

Control of Mercury, Dioxins/Furans, and Particulate Matter Emissions from Sewage Sludge Incinerators for Compliance with New US EPA Regulations

Hans Tandon¹, Mark Colonna², Louis Barry³, Christopher Doelling⁴

¹APC Technologies, Inc., Pittsburgh, Pennsylvania

²APC Technologies, Inc., Pittsburgh, Pennsylvania

³Chavond-Barry Engineering Corp., Blawenburg, New Jersey

⁴Chavond-Barry Engineering Corp., Blawenburg, New Jersey

¹Email: htandon@apctechnologies.net

²Email: mcolonna@apctechnologies.net

³Email: ltbarry@chavond-barry.com

⁴Email: cmdoelling@chavond-barry.com

ABSTRACT

In 2011, the U.S. Environmental Protection Agency (EPA) promulgated emission limits and compliance schedules for control of airborne emissions from new and existing sewage sludge incinerators (SSIs). The emission limits established apply to emissions of particulate matter, hydrogen chloride (HCl), carbon monoxide (CO), dioxins/furans, mercury, oxides of nitrogen (NO_x), sulfur dioxide (SO₂), cadmium, lead, and fugitive emissions from ash handling. While some facilities were already in compliance with the new EPA regulations without additional controls, many facilities found that additional, advanced emission control equipment would be needed, most often for removal of mercury emissions.

Since promulgation of the new rules, a number of wastewater treatment plants (WWTPs) utilizing SSIs have installed advanced air emission control equipment and conducted emission compliance tests. This paper documents the technical approach, emission testing results, and operating experiences for four SSIs that commenced operation of advanced air emission control systems during 2016.

KEYWORDS

Sewage sludge incinerators (SSIs), Fluidized Bed Incinerators (FBIs), incinerator emissions, mercury emissions, particulate matter emissions, dioxins/furans emissions, activated carbon systems, carbon adsorption, high-efficiency particulate filters, carbon bed hot spots.

INTRODUCTION AND BACKGROUND

In 2011, the U.S. EPA promulgated emission limits and compliance schedules for control of airborne emissions from SSIs. 40 Code of Federal Regulations (CFR) Part 60 Subparts LLLL and MMMM establish such requirements for New SSIs – with ‘New SSI’ being an SSI that either commenced construction after 14 October 2010 or commenced modification after 21 September 2011 – and Existing SSIs, respectively. The newly-established emission limits apply to emissions of particulate matter, HCl, CO, dioxins/furans, mercury, NO_x, SO₂, cadmium, lead, and fugitive emissions from ash handling. While some facilities found themselves already in compliance with the new EPA regulations without additional emission control equipment, many

facilities found that advanced emission control equipment would be needed, most often for additional removal of mercury emissions. The federal deadline for demonstrating compliance with the emission limits was March of 2016; while this deadline has passed, a significant number of facilities are currently in the process of implementing projects or still determining a path of action. This paper presents design, operational, and performance information on air emission control systems for mercury, dioxins/furans, and particulate matter installed for four SSIs, each of which commenced operation of the advanced emission control equipment during 2016. The paper presents a discussion of key design considerations for the advanced emission control systems for the four SSIs, a description of the emission control equipment installed at the sites, compliance testing results, and a summary of operating experience to date with the systems. The information provided herein has been developed to help the regulated community better understand these emission control systems and to aid facilities that are in the process of executing, or considering implementation of, similar projects.

PROCESS AND EMISSIONS DATA

The four SSIs studied in this paper are all Fluidized Bed Incinerators (FBIs) located in the United States. The four incinerators have typical feed rates and other process parameters as shown in Table 1.

Table 1. Selected Process Information for SSIs.

	FBI#1	FBI#2	FBI#3	FBI#4
FBI Sludge feed rate, dry kg/hr (dry lbs/hr)	1,180 (2,600) ⁽¹⁾	4,990 (11,000) ⁽¹⁾	950 (2,100) ⁽²⁾	1,020 (2,250) ⁽¹⁾
Gas exhaust volumetric flow rate, Nm ³ /hr (SCFM)	13,780 (8,200) ⁽¹⁾	48,740 (29,000) ⁽²⁾	10,080 (6,000) ⁽²⁾	11,430 (6,800) ⁽¹⁾
Existing air emission control equipment (prior to addition of advanced emission controls) ⁽³⁾	<ul style="list-style-type: none"> • Venturi scrubber • Tray scrubber • WESP 	<ul style="list-style-type: none"> • Venturi scrubber • Tray scrubber • WESP 	<ul style="list-style-type: none"> • Venturi scrubber • Tray scrubber • WESP 	<ul style="list-style-type: none"> • Venturi scrubber • Tray scrubber • WESP

⁽¹⁾ Maximum level.

⁽²⁾ Typical level.

⁽³⁾ WESP= Wet electrostatic precipitator.

Emission limits and data on stack emission rates for pertinent contaminants prior to the installation of advanced emission control equipment to meet the new regulations are shown in Table 2.

Table 2. Emission Limits and Emission Levels Prior to Installation of Advanced Emission Controls.

	<i>Emission Levels Prior to Installation of Advanced Emission Controls</i>				Regulatory Limit- New SSIs	Regulatory Limit- Existing SSIs
	FBI#1	FBI#2	FBI#3	FBI#4		
Mercury emissions, mg/dscm @ 7% O ₂	0.750 ⁽¹⁾	0.178 ⁽¹⁾	0.093 ⁽²⁾	0.074 ⁽²⁾	0.0010	0.037
Particulate matter emissions, mg/dscm @ 7% O ₂	N/A	3.8 ⁽¹⁾	12.0 ⁽²⁾	1.5 ⁽²⁾	9.6	18
Dioxins/furans emissions, ng/dscm @ 7% O ₂ ⁽³⁾	N/A	N/A	0.095 (TMB) 0.0032 (TEQ)	0.12 (TMB) 0.0072 (TEQ)	0.013 (TMB) 0.0044 (TEQ)	1.2 (TMB) 0.10 (TEQ)
Cadmium emissions, mg/dscm @ 7% O ₂	N/A	N/A	3.4E-04	0.0031	0.0011	0.0016
Lead emissions, mg/dscm @ 7% O ₂	N/A	N/A	0.0054	0.086	6.2E-04	0.0074

N/A = Not available

⁽¹⁾ Maximum levels given.

⁽²⁾ Measured during prior stack testing.

⁽³⁾ TMB= Total mass basis; TEQ= Total equivalents basis. The regulation requires that one of the two standards be met.

The following can be concluded from Table 2:

- Mercury was the contaminant requiring the highest removal efficiencies by the advanced air emission control equipment.
- Mercury removal efficiencies required to meet the regulations varied from FBI to FBI, ranging up to 99.87% for meeting the ‘new’ incinerator emission limit and up to 95.1% for meeting the ‘existing’ incinerator emission limit.
- To safely meet the emission limits, some additional removal of particulate matter, dioxins/furans, lead and cadmium was also required of the advanced air emission control equipment to be installed at several of the facilities.

KEY DESIGN CONSIDERATIONS FOR NEW EMISSION CONTROL EQUIPMENT

To achieve the high removal efficiencies required to reduce mercury emissions to below regulatory limits, an adsorber containing a fixed bed (or beds) of sulfur-impregnated activated carbon is an essential emission control component to add to the existing facility emission controls. Fixed beds of activated carbon, however, in turn dictate a number of critical design requirements and considerations as described below.

Particulate-Free Exhaust Gas

The exhaust gas must be essentially free of particulate. It has been shown that media beds of all types will collect significant amounts of particulate over time, including submicron-sized particulate, unless the particulate is substantially removed prior to the media bed. Particulate build-up in the carbon bed creates multiple problems. On a micro level, particulate build-up on a carbon granule or pellet blocks gas entry into the pores of the carbon, where the mercury would normally adsorb and react with elemental sulfur to form mercuric sulfide. On a macro level, particulate build-up can block off sections of the carbon bed from gas flow, which in turn results in two problems: 1) the exhaust gas travels through a smaller cross-sectional area of the bed, increasing the gas velocity and decreasing the contact time between gas and carbon; and 2) the squeezing of the gas flow through a smaller area of the bed increases the differential pressure across the bed. Both of these situations commonly lead to a premature change-out of the carbon bed, typically a very expensive event.

It could be posited that given the existing particulate emission control equipment (i.e., venturi scrubber and WESP) located upstream of the carbon bed, adequate particulate control already exists at these facilities; however, it is not unusual for 90-140 g/hr (0.2 or 0.3 lbs/hr) of very fine particulate to remain in the exhaust downstream of these devices. For a 24-hr/day, 5-day/week operation, 140 g/hr (0.3 lbs/hr) of fine particulate becomes 820 kg/yr (1,800 lbs/yr) of particulate matter entering the carbon bed.

The removal of fine particulate serves two critical, additional functions in the system: 1) particulate matter, cadmium, and lead – for which the 2011 regulations require further emission reductions for all three – are removed; and 2) mercury that is loosely adsorbed on fine particulate matter is removed, helping ensure that mercury emission limits are met.

Condensation Prevention

Condensation must be prevented in the carbon bed and adsorber vessel. The FBI exhaust gases are scrubbed for particulate and acid gas control and typically are between 27° and 43°C (80° and 110°F) and laden with water vapor at saturation (i.e., 100% relative humidity) as they enter the advanced air emission control system. Condensation occurs rapidly when a moist gas stream is cooled, e.g., by encountering a carbon media bed that is colder than the exhaust gas dew point. Condensation in the pores of the carbon pellets or granules creates a barrier between the exhaust gas and the carbon pores. Although gas diffusion through this liquid layer can occur, the diffusional kinetics are much slower and require minutes of contact time to provide the required level of adsorption; however, gas-phase carbon systems have contact times on the order of seconds. Because of this, the presence of condensation causes the affected parts of the carbon bed to be rendered temporarily useless for mercury removal, and overall removal efficiencies by the carbon bed can decrease.

In addition to the problem described above, the presence of acid gases such as SO₂ in the exhaust gas together with high water content in the gas can lead to acid formation in the carbon bed, which in turn can lead to the carbon bed plugging issues as described in the discussion of particulate above.

Provisions To Avoid Carbon Bed Fires and Bed Hot Spots

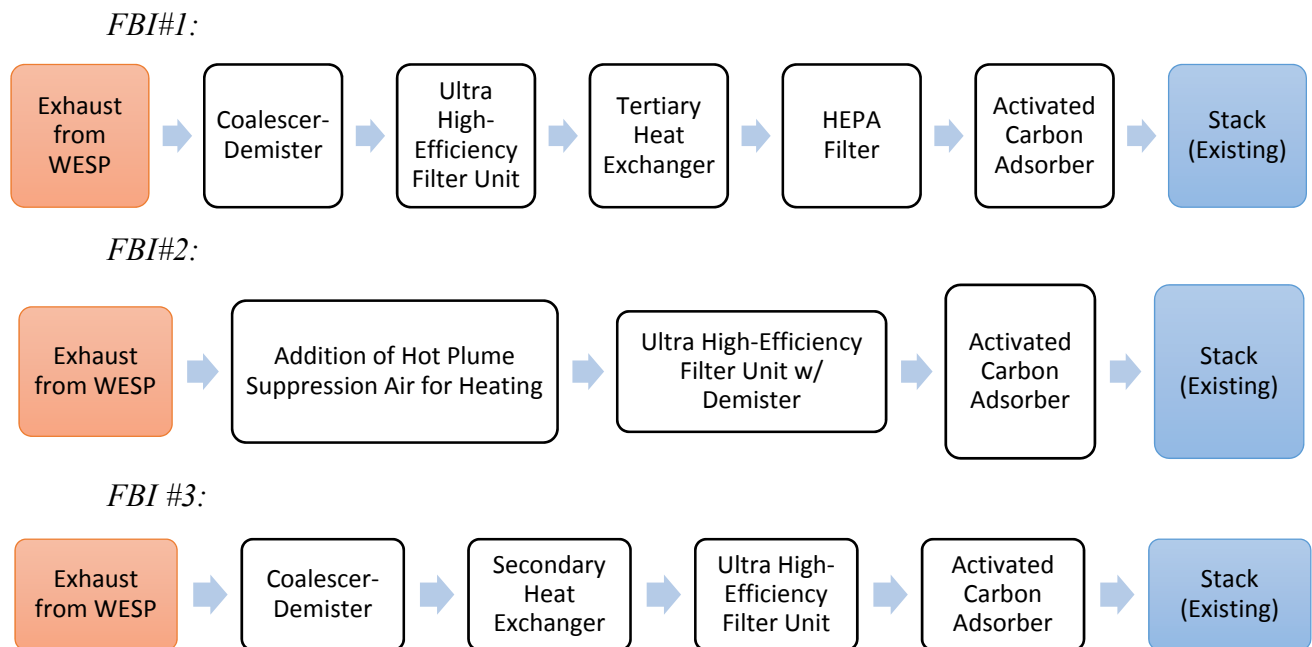
When not properly designed, activated carbon beds can experience bed hot spots and fires. This behavior has been observed on multiple occasions at incinerator facilities, in some cases melting the adsorber vessel and causing months of incinerator downtime. Such thermal events occur when localized areas in the carbon bed experience temperature increases to the point that oxidation begins. Temperature increases can occur because of high adsorption rates, as adsorption is an exothermic process, or as a result of other factors. The phenomena of carbon bed hot spots and fires in fixed activated carbon beds for mercury emissions control, and countermeasures that can be implemented to mitigate this risk, have been documented in other technical papers (Soelberg, Enneking, Kovach, 2011).

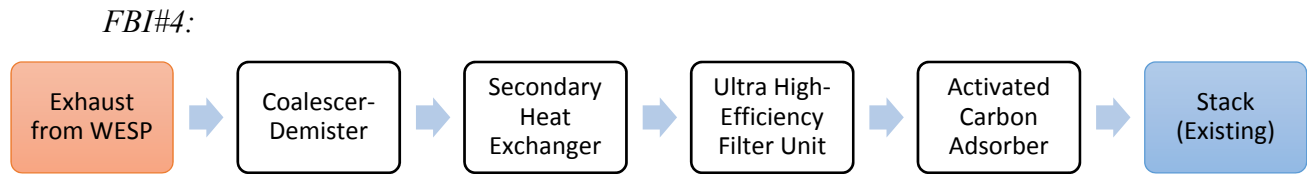
DESCRIPTION OF ADVANCED EMISSION CONTROL EQUIPMENT

To achieve the high removal efficiencies required to reduce mercury emissions to below regulatory limits, a fixed bed of sulfur-impregnated activated carbon is the most essential additional piece of emission control equipment needed. And as already discussed, fixed beds of activated carbon require a clean and fairly dry gas stream to function properly for an extended period. As such, a few equipment components to condition the exhaust gas were required for the advanced air emission control systems installed. This section discusses in more detail each of the advanced emission control system components.

For the four FBIs reviewed for this report, the sequence of additional emission control equipment was installed as shown in Figure 1. Note that the equipment for pre-heating and maintaining heat in the system during start-ups and hot standby periods is not shown in Figure 1.

Figure 1. Advanced Emission Control Equipment Installed for FBI #'s 1, 2, 3, and 4.





The process steps shown in Figure 1 are discussed in greater detail below.

High-Efficiency Coalescer-Demister

Although there is typically some mist elimination upstream of the new, advanced emission control equipment, it is critical that this step be performed with high removal efficiencies on fine droplet sizes to prevent free water from reaching the activated carbon bed. This is accomplished either through a stand-alone coalescer-demister as in the FBI #'s 1, 3, and 4 designs, or in conjunction with the particulate removal step as in the FBI#2 system design. Mist elimination is best accomplished through a two-step process. The first step utilizes a mesh-type coalescer or a synthetic filter media to grow droplets from very small diameter sizes (including some less than one micron) to droplets with diameters of tens or hundreds of microns, or larger. The second collection step uses a profile-type (i.e., customized profile plate design or chevron) element to catch and drain the coalesced droplets from the preceding step. Where stand-alone, these combined coalescer-demisters can be designed to be quite compact in size, with a unit of 1m long x 1m wide x 1m high servicing approx. 12,600 Nm³/hr (7,500 SCFM). Given the presence of some particulate in the exhaust gas streams exiting the WESPs in these applications, the coalescer-demister units should have integral spray wash equipment to allow for self-cleaning while on line in case solid particulate is collected by the coalescer.

High-Efficiency Fine Particulate Filter

For reasons described previously, it is essential to both the proper performance and the longevity of the carbon bed that fine particulate be removed upstream of the carbon bed.

Also as noted previously, removing fine particulate has two additional, important functions in the system: 1) particulate matter, cadmium, and lead – for which the 2011 regulations require further emission reductions for all three contaminants – are removed in this step; and 2) mercury that is loosely adsorbed on fine particulate matter is removed, helping ensure that mercury emission limits are met.

In cases where fine particulate removal is combined with mist elimination and significant amounts of free water can still be present in the exhaust gas, as in the system design for FBI#2, the required particulate and mist removal can be accomplished using an automatic-advancing type filter unit, where the filter unit is made to handle both solid-phase and liquid-phase particulate. This high-efficiency filter device, used on all of the advanced air emission control systems studied, utilizes a synthetic filter media presented in roll form, with the clean roll on one end and the take-up (dirty) filter spooled up on the opposite end of the unit. The filter unit advances a small section of fresh filter media into the filtration chamber automatically based on differential pressure across the filter. When the end of a roll is reached, an operator must install a clean filter roll on the unit; this filter roll replacement is performed in a few minutes and while

the unit and system are running (i.e., there is no downtime for the FBI or emission control equipment). Filter rolls commonly last from on the order of a few weeks to a few months each.

In cases where fine mist droplets have been removed upstream by a stand-alone demister unit and the relative humidity of the exhaust gas has been reduced via exhaust gas reheating, a fixed filter using consumable (i.e., disposable) filter elements such as HEPA filters can be used for removing fine particulate with very high removal efficiencies. This type of filter unit does not have automatic advancement of clean filter media into the filtration chamber and as such, filter elements must be changed out when the FBI and emission control equipment is not operating, unless there is a redundant filter bank.

Exhaust Gas Reheater

To prevent condensation in the carbon bed(s) and carbon adsorption vessel, the relative humidity of the exhaust gas must be reduced from near-saturation points at the exit of the wet scrubbers/WESP to a point such that the gas retains 75% relative humidity or less as it passes through the carbon bed. This is accomplished by heating the exhaust gas stream upstream of its entrance to the carbon bed. An increase in temperature on the order of 20°C is typically required to accomplish this objective. Commonly, the reheater is an existing heat exchanger at the plant or a new heat exchanger.

For the FBI#1 system, this step was accomplished by installing a small, tertiary heat exchanger on the outlet of the existing secondary heat exchanger and sending a portion of the gases, with volumetric flows rates automatically controlled via temperature control loops to achieve the desired magnitude of reheating through the tertiary heat exchanger.

In the FBI#2 system, the gas heating step was accomplished by diverting a small portion of a clean, high-temperature gas stream already used at the facility for plume suppression. Diverted gas is introduced into the incinerator exhaust gas stream just upstream of the emission control system. Flow rates for the diverted gas are adjusted as needed to maintain the desired temperature in the gas entering the emission control system.

For the FBI #'s 3 and 4 systems, this step was accomplished by recycling a portion of the clean exhaust gas leaving the carbon bed back through the FBI's secondary heat exchanger and then adding a portion of the reheated exhaust gas back into the exhaust gas stream upstream of where the gas enters the ultra-high-efficiency particulate filter (refer Figure 1).

Carbon Adsorption Vessel and Activated Carbon Bed(s)

The carbon adsorption vessel (or vessels) is designed to provide adequate contact time between the carbon and the gas to be treated, ease of operation and maintenance, and to facilitate monitoring of the carbon bed. All of the systems reviewed in preparation of this report operate in down-flow configuration. This configuration removes the possibility of fluidizing the carbon bed during high-flow or high-pressure situations. Fluidization can compromise system performance by breaking down carbon granules or pellets and promoting channeling of the gas flow through the bed. Carbon adsorber geometry can vary based on site-specific requirements or constraints, but circular vessels are most commonly used. Vessels should be insulated to make sure added heat is retained and operating temperatures are maintained to the extent possible. Because

emissions from SSIs can be corrosive in nature, 316SS and FRP are typical materials of construction for mercury adsorber vessels.

Adsorber vessels typically include ports for:

- Loading and unloading of carbon;
- Collection of gas or carbon samples;
- Monitoring temperature;
- Monitoring pressure (and differential pressure across the bed(s)); and
- Maintenance access above and below the carbon bed(s).

Carbon bed configurations can be single-bed or multiple-bed. Multiple-bed systems allow for monitoring between beds which allows for easier replacement of portions of the overall carbon charge in the vessel, but multiple beds typically make the adsorption vessels larger and heavier. With proper monitoring, single-bed systems can be used. A number of proven vendors provide sulfur-impregnated carbon media which can be used in the bed(s) to adsorb mercury. Selection of a carbon product will vary by application depending on a number of factors, including system operating temperature. The volume of carbon used in a system will also vary by application based on factors including required mercury efficiency and required lifespan of the carbon.

Start-up and Hot Standby Equipment

Introducing warm, moist gas to a cold carbon bed can cause condensation to occur in the bed, reducing system performance as previously discussed. Therefore, it is important to have a method for properly warming the bed before sending SSI exhaust to the bed for treatment. This is commonly referred to as Cold Start Mode for the emission control system. This heating can be achieved in a number of ways, but the most common method is to introduce heated ambient air (or other clean, dry, heated gas) to the vessel until the bed achieves operating temperature. Then the bed is ready to receive SSI exhaust with low risk of condensation.

This process can be performed using duct heaters or heat exchangers, or other available safe sources of heat, and can be enhanced by recycling the heated gas that passes through the vessel to take advantage of the remaining heat value in the gas exiting the vessel. Instrumentation must be employed to monitor the heating process to confirm when the operating temperature is achieved and to ensure the heating process is controlled and safe.

This same approach is employed for times when the SSI is temporarily down but the emission control system needs to stand ready to operate upon SSI restart. The operating temperature is maintained in the adsorber vessel and carbon bed(s) using the same equipment and procedures used to heat the system during Cold Start Mode. This operating mode is typically referred to as Hot Standby Mode.

System Controls

The emission control system is controlled using logic programmed specifically for the system and for the facility being served. The controls can be housed in a stand-alone system control panel or embedded into existing facility control systems. In either case, the controls must be integrated with existing facility systems, equipment, and procedures. The system controls will,

among other functions, include sequencing for valves, dampers, and fans, take signals from various system instruments, and provide alarming and notification protocols.

COMPLIANCE TESTING RESULTS AND DISCUSSION

Table 3 below presents the results of compliance emission testing conducted for each of the FBIs subsequent to system commissioning.

Mercury Results

Test results showed that mercury concentrations were reduced to well below not only the regulatory mercury emission limit for Existing SSIs, which is the applicable regulatory limit for the four FBIs, but also well below the mercury emission limit for New SSIs. The lowest emissions were measured at FBI#1, where stack mercury emissions were less than 1% of the regulatory limit for New SSIs and less than 0.03% of the emission limit for Existing SSIs.

For two of the FBIs, mercury emissions in the stack were compared to the mercury loading entering the FBI via sludge feed, by using the sludge feed rates and mercury concentrations in the sludge, with this comparison showing 99.98% and 99.8% mercury removal for FBI#’s 1 and 2, respectively.

Table 3. Compliance Emission Testing Results after Commissioning.

	Regulatory Limit- <i>New SSIs</i>	Regulatory Limit- <i>Existing SSIs</i>	FBI#1	FBI#2	FBI#3	FBI#4
Mercury emissions, mg/dscm @ 7% O ₂ (removal efficiency)	0.0010	0.037	9.76E-06 (99.98%)	4.3E-05 (99.8%)	5.37E-04	2.7E-04
Particulate matter emissions, mg/dscm @ 7% O ₂	9.6	18	0.872	N/A	2.26	6.04
Dioxins/furans emissions, ng/dscm @ 7% O ₂ ⁽¹⁾	0.013 (TMB) 0.0044 (TEQ)	1.2 (TMB) 0.10 (TEQ)	0.00452 (TMB) 7.16E-05 (TEQ)	N/A	4.37E-03 (TEQ)	0.0017 (TEQ)
Cadmium, emissions mg/dscm @ 7% O ₂	0.0011	0.0016	8.36E-05	N/A	1.16E-04	1.4E-04
Lead emissions, mg/dscm @ 7% O ₂	6.2E-04	0.0074	7.98E-04	N/A	3.64E-04	1.99E-04

⁽¹⁾ TMB= Total mass basis; TEQ= Total equivalents basis. The regulation requires that one of the two standards be met.

⁽²⁾ Percentages listed for mercury emissions are removal efficiencies.

Particulate Matter Results

As with for mercury, test results showed that particulate matter concentrations were reduced to well below not only the regulatory emission limit for particulate matter for Existing SSIs, which

again is the applicable regulatory limit for the four FBIs, but also well below the particulate matter emission limit for New SSIs. The lowest emissions were again measured at FBI#1, where stack emissions were less than 10% of the regulatory limit for New SSIs and less than 5% of the emission limit for Existing SSIs. Note that the advanced air emission control system for FBI#1 includes a HEPA filter, which provided a second advanced stage of particulate removal.

Dioxins/Furans Results

Test results showed that dioxins/furans concentrations were reduced to below the applicable regulatory emission limit for Existing SSIs at the three sites where it was measured and reported.

The lowest emissions for this contaminant group were again measured at FBI#1, where the more stringent standard for New SSIs was easily met. Measured emissions at FBI#3 also met the more stringent standard for New SSIs, although only by a small margin. For FBI#4, dioxins/furans emissions met the standard for Existing SSIs.

Cadmium and Lead Results

Test results showed that measured cadmium concentrations in the stack easily met both standards -- for both Existing and New SSIs -- at the three sites where it was measured and reported, with the highest measured concentration being less than 15% of the stricter new incinerator standard.

For lead, measured concentrations in the stack easily met the standard for Existing SSIs at the three sites where it was measured (FBI#'s 1, 3, 4). At FBI#'s 3 and 4, measured concentrations met the standard for New SSIs also, while at FBI#1, the average measured concentration slightly exceeded the standard for New SSIs.

Carbon Bed Hot Spots

All of the advanced emission control systems have been in operation for between one and two years as of this writing. None of the emission control systems on the four FBIs has had any issues with regard to carbon bed hot spots or carbon bed fires, indicating that the respective system designs provided well for the prevention of bed hot spots and fires, as well as that the type of carbon being used is thermally stable.

Condensation and Particulate in Carbon Bed

Regarding condensation and particulate build-up, inspection of the activated carbon in the adsorbers for FBI #'s 1, 3 and 4 after one year revealed that the activated carbon pellets in the beds had fully maintained their original form and appearance and did not show signs of particulate build-up in the carbon bed. Differential pressures across these carbon beds have been stable over time, supporting that there are not build-up problems in the beds.

With some of the systems, a gas temperature rise was observed across the carbon bed during system start-up or during the switch from Hot Standby to Normal Operating mode. At FBI#1 for example, if the carbon beds had been in Hot Standby mode over a weekend, during which warm, dry gas was passed through the carbon beds to keep them at approximately 57°C (135°F), then when moist incinerator gases of the same temperature were introduced to the carbon beds (i.e., when system was switched from Hot Standby to Normal Operating mode), gas temperatures at the exit of the carbon beds would rise as high as 69°C (157°F). This temperature rise of

approximately 12°C (22°F) from the inlet to the outlet of the carbon beds indicated condensation in the pores of the activated carbon when the moist FBI exhaust gas passed through the carbon beds after the beds had been dried considerably during Hot Standby mode. The heat of condensation/adsorption led to the temperature rise across the carbon bed. Once the moisture level in the activated carbon was in equilibrium with the moisture level of the exhaust gas, gas temperatures at the exit of the carbon beds decreased to match the temperatures at the inlet to the beds.

Condensation has been observed on occasion in the FBI#2 carbon adsorption vessels, which were not insulated and are located outdoors. There also have been several reported instances of higher than expected particulate levels at the inlet to the emission control system, which has resulted in the observation of some particulate inside the vessels.

Particulate Filter Change-Out Frequencies

Particulate filter media change-out frequencies for the various types of filtration equipment at all sites were observed to be in expected ranges. For the automatic-advancing filters, filter roll change-out frequencies have averaged approximately monthly. The HEPA filters at FBI#1 have been changed out approximately every six months.

CONCLUSIONS

In response to U.S. EPA emission limits promulgated in 2011 for control of airborne emissions from SSIs, multiple WWTPs in the U.S. have installed advanced air emission control equipment. The most common objective of these projects has been to reduce mercury emissions; however, some facilities also required advanced emission controls to reduce levels of particulate matter, dioxins/furans, cadmium and/or lead. This paper examined the experiences of four FBIs in the U.S. for which advanced emission controls were implemented. The advanced emission controls have been operating at the sites for between one and two years.

Key design requirements for the advanced air emission controls equipment included:

- Removal of fine particulate upstream of the carbon bed for protection of the downstream carbon bed; for advanced removal of fine particulate matter, cadmium, and lead; and for removal of mercury loosely adsorbed to particulate matter;
- Prevention of condensation in the carbon bed; and
- Prevention of carbon bed hot spots and bed fires.

The advanced emission control equipment installed on the four FBIs included:

- High-efficiency coalescer-demister;
- Gas reheater;
- High-efficiency fine particulate filter (one or two stages);
- An activated carbon adsorption vessel or vessels containing one or more beds of sulfur-impregnated activated carbon;
- Start-up and hot standby heater system;
- Instrumentation and controls.

After installation and commissioning of the systems described above, compliance testing results for all four FBIs showed:

- Emissions of mercury not only met the emission standards for Existing SSIs but also met the emission standards for New SSIs for all of the incinerators.
- Measured emissions for particulate matter and cadmium also met emission standards for Existing SSIs and New SSIs.
- For dioxins/furans and lead, measured emissions all met the standards for Existing SSIs and in some cases, also met the standards for New SSIs.

Compliance testing was conducted at two sites after one year of operation, with both of those sites meeting all applicable regulatory emission standards.

Importantly, none of the advanced air emission control systems has had any issues with regard to carbon bed hot spots or carbon bed fires, indicating the safety of the designs utilized.

The activated carbon in three of the FBIs was observed after a year of operation to be clean, free of build-up, and holding their original/virgin form and appearance. At the fourth site (FBI#2), which operates uninsulated vessels outdoors, some signs of condensation and particulate build-up were observed after one year of operation.

Replacement filter costs at all sites have been low and as were projected.

While the installed advanced air emission control systems described herein have allowed the respective WWTPs to meet the new EPA air emission regulations for airborne emissions from SSIs for one to two years as of this writing at all sites, it will be valuable to confirm the continued performance of these systems over the next several years.

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