Incremental variable O&M costs for sorbent, including incremental price difference for upgrading PAC, if applicable. |
| VOMW ($/MWh) = U/2000*X/A | $ | - | Variable O&M costs for waste disposal that includes the incremental sorbent waste |
| VOMP ($/MWh) = 0 | $ | - | Additional power consumption is assumed to be a negligible amount compared to the current system requirements. |
| **VOM ($/MWh) = VOMR + VOMW + VOMP** | **$** | **0.07** | |

# Mercury Control Incremental Operating Cost Methodology

## Table 2. Example Complete O&M Estimate for Increased ACI Rate on Lignite-fired Boiler w/ Baghouse

Fill in the yellow cells with the known data inputs. The resulting costs are tabulated below. Variable names are defined as outlined in the table.

| Variable | Designation | Units | Value | Calculation |
|---|---|---|---|---|
| Unit Size (Gross) | A | MW | 500 | <--- User Input |
| Gross Heat Rate | B | Btu/kWh | 9500 | <--- User Input |
| Uncontrolled Hg Rate | C | lb/TBtu | 6 | <--- User Input. Enter Hg emission rate with no controls. |
| Current Controlled Hg Rate | D | lb/TBtu | 4.00 | <--- User Input. Enter the current control rate when injecting the design rate. |
| Additional System Capacity Remaining | E | | 20% | <--- User Input. S&L recommends not exceeding 20%. Note this will be applied as additional capacity (i.e. current injection rate plus X%). |
| New Controlled Hg Rate Basis | | | Model Estima | <--- User Input. Select basis for controlled emission rate. |
| | | | 1.20 | |
| Estimated Best Hg Controlled Rate | | lb/TBtu | 1.10 | Calculated based on specified remaining capacity (Line E) with minimum values set at 1.1 lb/TBtu for Lignite, or 0.25 lb/TBtu for PRB or bituminous fuel. |
| New Controlled Hg Rate | F | lb/TBtu | 1.10 | |
| Type of Coal | G | | Lignite | <--- User Input |
| Existing PM Control | H | | Baghouse | <--- User Input |
| Current Sorbent | J | | Standard PAC | <--- User Input |
| New Selected Sorbent | K | | Premium P<br>1 | Lignite requires standard PAC for control rates >=4 lb/TBtu. PRB and Bituminous require standard PAC for control rates >=1.2 lb/Tbtu. Lignite requires Halogenated Premium PAC to achieve 1.1-4 lb/TBtu. PRB and Biminous fuels require Premium PAC for 0.25-1.2 lb/Tbtu. Additionally, PRB and Lignite fuels require halogenated PAC in any case in order to convert Hg from elemental to ionic for more efficient capture. Although both standard and premium PAC can in some cases achieve the same emission rate with different injection rates, it is assumed the most efficient selection is relative to current MATS limit (4.0 lb/TBtu for Lignite and 1.2 lb/TBtu for PRB and Bituminous). |
| Existing Injection Rate | L | | Model Estimated<br>2 | If current injection rate (lb/Mmacf) is known, select User Entered. If not, enter Model Estimated. |
| | | | | |
| Estimated Injection Rate | | lb/MMacf | 1.9 | Injection rate calculated based on the current outlet emission rate, fuel type and PM removal type. |
| New Injection Rate | M1 | lb/MMacf | 1.8 | New injection rate calculated based on the new outlet emission rate, fuel type and PM removal type. Limited to remaining system capacity increase, applied to current injection rate, based on no modifications to existing equipment. |
| New Estimated Emission Rate | M2 | lb/TBtu | 1.1 | |
| Additional Control | N | % | 72.5 | = (D-E)/D*100 |
| Heat Input | P | Btu/hr | 4.75E+09 | = A*B*1000 |
| Flue Gas Rate | Q | acfm | 2,066,250 | Downstream of an air preheater<br>For Bituminous Coal = A*B*0.362<br>For PRB Coal = A*B*0.400<br>For Lignite Coal = A*B*0.435 |
| Total Sorbent Feed | R1 | lb/hr | 224 | = Q*60*M1/1000000 |
| Estimated Current | R2 | lb/hr | 235 | = Q*60*L/1000000 |
| Total Sorbent Waste | S | lb/hr | 224 | = R1 |
| Incremental Sorbent Feed Rate | T | lb/hr | -11 | = Q*60*(M1-L)/1000000 |
| Incremental Sorbent Waste Rate | U | lb/hr | -11 | = T |
| Current Sorbent Cost - Delivered | V | $/ton | 880 | <--- User input cost (Standard PAC = $880, Halogenated PAC = $1040, Premium PAC = $1080 and Halogenated Premium PAC = $1280) |
| Sorbent Cost - Delivered | W | $/ton | 1080 | <--- User input cost (Standard PAC = $880, Halogenated PAC = $1040, Premium PAC = $1080 and Halogenated Premium PAC = $1280) |
| Waste Disposal Cost | X | $/ton | 30 | <--- User Input |

**Costs are all based on 2021 dollars**

**Estimated Existing Variable O&M Cost**

| | | | |
|---|---|---|---|
| VOMR ($/MWh) = (R2*V)/(2000*A) | $ | 0.21 | Estimated current variable O&M costs for sorbent. |
| VOMW ($/MWh) = R2/2000*X/A | $ | 0.01 | Estimated current variable O&M costs for waste disposal. |
| VOMP ($/MWh) = 0 | | | Not estimated |
| **VOM ($/MWh) = VOMR + VOMW + VOMP** | **$** | **0.21** | |

**Incremental Variable O&M Cost**

| | | | |
|---|---|---|---|
| VOMR ($/MWh) = [(T*W+(R2)*(W-V)]/(2000*A) | $ | 0.04 | Incremental variable O&M costs for sorbent, including incremental price difference for upgrading PAC, if applicable. |
| VOMW ($/MWh) = U/2000*X/A | $ | - | Variable O&M costs for waste disposal that includes the incremental sorbent waste |
| VOMP ($/MWh) = 0 | $ | - | Additional power consumption is assumed to be a negligible amount compared to the current system requirements. |
| **VOM ($/MWh) = VOMR + VOMW + VOMP** | **$** | **0.04** | |

# Mercury Control Incremental Operating Cost Methodology

## Table 3. Example O&M Estimate for Increased ACI Rate on PRB-fired Boiler w/ Baghouse

Fill in the yellow cells with the known data inputs. The resulting costs are tabulated below. Variable names are defined as outlined in the table.

| Variable | Designation | Units | Value | Calculation |
|---|---|---|---|---|
| Unit Size (Gross) | A | MW | **500** | <--- User Input |
| Gross Heat Rate | B | Btu/kWh | **9500** | <--- User Input |
| Uncontrolled Hg Rate | C | lb/TBtu | **6** | <--- User Input. Enter Hg emission rate with no controls. |
| Current Controlled Hg Rate | D | lb/TBtu | **1.20** | <--- User Input. Enter the current control rate when injecting the design rate. |
| Additional System Capacity Remaining | E | | **20%** | <--- User Input. S&L recommends not exceeding 20%. Note this will be applied as additional capacity (i.e. current injection rate plus X%). |
| New Controlled Hg Rate Basis | | | Model Estima | <--- User Input. Select basis for controlled emission rate. |
| | | | 1.20 | |
| Estimated Best Hg Controlled Rate | | lb/TBtu | 0.52 | Calculated based on specified remaining capacity (Line E) with minimum values set at 1.1 lb/TBtu for Lignite, or 0.25 lb/TBtu for PRB or bituminous fuel. |
| New Controlled Hg Rate | F | lb/TBtu | 0.52 | |
| Type of Coal | G | | PRB | <--- User Input |
| Existing PM Control | H | | Baghouse | <--- User Input |
| Current Sorbent | J | | Standard PAC | <--- User Input |
| New Selected Sorbent | K | | Premium P<br>1 | Lignite requires standard PAC for control rates >=4 lb/TBtu. PRB and Bituminous require standard PAC for control rates >=1.2 lb/Tbtu. Lignite requires Halogenated Premium PAC to achieve 1.1-4 lb/TBtu. PRB and Biminous fuels require Premium PAC for 0.25-1.2 lb/Tbtu. Additionally, PRB and Lignite fuels require halogenated PAC in any case in order to convert Hg from elemental to ionic for more efficient capture. Although both standard and premium PAC can in some cases achieve the same emission rate with different injection rates, it is assumed the most efficient selection is relative to current MATS limit (4.0 lb/TBtu for Lignite and 1.2 lb/TBtu for PRB and Bituminous). |
| Existing Injection Rate | L | | Model Estimated<br>2 | If current injection rate (lb/Mmacf) is known, select User Entered. If not, enter Model Estimated. |
| | | | | |
| Estimated Injection Rate | | lb/MMacf | 1.8 | Injection rate calculated based on the current outlet emission rate, fuel type and PM removal type. |
| New Injection Rate | M1 | lb/MMacf | 2.2 | New injection rate calculated based on the new outlet emission rate, fuel type and PM removal type. Limited to remaining system capacity increase, applied to current injection rate, based on no modifications to existing equipment. |
| New Estimated Emission Rate | M2 | lb/TBtu | 0.5 | |
| Addtitional Control | N | % | 56.8 | = (D-E)/D*100 |
| Heat Input | P | Btu/hr | 4.75E+09 | = A*B*1000 |
| Flue Gas Rate | Q | acfm | 1,900,000 | Downstream of an air preheater<br>For Bituminous Coal = A*B*0.362<br>For PRB Coal = A*B*0.400<br>For Lignite Coal = A*B*0.435 |
| Total Sorbent Feed | R1 | lb/hr | 246 | = Q*60*M1/1000000 |
| Estimated Current | R2 | lb/hr | 205 | = Q*60*L/1000000 |
| Total Sorbent Waste | S | lb/hr | 246 | = R1 |
| Incremental Sorbent Feed Rate | T | lb/hr | 41 | = Q*60*(M1-L)/1000000 |
| Incremental Sorbent Waste Rate | U | lb/hr | 41 | = T |
| Current Sorbent Cost - Delivered | V | $/ton | **880** | <--- User input cost (Standard PAC = $880, Halogenated PAC = $1040, Premium PAC = $1080 and Halogenated Premium PAC = $1280) |
| Sorbent Cost - Delivered | W | $/ton | **1080** | <--- User input cost (Standard PAC = $880, Halogenated PAC = $1040, Premium PAC = $1080 and Halogenated Premium PAC = $1280) |
| Waste Disposal Cost | X | $/ton | **30** | <--- User Input |

**Costs are all based on 2021 dollars**

**Estimated Existing Variable O&M Cost**

| | | | |
|---|---|---|---|
| VOMR ($/MWh) = (R2*V)/(2000*A) | $ | 0.18 | Estimated current variable O&M costs for sorbent. |
| VOMW ($/MWh) = R2/2000*X/A | $ | 0.01 | Estimated current variable O&M costs for waste disposal. |
| VOMP ($/MWh) = 0 | | | Not estimated |
| **VOM ($/MWh) = VOMR + VOMW + VOMP** | **$** | **0.19** | |

**Incremental Variable O&M Cost**

| | | | |
|---|---|---|---|
| VOMR ($/MWh) = [(T*W+(R2)*(W-V)]/(2000*A) | $ | 0.09 | Incremental variable O&M costs for sorbent, including incremental price difference for upgrading PAC, if applicable. |
| VOMW ($/MWh) = U/2000*X/A | $ | 0.00 | Variable O&M costs for waste disposal that includes the incremental sorbent waste |
| VOMP ($/MWh) = 0 | $ | - | Additional power consumption is assumed to be a negligible amount compared to the current system requirements. |
| **VOM ($/MWh) = VOMR + VOMW + VOMP** | **$** | **0.09** | |

# Mercury Control Incremental Operating Cost Methodology

## Table 4. Example Complete O&M Estimate for Increased ACI Rate on a PRB-fired Boiler w/ ESP

Fill in the yellow cells with the known data inputs. The resulting costs are tabulated below. Variable names are defined as outlined in the table.

| Variable | Designation | Units | Value | Calculation |
|---|---|---|---|---|
| Unit Size (Gross) | A | MW | **500** | <--- User Input |
| Gross Heat Rate | B | Btu/kWh | **9500** | <--- User Input |
| Uncontrolled Hg Rate | C | lb/TBtu | **6** | <--- User Input. Enter Hg emission rate with no controls. |
| Current Controlled Hg Rate | D | lb/TBtu | **1.20** | <--- User Input. Enter the current control rate when injecting the design rate. |
| Additional System Capacity Remaining | E | | **20%** | <--- User Input. S&L recommends not exceeding 20%. Note this will be applied as additional capacity (i.e. current injection rate plus X%). |
| New Controlled Hg Rate Basis | | | Model Estima | <--- User Input. Select basis for controlled emission rate. |
| | | | 1.20 | |
| Estimated Best Hg Controlled Rate | | lb/TBtu | 0.52 | Calculated based on specified remaining capacity (Line E) with minimum values set at 1.1 lb/TBtu for Lignite, or 0.25 lb/TBtu for PRB or bituminous fuel. |
| New Controlled Hg Rate | F | lb/TBtu | 0.52 | |
| Type of Coal | G | | PRB | <--- User Input |
| Existing PM Control | H | | ESP | <--- User Input |
| Current Sorbent | J | | Standard PAC | <--- User Input |
| New Selected Sorbent | K | | Premium P<br>1 | Lignite requires standard PAC for control rates >=4 lb/TBtu. PRB and Bituminous require standard PAC for control rates >=1.2 lb/Tbtu. Lignite requires Halogenated Premium PAC to achieve 1.1-4 lb/TBtu. PRB and Biminous fuels require Premium PAC for 0.25-1.2 lb/Tbtu. Additionally, PRB and Lignite fuels require halogenated PAC in any case in order to convert Hg from elemental to ionic for more efficient capture. Although both standard and premium PAC can in some cases achieve the same emission rate with different injection rates, it is assumed the most efficient selection is relative to current MATS limit (4.0 lb/TBtu for Lignite and 1.2 lb/TBtu for PRB and Bituminous). |
| Existing Injection Rate | L | | Model Estimated<br>2 | If current injection rate (lb/Mmacf) is known, select User Entered. If not, enter Model Estimated. |
| | | | | |
| Estimated Injection Rate | | lb/MMacf | 3.0 | Injection rate calculated based on the current outlet emission rate, fuel type and PM removal type. |
| New Injection Rate | M1 | lb/MMacf | 3.6 | New injection rate calculated based on the new outlet emission rate, fuel type and PM removal type. Limited to remaining system capacity increase, applied to current injection rate, based on no modifications to existing equipment. |
| New Estimated Emission Rate | M2 | lb/TBtu | 0.5 | |
| Addtitional Control | N | % | 57.0 | = (D-E)/D*100 |
| Heat Input | P | Btu/hr | 4.75E+09 | = A*B*1000 |
| Flue Gas Rate | Q | acfm | 1,900,000 | Downstream of an air preheater<br>For Bituminous Coal = A*B*0.362<br>For PRB Coal = A*B*0.400<br>For Lignite Coal = A*B*0.435 |
| Total Sorbent Feed | R1 | lb/hr | 410 | = Q*60*M1/1000000 |
| Estimated Current | R2 | lb/hr | 342 | = Q*60*L/1000000 |
| Total Sorbent Waste | S | lb/hr | 410 | = R1 |
| Incremental Sorbent Feed Rate | T | lb/hr | 68 | = Q*60*(M1-L)/1000000 |
| Incremental Sorbent Waste Rate | U | lb/hr | 68 | = T |
| Current Sorbent Cost - Delivered | V | $/ton | **880** | <--- User input cost (Standard PAC = $880, Halogenated PAC = $1040, Premium PAC = $1080 and Halogenated Premium PAC = $1280) |
| Sorbent Cost - Delivered | W | $/ton | **1080** | <--- User input cost (Standard PAC = $880, Halogenated PAC = $1040, Premium PAC = $1080 and Halogenated Premium PAC = $1280) |
| Waste Disposal Cost | X | $/ton | **30** | <--- User Input |

**Costs are all based on 2021 dollars**

**Estimated Existing Variable O&M Cost**

| | | | |
|---|---|---|---|
| VOMR ($/MWh) = (R2*V)/(2000*A) | $ | 0.30 | Estimated current variable O&M costs for sorbent. |
| VOMW ($/MWh) = R2/2000*X/A | $ | 0.01 | Estimated current variable O&M costs for waste disposal. |
| VOMP ($/MWh) = 0 | | | Not estimated |
| **VOM ($/MWh) = VOMR + VOMW + VOMP** | **$** | **0.31** | |

**Incremental Variable O&M Cost**

| | | | |
|---|---|---|---|
| VOMR ($/MWh) = [(T*W+(R2)*(W-V)]/(2000*A) | $ | 0.14 | Incremental variable O&M costs for sorbent, including incremental price difference for upgrading PAC, if applicable. |
| VOMW ($/MWh) = U/2000*X/A | $ | 0.00 | Variable O&M costs for waste disposal that includes the incremental sorbent waste |
| VOMP ($/MWh) = 0 | $ | - | Additional power consumption is assumed to be a negligible amount compared to the current system requirements. |
| **VOM ($/MWh) = VOMR + VOMW + VOMP** | **$** | **0.14** | |