Preliminary Analysis of Mercury Control Options for Naugatuck Sewage Sludge Incinerator

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Table of Contents

Executive Summary v
1.0 Introduction 1
2.0 Basis Of Technical and Economic Evaluations 2
2.1 Process Description 2
2.2 Emissions and Process Data 3
3.0 Mercury Control Regulatory Background 6
3.1 Existing Regulatory Requirements 6
3.2 Future/Pending Regulatory Requirements 6
4.0 Mercury Control Options 8
4.1 Mercury Control Technical Considerations 8
4.2 Identification of Mercury Control Options 8
4.2.1 Wet Scrubbing With and Without Chemical Conversion 9
4.2.2 Wet ESP (WESP) Alone or In Combination with Other Wet Scrubbers 12
4.2.3 Fixed Bed Activated Carbon Adsorption (ACA) 13
4.2.4 Ultra high-efficiency filter (UHF) followed by Activated Carbon Adsorption 13
4.2.5 UHF followed by Multiple Carbon Impregnated Filters In Series 13
4.2.6 Activated Carbon Injection Ahead of Fabric Filter 14
4.3 Mercury Control System Operating Experience at SSIs 14
4.3.1 Mattabassett District – Fixed Bed Activated Carbon Adsorption 15
4.3.2 Ypsilanti, MI – Fixed Bed Activated Carbon Adsorption 16
4.3.3 Buffalo, MN – Activated Carbon Injection with Fabric Filter 17
4.4 Mercury Control Technology Hierarchy 18
4.5 Cost Effectiveness Analysis and Other Considerations 19
4.5.1 Cost Impact Analysis 19
4.5.2 Energy Impact Analysis 37
4.5.3 Environmental Impact Analysis 37
4.6 Conclusions 38
5.0 References 40

Tables

Table ES-1-1 – Summary of Mercury Control Options and Cost Analysis Results vi
Table 2-1 – Summary of Process and Pollutant Emissions Test Data 5
Table 4-1 – Summary of Mercury Controls, Permit Limits and Test Data for SSIs 10
Table 4-2 – Mercury Control Technology Hierarchy 19
Table 4-3 – Capital and O&M Costs for Tri-Mer Wet Scrubbing System 23
Table 4-4 – Capital and O&M Costs for UHF and Carbon Adsorption 27
Table 4-5 – Capital and O&M Costs for Carbon Injection and Fabric Filtration 31
Table 4-6 – Capital and O&M Costs for UHF and Carbon Impregnated Filters 35
Table 4-7 – Capital and O&M Costs for Mercury Control Options 37

Figures

Figure 2-1 – Process Flow Diagram 4
Figure 4-1 – Process Flow Diagram – Tri-Mer/ADA System 22
Figure 4-2 – Process Flow Diagram – UHF and Fixed Bed Carbon Bed 26
Figure 4-3 – Process Flow Diagram – Carbon Injection and Fabric Filtration 30
Figure 4-4 – Process Flow Diagram – UHF and Carbon Impregnated Filters 34

GLOSSARY

ACA	Activated Carbon Adsorption
ACFM	Actual Cubic Feet per Minute
ACI	Activated Carbon Injection
AGR	Acid Gas Removal system
AQA	Air Quality Associates
ARI	Alternative Resources Inc.
ACA	Activated Carbon Adsorption
BACT	Best Available Control Technology
CAA	Clean Air Act
CIF	Carbon Impregnated Filter
CO	Carbon Monoxide
CTDEP	Connecticut Department of Environmental Protection
DSCFM	Dry Standard Cubic Feet per Minute
DT	Dry Tons
EGU	Electric Generating Unit
EPA	Environmental Protection Agency
FBI	Fluid Bed Incinerator
FF	Fabric Filter
HAPs	Hazardous Air Pollutants
Hg	Mercury
ID	Induced Draft
ITS	Impingement Tray Scrubber
MACT	Maximum Achievable Control Technology
MDC	Metropolitan District Commission
MHI	Multiple Hearth Incinerator
MIHA	M.I. Holzman & Associates, LLC
MVS	Multiple Venturi Scrubber
MWC	Municipal Waste Combustor
MWI	Medical Waste Incinerator
NAAQS	National Ambient Air Quality Standard
NaOCl	Sodium Hypochlorite
NACWA	National Association of Clean Water Agencies
NO2	Nitrogen Dioxide
NOx	Nitrogen Oxides
NWPCA	Borough of Naugatuck Water Pollution Control Authority
NWWTP	Borough of Naugatuck's Wastewater Treatment Plant
OAR	EPA Office of Air and Radiation
ORCR	EPA's Office of Resource Conservation and Recovery

O&M	Operation & Maintenance
OSWI	Other Solid Waste Incinerators
Pb	Lead
PBS	Packed Bed Scrubber
PLC	Programmable Logic Controller
PM	Particulate Matter
POTW	Publicly Owned Treatment Works
RCRA	Resource Conservation and Recovery Act
SCADA	Supervisory Control and Data Acquisition
SO2	Sulfur Dioxide
SSI	Sewage Sludge Incinerator
TCLP	Toxic Characteristic Leaching Procedure
TMDL	Total Maximum Daily Load
UHF	Ultra High Efficiency Filter
VOC	Volatile Organic Compounds
VPS	Venturi Pack Scrubber
VS	Venturi Scrubber
WESP	Wet Electrostatic Precipitator
WHB	Waste Heat Boiler
WPCA	Water Pollution Control Authority
WWTP	Wastewater Treatment Plant
YCUA	Ypsilanti Community Utilities Authority

EXECUTIVE SUMMARY

This document presents the results of a planning-level technology and cost assessment for controlling mercury (Hg) emissions from the sewage sludge incinerator (SSI) at the Borough of Naugatuck's Wastewater Treatment Plant (NWWTP). The analyses were conducted to provide the Borough of Naugatuck Water Pollution Control Authority (NWPCA) with a better perspective of the implications and potential cost impacts of future mercury control requirements applicable to its biosolids incinerator.

This preliminary Hg control assessment is not intended to satisfy the detailed scope of analyses that may be required by a pending consent order, recently issued in draft by the CT Department of Environmental Protection (CTDEP) to the NWPCA. However, the preliminary assessment identifies potentially-applicable and/or commercially-available Hg control technologies that may merit further evaluation and the potential need for pilot testing by the NWPCA and summarizes estimated Hg control performance, capital and operating costs and other impacts. The information presented herein is based on review of equipment vendor budgetary proposals, discussions with operators of existing commercial and pilot test applications of the technologies and other information.

Table ES-1-1 summarizes for the mercury control options evaluated the estimated capital and annualized operating costs and Hg removal performance. All listed options are considered commercially available (as defined by USEPA) as vendor budgetary proposals were obtained, although the operating history of certain available technologies is short and/or, in some cases "spotty", as described below. Carbon injection with fabric filtration has been demonstrated on at least two (2) sewage sludge incinerators (SSI) in the U.S. Based on discussions with the operator of one of the installations, the system appears to be performing as designed. Both installations were on new, rather than retrofitted SSIs. Fixed bed carbon adsorption has been installed at one SSI in CT as a long-term demonstration project under a consent order and at least one permanent SSI application in MI. Both installations have experienced operational problems associated with particulate, moisture and/or other SSI flue gas constituents affecting the integrity and performance of the activated carbon. An ultra high efficiency filter (UHF) located upstream of the carbon bed has potential to alleviate these problems, but has been evaluated only in a limited pilot test at an SSI in CT. For these reasons, fixed bed carbon adsorption is not currently considered demonstrated in practice to the extent that it could be regarded as technically feasible in this application. An additional concern for this option is that the spent carbon will likely require management as hazardous waste, based on operating experience at the CT demonstration project installation. UHF combined with a series of fixed carbon-impregnated filters has also been evaluated in a limited pilot test at one SSI in CT and may have potential cost and operating benefits compared to fixed bed carbon systems; however, Hg removal efficiency may be lower with that option. The hypochlorite wet scrubbing option has not been applied to our knowledge at any SSI, although it has been used in the mining industry for Hg control. Differences in the flue gas composition between combustion and non-combustion exhaust streams, namely high carbon monoxide (CO) and carbon dioxide (CO_2) concentrations in combustion flue gas, may make the technology impractical in an SSI application due to the potential for high pH adjustment chemical (e.g. sodium hydroxide) consumption rates and the associated cost impact. Therefore, the only technology considered both commercially available and demonstrated in practice (although for a short period of time) in this application is carbon injection with fabric filtration. However, associated costs are significant.

The lowest capital and operating costs of the identified options are associated with the UHF with carbon-impregnated filters. However, this option offers the lowest percent mercury control. The vendor

(APC Technologies) predicts control efficiencies of between 70% and 90% for temperatures below 160ºF. The approximate exhaust temperature after existing controls is currently 200ºF. Therefore, a heat exchanger would be needed to further cool the flue gas for that option. At 200ºF, the vendor estimates that the Hg control efficiency would be reduced to about 50%. UHF with fixed bed carbon adsorption presents the next lowest capital and operating cost option. The capital and annualized operating costs of the other two (2) options (hypochlorite wet scrubbing and carbon injection with fabric filtration) are similar and the highest of the identified options, based on the assumptions used in this analysis. Please note, however, that the operating costs for the Tri-Mer wet scrubbing option are less certain since the vendor did not supply a complete estimate. The chemical costs were scaled from information previously provided for another sewage sludge incinerator.

Table ES-1-1 – Summary of Mercury Control Options and Cost Analysis Results

	Tri-Mer Hypochlorite Scrubber[1]	UHF and Fixed Bed Carbon Adsorption	Carbon Injection and Fabric Filter[2]	UHF and Carbon-Impregnated Filters[3]
Commercial Availability	Yes	Yes	Yes	Yes
Demonstrated at full-scale SSI or similar application	No	No[4]	Yes	No
Capital Cost (Installed)	$1,892,000	$1,152,000	$1,941,000	$734,000
Annualized Operating Cost	$734,700	$541,900	$608,000	$424,000
Percent Mercury Removed	90%	85%	85%	50%
Pounds of Mercury Removed	56.7	53.6	53.6	31.5
$/lb of Mercury Removed	$13,000	$10,100	$11,400	$13,500

Notes:

1. Operating costs highly uncertain since they were not provided by the vendor who cited issues with high CO and CO_2 flue gas concentrations after providing the budgetary proposal.
2. Not including removal of the wet system or associated downtime for installation. Operating cost does not include cost of lime for SO_2 and acid gases, if needed.
3. Assumed exhaust temperatures above 200 ºF. If heat exchanger added, capital and operating costs, percent control and pounds of mercury removed all would increase. Vendor estimates heat exchanger capital cost to be ~$50K.
4. Installed in one full-scale demonstration and one commercial application, both with operational problems/premature carbon bed degradation; therefore, long-term reliability has not been demonstrated

Based on the information presented in this report, further, more detailed evaluation of each of the identified options is required to evaluate long-term performance and reliability of the systems and refine the cost estimates. In addition, other operational issues associated with each alternative should be investigated, such as available space for each option, longer start-up times, more frequent shut-downs, effects on other air pollutant emissions, and effects on stack parameters (which may require revised air dispersion modeling for all criteria pollutants). Pilot testing may need to be considered for the best one or two options. NWPCA should also consider performing air quality modeling studies to evaluate the effect (positive or negative) of additional mercury controls on mercury deposition to nearby water bodies.

1.0 INTRODUCTION

This document presents the results of a planning-level technology and cost assessment for controlling mercury (Hg) emissions from the sewage sludge incinerator (SSI) at the Borough of Naugatuck's Wastewater Treatment Plant (NWWTP). The analyses were conducted for the Borough of Naugatuck Water Pollution Control Authority (NWPCA) by Alternative Resources Inc. (ARI) in collaboration with Air Quality Associates (AQA) and M.I. Holzman & Associates, LLC (MIHA) to provide the NWPCA with a better perspective of the implications and potential cost impacts of future mercury control requirements applicable to its biosolids incinerator.

The work was prompted, in part, by recent meetings between representatives of the Connecticut Department of Environmental Protection (CTDEP) and SSI operators in Connecticut in which CTDEP's intent to reduce mercury emissions was discussed. CTDEP also recently (on or about July 24, 2009) issued a draft mercury reduction consent order (No. 8282) to the NWPCA, soliciting comments within 30 days. As currently drafted, the consent order would require the NWPCA to retain consultants (within 90 days of final issuance of the order) to conduct a detailed evaluation of mercury reduction methods for the facility's SSI, including a proposal to implement the selected technology.

Although not intended to satisfy the detailed scope of analyses required by the draft consent order, the preliminary assessment summarized in this document is intended to meet the following objectives:

1. Define basis of technical and economic evaluations, including a summary of process and emissions parameters based on available emissions test data (2004 – 2008) from the NWPCA's SSI.
2. Summarize existing Hg regulatory requirements and standards applicable to SSIs in CT and other states.
3. Summarize Hg control technologies, permit limits and available test results from existing SSIs, based on review of permits, test reports and other literature as well as from discussions with SSI operators.
4. Based on permit data and literature review, as well as discussions with potential Hg control equipment vendors, identify existing and emerging mercury control technologies that are applicable or potentially transferable to the NWPCA's SSI.
5. Evaluate the technical feasibility considerations associated with each of the identified potentially-applicable Hg control options.
6. Develop budgetary capital and operating cost estimates for the technically-feasible Hg control options based on Hg control vendor budgetary proposals and other O&M cost estimation procedures.
7. Evaluate the energy and environmental impacts of the most technically feasible mercury control options.
8. Summarize requirements for further Hg control evaluation.

2.0 BASIS OF TECHNICAL AND ECONOMIC EVALUATIONS

The mercury control technology and cost effectiveness analyses were performed based on the process descriptions and baseline emissions, as summarized in this section.

2.1 Process Description[1]

The Borough of Naugatuck operates a 10.3 million gallon per day publicly owned treatment works (POTW) that processes nonhazardous municipal and industrial waste water and incinerates approximately 51 dry tons of municipal sludge per day. The facility commenced construction on August 15, 1972 and has been operated since 1973. A fluidized bed incinerator (FBI) is used to incinerate sludge. The FBI (also referred to herein as a sewage sludge incinerator or SSI) began operation in 2004 when it replaced two (2) multiple hearth incinerators (MHIs) in order to reduce air pollutant emissions. Both MHIs were permanently shutdown in 2003. Other emission units include four (4) residential heating boilers, one (1) emergency generator, a sludge filter press washer heater, and a 30-gallon parts washer. Other process equipment at the POTW include settling tanks, aeration tanks, thickening tanks, holding tanks, and sludge belt filter presses.

The Zimpro FBI has a sludge design feed rate of 3.5 DT/hr. Sludge is fed to the bottom of the sand bed where air is injected at high pressure under the bed, fluidizing the sand and the sludge. Processing of sludge within the sand bed consists of evaporation of water and pyrolysis of organic material. The remaining carbon and combustible gases are burned in the freeboard area above the sand bed. Oil lances are located within the sand bed and are fired, if necessary, to maintain the desired combustion temperature. All ash generated in the combustion chamber leaves the top of the incinerator.

The incinerator includes an integral sludge dryer system to reduce sludge moisture and the consumption of auxiliary fuel. A waste heat recovery unit extracts heat from the incinerator flue gas to generate steam or heat a thermal oil transfer fluid. The steam or hot oil is used to indirectly heat the sludge in the dryer. Water is evaporated from the heated sludge and is collected by cooling/condensation. The non-condensable exhaust gases from the dryer are fed to the incinerator; therefore, the dryer does not generate any air emissions directly to the atmosphere. The dried sludge is then fed to the incinerator where it is combusted with a reduced need for auxiliary fuel.

A single burner is located near the air injection at the bottom of the bed. This burner is used to pre-heat the incinerator during start up. Lances are used to inject fuel into the bed to control bed temperature. Higher fuel injection rates are necessary when sludge solids content are lowest and moisture highest.

After the flue gas passes through the waste heat recovery unit, particulate matter is removed by a combined venturi and impingement tray scrubber system (VS/ITS), and wet electrostatic precipitators (WESP). The venturi section consists of a narrow, adjustable throat, which increases gas velocity, turbulence and contact with added water,

in order to collect ash particles and acid gases. The impingement tray scrubber provides cool plant effluent, which removes additional particulate and acid gases. There are two identical WESPs located in parallel after the VS/ITS. When the WESP system is operating (i.e., when not out of service for occasional maintenance and repair), only one of the two WESPs are in use. Each WESP makes use of an electric field to attract small particles to collection plates. The particles are removed by flushing the collection plates with water. A process flow diagram showing the waste heat recovery and flue gas control system downstream from the FBI is presented in Figure 2-1.

Other FBI system parameters or specifications as listed in the NWPCA's Title V permit[1] are as follows:

- Gas Flow Rate: 11,050-14,250 scfm @ 68 °F, wet at stack exit
- Incinerator Combustion Temperature: 1550 °F typical during normal steady state or quasi-steady state operations
- Incinerator Residence Time: 3-6 seconds during normal steady state or quasi-steady state operations
- Sludge Heat Content: 7,000–8,000 Btu/lb, moisture free basis, typical
- Start Up Burner Auxiliary Fuel Rate: ≤ 85 gph for no. 2 oil; ≤ 12,070 cu. ft./hr for natural gas
- Lance Burner Auxiliary Fuel Rate: ≤ 225 gph for no. 2 oil; ≤ 32,000 cu. ft./hr for natural gas
- Wet Electrostatic Precipitator (WESP) Manufacturer and Model: each is a Sonic Environmental Systems, Sonickleen, Model WESP-61-10H13.
- Scrubber Type: Venturi with concurrent flow plus impingement tray with countercurrent flow
- Stack Exhaust Gas Flow Rate: normal range is 14,835 acfm – 17,387 acfm
- Stack Minimum Distance to Property Line: 206 ft.
- Minimum Stack Height: 150 ft.
- Stack Exit Gas Temperature Range: 150 – 250 ºF (typical at normal operating conditions)

2.2 Emissions and Process Data

Emissions and process parameters for existing conditions on and the FBI have been tested numerous times between 2004 and 2008 for compliance demonstration and informational purposes. Table 2-1 summarizes the average and range of relevant process and pollutant emissions data representing existing conditions for the FBI.

Overall, the NWPCA Hg emissions data ranged between 20 and 156 $\mu g/m^3$, or 0.0004 to 0.0035 lb/dry-ton of sludge input. At the maximum 3.5 DT/hr sludge throughput, this would equate to about 134 grams/24-hours, which is 24 times lower than the currently applicable regulatory requirement (3,200 grams/24-hours) in the EPA National Emission Standards for Hazardous Air Pollutants, Subpart E – National Emission Standard for Mercury (40 CFR Part 61, Subpart E).

Figure 2-1 – Process Flow Diagram

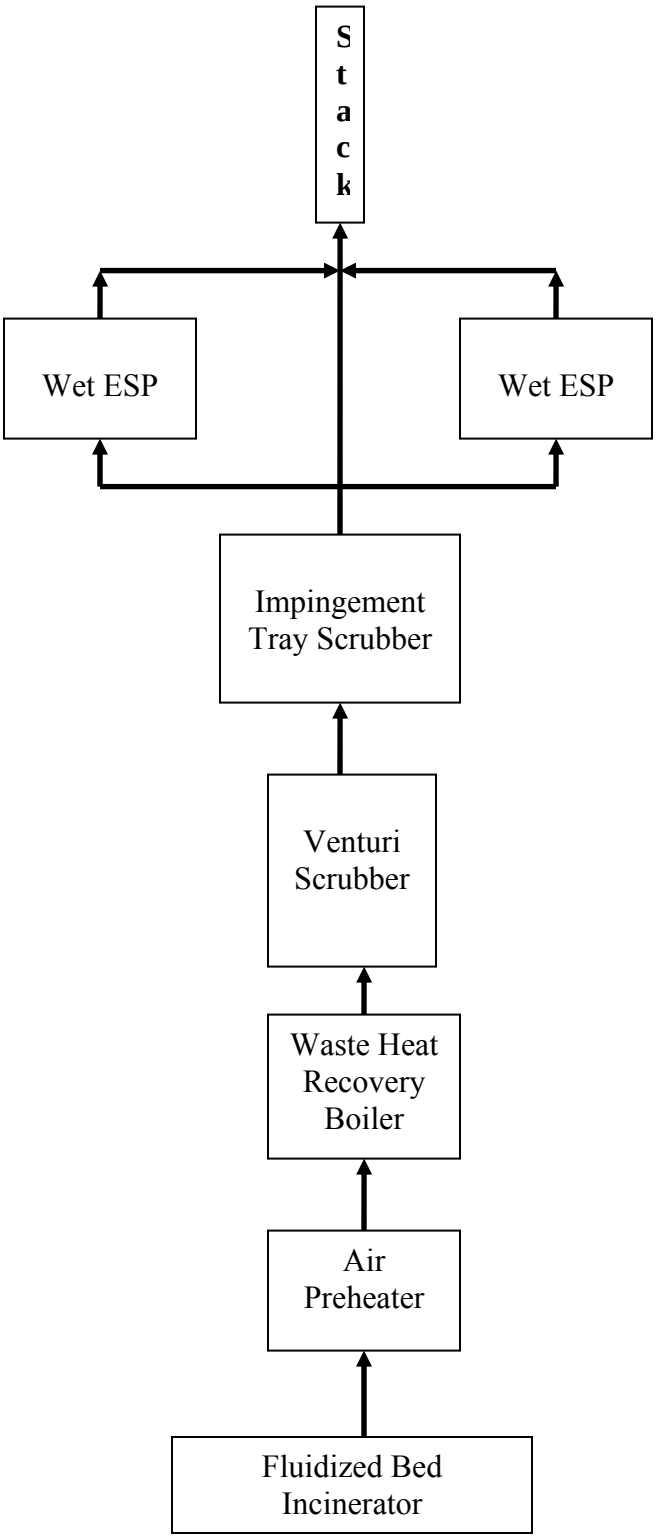

Table 2-1 – Summary of Process and Pollutant Emissions Test Data

	FBI (Existing Conditions)			
	Avg.	**Min.**	**Max.**	**# of Data Points**
Feed Rate, DTPH	3.18	2.95	3.57	15
Stack Temp., deg. F	202	170	231	15
DSCFM	13,879	13,134	14,786	15
% H_2O	4.25	2.1	8.2	15
% CO_2	9.78	8.00	12.48	15
% O_2	9.36	6.22	11.38	15
PM, lb/hr	<0.08	<0.04	<0.12	3
PM, lb/dry ton	<0.02	<0.01	<0.04	3
NO_X, ppm dry	23.7	18.2	32.0	3
NO_X, lb/hr	2.25	1.70	3.05	3
NO_X, lb/dry ton	0.70	0.55	0.94	3
SO_2, ppm dry	55.4	53.1	58.0	3
SO_2, lb/hr	7.32	6.95	7.75	3
SO_2, lb/dry ton	29.0	25.7	31.3	3
CO, ppm dry	1.4	0.9	1.8	3
CO, lb/hr	0.08	0.05	0.11	3
CO, lb/dry ton	0.02	0.02	0.03	3
THC, ppm wet	<0.02	<0.02	0.03	3
THC, lb/hr	<0.01	<0.01	0.01	3
THC, lb/dry ton	<0.01	<0.01	0.01	3
HCl, ppm dry	<0.4	<0.4	<0.5	3
HCl, lb/hr	<0.03	<0.03	<0.03	3
HCl, lb/dry ton	<0.009	<0.009	<0.009	3
Hg, $\mu g/m^3$	73.8	20.3	156.2	15
Hg, lb/hr	0.0049	0.0014	0.01	15
Hg, lb/dry ton	0.017	0.0004	0.0035	15
Hg, grams/24-hours	53.3	14.9	113.4	15

3.0 MERCURY CONTROL REGULATORY BACKGROUND

Mercury is recognized as a potent neurotoxin that poses risks to human health from consumption of fish containing the toxic metal. The majority of mercury in the environment is released into air, but reaches waterbodies through atmospheric deposition, where it bioaccumulates in fish. On December 20, 2007, the US EPA approved the Northeast Regional Mercury Total Maximum Daily Load (TMDL), a regional plan to reduce mercury entering states' waters and focused on reducing atmospheric deposition of mercury. Although northeast regional mercury emissions have decreased by approximately 70 percent between 1998 and 2002, achieved primarily through stringent emission limits on municipal waste combustors (MWC) and medical waste incinerators (MWI), with further reductions achieved from coal-fired power plants beginning in 2008, additional mercury reductions from other emissions sources will be needed to meet aggressive TMDL goals. SSIs are being targeted as one of the larger remaining mercury emissions sources after MWCs, MWIs and coal-fired power plants.

3.1 Existing Regulatory Requirements

Mercury-related regulatory requirements currently applicable to the NWPCA's SSI are summarized as follows:

Regulatory Limit/Requirement	Citation
3200 grams/24-hr (7.1 lb/24-hrs)	40 CFR Part 61, Subpart E {40 CFR 61.52(b)]; 40 CFR Part 503 Subpart E (40 CFR 503.43(b); Permit No. 109-0081
Maximum Allowable Stack Concentration	RCSA § 22a-174-29
Annual stack test	CGS § 22a-191a(b)

3.2 Future/Pending Regulatory Requirements

CTDEP is currently in the process of negotiating consent orders with each of the SSI owners/operators in CT that will ultimately require evaluation and implementation of additional mercury controls at each incinerator. The NWPCA was issued draft Order No. 8282 on or about July 25, 2009, soliciting comments within 30 days. The draft consent order does not contain any specific Hg emission limits or identify specific controls or performance criteria. Instead, as currently drafted, the consent order would require the WPCA to retain consultants (within 90 days of final issuance of the order) to conduct a detailed evaluation of mercury reduction methods for the facility's SSI and to submit a detailed report within one year of CTDEP's approval of the consultants summarizing the results of the evaluation. The final evaluation report must also include a proposal to implement the selected technology or technologies.

Another regulatory issue potentially affecting SSI control requirements in the near future is EPA's pending ruling on whether sewage sludge will be re-classified as solid waste,

which could subject SSIs to more stringent regulation under the Clean Air Act (CAA) Section 129 instead of under CAA Section 112. According to the National Association of Clean Water Agencies (NACWA), EPA's Office of Resource Conservation and Recovery (ORCR, formerly the Office of Solid Waste) will likely propose a definition of solid waste under Subtitle D of the Resource Conservation and Recovery Act (RCRA) that includes biosolids.[2,3] EPA is under a recently extended court-ordered deadline to propose the new definition by April 15, 2010 in order to resolve a legal challenge involving EPA's previous rulemakings on commercial and industrial solid waste incineration. The ORCR rulemaking was initiated to determine how SSIs should be regulated under the CAA.

In response to ORCR's preliminary determination that biosolids would presumably be defined as a solid waste, officials in the EPA Office of Air and Radiation (OAR) notified NACWA that they are proceeding with a separate rulemaking to develop standards under CAA Section 129 with a recently extended December 16, 2010 deadline. Standards developed under CAA Section 129 would be more stringent than those previously under development under Section 112 and would apply Maximum Achievable Control Technology (MACT) standards to each individual SSI. According to EPA's January 2, 2009 Advance Notice of Proposed Rulemaking (74 Fed. Reg. 41), Sections 112 and 129 differ in three primary respects[4]:

1. CAA Section 112 requires that MACT standards be established for major sources of hazardous air pollutant (HAP) emissions, but provides discretionary authority to establish MACT standards for area sources of HAP emissions. On the other hand, CAA Section 129 MACT standards apply across the board to all solid waste incineration units in a given category regardless of size.
2. CAA Section 129 requires that emission standards be set for specific HAPs and certain pollutants that are not classified as CAA Section 112 HAP. Specifically, CAA section 129 requires numeric emission limitations for the following nine pollutants: cadmium, carbon monoxide, dioxins/furans, hydrogen chloride, lead, mercury, nitrogen oxides, particulate matter, opacity and sulfur dioxide. EPA also has the discretion under Section 129 to establish standards for other pollutants.
3. CAA section 129 includes requirements for operator training, pre-construction site assessments, and monitoring that are not included in CAA section 112.

4.0 MERCURY CONTROL OPTIONS

4.1 Mercury Control Technical Considerations

With the exception of mercury, most metals have sufficiently low vapor pressures at typical air pollution control system operating temperatures that condensation occurs prior to particulate matter (PM) collection in the control device.[5] Conversely, mercury has a high vapor pressure at typical air pollution control system operating temperatures, and collection by PM control devices is highly variable. The literature on mercury speciation suggests that elemental mercury (Hg^0) exists at incineration temperatures in the flue gas, because it is thermodynamically and kinetically favored over all oxidized species.[6,7] Elemental Hg^0 is relatively insoluble in water and is unaffected by wet scrubbing systems. However, as the flue gas cools in the heat recovery and wet scrubber system, Hg^0 either remains as a mono-atomic species or is oxidized to form an ionic water-soluble compound (Hg^+), such as mercuric chloride, or insoluble solids such as mercuric oxides or sulfides. Accordingly, the proportion of Hg^0 to Hg^+ determines the effectiveness of traditional PM and wet scrubber control systems. The portion of elemental mercury in the flue gas of SSIs and coal-fired boilers is reported at about 30 – 50 percent as Hg^0, higher than the portion found in MWC flue gas. SSI flue gas also typically has a higher sulfur to chloride ratio than coal-fired boilers and MWCs.[8]

4.2 Identification of Mercury Control Options

Potentially applicable add-on control techniques identified as capable of controlling mercury compound emissions from SSIs are as follows, with options grouped by those that could potentially be applied at the existing incineration facility downstream of the existing heat recovery and wet scrubber systems and those applicable directly downstream of the heat recovery boiler (i.e., in lieu of or upstream of the existing wet scrubbers):

Applicable Downstream of Existing Wet Scrubbers:

- Wet scrubbing with conversion of elemental Hg^0 into a more soluble species that can be absorbed in a scrubber (e.g., NaOCl injection);
- Reheat flue gas and ultra high-efficiency filter (UHF) or other submicron PM pre-filter followed by activated carbon adsorption (fixed bed adsorber); and
- Reheat flue gas and UHF followed by carbon impregnated filter(s).

Applicable Downstream of Heat Recovery Boiler:

- Activated carbon injection with fabric filter.

Additional mercury controls considered to be in the developmental stage for coal-fired power plants or other waste incinerators and possibly applicable to SSIs involve

alternative sorbent injection, such as sodium tetrasulfide, polysulfides and amended silicates.

Control alternatives were identified based upon:

- Review of EPA's RACT/BACT/LAER Clearinghouse;
- Review of technical journals;
- Review of permits and test data for other SSIs;
- Contact with state regulatory agency officials;
- Discussions with and data provided by air pollution control equipment vendors; and
- Contacts with wastewater treatment and sewage sludge incineration industry operators.

Information compiled from the data gathering efforts pertaining to mercury controls, permit limits and test data from SSI facilities are summarized in Table 0-1. Of the 14 SSIs for which both emissions data and permit limits were located, only four facilities (Mattabassett District, CT; Ypsilanti, MI; St. Paul, MN; and Buffalo, MN) were identified as employing specific control technologies for mercury emissions. As discussed further below, two types of activated carbon adsorption systems were installed at the Mattabassett District in a pilot demonstration program under a CTDEP consent order to abate internal mercury releases and exceedances of mercury regulatory limits at that facility. At Ypsilanti, MI a proprietary prefiltration and activated carbon adsorption system was installed by the same supplier of the pilot control systems at the Mattabasset District (Donau Carbon).[9] The mercury control systems installed at St. Paul, MN includes carbon injection and a fabric filter system installed downstream of wet scrubbers, a WESP and flue gas reheat. The air pollution control system at the Buffalo, MN WWTP is a carbon/lime injection with fabric filter system designed for control of multiple pollutants, including mercury.

4.2.1 Wet Scrubbing With and Without Chemical Conversion

As discussed in Section 4.1, mercury speciation or partitioning in combustion systems can significantly affect mercury control efficiency by wet scrubbing systems. If elemental Hg^0 is predominant, the mercury will be insoluble and not removed by wet scrubbing. However, gaseous forms of ionic Hg^{2+}, such as mercuric chloride ($HgCl_2$) are generally water soluble and can be absorbed in wet scrubbers. Mercury compounds that are in a solid phase at flue gas cleaning temperatures, such as mercuric oxide (HgO) and sulfide (HgS), or mercury that is adsorbed onto the surface of other particles may be effectively controlled with wet scrubbers designed to achieve high particulate control efficiency.[10,11] To effectively remove mercury to low levels by condensation, the flue gas must be cooled to less than 50 ºF, which is impractical. Therefore, condensation alone is seldom used for mercury control.

Table 0-1 – Summary of Mercury Controls, Permit Limits and Test Data for SSIs

Facility /Location	State	Incinerator Type	Process Information	Instal. Date of Controls	PM/Metals Controls	Additional Mercury Controls	Mercury Permit Limit	Mercury Test Data
Naugatuck	CT	FBI	3.125 DTPH	2004	VS + ITS + WESP		3,200 grams/24 -hrs	4.0E-04 – 3.5E-03 lb/DT; (15-113 grams/24-hrs.)[12,13]
MDC Hartford Nos. 1 and 2	CT	MHI	2.5 DTPH	1999	VPS		3,200 grams/24 -hrs	1.7E-03 – 3.8E-03 lb/DT; (46-103 grams/24-hrs.)[13]
New Haven	CT	MHI	1.66 DTPH	2004	VS + ITS + WESP		3,200 grams/24 -hrs	1.6E-03 – 4.4E-03 lb/DT; (29-80 grams/24-hrs.)[13]
Waterbury	CT	FBI	~2 - 3.5 DTPH	1998	VS + PBS + WESP		3,200 grams/24 -hrs	9.4E-04 – 5.0E-03 lb/DT; (35-190 grams/24-hrs.)[13]
Mattabassett	CT	FBI	1.55 DTPH	2003	VS + ITS	Flue Gas reheat + ACA (fixed bed)	266 $\mu g/m^3$, 3,200 grams/24 -hrs	4.0E-04 – 5.9E-03 lb/DT; (7-99 grams/24-hrs.)[13] <10% to 98+% control eff.[29]
Fitchburg	MA	MHI	2.295 DTPH	1997	VPS + WESP		3,200 grams/24 -hrs	39 grams/24-hrs.[14]
Lynn	MA				VS + ITS + WESP			2.2 grams/24-hrs.[14]
Brockton	MA				ITS		3,200 grams/24 -hrs	96 grams/24-hrs. [14]
Fall River	MA				ITS + WESP		3,200 grams/24 -hrs	16 grams/24-hrs.[14]

Facility /Location	State	Incinerator Type	Process Information	Instal. Date of Controls	PM/Metals Controls	Additional Mercury Controls	Mercury Permit Limit	Mercury Test Data
UBWPAD Milbury	MA	MHI (2)	3.0 DTPH (each)	2006	VS+ITS+ WESP		3200 grams/24 -hrs	1.01E-03 lb/DT; (33 grams/24-hrs.) Approx 14% control[15]
Woonsocket	RI	MHI			VS + ITS + WESP		3,200 grams/24 -hrs	0.24 grams/24-hrs.[16]
Canton, 2 units	OH	MHI	1.08 DTPH	1997	VPS		3,200 grams/24 -hrs	121 $\mu g/m^3$
East Norriton, Plymouth, Whitpain Joint Sewer Authority	PA	MHI	5.5 WTPH	1999	PBS + MVS		3,200 grams/24 -hrs	41 grams/24-hrs.[17]
Ypsilanti	MI	FBI	3.15 DTPH	2005	VS+ITS+ WESP	Flue Gas Reheat + ACA (fixed bed)	6.9E-04 lb/DT; 3200 grams/24 -hrs	2.8E-06 lb/DT; (0.093 grams/24-hrs)[18]
St. Paul	MN	FBI (3)	4.375 DTPH (each)	2005	FF+PBS+ RJS+ WESP	ACI and FF	3.6E-03 lb/DT	6.0E-07 lb/DT; (0.039 grams/24-hrs.)[15]
Buffalo	MN	TGI	0.31 DTPH	2008	ACI/LI + FF	ACI and FF	3 lbs./yr 80% control (1.1E-03 lb/DT)	6.1E-06 lb/DT; (0.014 grams/24-hrs.)[19]

ACA = Activated carbon adsorber (fixed bed) with moisture and fine particulate filters
ACI = Activated carbon injection
FBI = Fluidized bed incinerator
FF = Fabric filter
ITS = Impingement tray scrubber
LI = Lime injection (for SO_2 control)
MHI = FBI incinerator
MVS = Multiple venturi scrubber
PBS = Packed bed scrubber
RJS = Ring jet scrubber
TGI = Travelling grate incinerator
UHF+CIF = Ultra high-efficiency filter followed by carbon impregnated filter
VPS = VenturiPak scrubber (EnviroCare International, Inc.)
VS = Venturi scrubber
WESP = Wet electrostatic precipitator

Mercury removal efficiencies in wet scrubbers without chemical conversion have been reported in the literature to range from 0 to 80 percent, with the control effectiveness a function of the mercury species. However, it is not known whether the variability is due to differences in mercury speciation or low mercury concentrations in the sludge and flue gas.

If the mercury is oxidized to a soluble ionic species, such as chloride or oxide, high efficiency control by absorption in wet scrubbers can be achieved. As further discussed in Section 4.5.1.1, Tri-Mer Corporation is currently marketing a two-step reactive wet scrubbing process for Hg control that it developed in cooperation with ADA Technologies, Inc.[20,21] In the first step of the process, sodium hypochlorite is used to convert Hg vapor to soluble mercuric oxides that are removed in a packed tower scrubber. The mercuric oxide is then separated from scrubber liquid blowdown and transferred to a secondary reactor vessel, where proprietary chemistry is used to convert it to mercuric sulfide, which is a stable, highly insoluble form of mercury that can be disposed of as non-hazardous waste. Pilot testing conducted by ADA Technologies under an EPA grant has also indicated that a hybrid wet scrubbing system consisting of a venturi scrubber and shorter packed bed could be as effective as a single stage packed bed scrubber.[22] This result raises the potential that the NWPCA's existing wet scrubbing system could be retrofitted with the chemical reaction technology for oxidizing, scrubbing and converting Hg to insoluble mercuric sulfide for disposal as a nonhazardous waste. However, as discussed in Section 4.5.1.1, high CO_2 and CO levels in SSI flue gas would likely require high chemical consumption to maintain proper operation of this system; pilot testing would need to be performed to determine its technical feasibility.

4.2.2 Wet ESP (WESP) Alone or In Combination with Other Wet Scrubbers

WESPs have been used in a number of SSI applications for control of PM and metal compound emissions, typically in combination with ITS and/or VS. WESPs typically applied to SSIs operate in the following manner:

- The hot gas stream is initially quenched either by upstream equipment or by water sprays within the WESP vessel.
- The gas stream passes through a series of discharge electrodes, which are negatively charged. This voltage creates a corona around the electrode, which induces a negative charge in the PM passing through the corona.
- A grounded surface, or collector electrode, surrounds the discharge electrode. Charged particles collect on the grounded surface.
- PM is removed from the collector surface by intermittent water sprays directed within the electrode grounding surface assembly.

As with other wet scrubbers without chemical oxidation, WESPs are ineffective at mercury control if the mercury speciation is predominately in the gaseous and insoluble Hg^0 form. However, conversion to soluble $HgCl_2$ or solid HgO or HgS forms, due to

reactions occurring in the flue gas or from chemical addition, could improve overall mercury control efficiency and merits further investigation.

4.2.3 Fixed Bed Activated Carbon Adsorption (ACA)

Activated carbon adsorption (ACA) systems typically consist of a single vessel containing a bed of activated carbon, which may be specifically blended or formulated for mercury applications. The adsorber is typically operated below 160°F. Temperatures below the flue gas dew point enhance condensation of moisture, which competes for mercury on the carbon, and higher temperatures decrease the adsorptive capacity. At low concentrations of mercury in the flue gas, which is the typical case for SSI applications, the adsorption process could become mass transfer limited and reduce the removal efficiency. A high carbon-to-mercury ratio is typically required in SSI cases. Mercury removal efficiencies as high as 99 percent have been reported with the technology. Disadvantages of carbon adsorption in SSI applications, as further discussed in Section 4.3, include potential for plugging and deactivation of the carbon due to the presence of submicron particulate in the flue gas, resulting in premature bed replacement and excessive spent carbon disposal costs.

4.2.4 Ultra high-efficiency filter (UHF) followed by Activated Carbon Adsorption

One solution to premature fouling of carbon in fixed bed ACA systems applied to SSIs is the use of an ultra-high efficiency filter (UHF^{TM})[23] system upstream of the carbon bed. The UHF system was evaluated by The Mattabassett District in Cromwell, CT as part of a short-term demonstration test and found to effectively reduce submicron particulate in the flue gas by more than 90 percent. However, no long term test was conducted and the District continues to experience relatively frequent carbon replacement intervals. The District's experience evaluating ACA for mercury control is illustrative of the technical issues affecting application of ACA to SSIs and is summarized in Section 4.3.

4.2.5 UHF followed by Multiple Carbon Impregnated Filters In Series

Additional pilot tests at the Mattabassett District also evaluated the effectiveness of a UHF in series with one or multiple carbon-impregnated cloth filters in lieu of the fixed carbon bed. The short-term tests indicated that approximately 30 percent Hg reduction was achievable across each carbon filter stage and a total of 64 to 67 percent was indicated across three carbon filters in series.[24,25] However, no long term testing of carbon-impregnated filters was performed at Mattabassett nor has any other long term Hg control evaluations of this technology been identified. A potential advantage to this technology over fixed bed ACA would be the possible disposal of spent media as a non-hazardous waste as well as lower pressure drop/fan costs and much less downtime for media replacement than a fixed bed carbon system. The short-term testing at the Mattabassett District indicated that spent filters did not fail the TCLP test.

4.2.6 Activated Carbon Injection Ahead of Fabric Filter

The combined use of fabric filters with sorbent injection systems has been utilized for many years in the MWC, coal-fired power, as well as other industries as a way to enhance the removal of mercury and other pollutants such as dioxins, furans, and a wide range of heavy metals. Fabric filters, also known as baghouses, filter out the particles from the flue gas stream through a tightly woven fabric by sieving, impaction and other mechanisms. The dust cake which forms on the filter from the collected particulates can significantly increase particulate and mercury collection efficiency. With a powdered activated carbon injection (ACI) system upstream of the fabric filter, the carbon enriched dust cake on the fabric serves as a fixed bed reactor providing excellent contact between the mercury laden flue gas and the reactive carbon. A fabric filter provides a relatively long residence time of several minutes compared to an electrostatic precipitator (ESP), which may only have 2-3 seconds of contact. This enhanced filter cake provides higher inherent removal of mercury with much lower required sorbent injection rates, thus reducing the overall operation and maintenance (O&M) costs associated with sorbent injection for mercury control.

Fabric filters can also be utilized downstream of dry scrubber systems for SO2 and acid gas control. However, fabric filters cannot be used downstream of wet scrubber systems without flue gas reheating (to about 180ºF) in order to avoid the potential for filter media blinding by the wet flue gas. In the case of the NWPCA SSI, an alternative to flue gas reheating would be to replace the existing wet scrubbing systems with dry sorbent injection or spray dry scrubbers ahead of fabric filters. As the incinerator flue gas would still need to be cooled prior to entering the baghouse, a dry heat recovery process, such as the existing heat recovery boiler, could be used for the dual purposes of flue gas cooling and energy recovery.

Two SSI facilities in MN have been identified (St. Paul and Buffalo, MN) where SSIs have been equipped with activated carbon injection and fabric filters.[26,27] Operating experience with this technology at the Buffalo WWTP, based on a telephone interview and review of performance test data, is summarized in Section 4.3.

4.3 Mercury Control System Operating Experience at SSIs

Four (4) SSI facilities in the US have been identified that currently employ dedicated mercury control systems. Two (2) facilities, The Mattabassett District in Cromwell, CT and the Ypsilanti Community Utilities Authority (YCUA) in Ypsilanti, MI have variations of a fixed bed activated carbon adsorption system. The other two (2) facilities, the City of Buffalo WWTP in Buffalo, MN and the Metropolitan WWTP in St. Paul, MN, have dry activated carbon injection/baghouse systems. Information obtained from operators or other knowledgeable individuals representing three (3) of these facilities is summarized in this subsection.

4.3.1 Mattabassett District – Fixed Bed Activated Carbon Adsorption

The Mattabassett District operates a 1.55 DT/h FBI at its 20 MGD regional WWTP. Existing FBI emissions controls include a VS + ITS and a fixed bed activated carbon adsorber being used as a long-term demonstration project. Pursuant to CTDEP administrative orders, the District was required to evaluate new and emerging mercury removal technologies to address stricter mercury limits for its FBI. After initially evaluating electrostatic precipitation, fabric filtration, carbon injection, chemical injection and carbon adsorption, the District installed a full-scale horizontal fixed bed ACA system in 2002 for a long term demonstration program. The system worked satisfactorily for a short period of time and demonstrated 98 percent mercury removal efficiency during initial testing. However, numerous problems were subsequently encountered, namely[24,25]:

- Breaking down of the clay inerts in the carbon, potentially due to NaOH carryover;
- Fouling of the perforated plates holding the carbon;
- Inability to maintain proper temperature in the canister;
- Excessive moisture in the carbon;
- Rapid depletion of the carbon; and
- Mercury-laden waste was classified as a hazardous waste.

The District conducted extensive testing and research on the carbon system to resolve the above problems. Some of the attempted improvements included:

- Used Supervisory Control and Data Acquisition (SCADA) system to control temperatures in the carbon;
- Changed carbon type from clay-based to zeolite-based;
- Replaced mesh pad demister with demister tray;
- Increased flue gas temperature with additional reheat to maintain ACA operating temperature above dew point;
- Insulated the ACA vessel to avoid moisture condensation and freezing;
- Redesigned inlet air diffuser;
- Tried polypropylene mesh to hold the carbon;
- Tried moving roll Ultra High Efficiency Filter (UHF) to capture sub-micron particles prior to the carbon; and
- Tried Carbon Impregnated Filter (CIF) system in series with UHF.

The main problem stemmed from fouling of the carbon due to the presence of sub-micron particulate in the flue gas. It was also theorized that siloxanes, originating from the combustion of residues from shampoos and cosmetics in the sludge, caused formation of the submicron PM, contributing to inactivation and premature replacement of the carbon.

Based on recent discussions with past and current operators of the facility[28,29] as well as with the vendor (Donau Carbon) who assisted in the design and troubleshooting of the

ACA demonstration project equipment[30], additional changes have been made to the ACA demonstration unit during the past several years to improve performance and reduce operating costs. Despite the encouraging results from testing of the UHF media upstream of the ACA vessel, Mattabassett District continues to operate the ACA system without pre-filtration of submicron PM. (The District is in the process of performing the engineering design and going out to bid for a replacement FBI and air pollution control system, including a more permanent ACA system that will likely utilize a moving bed UHF). As a result of the submicron PM loading, carbon replacement frequency is still significantly higher than originally projected by the vendor based on mercury adsorption capacity alone. To minimize carbon replacement and disposal costs, the District has changed from a 4 mm to 9 mm activated carbon nominal particle size and is now able to run up to approximately 11 months before changing media, instead of the previous quarterly replacement schedule. According to the operator, the decision to change the media is based on observation of the physical condition of the media and pressure drop across the vessel.

Hg emissions testing, as required annually be state statute, has generally demonstrated compliance with the 266 $\mu g/m^3$ Hg permit limit and Hg removal efficiency has typically been documented in the 80 to 98 percent range. However, as the testing is generally performed within 1 to 5 days of a complete carbon change out, Hg outlet emissions and control performance over time are not well established. One test conducted in 2008, about 2 months after carbon replacement, demonstrated compliance with the permit limit; however control efficiency was significantly lower than other tests conducted with fresh carbon.

Spent carbon also continues to be disposed of as a RCRA hazardous waste as it fails the Toxic Characteristic Leaching Procedure (TCLP) test for Hg and other metals. Consequently, the waste carbon must be shipped to Stablex in Quebec, Canada at a cost of approximately $5,000 per bed change out.[28]

Based on the results of ongoing testing and operating experience, the District will likely move forward with the concept of a moving roll UHF with a vertical fixed-bed ACA vessel (and flue gas reheat to 150ºF prior to the UHF) as the most promising permanent solution for mercury control at its facility. According to the District's FBI operators, the combination of technologies appears to be the most feasible with respect to minimizing moisture, maintaining proper temperature and preventing fouling, necessary for optimizing the carbon replacement frequency.

4.3.2 Ypsilanti, MI – Fixed Bed Activated Carbon Adsorption

One other SSI, at the YCUA WWTP in Ypsilanti MI, has been identified with a permanent vertical fixed bed ACA system for mercury control. This system was designed and supplied by Donau Carbon Corporation, the same vendor that provided technical advice and equipment used for the demonstration program at the Mattabassett District. This permanent system differs somewhat from the temporary system at Mattabassett. The vessel contains a pre-filter section containing zeolite media to absorb

moisture and remove fine PM, followed by three thin activated carbon beds in series and held together with fiberglass grids. A flue gas re-heater with coalescing filter is also used upstream of the ACA vessel to heat the flue gas above the dew point and separate out condensable moisture after the FBI's VS/ITS and WESP. The system was first started up in January 2006. According to the chief operator at the facility, the unit operated normally for about two years until pressure drop across the vessel increased from 3 in. to 10 in. w.c., causing an exceedance of a permit condition and a system shut down from January to May of 2008. During the shut down, it was determined that the prefilter had malfunctioned and the fiberglass grids and carbon had deteriorated. Different theories on the causes included alum carryover to the prefilter, excess moisture condensation in the carbon, fluoride attack of the fiberglass and sulfuric acid formation and deterioration of the carbon.[31,32,30] The solutions that were implemented included:

- Replacement of the carbon;
- Replacement of the support grids with grids manufactured from a higher grade resin;
- Maintenance of a minimum 150ºF operating temperature in the ACA system; and
- Installation of relative humidity meters at the inlet and outlet of the ACA vessel to better monitor moisture conditions.

The unit was started up again in May 2008 and stack testing was performed again in December 2008, demonstrating compliance with the permit limit. About 80 percent Hg control efficiency was also measured during the December 2008 test after 6 months of operation without changing the carbon. With regard to spent carbon disposal, the operator stated that it is managed as a special waste, rather than a RCRA hazardous waste. It is believed that the sulfur impregnation in the carbon forms mercuric sulfide that is not leached out during TCLP testing.

4.3.3 Buffalo, MN – Activated Carbon Injection with Fabric Filter

The City of Buffalo WWTP in Buffalo, MN began operating a new SSI facility in December 2008 that is believed to be one of only two SSI facilities in the US that use dry activated carbon injection for Hg control. The Buffalo WWTP uses a travelling-grate type SSI rated at 625 dry lb/hr sludge input, followed by a heat recovery unit that provides heated air to the facility's biosolids belt dryer. Following the heat exchanger, the SSI flue gas is treated with activated carbon injection, lime injection and a baghouse (for mercury, other metals and SO_2 control), followed by a secondary combustion chamber for VOC and CO control.[26] According to the chief operator of the WWTP, there have been no operational or Hg control performance problems since startup of the system, which was provided by Bundy Environmental Technology.[33,34] Powdered activated carbon and lime are fed from bags via screw auger and injected into the flue gas ahead of a baghouse. The carbon injection rate is typically about 1 lb/hr. A stack test for PM and Hg emissions was performed in May 2009 to demonstrate compliance with permit conditions. Hg emissions in the stack were measured at 0.16 µg/m^3 (corrected to dry, standard conditions), which is equivalent to 0.0000013 lb/hr or 0.011 lb/year.[35] According to the operator, byproducts collected in the baghouse, which include spent

carbon, lime, reaction products and flyash, are disposed of in a special waste landfill and not subject to management as a RCRA hazardous wate.

4.4 Mercury Control Technology Hierarchy

From review of SSI permit limits for mercury, it can be seen in Table 0-1 that only recently constructed SSI installations with specific Hg controls (Mattabassett, CT; Ypsilanti, MI, St. Paul, MN and Buffalo, MN) have more stringent limitations than the 3,200 grams/24-hours limitation in 40 CFR Part 61, Subpart E. Based on a review of test data summarized in Table 0-1 Hg emissions from all SSIs are well below the 3,200 grams/24-hour limitation, regardless of the incineration or air pollution control technology. The highest tested mercury rate that was found is about 190 grams/24-hours from the Waterbury, CT FBI and emission data from other facilities that do not have dedicated Hg control systems ranged between less than 1 and 190 grams/24-hours. However, as discussed in Section 4.2.1, it is not know whether this variability is due to differences in mercury concentrations in the sludge or mercury speciation in the flue gas. In general, facilities summarized in Table 0-1 that are equipped with WESPs have lower tested mercury emissions than those equipped with other wet scrubbers. However, the Waterbury WPCF in CT, which is equipped with a VS, PBS and WESP, had the highest tested mercury emission rates at 190 grams/24-hours. Also, an FBI facility in Cincinnati, equipped only with a VS/ITS system reported mercury control efficiencies of 56 to 73 percent.[36] Clearly, however, the most recently constructed SSI facilities with dedicated mercury control systems (Ypsilanti, MI; St. Paul, MN; and Buffalo, MN) each achieved significantly lower tested Hg emission rates than any other SSI without specific Hg controls. Each achieved less than 0.1 grams/24-hours, ranging between 0.014 and 0.096 grams/24-hours among the three facilities.

The estimated control technology hierarchy/performance ranking for available mercury control options is summarized in Table 0-2 based upon review of technical considerations, permit limits, test data, vendor information and discussions with operators of existing Hg control systems in the SSI industry. Because each of the identified potentially-applicable technologies is considered to have limited or no operating experience specific to SSIs, a range of estimated control efficiencies associated with each technology is provided. The control efficiency ranges are also considered preliminary and conservatively low. In general, the high end of the estimated Hg control efficiency ranges for three of the technologies, (1) wet scrubbing with chemical conversion of Hg^0; (2) fixed bed activated carbon adsorption; and (3) activated carbon injection with a fabric filter; are considered roughly equivalent at this stage (90+ percent), despite higher efficiencies being reported by vendors and suggested by isolated performance testing.

Table 0-2 – Mercury Control Technology Hierarchy

Mercury Control Option	Technical Feasibility Assessment	Commercial Availability	Estimated Control Efficiency	Mercury Emissions in lb/yr for NWPCA SSI[1]
Wet ESP	Negligible control of mercury	Yes	0 to 15%	63
UHF + carbon-impregnated filters in series	Possible, but requires further evaluation / demonstration	Yes, but requires further demonstration on SSIs	30-70%	32
Wet scrubbing w/ conversion of Hg^0	Possible, but requires fixation of mercury in an insoluble form and further evaluation / demonstration	Yes, but requires further demonstration on SSIs	80-90%+[(a)]	12 or less
Flue gas reheat + pre-filter + activated carbon adsorption (fixed bed)	Proven and very effective; but requires further evaluation / demonstration of long-term effectiveness	Yes, but requires further demonstration on SSIs	80-90%+	12 or less
Activated carbon injection + fabric filter baghouse	Proven and very effective	Yes, but requires further demonstration on SSIs	80-90%+[(b)]	12 or less

Notes: (a) Demonstrated 99% control at higher inlet mercury concentrations, not at SSI.
(b) Vendor claims 98%; however, this depends on the condition of the carbon.

4.5 Cost Effectiveness Analysis and Other Considerations

The following section presents a preliminary evaluation of the economic, energy and environmental impacts of mercury control technologies for the NWPCA.

4.5.1 Cost Impact Analysis

The following mercury control technologies were evaluated for the NWPCA's FBI:

1. Tri-Mer Hypochlorite scrubber

[1] CTDEP estimate of uncontrolled annual Hg emissions based on 2007 stack test and sludge incineration rate data was 63 lb/yr. Estimated controlled emissions based on low end of range of control technology efficiency estimates.[13]

2. Flue gas reheat + Ultra high efficiency filter (UHF) + Carbon adsorption in a fixed bed
3. Carbon Injection + Fabric filter
4. UHF + carbon-impregnated filters in series

4.5.1.1 Tri-Mer Hypochlorite Scrubber

Wet scrubbing with sodium hypochlorite addition has the potential to effectively remove mercury from a flue gas stream by converting the mercury to a mercuric oxide solid which is soluble in water. The problem with this approach is that the mercury ends up in the scrubber water that is eventually discharged with the plant effluent to a nearby body of water. One of the primary environmental objectives of controlling mercury is to prevent it from entering surface waters to prevent its bio-accumulation in fish. Recently Total Maximum Daily Limits (TMDLs) of mercury have been established for thousands of water bodies in an effort to control the accumulation of mercury in fish. Therefore, a wet scrubbing technology was sought for this alternative that would not only remove the mercury from the flue gas but also fix the mercury in an insoluble form so that it could be disposed of as a solid in a landfill and be kept out of the aquatic environment.

Based on these objectives, a wet scrubbing technology was identified that is currently being marketed by Tri-Mer Corporation. Tri-Mer, in cooperation with ADA Technologies, Inc., has developed a wet scrubbing process which removes mercury from the flue gas and then using proprietary chemistry converts the mercury to mercuric sulfide, which is a stable form of mercury that can be disposed of as non-hazardous waste. This technology is schematically shown in Figure 0-1. A 20-foot tall packed bed tower is utilized to oxidize the mercury to mercuric oxide solids and the solids are separated from the scrubbing liquid which can then be re-circulated. The solids are sent to a reactor where they are converted to mercuric sulfide (HgS). In the reactor, the excess sodium hypochlorite is first neutralized, followed by the reaction with sulfide to HgS and finally a reagent is added to scavenge the excess sulfide. The system can be designed to be either continuous or batch. The capital and operations and maintenance (O&M) costs are presented in Table 0-3. The Tri-Mer scrubbing system would be located downstream of the existing WESPs at the NWPCA. It is assumed that the tower would operate continuously and the reactor would operate as a batch operation, where the circulating liquid is periodically bled off and sent to the reactor. Therefore, operator hours are highest for this option.

The product slurry would be classified as a non-hazardous waste since it reportedly will not leach mercury. However, since the product does contain mercury, albeit in insoluble form as mercuric sulfide, it likely will require handling as a special waste. As such, the process by-product would require separate storage in drums and contracting with a special waste hauling/disposal company for ultimate disposal. A relatively small amount of the product slurry is generated, approximately 2,500 pounds per year, which would equate to about 5 to 6 drums per year. It is noted that Mattabassett District in Cromwell, CT has a special waste company haul away and dispose of its mercury laden activated

carbon at a cost of $2,500 for 9 drums, which equates to about $1.50 per pound. The estimated cost for disposal of the mercuric sulfide product is $4,000 per year. The quantities of reagents needed were not provided by the vendor in a timely fashion; therefore, quantities were scaled from previously provided information on another similar application. The vendor also expressed concern over the levels of CO and CO_2 in the flue gas (after providing the budgetary proposal). The CO will react with the sodium hypochlorite to form CO_2. The CO_2 will dissolve to become carbonic acid and lower the pH below the desired range. Therefore, additional sodium hydroxide would be required to maintain proper pH levels.

The Tri-Mer scrubbing system could provide approximately 80% to 99+% control of mercury which would result in annual mercury emissions of 0.63 to 12.6 pounds per year. The capital cost for this alternative is estimated to be $1,892,000 and the annualized construction and O&M cost is approximately $734,700 per year. Based on 90% control of mercury, the cost per pound of mercury removed is $13,000. Please note that this cost estimate is the least certain of the four technologies evaluated due to the fact that the vendor did not provide the quantity of sodium hydroxide required to maintain pH.

Figure 0-1 – Process Flow Diagram – Tri-Mer/ADA System

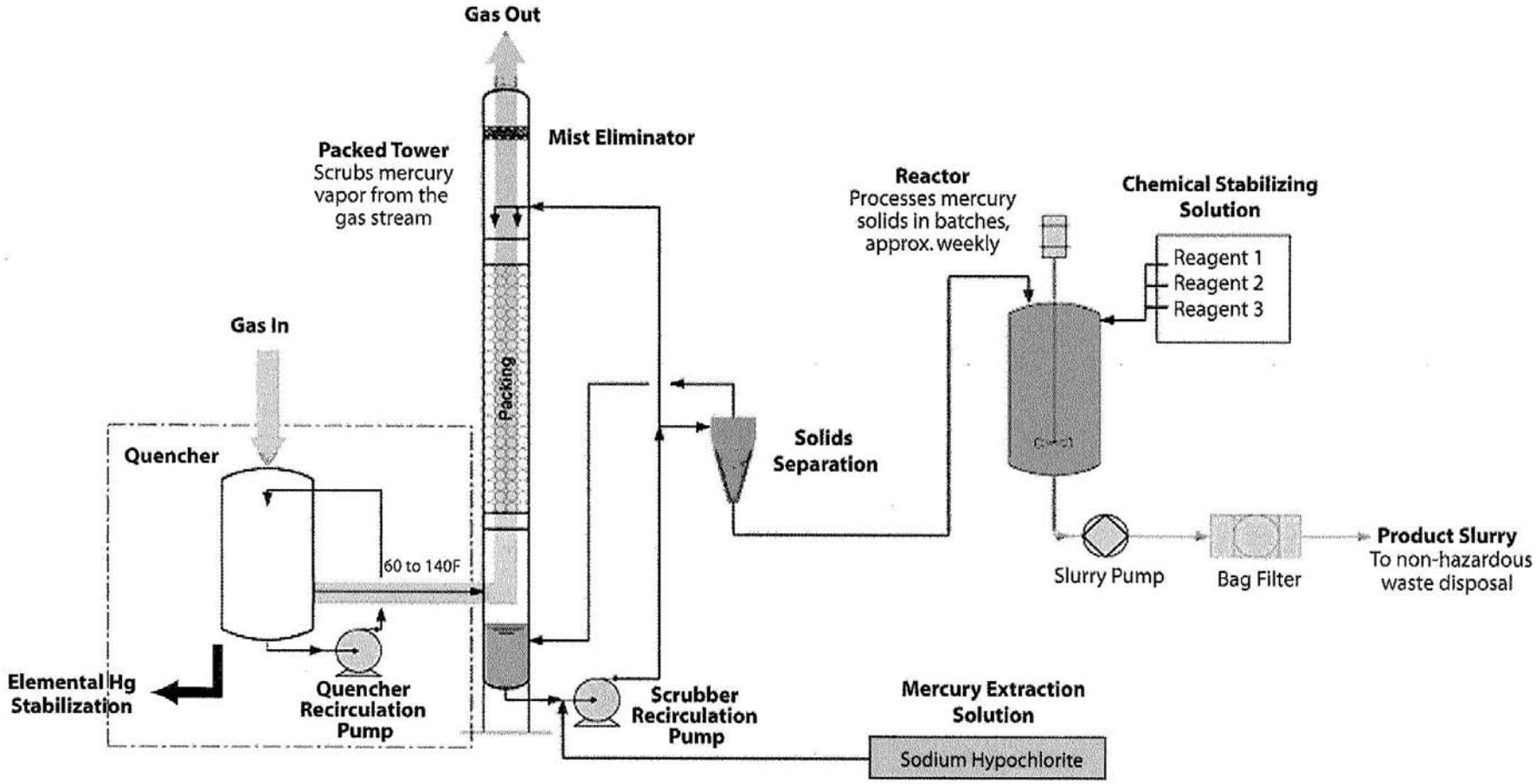

Table 0-3 – Capital and O&M Costs for Tri-Mer Wet Scrubbing System

Capital Costs			
	Cost	**Basis**	**Reference**
DIRECT COSTS:			
PURCHASED EQUIPMENT			
(a) Control Equipment (BE)	$698,000	Vendor-supplied	Tri-Mer, 8/17/2009
(b) Auxiliaries	included		
(c) Instrumentation & Controls	included		
(e) Tax	$34,900	5% of (1a)-(1c)	
(e) Freight	$34,900	5% of (1a)-(1c)	OAQPS, Table 1.3.
TOTAL PURCHASED EQUIPMENT (PE):	**$767,800**		
DIRECT INSTALLATION COSTS			
(a) Foundations and supports	$92,100	0.12 x PE	OAQPS, Table 1.3.
(b) Handling and erection	$307,100	0.40 x PE	OAQPS, Table 1.3.
(c) Electrical	$7,700	0.01 x PE	OAQPS, Table 1.3.
(d) Piping	$230,300	0.3 x PE	OAQPS, Table 1.3.
(e) Insulation for ductwork	$7,700	0.01 x PE	OAQPS, Table 1.3.
(f) Painting	$7,700	0.01 x PE	OAQPS, Table 1.3.
Total Direct Installation Costs	$652,600	0.85 x PE	
TOTAL DIRECT COST (TDC):	**$1,420,400**		
INDIRECT COSTS:			
INDIRECT INSTALLATION			
(a) Engineering & Supervision	$142,000	10% of TDC	OAQPS, Table 1.3.
(b) Construction & Field Expenses	$142,000	10% of TDC	OAQPS, Table 1.3.
(c) Contractor Fees	$71,000	5% of TDC	
(d) Contingencies	$42,600	3% of TDC	OAQPS, Table 1.3.
OTHER INDIRECT COSTS			
(a) Startup & Performance Tests	$42,600	3% of TDC	
(b) Working Capital	$31,500	30 days O&M cost	
TOTAL INDIRECT COST:	**$471,700**		
TOTAL CAPITAL COST (TCC):	**$1,892,000**		
Annualized Costs			
	Cost	**Basis**	**Reference**
DIRECT OPERATING COSTS:			
DIRECT LABOR (DL)			
Additional Labor	2,190	hours/year	2 hours per shift (3 shifts/day)
(a) Operators	$76,650	@$35/hr	
(b) Supervisors	$11,500	15% of operating labor	OAQPS, Table 1.4.
MAINTENANCE			
Additional Maintenance	1,314	hours/year	15-20% of operating hrs
(a) Labor (ML)	$59,130	@$45/hr	for control systems
(b) Material	$59,130	100% maintenance labor	OAQPS, Table 1.4.
(c) Supervisors	$8,900	15% of operating labor	OAQPS, Table 1.4.

POWER (115 kw x 8760 hr/yr x $0.1549/kwhr x 0.80 util. factor)	$125,000	40 hp pump; 50 hp fan	Energy Information Admin
CONTROL SYSTEM		3 hp mixer	for electricity cost
(a) Chemicals for Conversion of Hg to HgS			
Sodium Hypochlorite for tower	$18,750	Scaled from CDM estimate	
Sodium Hydroxide for tower	$18,750	Scaled from CDM estimate	
Neutralizing Agent for reactor	$315	$5/lb mercury	
Sulfurizing Agent for reactor		for all reactor reagents	
Sulfur Scavenging Agent for reactor		combined	
Sales Tax ($)	$1,891		
(b) HgS Slurry Disposal			
Cost per pound	$1.50	$1.50/lb	Assume special handling
Pounds per year Disposed	2,500	Hg to HgS; 20% solids	
Cost per year	$3,750		
SUBTOTAL O&M COSTS:	**$383,766**		
INDIRECT OPERATING COSTS:			
OVERHEAD	$129,200	60% of O&M labor	OAQPS, Table 1.4.
INSURANCE	$18,900	1% of Total Capital Cost	OAQPS, Table 1.4.
ADMINISTRATION	$37,800	2% of Total Capital Cost	OAQPS, Table 1.4.
CAPITAL RECOVERY	$165,000	20 yr life, 6% interest rate	OAQPS, Table 1.4.
ANNUALIZED COST:	**$734,700**		
HG EMISSION RATE (LB/YR)	63.00		
HG CONTROL EFFICIENCY (%)	90%		
EMISSIONS CONTROLLED (LB/YR)	56.70		
OVERALL COST EFFECTIVENESS ($/LB):	**$13,000**		

Notes:
The cost of a building to house the control system has not been included (if needed); the cost of some auxiliary equipment may not have been included. The tower reagents cost was not available. Tri-Mer indicated the percent levels of CO and CO2 would require increased amounts of reagents over other systems. OAQPS Control Cost Manual Sixth Edition, Section 5.2, Chapter 1, United States Environmental Protection Agency, January 2002. EPA/452/B-02-001.
Capital Costs: APC Technologies 07/29/2009

4.5.1.2 Ultra High Efficiency Filter and Carbon Adsorption

This alternative consists of using the existing scrubbers, WESPs and ID fans and adding flue gas reheat, UHF (or other submicron PM pre-filter system, such as that used at the Ypsilanti, MI WWTP) and a carbon adsorption bed for mercury control. The arrangement of the FBI and APC equipment is schematically shown in Figure 0-2. Because of the increased pressure drop through the new UHF (or other pre-filter), the new carbon bed, and the existing wet scrubbers, it was assumed that a new ID fan would be required to convey the flue gas through the new APC equipment. Note that at temperatures above 160°F the adsorptive properties of the carbon start to diminish, therefore, a heat exchanger could be considered, since the stack tests show temperatures on average are 200°F. The cost of a heat exchanger has not been included in this estimate; however, the vendor provided a capital cost of approximately $50,000 for a heat exchanger just before completion of this report. The UHF and carbon adsorption train would be housed indoors. However, an evaluation of available existing space has not been performed as part of this preliminary study.

The capital and O&M costs for this alternative are presented in Table 0-4. The estimated construction cost is $1,152,000 and the annualized construction and O&M cost is $541,900. Note it is assumed that the mercury laden carbon would have to be disposed of as hazardous waste at an estimated cost of $1.50 per pound. The estimated quantity of spent carbon to be disposed of is 6 tons per year (based on the vendor's estimate) which will result in an annual disposal cost of $18,000 per year. Based on the assumption that the process will provide at least 85% control of mercury, the cost per pound of mercury removed is estimated at $10,100.

Figure 0-2 – Process Flow Diagram – UHF and Fixed Bed Carbon Bed

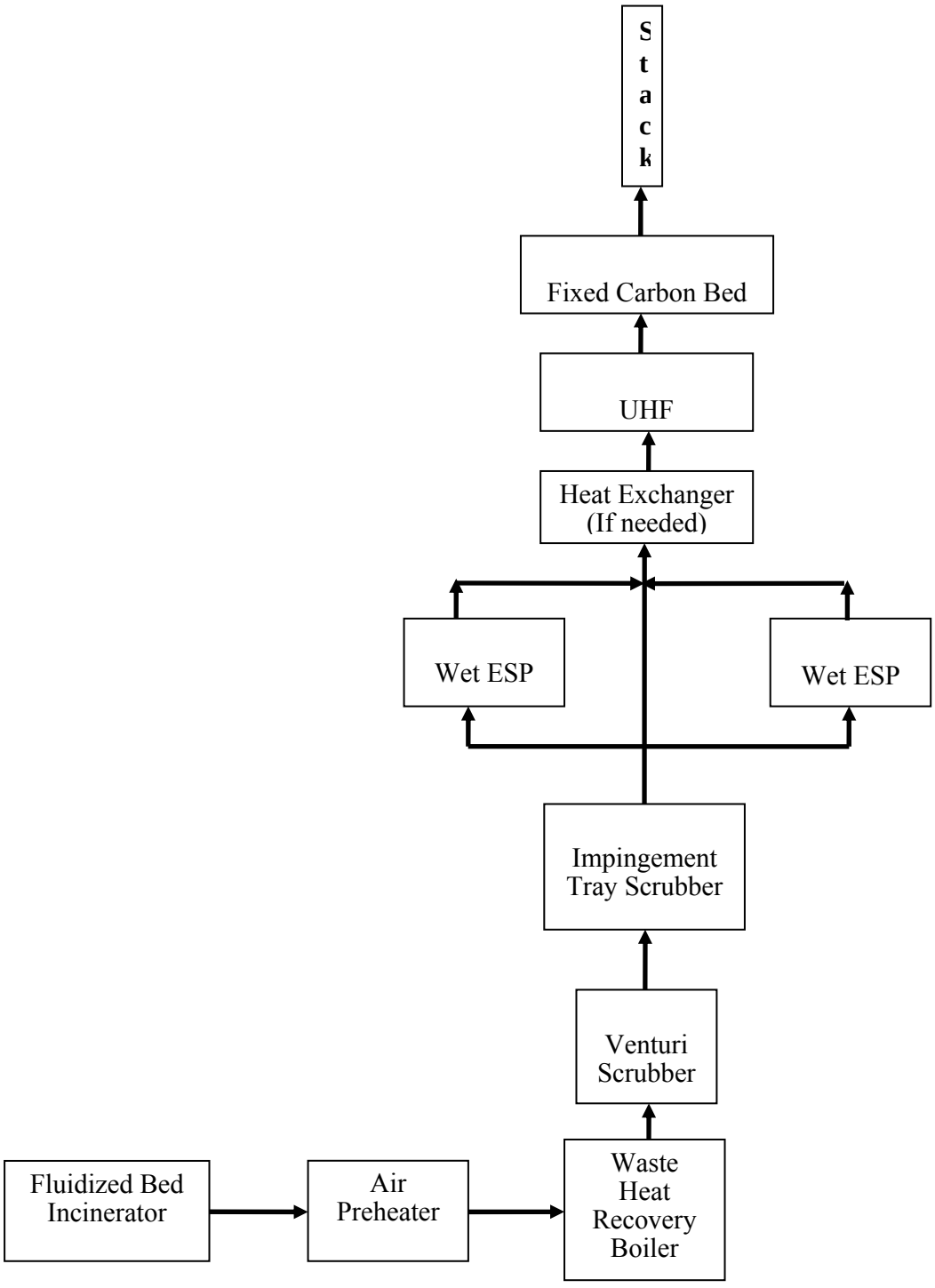

Table 0-4 – Capital and O&M Costs for UHF and Carbon Adsorption

Capital Costs			
	Costs	**Basis**	**Reference**
DIRECT COSTS:			
PURCHASED EQUIPMENT			
(a) Control Equipment (BE)	$588,160	Vendor-supplied	APC Technologies, 7/29/2009
(b) Auxiliaries	$37,200	Vendor-supplied (fan)	
(c) Instrumentation & Controls	included		
(e) Tax	$31,300	5% of (1a)-(1c)	OAQPS, Table 1.3.
(e) Freight	$31,300	5% of (1a)-(1c)	
TOTAL PURCHASED EQUIPMENT (PE):	**$688,000**		
DIRECT INSTALLATION COSTS			
(a) Foundations and supports	$55,000	0.08 x PE	OAQPS, Table 1.3.
(b) Handling and erection	$96,300	0.14 x PE	OAQPS, Table 1.3.
(c) Electrical	$27,500	0.04 x PE	OAQPS, Table 1.3.
(d) Piping	$13,800	0.02 x PE	OAQPS, Table 1.3.
(e) Insulation for ductwork	$6,900	0.01 x PE	OAQPS, Table 1.3.
(f) Painting	$6,900	0.01 x PE	OAQPS, Table 1.3.
Total Direct Installation Costs	$206,400	0.30 x PE	
TOTAL DIRECT COST (TDC):	**$894,400**		
INDIRECT COSTS:			
INDIRECT INSTALLATION			
(a) Engineering & Supervision	$89,400	10% of TDC	OAQPS, Table 1.3.
(b) Construction & Field Expenses	$44,700	5% of TDC	OAQPS, Table 1.3.
(c) Contractor Fees	$44,700	5% of TDC	
(d) Contingencies	$26,800	3% of TDC	OAQPS, Table 1.3.
OTHER INDIRECT COSTS			
(a) Startup & Performance Tests	$26,800	3% of TDC	OAQPS, Table 1.3.
(b) Working Capital	$25,000	30 days O&M cost	
TOTAL INDIRECT COST:	**$257,400**		
TOTAL CAPITAL COST (TCC):	**$1,152,000**		
Annualized Costs			
	Costs	**Basis**	**Reference**
DIRECT OPERATING COSTS:			
DIRECT LABOR (DL)			
Additional Labor	1,095	hours/year	1 hour per shift (3 shifts/day)
(a) Operators	$38,325	@$35/hr	
(b) Supervisors	$5,700	15% of operating labor	OAQPS, Table 1.6.
MAINTENANCE			
Additional Maintenance	1,314	hours/year	15-20% of operating hrs
(a) Labor (ML)	$59,130	@$45/hr	for control systems
(b) Material	$59,130	100% maintenance labor	OAQPS, Table 1.6.
(c) Supervisors	$8,900	15% operating labor	OAQPS, Table 1.6.
POWER			

(45 kw x 8760 hr/yr x $0.1549/kwhr x 0.80 util. factor)	$49,000		Energy Information Admin for electricity cost
CONTROL SYSTEM			
(a) Carbon / UHF			
Annual Carbon replacement cost ($)	$60,000	Vendor-supplied	APC Technologies, 7/29/2009
Annual UHF Replacement cost ($)	$3,000		24,000 lbs (~$5 per lb)
Sales Tax ($)	$3,150		Replace both every 2 years
(b) Carbon Disposal			
Cost per pound	$1.50	$1.50/lb	Assume hazardous waste
Pounds per year Disposed	12,000		
Cost per year	$18,000		
SUBTOTAL O&M COSTS:	**$304,335**		
INDIRECT OPERATING COSTS:			
OVERHEAD	$102,700	60% of O&M labor	OAQPS, Table 1.6.
INSURANCE	$11,500	1% of Total Capital Cost	OAQPS, Table 1.6.
ADMINISTRATION	$23,000	2% of Total Capital Cost	OAQPS, Table 1.6.
CAPITAL RECOVERY	$100,400	20 yr life, 6% interest rate	OAQPS, Table 1.6.
ANNUALIZED COST:	**$541,900**		
HG EMISSION RATE (LB/YR)	63.00		
HG CONTROL EFFICIENCY (%)	85%		
EMISSIONS CONTROLLED (LB/YR)	53.55		
OVERALL COST EFFECTIVENESS ($/LB):	**$10,100**		

Notes:
The cost of a building to house the control system has not been included (if needed); the cost of some auxiliary equipment may not have been included (such as heat exchanger). It is assumed that compressed air is available (no cost has been added for this). OAQPS Control Cost Manual Sixth Edition, Section 3, Chapter 1, United States Environmental Protection Agency, January 2002. EPA/452/B-02-001.
Capital Costs: APC Technologies 07/29/2009

4.5.1.3 Carbon Injection and Fabric Filtration

This alternative would involve removal of the existing wet scrubber/WESP air pollution control train, but would retain the existing heat recovery system in order to provide a dry flue gas to the new dry carbon injection and fabric filter (FF) trains. It has also been assumed that a dry reagent (hydrated lime or sodium bicarbonate) injection would be used for SO_2 and other acid gas control that is currently accomplished in the existing wet scrubber system. The reagent and carbon are independently fed and automatically blended prior to the delivery and injection.

After the carbon and dry reagent are injected, the polluted flue gas flows into the fabric filter (baghouse). Virtually all solid particulate is filtered out. The accumulation of particulate on the bags forms a "filter cake" that helps fill the voids between bag fibers and enhances the filtration efficiency. Also, the unreacted reagent becomes a part of the filter cake and provides a considerable amount of additional gas scrubbing. Contact between the flue gas and reagent is particularly intimate because of the dense cake and very slow gas movement.

The build-up of particulate on the bags causes a restriction to flow (increase in pressure drop) and periodically the bags are cleaned by a jet of compressed air that is blown down the inside of the bags. The bag inflates rapidly, snaps when it reaches its full diameter, and the particulate on the outside of the bag is thrown off and settles into the hopper where it is removed to disposal. Cleaned flue gas is ducted to the ID fan and discharged to atmosphere.

As an alternative to removal of the wet system (and the requirement of lime injection), the flue gas exiting the FF could be ducted back to the existing wet scrubbers for removal of acid gases. In that scenario, the scrubber exhaust gas would then be conveyed by a new ID fan and discharged to the existing stack. A new ID fan is presumed to be necessary due to the increased pressure through the system. A pneumatic flyash conveyance system will be required to collect the flyash from the bottom of the FF and transport it to a flyash storage silo. We would also recommend a bypass around the carbon injection system and fabric filter to provide particulate and acid gas control in the existing scrubber system when the fabric filter is down for maintenance. However, a bypass is not included in Figure 0-3.

The flyash from the fabric filter would be a mixture of particulate matter, activated carbon and mercury and would likely not be classified as hazardous waste, based on experience at the Buffalo and St. Paul WWTPs in MN. The capital and O&M costs for this alternative are presented in Table 0-5. The estimated construction cost is $1,941,000 and the total annual O&M cost is $608,000. Based on an estimated 85% control of mercury, the cost per pound of mercury removed is $11,400. Please note that these costs do not include the cost of removing the wet system (if that is required) or the cost of the downtime during construction.

Figure 0-3 – Process Flow Diagram – Carbon Injection and Fabric Filtration

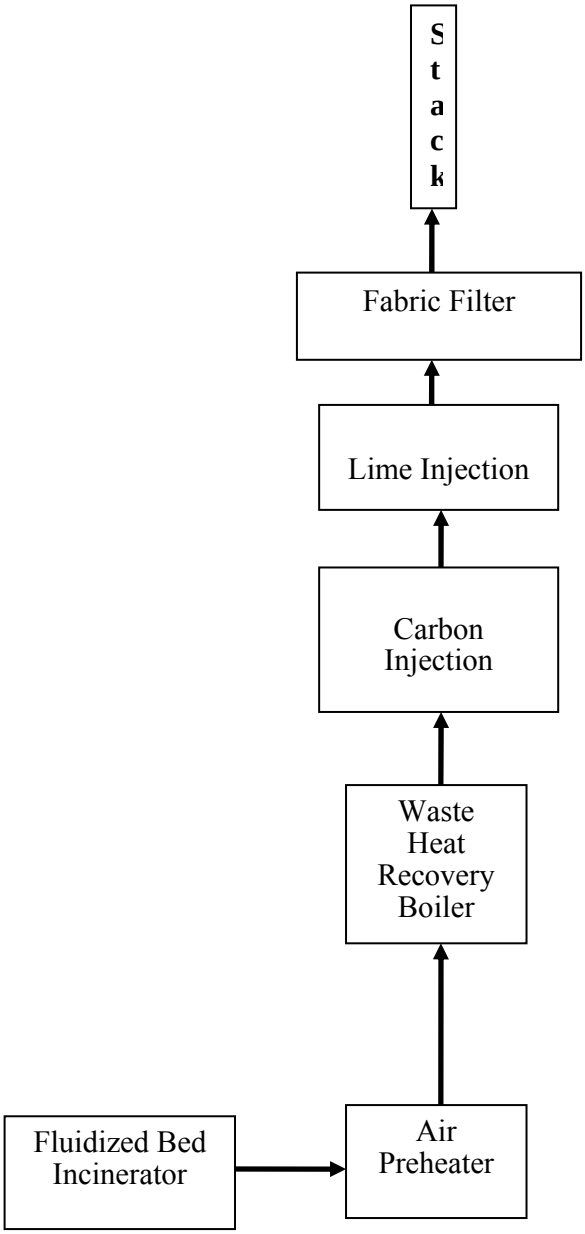

Table 0-5 – Capital and O&M Costs for Carbon Injection and Fabric Filtration

Capital Costs			
	Costs	**Basis**	**Reference**
DIRECT COSTS:			
PURCHASED EQUIPMENT			
(a) Control Equipment (BE)	$682,700	Vendor-supplied	APC Technologies, 08/08/2009
(b) Auxiliaries	$37,200	Vendor-supplied (fan)	
(c) Instrumentation & Controls	included		
(e) Tax	$36,000	5% of (1a)-(1c)	
(e) Freight	$36,000	5% of (1a)-(1c)	OAQPS, Table 1.9.
TOTAL PURCHASED EQUIPMENT (PE):	**$791,900**		
DIRECT INSTALLATION COSTS			
(a) Foundations and supports	$31,700	0.04 x PE	OAQPS, Table 1.9.
(b) Handling and erection	$396,000	0.50 x PE	OAQPS, Table 1.9.
(c) Electrical	$63,400	0.08 x PE	OAQPS, Table 1.9.
(d) Piping	$7,900	0.01 x PE	OAQPS, Table 1.9.
(e) Insulation for ductwork	$55,400	0.07 x PE	OAQPS, Table 1.9.
(f) Painting	$31,700	0.04 x PE	OAQPS, Table 1.9.
Total Direct Installation Costs	$586,100	0.74 x PE	
TOTAL DIRECT COST (TDC):	**$1,378,000**		
INDIRECT COSTS:			
INDIRECT INSTALLATION			
(a) Engineering & Supervision	$137,800	10% of TDC	OAQPS, Table 1.9.
(b) Construction & Field Expenses	$275,600	20% of TDC	OAQPS, Table 1.9.
(c) Contractor Fees	$68,900	5% of TDC	
(d) Contingencies	$41,300	3% of TDC	OAQPS, Table 1.9.
OTHER INDIRECT COSTS			
(a) Startup & Performance Tests	$13,800	1% of TDC	OAQPS, Table 1.9.
(b) Working Capital	$25,800	30 days O&M cost	
TOTAL INDIRECT COST:	**$563,200**		
TOTAL CAPITAL COST (TCC):	**$1,941,000**		
Annualized Costs			
	Costs	**Basis**	**Reference**
DIRECT OPERATING COSTS:			
DIRECT LABOR (DL)			
Additional Labor	1,095	hours/year	1 hour per shift
(a) Operators	$38,325	@$35/hr	
(b) Supervisors	$5,700	15% of operating labor	OAQPS, Table 1.11.
MAINTENANCE			
Additional Maintenance	1,314	hours/year	15-20% of operating hrs
(a) Labor (ML)	$59,130	@$45/hr	for control systems
(b) Material	$59,130	100% of maintenance labor	OAQPS, Table 1.11.

(c) Supervisors	$8,900	15% of operating labor	OAQPS, Table 1.11.
POWER (45 kw x 8760 hr/yr x $0.1549/kwhr x 0.80 util. factor)	$49,000		Energy Information Admin for cost
CONTROL SYSTEM			
(a) Carbon			
Carbon cost per pound($)	$2.50		
Carbon needed (lb/hour)	4	Vendor-supplied	Vendor Information
Carbon needed (lb/year)	35,040		
Carbon cost per year($)	$87,600		
Sales Tax ($)	$4,380		
(b) Carbon Disposal			
Cost per pound	$70.00	per ton	Assume nonhazardous
Tons per year Disposed	18		
Cost per year	$1,226		
SUBTOTAL O&M COSTS:	**$313,400**		
INDIRECT OPERATING COSTS:			
OVERHEAD	$67,200	60% of DL + ML	OAQPS, Table 1.11.
INSURANCE	$19,400	1% of Total Capital Cost	OAQPS, Table 1.11.
ADMINISTRATION	$38,800	2% of Total Capital Cost	OAQPS, Table 1.11.
CAPITAL RECOVERY	$169,200	20 yr life, 6% interest rate	
ANNUALIZED COST:	**$608,000**		
HG EMISSION RATE (LB/YR)	63.00		
HG CONTROL EFFICIENCY (%)	85%		
EMISSIONS CONTROLLED (LB/YR)	53.55		
OVERALL COST EFFECTIVENESS ($/LB):	**$11,400**		

Notes:
The cost of a building to house the control system has not been included (if needed); the cost of some auxiliary equipment may not have been included. It is assumed that compressed air is available (not cost has been added for this). The cost of removal of the wet system is not included in this cost analysis. The cost of lime is not included. OAQPS Control Cost Manual Sixth Edition, Section 6, Chapter 1, United States Environmental Protection Agency, January 2002. EPA/452/B-02-001. Capital Costs: APC Technologies. Bundy Environmental also provided an estimate of $465,000 which did not include a reagent supply system.

4.5.1.4 UHF and Carbon-Impregnated Filters In Series

This alternative also incorporates the existing scrubbers, WESP and flue gas reheat as with the UHF + fixed bed carbon adsorption process described in Section 4.5.1.2. Following the wet ESPs, the flue gas will be directed to the UHF and then to the carbon filters in series. This arrangement consists of a 316SS vessel including all internal trays and other internal supports for the impregnated filter media and external access doors, inlet and outlet transitions to the vessel, an initial set of specialty impregnated filter media, and instrumentation. Preliminary dimensions for the vessel are 20' x 12' x 22'H; however the vendor indicates that the unit can be configured in different ways to meet available space. Space will be needed around the unit for filter change-out. The benefit to this system over the fixed bed system is the simple design (which requires no controls and minimal maintenance) as well as lower pressure drop through the system. Other vendor-reported (APC Technologies) advantages are that this system avoids the plugging and operational problems associated with carbon beds and requires no process downtime for carbon media change-out. The system utilizes much less activated carbon than the amount required by activated carbon injection, or comparable or less than an activated carbon bed.

A total of 4 filters would be used in series. According to the vendor, if exhaust temperatures are lowered to 160 ºF with a heat exchanger, the control efficiency of each pass is approximately 30-50%, giving an overall efficiency of 70% to 90%. Above 160 ºF, the control efficiency will be lower and can be determined through pilot testing. For the purpose of this analysis, we have not assumed a heat exchanger will be used and estimated an overall control efficiency of 50%. The filters may need to be replaced twice per month if the temperature is above 160 F versus once per month with temperatures below. Therefore, further investigation into the use of a heat exchanger is warranted for this option.

The process flow diagram for this system is shown in Figure 0-4. The capital and O&M costs for this alternative are presented in Table 0-6. The estimated construction cost is $734,000 and the total annual O&M cost is $424,000. It is assumed that the mercury laden carbon filters will not require disposal as hazardous waste. Based on an estimated 50% control of mercury, the cost per pound of mercury removed is $13,500.

Figure 0-4 – Process Flow Diagram – UHF and Carbon Impregnated Filters

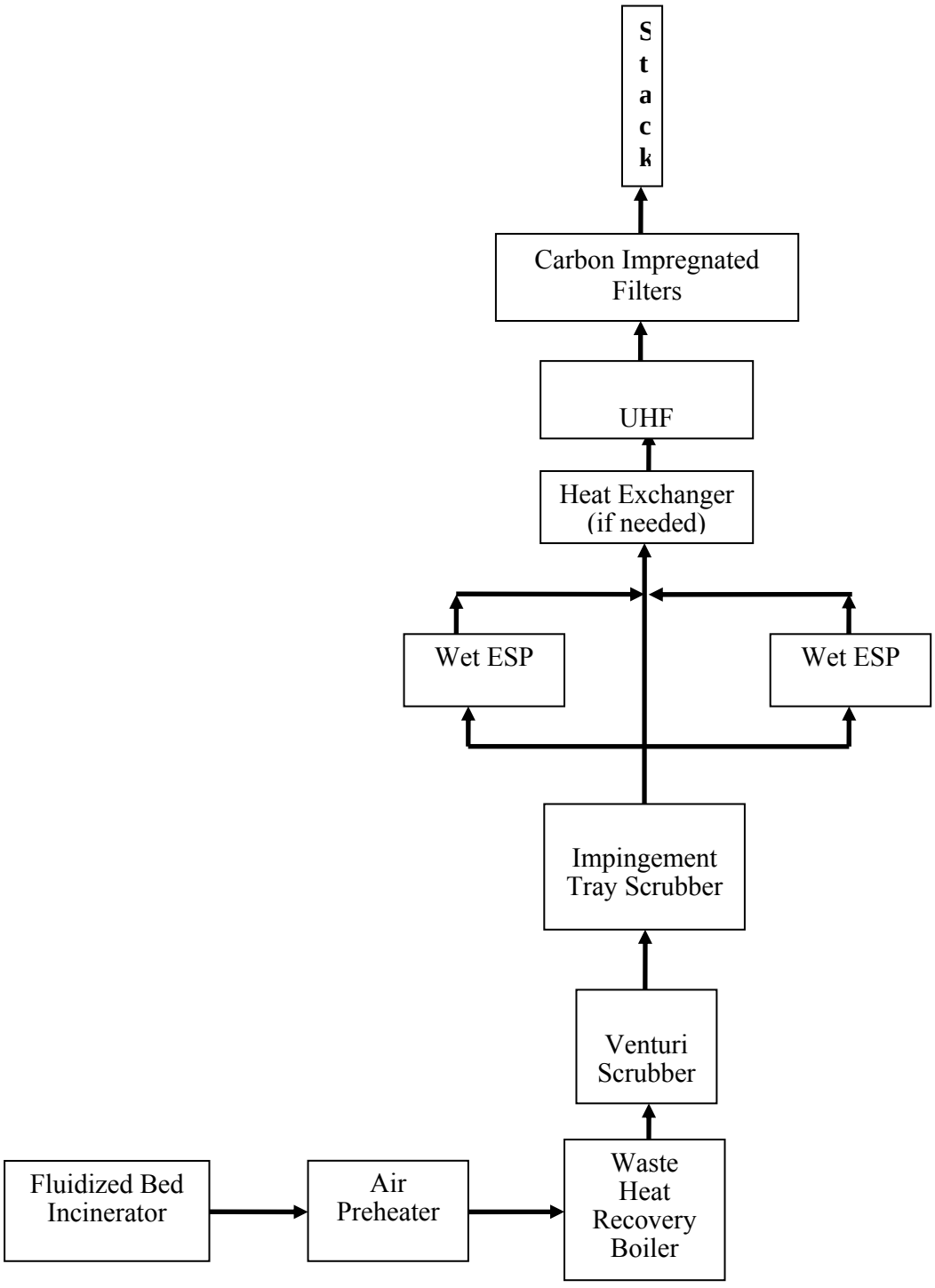

Table 0-6 – Capital and O&M Costs for UHF and Carbon Impregnated Filters

Capital Costs			
	Costs	**Basis**	**Reference**
DIRECT COSTS:			
PURCHASED EQUIPMENT			
(a) Control Equipment (BE)	$370,700	Vendor-supplied	APC Technologies, 08/25/2009
(b) Auxiliaries	$25,000	Vendor-supplied (fan)	
(c) Instrumentation & Controls	included		
(e) Tax	$19,800	5% of (1a)-(1c)	
(e) Freight	$19,800	5% of (1a)-(1c)	OAQPS, Table 1.3.
TOTAL PURCHASED EQUIPMENT (PE):	**$435,300**		
DIRECT INSTALLATION COSTS			
(a) Foundations and supports	$34,800	0.08 x PE	OAQPS, Table 1.3.
(b) Handling and erection	$60,900	0.14 x PE	OAQPS, Table 1.3.
(c) Electrical	$17,400	0.04 x PE	OAQPS, Table 1.3.
(d) Piping	$8,700	0.02 x PE	OAQPS, Table 1.3.
(e) Insulation for ductwork	$4,400	0.01 x PE	OAQPS, Table 1.3.
(f) Painting	$4,400	0.01 x PE	OAQPS, Table 1.3.
Total Direct Installation Costs	$130,600	0.30 x PE	
TOTAL DIRECT COST (TDC):	**$565,900**		
INDIRECT COSTS:			
INDIRECT INSTALLATION			
(a) Engineering & Supervision	$56,600	10% of TDC	OAQPS, Table 1.3.
(b) Construction & Field Expenses	$28,300	5% of TDC	OAQPS, Table 1.3.
(c) Contractor Fees	$28,300	5% of TDC	
(d) Contingencies	$17,000	3% of TDC	OAQPS, Table 1.3.
OTHER INDIRECT COSTS			
(a) Startup & Performance Tests	$17,000	3% of TDC	OAQPS, Table 1.3.
(b) Working Capital	$20,400	30 days O&M cost	
TOTAL INDIRECT COST:	**$167,600**		
TOTAL CAPITAL COST (TCC):	**$734,000**		
Annualized Costs			
	Costs	**Basis**	**Reference**
DIRECT OPERATING COSTS:			
DIRECT LABOR (DL)			
Additional Labor	548	hours/year	1/2 hour per shift
(a) Operators	$19,163	@$35/hr	
(b) Supervisors	$2,900	15% of operating labor	OAQPS, Table 1.6.
MAINTENANCE			
Additional Maintenance	1,314	hours/year	15-20% of operating hrs
(a) Labor (ML)	$59,130	@$45/hr	for control systems
(b) Material	$59,130	100% of maintenance labor	OAQPS, Table 1.6.
(c) Supervisors	$8,900	15% of operating labor	OAQPS, Table 1.6.

POWER (30 kw x 8760 hr/yr x $0.1549/kwhr x 0.80 util. factor)	$33,000	Fan and moving parts	Energy Information
CONTROL SYSTEM			Admin for cost
(a) Carbon Filters / UHF			
Replacement Carbon Filter Costs per year($)	$60,000	Vendor-supplied	200 F scenario
Replacement UHF Costs per year($)	$3,000	Vendor-supplied	Vendor Information
Sales Tax ($)	$3,150		
(b) Carbon Disposal			
Cost per ton	$70.00	per ton	Assume nonhazardous
Tons per year Disposed	1.95	Vendor-supplied	
Cost per year	$137		
SUBTOTAL O&M COSTS:	**$248,509**		
INDIRECT OPERATING COSTS:			
OVERHEAD	$89,500	60% of O&M Labor	OAQPS, Table 1.6.
INSURANCE	$7,300	1% of Total Capital Cost	OAQPS, Table 1.6.
ADMINISTRATION	$14,700	2% of Total Capital Cost	OAQPS, Table 1.6.
CAPITAL RECOVERY	$64,000	20 yr life, 6% interest rate	OAQPS, Table 1.6.
ANNUALIZED COST:	**$424,000**		
HG EMISSION RATE (LB/YR)	63.00		
HG CONTROL EFFICIENCY (%)	50%		
EMISSIONS CONTROLLED (LB/YR)	31.50		
OVERALL COST EFFECTIVENESS ($/LB):	**$13,500**		

Notes:

The cost of a building to house the control system has not been included (if needed); the cost of some auxiliary equipment may not have been included. It is assumed that compressed air is available (no cost has been added for this). OAQPS Control Cost Manual Sixth Edition, Section 3, Chapter 1, United States Environmental Protection Agency, January 2002. EPA/452/B-02-001
Capital Costs: APC Technologies

4.5.1.5 Summary of Costs

The capital and O&M costs of each of the four technologies considered is summarized in Table 0-7.

Table 0-7 – Capital and O&M Costs for Mercury Control Options

Technology	Capital Cost (Installed)	Annualized Operating Cost	$/lb of Mercury Removed
Tri-Mer Hypochlorite Scrubber[1]	$1,892,000	$734,700	$13,000
UHF and Carbon Adsorption[2]	$1,152,000	$541,900	$10,100
Carbon Injection and Fabric Filter[3]	$1,941,000	$608,000	$11,400
UHF and Carbon-Impregnated Filters[4]	$734,000	$424,000	$13,500

Notes:

1. Operating costs highly uncertain since they were not provided by the vendor who cited issues with high CO and CO_2 flue gas concentrations after providing the budgetary proposal.
2. Installed in one full-scale demonstration and one commercial application, both with operational problems/premature carbon bed degradation, therefore, long-term reliability has not been demonstrated
3. Not including removal of the wet system or associated downtime for installation. Operating cost does not include cost of lime for SO_2 and acid gases, if needed.
4. Assumed exhaust temperatures above 200 ºF. If heat exchanger added, capital and operating costs, percent control and pounds of mercury removed all would increase. Vendor estimates heat exchanger capital cost to be ~$50K.

4.5.2 Energy Impact Analysis

Estimated energy usages for each of the mercury control alternatives are listed below.

- **Tri-Mer Hypochlorite Scrubber –** Power Usage: 115 kilowatts
- **UHF and Carbon Adsorption** – Power Usage:45 kilowatts
- **Carbon Injection and Fabric Filtration** – Power Usage: 45 kilowatts
- **UHF and Carbon-Impregnated Filters** –Power Usage: 30 kilowatts

4.5.3 Environmental Impact Analysis

The environmental impacts of the mercury control alternatives are as follows:

- **Tri-Mer Hypochlorite Scrubber –**
  - Removes an estimated 57 pounds per year of mercury from the environment.
  - Requires the disposal of approximately 2,500 pounds per year of mercuric sulfide sludge that would likely be classified as non-hazardous, special waste.

- **UHF and Fixed Bed Carbon Adsorption** –
  - Removes an estimated 54 pounds per year of mercury from the environment.
  - Requires the disposal of approximately 6 tons per year of mercury laden activated carbon that would most likely be classified as hazardous waste.

- **Carbon Injection and Fabric Filtration**
  - Removes an estimated 54 pounds per year of mercury from the environment.
  - Requires the disposal of approximately 18 tons per year of mercury laden flyash that would likely be classified as non-hazardous, special waste.

- **UHF and Carbon-Impregnated Filters**
  - Removes an estimated 32 pounds per year of mercury from the environment.
  - Requires the disposal of approximately 2 tons per year of mercury laden filter media that would likely be classified as non-hazardous, special waste.

The UHF with carbon-impregnated filters has the lowest mercury control efficiency and therefore would allow up to 31 pounds of mercury per year to be released to the atmosphere versus 6 to 12 pounds per year for the other alternatives based on conservatively low efficiency estimates. The Tri-Mer wet scrubber alternative has the advantage that it generates the least amount of residual material containing mercury which would require disposal. The residual material from the Tri-Mer scrubber, as well as that from the carbon injection with fabric filter and UHF with carbon-impregnated filter options would be likely non-hazardous, whereas the residual material from the fixed bed carbon adsorption alternative would most likely be classified as hazardous, based on experience at the Mattabassett District.

4.6 Conclusions

The following are the salient points from this preliminary analysis of Hg control options for the NWPCA:

- Each technology alternative has very limited commercial operating history in SSI Hg control applications. Further evaluation, including pilot testing, should be performed before making any final decision to install a particular technology.
- The most mature technologies at this time appear to be activated carbon injection with fabric filter and fixed bed carbon adsorption.
- Based on limited operational history in SSI Hg control applications (at the Buffalo and St. Paul, MN WWTPs), the carbon injection with fabric filter alternative appears to have experienced fewer problems than fixed bed carbon adsorption. In addition, the byproduct flyash with mercury-laden carbon will likely not require disposal as a hazardous waste. Additional interviews of operators at the Buffalo and St. Paul WWTPs and/or site visits should be conducted to obtain further information on system operation and reliability at that facility.
- Fixed bed carbon adsorption has been used for Hg control at only two facilities: at the Mattabassett District in Cromwell, CT as part of an approximate 5-year demonstration program and at the Ypsilanti WWTP in MI with less than two years of commercial operation. Both installations have experienced problems with carbon fouling/degradation

due to a combination of submicron particulate and moisture carryover and chemical attack, leading to premature carbon replacement. There also appears to be very limited data on the effectiveness of Hg control as a function of time after carbon bed replacement as most of the performance testing has been performed at the two facilities with relatively fresh carbon. In addition, based on experience at the Mattabassett District, there is a high likelihood that spent carbon will require disposal as a hazardous waste.

- The use of a moving bed UHF system for pre-filtering of submicron particulate ahead of a fixed bed carbon unit has only been subject to very limited testing in this application at the Mattabassett District. Although one vendor has been identified with UHF experience in other applications, further long-term testing is recommended to further evaluate the suitability of this technology as a pre-filter in SSI Hg control applications.
- The use of a UHF ahead of a series of carbon-impregnated filters has potential promise in terms of reduced capital and operation cost, reduced downtime, and waste media disposal as non-hazardous waste. However, the Hg removal efficiency is estimated to be significantly lower than any of the other alternatives and no long term testing of this technology in this application has been conducted.
- One vendor (Tri-Mer Corporation) has been identified with a commercially available chemical conversion wet scrubbing system that claims 99+ percent control efficiency. Although a promising technology, no applications specific to SSIs have been identified. In addition, high CO and carbon dioxide CO_2 concentrations in combustion flue gas may make the technology impractical in an SSI application due to the potential for high pH adjustment chemical (e.g. sodium hydroxide) consumption rates and the associated cost impact. Therefore, it is recommended that pilot testing be performed to demonstrate viability at an SSI.
- Pilot testing conducted by the developer of the Tri-Mer wet scrubbing technology (ADA Technologies Inc.) under an EPA grant has also indicated that a hybrid wet scrubbing system consisting of a venturi scrubber and shorter packed bed could be as effective as a single stage packed bed scrubber when used with appropriate chemical addition. This result raises the potential that the NWPCA's existing wet scrubbing system could be retrofitted with the technology for oxidizing, scrubbing and converting Hg to insoluble mercuric sulfide for disposal as a nonhazardous waste. NWPCA should conduct further evaluation of this potential retrofit technology, which may result in the lowest capital and operating cost impacts.

Based on the information presented in this report, further, more detailed evaluation of each of the identified options is required to evaluate long-term performance and reliability of the systems and refine the cost estimates. In addition, other operational issues associated with each alternative should be investigated, such as available space for each option, longer start-up times, more frequent shut-downs, effects on other air pollutant emissions, and effects on stack parameters (which may require revised air dispersion modeling for all criteria pollutants). Pilot testing may need to be considered for the best one or two options. NWPCA should also consider performing air quality modeling studies to evaluate the effect (positive or negative) of additional mercury controls on mercury deposition to nearby water bodies.

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