SEWAGE SLUDGE INCINERATION: MEETING AIR EMISSIONS REGULATIONS IN THE NINETIES AND BEYOND

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NOMENCLATURE

BACT	Best Available Control Technology
CE	Control Efficiency
CEMS	Continuous Emission Monitoring System
DF	Dispersion Factor
EPA	Environmental Protection Agency
ESP	Electrostatic Precipitator
MHF	Multiple Hearth Furnace
NESHAP	National Emission Standards for Hazardous Air Pollutants
NJDEPE	New Jersey Department of Environmental Protection and Energy
NSPS	New Source Performance Standards
PSD	Prevention of Significant Deterioration
SF	Sludge Flow Rate
THC	Total Hydrocarbons
USEPA	United States Environmental Protection Agency
WESP	Wet Electrostatic Precipitator

ABSTRACT

Increased visibility of incineration in the public eye, as well as the recent and continuing promulgation of regulations on both the state and federal levels, are forcing sewage sludge incineration facilities to take a new look at their processes. Affecting municipal sewage sludge incinerators, final rules regulating handling of sewage sludge (40 CFR, Part 503) were published by the USEPA on February 19, 1993. This paper presents an overview of applicable federal regulations, with emphasis on Part 503; a discussion of parameters affecting Part 503-regulated air emissions from sewage sludge incinerators; and technical options available to attain compliance with the Part 503 regulations. Finally, case studies of two actual sludge incinerators and their projected compliance with Part 503 are presented.

REGULATIONS: POLLUTANTS OF CONCERN

The federal government has promulgated regulations affecting sewage sludge incinerators and toxic compounds that are potentially emitted into the atmosphere by such incinerators. Of significance are the Part 503 Regulations, which limit emissions of total hydrocarbons (THC) and seven heavy metals. In addition, other existing federal regulations limit emissions of particulate matter, carbon monoxide, nitrogen oxides, sulfur oxides, and other pollutants.

Federal 40 CFR 503, Subpart E ("Part 503")

Final rules, entitled "Standards for the Use or Disposal of Sewage Sludge" (Part 503 regulations), were developed under authority of the Clean Water Act. Subpart E of Part 503 regulates management practices and air emissions from municipal sewage sludge incinerators.

Subpart E regulates emissions of the following pollutants from sludge incinerators:

- beryllium
- mercury

- lead
- cadmium
- total chromium
- nickel
- arsenic
- total hydrocarbons

Part 503 also requires certain incinerator operating, monitoring, and reporting practices to be maintained, including installation and operation of a THC continuous emission monitoring system (THC CEMS).

Total Hydrocarbons. Part 503 limits the monthly average THC concentration in the stack to 100 ppmdv as propane (corrected to seven percent oxygen) using a heated (150°C/423°K) sample line. The limit is enforceable by the operation of a THC CEMS, in conjunction with measurements of oxygen and moisture. Hourly data points comprised of at least two valid readings per hour are to be summed over a one month period and divided by the number of operating hours to attain the average. Every February 19, the facility must report the 12 monthly averages of the previous calendar year. EPA Region V has issued guidance requiring four readings per hour, with a three hour running average, for demonstration of compliance. This guideline may or may not be adopted by other regions.

Metals. Part 503 sets health-based limits for emissions of the seven metals listed above. Facilities are required to ensure that mercury and beryllium fall below the National Emission Standards for Hazardous Air Pollutants (NESHAP) daily emission rate limits of 3,200 gm/day and 10 gm/day respectively. Lead is limited by its impact outside the property line. Lead's impact cannot exceed 10 percent of its National Ambient Air Quality Standard (NAAQS). Limits on the other four metals are based upon a health risk of one cancer in ten thousand.

The Part 503 regulations require determination of metal concentration limits in the incoming sludge by working "backwards" from the maximum allowable emissions or ambient concentrations. Equations to determine allowable concentrations utilize site- specific information such as:

- dispersion factor of pollutants from the top of the stack (DF),
- control efficiency of the incineration system (CE),
- sludge flow rate (SF).

Lead emissions are limited by Part 503 according to the following equation:

$$C = \frac{0.1xNAAQSx86,400}{DFx(1 - CE)xSF} \quad (1)$$

where:

C = Daily allowable concentration of metal in sewage sludge (mg/kg dry solids).
$NAAQS$ = National Ambient Air Quality Standards = 1.5 ug/m^3.

For arsenic, cadmium, total chromium, and nickel, concentration in the sludge is limited by the equation:

$$C = \frac{RSCx86,400}{DFx(1 - CE)xSF} \quad (2)$$

where:

RSC = Risk specific concentration (mg/m^3):
for arsenic: 0.023
for cadmium: 0.057
for nickel: 2.0
for chromium, RSC depends upon the type of incinerator and control equipment.

Part 503 requires that the facility generate the needed information (DF, CE, etc.) specific to the site and incinerator. While EPA Headquarters have issued guidelines on how facilities determine these values, the EPA regions have been given discretion to make their own interpretations.

Simultaneous stack testing and sludge sampling and analysis are required to determine the control efficiency, which is defined as control of the metal, not only by the air pollution control equipment, but by the furnace as well (control by the total incinerator system). The emission rates of the seven metals must be measured in the stack and compared to inlet rates determined by measuring their concentrations in the incoming sludge.

Permits, Recordkeeping, and Compliance. Permit applications containing established Part 503 metal concentration limits were due on August 18, 1993. If a facility was unable to complete their determination by this date, the EPA allowed the submittal of protocols for dispersion modeling and emissions testing. The EPA (or state, if delegated authority) will issue Part 503 permits containing the concentration limits of the metals in the incoming sludge, as well as incinerator operating limits such as furnace temperature and air pollution control equipment operating parameters. These operating limits will be based on the conditions during testing.

Because Part 503 is self-monitoring, facilities must demonstrate continuous compliance with the standards. Part 503 requires regular sludge sampling and analysis for the seven applicable metals to demonstrate that concentrations of these metals in the sludge do not exceed the limits. Continuous emission monitoring of the hydrocarbons in

the stack (described above) is also required. Recordkeeping of other operating parameters are required, as well.

Steps to be Taken if Limits are Exceeded. If the calculated allowable concentrations in the sludge are not acceptable (for instance, they have been approached or exceeded by historical data), the facility should take action to raise the limits. This can best be done by enacting changes that would raise the CE or reduce the DF or SF. Some options include:

- reduce the feed rate of the sewage sludge,
- improve efficiency of air pollution control equipment (a stack test would have to be conducted to demonstrate the improvement),
- change parameters that would improve pollutant dispersion, such as stack temperature, stack exit velocity, or stack height (modeling studies would have to be performed again), and
- optimize furnace operation (retesting would be required).

New Source Performance Standards (NSPS) for Sewage Treatment Plants, 40 CFR, Part 60.150

Part 60, Subpart 150 of the NSPS regulations is applicable to sewage sludge incinerators built or modified after June 11, 1973. This regulation has not been modified since the 1970's, but changes in the regulation are expected later in the decade.

The only emission limitation of NSPS is for particulate matter. Emissions cannot exceed 0.65 gm/dry kg sludge input (1.30 lb/dry ton). Opacity from the stack cannot exceed 20 percent. The regulation contains several monitoring requirements. For a multiple hearth incinerator, the following parameters must be continually recorded:

- sludge feed rate,
- pressure drop across a wet scrubber,
- oxygen content of the exhaust stream (upstream of any source of dilution air),
- temperature at each hearth (minimum of one thermocouple in the drying and cooling zone and two thermocouples in the combustion zone), and
- fuel flow to each incinerator.

NSPS also requires that a grab sample of the sludge being fed to the incinerator be taken daily and analyzed to determine dry sludge content and volatile solids content. Grab samples must be easily obtainable by enforcement personnel.

Incinerators with particulate matter emission rates of 0.38 gm/dry kg sludge (0.75 lb/dry ton) or less are exempt from all of the monitoring requirements stated above.

National Emission Standards for Hazardous Air Pollutants (NESHAP), 40 CFR Part 61, Subparts C and E

Subparts C and E of NESHAP contain emission limits for beryllium and mercury based upon health standards. These limitations are worked into the equations for calculating sludge limits of the Part 503 regulations, and were discussed previously.

Prevention of Significant Deterioration (PSD), 40 CFR, Part 52.21

The federal PSD regulations were written to limit increases in emissions of pollutants in areas which are in attainment with state and federal standards so that attainment status is not jeopardized. PSD applies to major sources only, defined for sewage sludge incinerators as potentially emitting 250 tons per year (227 Mg per year) or more of any pollutant regulated under the Clean Air Act. The potentially applicable pollutants and their current maximum allowable (*de minimis*) increases are listed in the following table.

Pollutant	Current Maximum Allowable Increase in Emissions, tons per year (Mg per year)
Carbon Monoxide	100 (91)
Nitrogen Oxides	40 (36.3)
Sulfur Oxides	40 (36.3)
Volatile Organic Compounds	40 (36.3)
Particulate Matter (under 10 microns)	15 (13.6)
Lead	0.6 (0.54)
Mercury	0.1 (0.091)
Beryllium	0.0004 (0.00036)
Sulfuric Acid	7 (6.4)

If emissions of a pollutant are projected to exceed the *de minimis* limits, that pollutant must be controlled by the Best Available Control Technology (BACT). This is the most stringent control technology available, taking into consideration environmental, economic, and energy factors. In addition, an impacts analysis with site-specific air dispersion modeling is also required to demonstrate that impacts will not exceed certain levels.

EFFECT OF FURNACE OPERATING PARAMETERS

Emissions data from various tests of sewage sludge incinerators have been studied to determine the effect of fur-

nace operating parameters on emissions of THC, heavy metals, and particulate matter.

Particulate emissions are an important consideration in evaluating compliance with Part 503 regulations, since the results of this study indicate that control of fine particulates (less than 1 micron) is imperative to the reduction of heavy metals from the exit gas stream. Most heavy metals contained in sewage sludge are vaporized at the high incineration temperatures, and are emitted either in the volatile state, or if condensation has occurred, attached to particulate matter. Heavy metals tend to condense onto fine particulates because of the relatively large surface area available.

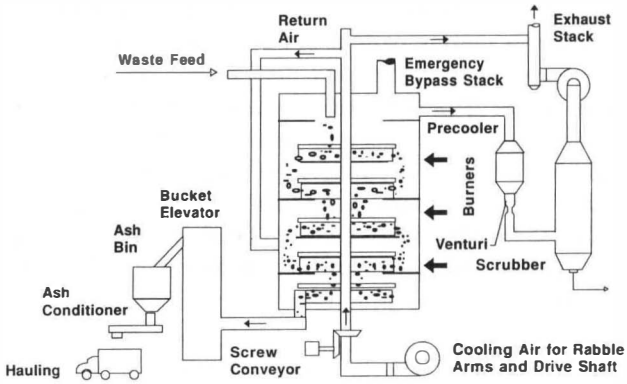

FIG. 1. TYPICAL MULTIPLE HEARTH FURNACE

Furnace Type

Emissions from two furnace types are discussed; multiple hearth and fluid bed. Since the majority of operating incinerators within the U.S. are multiple hearth units, the majority of data has been collected from such installations. A description of the two furnace types follows:

The multiple hearth furnace (MHF) consists of a cylindrical refractory lined steel shell housing a series of solid hearths, one above the other. A typical MHF system is shown in Figure 1. A hollow, vertical shaft passes through the center of the furnace. Rabble arms are attached to the center shaft above each hearth, and the entire shaft/arm arrangement rotates at approximately one rpm. Sludge is fed to the top hearth of the furnace, and passes down through each successive hearth. Teeth attached to the rabble arms move the sludge through the furnace, continuously exposing fresh surface area. On alternate hearths, the sludge moves from the periphery to the center, where it falls through an annular opening around the center shaft to the hearth below. On the hearth below, the teeth direct the sludge toward the periphery, where it falls through a series of openings around the hearth perimeter to the next hearth. Combustion air enters at the bottom of the furnace, and flue gas exits the top hearth at a temperature normally in the range of 600°F to 1000°F (589°K to 811°K). Cooling air passes through the center shaft and through each rabble arm, and is then discharged through the top of the shaft at 200°F to 450°F (366°K to 505°K). This hot air is sometimes reused as preheated combustion air or for steam plume suppression. The hearths are divided into three process zones. The top hearths are the drying zone, where moisture is evaporated from the sludge. The center hearths are the combustion zone, where the temperature can range from 1400°F to 1800°F (1033°K to 1255°K). Burn-out of ash occurs in the final cooling zone, consisting of the bottom hearths.

A fluid bed incinerator consists of a cylindrical refractory-lined shell containing a bed of sand, as illustrated in Figure 2. Pressurized combustion air (3.5 to 5.5

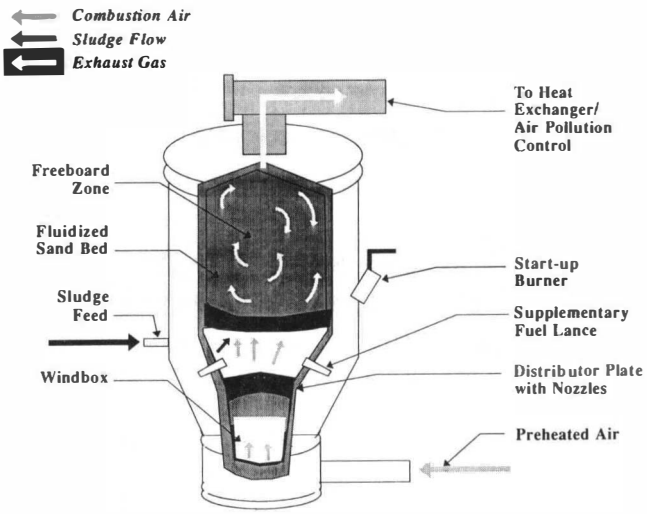

FIG. 2. FLUIDIZED BED SLUDGE INCINERATOR

psig/24,132 to 37,921 N/m^2) is introduced through openings (tuyeres) in the grid supporting the sand. Sludge cake is injected into the bed, where turbulence maximizes contact with air and ensures complete combustion with a low level of excess air. The fluidizing sand enhances heat transfer rates, further contributing to the combustion efficiency. Operating temperatures range from 1200°F to 1600°F (922°K to 1144°K).

THC Emissions. Because of the improved mixing and higher temperatures in fluid bed sewage sludge incinerators, these furnace types are more likely than multiple hearth units to comply with Part 503 THC limits. USEPA studies (Segall, et al., 1992; Chehaske, et al., 1991) found that THC emissions were significantly lower at a fluid bed installation than at the multiple hearth installations tested. Fluid bed furnaces provide a highly turbulent combustion environment, typically operate with exhaust temperatures in excess of 1400°F (1033°K), and

have THC emissions less than 10 ppmdv as propane at seven percent O_2.

Combustion within multiple hearth furnaces is inherently unstable, with relatively small variations in operating parameters, such as sludge feed rate, heating value, and moisture content causing significant variations in THC emissions. According to the data studied, multiple hearth furnaces operated conventionally with exhaust temperatures in the range of 700°F to 800°F (644°K to 700°K) typically have THC emissions exceeding 100 ppmdv. Multiple hearth furnaces often operate with less than perfect mixing in the combustion zones. The result of inadequate mixing is the formation of oxygen depleted pyrolysis pockets and low temperature quench pockets, thus leading to incomplete combustion. Typical operation of multiple hearth furnaces has resulted in wide variations in measured THC emissions. Emissions tests (Radian Corporation, 1989) on one multiple hearth furnace showed the THC emissions to range from 2 to 261 ppmdv.

Trace Metal Emissions. Available test data on metal emissions did not indicate notable variations in emission rates from fluid bed and multiple hearth furnaces.

Particulate Emissions. A significant amount of particulate matter is typically present in the flue gas exiting a fluid bed furnace, since all ash generated within the bed, along with some entrained sand, will exit through the furnace exhaust breeching. The ash generated within multiple hearth furnaces follows a different path from the exhaust gas (mostly dropping out at the bottom hearth), therefore, uncontrolled particulate emissions are significantly lower than that of fluid beds.

Operating Temperature, Turbulence

THC Emissions. By increasing turbulence, raising hearth temperatures, and operating with excess oxygen, combustion efficiency should improve, thus lowering THC emissions. Testing of one multiple hearth unit (Chehaske, et al., 1992) included furnace optimization by adding turbulence within the hearths, and by adding auxiliary fuel above the combustion hearths. Firing was done above the combustion hearths to avoid increased emissions of metals. During a 5-hour run under these conditions, the THC concentration was less than 30 ppmdv, a reduction from an average of about 90 ppmdv (as propane, corrected to seven percent O_2) during normal operation. During testing (Segall, et al., 1992) of a multiple hearth furnace under "improved combustion" conditions (higher hearth temperatures and excess oxygen), the THC concentrations were reduced by about 75%.

Trace Metal Emissions. Because of their low melting point and volatilization temperatures, arsenic, cadmium, mercury, and lead compounds tend to vaporize when incinerated. Metals in the vapor state are difficult to remove from the exhaust gas. The data studied (from the references) indicated lead emissions to be most temperature dependent, with emissions of the other metals showing, in most cases, little or no correlation to furnace temperature.

Steady State vs. Transient Operation

Most existing emissions data has been collected under relatively steady state furnace operation at optimum conditions, even though normal long-term operation is actually a combination of steady state and transient operations. Transients may be caused by feed rate changes, feed composition changes, or any other change or minor equipment malfunction during continued operation of the incinerator.

Various studies (Chehaske, et al., 1991; Hentz, et al., 1992; Knisley, et al., 1989; Vancil, et al., 1990) showed THC emission spikes as much as two orders of magnitude above normal operations during an incinerator upset, or when variations in the sludge feed occurred.

Of two test programs where transient operation was considered (Knisley, et al., 1989; Vancil, et al., 1990), results indicated slightly higher emission rates for arsenic, cadmium and lead (the more volatile metals) under transient operation. However, based on statistical tests, the increases in emissions were not significant. Emissions of beryllium, chromium and nickel were generally similar for both steady state and transient operations. From the limited data available, no significant difference in long-term, average metal emissions appears to exist between transient and steady state operation.

POLLUTION CONTROL EQUIPMENT

In order to comply with Part 503 regulations, it may be necessary to improve the system's control efficiency for certain pollutants. Most metal emissions will appear in the exhaust gas either in the vapor state or as fine particulate. Removal of heavy metals is most effectively accomplished by a two stage process. In the first stage, the volatilized metals are condensed onto fine particulate. In the second stage, the metal enriched fine particulate is collected. For sewage sludge incinerators, wet scrubbers are common devices for controlling particulate and metals emissions, while an afterburner is common for reducing THC emissions. Electrostatic precipitators (ESPs) are gaining popularity as a means of enhancing fine particulate collection. Each of these devices is described below. Alternate technologies, some of which have been used extensively to reduce emissions from other types of incinerators, are now emerging. Because of their limited history of use in conjunction with the incineration of sewage sludge, they will not be discussed.

Wet Scrubbers

Existing installations of sewage sludge incinerators typically include a venturi-type scrubber followed by an impingement tray tower to reduce emission rates of air pollutants. As the pressure drop across the venturi increases, kinetic energy increases, thus increasing the device's particulate collection efficiency. A quench section may precede the venturi to precool the exhaust gases, and a mist eliminator should follow the impingement tray tower to reduce the escape of free water droplets. Wet scrubbers are well suited to wastewater treatment plants, since the plant effluent can be used as the scrubbant and returned to the head of the plant after use.

THC Emissions. The use of wet scrubbers are not recommended as a means of THC emissions reduction, because many hydrocarbon species are insoluble in water. THC removal efficiencies by wet scrubber have been measured (Incinerator Rx Corporation, 1991), ranging from 3% to 31%.

Trace Metal Emissions. Several studies (Radian Corporation, 1989; Palazzolo, et al., 1988; Hentz, et al., 1992; Adams, et al., 1987) have considered the metal concentration in the flue gas particulate collected at the scrubber inlet and outlet. Test data showed the metal concentration in the particulate to be higher at the exit of the wet scrubber than at the entrance.

Hentz, et al. (1992) found that, following a multiple hearth, over one half the particulate mass leaving the wet scrubber was less than 0.6 microns in diameter. Analysis indicated that these submicron particles were enriched with volatile metals (cadmium, arsenic and lead). Approximately 70 percent of the metals leaving the wet scrubber were in the form of fine particulate of less than 0.3 microns in diameter. It was postulated that most volatilized metals condense within the wet scrubbers as small submicron particles. These submicron particles are not effectively removed by impact scrubbers, such as venturis or impingement towers.

Scrubber control efficiencies for metals were found to be higher following a fluid bed than following a multiple hearth. It has been postulated that the large amounts of inert material discharged from a fluid bed may provide sites for condensation of volatile metals within the wet scrubber, allowing their removal with larger particles (Segall, et al., 1992). Considering the six metals for which data was readily available (all Part 503-regulated metals, with the exception of mercury), the data showed wet scrubber control efficiencies greater than 99.5 percent downstream of a fluid bed. The data reviewed (from the references) exhibit a range of wet scrubber efficiencies following multiple hearth furnaces, generally below 99 percent.

Particulate Emissions. The venturi scrubber's particulate removal efficiency increases with the pressure drop across the unit, and decreases with particulate size. While wet scrubbers have proven effective in removing particulate matter greater than 2 microns in diameter, they are not effective in collecting finer particulate. Wet scrubbers require a large expenditure of energy to achieve a high removal efficiency for particles with diameters less than 2 to 3 microns, primarily due to decreased effectiveness of inertial mechanisms for separating very small particles from a gas stream. A summary of measured particle size distributions in the exhaust gas leaving the furnace and the wet scrubber is given in Table 1. The data shows that, as the gas flows through the wet scrubber, particles greater than 1 micron are collected, driving up the weight percentage of small particles.

TABLE 1 SEWAGE SLUDGE INCINERATOR EMISSIONS — PARTICULATE SIZE DISTRIBUTION

Ref.	Incinerator Type	APC	APC Pres. Drop, in. W.C. (N/m³)	Special Conditions	Wt. % of Particles Leaving Furnace < 10 μm	< 1 μm
MEASURED AT FURNACE EXIT						
4	MH 6 Hearths	Precooler/ Venturi Impingement Tray	20 (4977)	"Normal" - Cool Furn., AB off	< 25%	—
7	MH 11 Hearths	Multi-cyclone/ Waste Heat Boiler /Wet Scrubber *	—	—	60%	< 5%
9	MH 8 Hearths	Precooler/ Venturi/ Impingement Tray	25 (6221)	For both steady state & transient	50%	12%
19	FB	Venturi/ Impingement Tray	20 (4977)	—	96%	0%
MEASURED AT SCRUBBER EXIT						
4	MH 6 Hearths	Precooler/ Venturi/ Impingement Tray	20 (4977)	"Normal" - Cool Furn., AB off	—	53%
4	MH 6 Hearths	Precooler/ Venturi/ Impingement Tray	20 (4977)	Hot Furnace, AB off	—	87%
7	MH 11 Hearths	Multi-cyclone/ Waste Heat Boiler /Wet Scrubber *	—	—	—	75%
12	MH 11 Hearths	Venturi/ Impingement Tray	—	—	> 80%	—
17	MH 7 Hearths	Venturi/ Impingement Tray	30 (7465)	Zero-Hearth AB @ 1400°F	—	95%
20	FB	Venturi/ Impingement Tray	20 (4977)	—	> 99%	75%

* *Unique Wet Scrubber consisting of pre-quench, medusa, and elbair sections.*

Electrostatic Precipitators

Electrostatic Precipitators (ESPs) operate by conferring a charge on suspended particles and gas molecules through intense electric fields caused by high voltage discharge electrodes. The negatively charged matter is attracted to the positively charged collection plates. ESPs may be operated in the wet or dry mode. Dry ESPs are cleaned by a hammer mechanism which periodically raps the collection plates, dislodging the layer of particulates which has built up. Wet ESPs (WESPs) provide a constant film of water over the collection tubes to wash down captured material. WESPs are well suited to sewage sludge incin-

erators because of the moist nature of the exhaust gas and the availability of wastewater treatment.

THC Emissions. As with wet scrubbers, the use of WESPs is not recommended as a means of THC control, due to the fact that many hydrocarbon species are insoluble in water and are too stable to be charged. Tests have shown a reduction in THC emissions of approximately 50% across the WESP, probably as a result of the removal of organics bound to particulate matter (Adams, et al., 1987; Hentz, et al., 1992).

Trace Metal Emissions. The data studied showed that the ESP/WESP, while demonstrating relatively high efficiencies for all metals measured, consistently displayed higher collection efficiencies for the more volatile metals cadmium and lead (Carlson Associates, 1989; Hentz, et al., 1992; NETCO, 1990; Adams, et al., 1987). Cadmium and lead tend to vaporize when incinerated, and would condense and concentrate in the fine fraction of the particulates within the wet scrubber. Given this, the ESP would appear to be more effective in reducing fine particulate emissions less than one micron in diameter.

Particulate Emissions. The addition of an ESP/WESP following a wet scrubber system will increase the particulate control efficiency without expending significant excess energy. Within the wet scrubber, larger particulate matter is removed, and volatile metals are condensed onto smaller particles. Much of the submicron particulates are then removed in the ESP. Testing showed that a pilot scale dry ESP removed 98.7% of particulates less than 1 micron in diameter, while the wet scrubber removed 69.0% of that particulate size. At the same time, the wet scrubber was found to be more efficient at removing larger particles; the wet scrubber removed 99.8% of particulate greater than 10 microns in diameter, while the ESP removed only 97% of the particulate in this size range (Adams, et al., 1987). Both the wet scrubber and the ESP were found to remove virtually all particulate in the 1 to 10 micron range. The data presented in Table 2 shows ESP removal efficiencies ranging from 78% to over 98%. Measured particulate loadings at the outlets of systems consisting of a wet scrubber followed by a WESP were well within the NSPS limits, ranging from 0.001 to 0.055 kg/Mg dry sludge. WESPs are preferred over ESPs for sewage sludge incinerators.

Dry Scrubbers

"Dry"-type scrubbers, consisting of alkali treatment, such as a spray dryer absorber or lime injection followed by a baghouse, historically have not been used in sewage sludge incineration applications. The moist nature of the exhaust gas would tend to cause problems, such as formation of a muddy "cake" on the bags. Use of dry scrubbers should be limited to systems where the sludge has been dried to a high solids content (i.e., 90% or better) prior to incineration.

TABLE 2 SEWAGE SLUDGE INCINERATOR EMISSIONS—PARTICULATE MATTER

Ref	Incin. Type *	APC **	APC Pres. Drop, in. W.C. (N/m²)	Special Conditions	TOTAL PARTICULATE APC INLET (kg/Mg dry sludge)	TOTAL PARTICULATE APC OUTLET (kg/Mg dry sludge)	%Removal
2	MH	V/IT	—	"Normal" Furn. Op.	18.670	0.280	98.50%
2	MH	V/IT	—	Low CO Furn. Op.	16.250	0.390	97.60%
2	FB	V/IT	—	—	100.000	0.010	99.99%
2	FB	V/IT/PS WESP	—	Inlet @ WESP	0.010	0.002	78.00%
2 (Site 9)	MH	V/IT	—	"Normal" Furn. Op.	1.400	0.210	85.00%
2 (Site 9)	MH	V/IT	—	Low CO Furn. Op.	6.200	0.310	95.00%
2 (Site 9)	MH	V/IT	—	Low CO Furn. Op. Inlet @ WESP	0.310	0.040	87.00%
4	MH	P/V/IT/AB	20 (4977)	"Normal" - Cool Furn., AB off	43.300	1.240	97.14%
4	MH	P/V/IT/AB	20 (4977)	Hot Furn., AB on	184.000	0.550	99.70%
4	MH	P/V/IT	20 (4977)	Hot Furn., AB on	—	1.250	—
6	MH	V/IT/AB	30 (7465)	AB @ 1400°F	—	0.253	—
6	MH	V/IT/AB/PS WESP	30 (7465)	AB @ 1400°F, inlet @ WESP	0.065	0.001	98.27%
6	MH	V/IT/AB	30 (7465)	AB @ 1400°F	—	0.220	—
8	MH	IT	11 (2737)	Steady State	—	3.180	—
8	MH	IT	11 (2737)	Transient	—	2.630	—
9	MH	P/V/IT	25 (6221)	Steady State	8.500	0.410	95.18%
9	MH	P/V/IT	25 (6221)	Transient	8.400	0.380	95.48%
11	MH	2-C/V/IT	20 (4977)	—	16.400	0.318	98.06%
11	MH	PS ESP	0 (0)	—	19.700	0.309	98.43%
12	MH	V/IT/PS WESP	—	Inlet @ WESP	—	—	92.65%
13	MH	V(?)/IT	—	—	8.228	0.472	94.26%
13	MH	V(?)/IT/ WESP	—	Inlet @ WESP	0.472	0.055	88.46%
16	FB	V/IT	20 (4977)	—	—	0.396	—
18	FB	V/IT	20 (4977)	—	—	0.330	—
20	FB	V/IT	20 (4977)	—	—	0.530	—

* *MH = Multiple Hearth, FB = Fluid Bed.*
** *P = Precooler, V = Venturi, IT = Impingement tray-tower, C = Cyclone, PS = Pilot-Scale, AB = Afterburner.*

Afterburners

Some multiple hearth furnaces may require either an external or a zero-hearth afterburner to reduce THC emissions. An external afterburner is a separate combustion chamber through which the exhaust gas passes after leaving the furnace. The afterburner raises the temperature of the exhaust above the auto-ignition temperature of most hydrocarbon compounds, destroying THCs. A multiple hearth furnace may be retrofitted with a zero-hearth afterburner by rerouting the introduction of sludge from the top hearth to the hearth directly below, and installing burners at the top hearth. Retrofitting a furnace with an afterburner may necessitate modification to the downstream air pollution control and gas handling equipment to deal with the higher temperature and larger volume of exhaust gas.

The test results studied show that THC emissions decrease rapidly beginning at a furnace exit temperature of approximately 900°F (755°K) and continuing to approximately 1200°F (922°K). THC emissions were found to

vary dramatically while operating with a top hearth temperature maintained at less than 900°F (755°K), while THC levels remained relatively steady during testing with a top hearth temperature exceeding 1250°F (950°K). Even with an afterburner, there may still be excursions in THC emissions, due to the inherent unstable combustion conditions within a multiple hearth furnace. Zero-hearth afterburners may not offer the adequate gas mixing and retention time necessary for efficient reduction of THC emissions. Since the Part 503 THC limit is based on a one-month average, momentary excursions are not likely to affect compliance. Such systems, however, may have difficulty demonstrating compliance if located within EPA regions with stricter measurement requirements (i.e., EPA Region V).

Compliance at lower afterburner temperatures would probably be achievable if the gas phase turbulence within the hearths were increased, although exact modifications necessary to achieve this have not been fully developed by industry. One proprietary method for improving mixing within the hearths involves the addition of high velocity mixing jets. Turbulence may also be achieved by adjusting the burners to burn lean, thus maximizing the air flow rate through the furnace.

TWO CASE STUDIES

Emissions of Part 503-regulated metals and hydrocarbons from two sewage sludge incineration plants have been compiled. One plant operates a modern fluidized bed incinerator, and is located in a valley and relatively close to nearby residents. The second plant is located on flat terrain in a sparsely populated area, and operates three older multiple hearth incinerators which exhaust through a common stack. The data illustrates the impact of Part 503 on two very different plants.

Northwest Bergen County Utilities Authority, Waldwick, N.J.

The Northwest Bergen County Utilities Authority (NBCUA) operates a municipal wastewater treatment plant in Waldwick, N.J. Municipal sewage sludge generated at this plant is incinerated in a single existing fluidized bed incinerator at a rate of approximately 2000 dry lb/hr (907 dry kg/hr). The solids content of the sludge ranges from 22 to 28 percent. No. 2 fuel oil is co-combusted to maintain a freeboard temperature of 1500°F to 1650°F (1089°K to 1172°K). The exhaust gas passes through a tubular heat exchanger to preheat combustion air prior to entering a venturi/impingement tray tower with a total pressure drop of approximately 26 inches W.C. (6470 N/m^2). The exhaust from the incinerator exits from a stack 75 feet (22.86 meters) above grade. NBCUA is currently permitted by the New Jersey Department of Environmental Protection and Energy (NJDEPE), which set permit conditions in response to a risk analysis they conducted in order to meet a 1 in 100,000 cancer rate risk. Stack testing and simultaneous sludge sampling and analysis were performed shortly after startup of the incinerator during March and April of 1989.

Frank E. VanLare Water Pollution Control Plant, Rochester, N.Y.

The Monroe County Department of Environmental Services operates the Frank E. VanLare Water Pollution Control Plant (Van Lare). Sewage sludge generated at this plant is incinerated in any of three existing Nichols multiple hearth incinerators. Two of the furnaces are identical 11-hearth units with a maximum process rate of approximately 5000 lb/hr (2268 kg/hr) of dry sludge. The third furnace consists of 6 hearths and has a maximum process rate of approximately 2700 lb/hr (1225 kg/hr) dry sludge. The furnaces currently incinerate an average of about 65 short tons (59,000 kg) of dry sewage sludge per day, with an average solids content of approximately 20 percent. The top hearth on each of the three units has been converted to a zero-hearth afterburner. Each furnace is capable of utilizing either No. 2 fuel oil or natural gas as auxiliary fuel. Air pollution control equipment for each MHF consists of a quench section followed by a low pressure venturi (approximately 5-inches W.C./1244 N/m^2), and an impingement tray section. Once through the air pollution control equipment, the exhaust gas from all three units passes through a common exhaust stack, 175 feet (53.3 meters) above grade. The furnaces operate under an Air Certificate to Operate issued by the NYSDEC. Stack testing and simultaneous sludge sampling and analysis of one of the 11-hearth units was performed in May of 1993.

THC Emissions

THC emissions at the NBCUA incinerator were measured during three one-hour test runs in 1989. The average of the three measurements was 5.72 ppmdv at 7 percent O_2 (as propane), which is well below the Part 503 limit. Spikes of high THC concentrations were not observed. THC concentrations at NBCUA are typical of combustion-efficient fluidized bed furnaces.

THC emissions for each of three afterburner temperatures; 1100°F (866°K), 1200°F (922°K), and 1300°F (978°K), ± about 50°F (27.8°K) were measured at the furnace exit duct and at the stack at the Van Lare plant. The THC concentrations at the stack, for each of three runs (over two hours per run) are shown in Table 3. Hourly measurements of THC emissions at the stack versus afterburner temperature at the Van Lare Plant are shown graphically in Figure 3. The plot indicates that the relationship between THC emissions and afterburner temperature is not linear, with emissions dropping off rapidly

TABLE 3 THC EMISSIONS TESTING AT VAN LARE PLANT

Run	THC ppmdv @ 7% O, as propane
1100°F (866°K)	
#1	34.43
#2	102.54
#3	35.84
Average	57.60
1200°F (922°K)	
#1	16.58
#2	15.79
#3	16.13
Average	16.16
1300°F (978°K)	
#1	18.32
#2	26.08
#3	11.02
Average	18.47

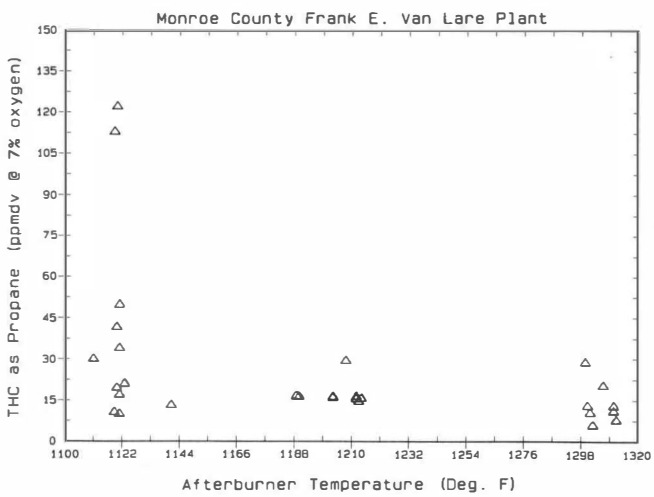

FIG. 3. THC VS. AB TEMPERATURE

when the afterburner temperature exceeds about 1120°F (878°K). At afterburner temperatures below about 1120°F (878°K), THC emissions at the stack exceeded 100 ppmdv at 7 percent oxygen during two hours of data collection. With the afterburner temperature at or above 1200°F (922°K), variation in THC emissions is low, with measurements typically below about 20 ppmdv as propane at 7 percent oxygen. This characteristic of THC emissions at Van Lare supports observations made from earlier test data in the references. As the afterburner temperature is increased, THC emissions show a slight increase, which is normally unexpected. This increase in THC emissions at the higher temperature may be due, in part, to an increase in natural gas use to maintain the afterburner at higher temperatures, with the burner not properly "tuned" or optimized. Another possibility is that the volume within the zero hearth is not large enough to allow sufficient gas retention, to achieve complete combustion.

TABLE 4 RESULTS OF 1989 SIMULTANEOUS SLUDGE AND STACK TESTING FOR METALS AT NBCUA

Pollutant	Metal Concentration in Sludge, mg/dry kg	Metal Inlet Rate, lb/hr (kg/hr)	Metal Emission Rate, lb/hr (kg/hr)	CE
Mercury	3.14	6.83×10^{-3} (3.10×10^{-3})	*no data*	*no data*
Beryllium	*no data*	*no data*	*no data*	*no data*
Lead	79.8	0.173 (0.078)	1.03×10^{-3} (4.67×10^{-4})	99.40%
Arsenic	1.18	2.57×10^{-3} (1.17×10^{-3})	1.26×10^{-4} (5.72×10^{-5})	99.95%
Cadmium	2.32	5.05×10^{-3} (2.29×10^{-3})	8.1×10^{-5} (3.67×10^{-5})	98.40%
Total Chromium	12.6	0.0274 (0.0124)	5.4×10^{-4} (2.45×10^{-3})	99.80%
Nickel	18.00	0.0392 (0.0178)	5.4×10^{-4} (2.45×10^{-4})	99.86%

Trace Metal Emissions

Metal concentrations, emissions, and control efficiencies at NBCUA are shown in Table 4. Data presented are averages of three test runs. Measurements of mercury and beryllium in the stack were not performed during 1989 testing at NBCUA. Control efficiencies for the remaining Part 503-regulated metals in the NBCUA incinerator system were 98% or greater.

The mercury concentration in the sludge at NBCUA was measured at 3.14 mg/dry kg. Even if the air pollution control equipment does not remove mercury from the flue gas, at the maximum daily sludge throughput of 2000 dry lb/hr (907 dry kg/hr), mercury emissions (68 gm/day) would still be less than the NESHAP limit of 3,200 mg/day. Even the highest concentration recorded in the last year (10.60 mg/dry kg) would not result in excessive emissions.

Sludge samples were not analyzed for beryllium during 1989 testing at NBCUA. Generally, beryllium concentrations are non-detectible, however, on one occasion over the last year, the beryllium concentration in the sludge was measured to be 0.97 mg/kg. To meet the NESHAP requirement of less than 10 gm/day beryllium emissions, a control efficiency of at least 53% is required. Information regarding the control efficiencies of the other metals measured during 1989 testing can be extrapolated to approximate the control efficiency for beryllium. For example, cadmium is much more volatile than beryllium and, therefore, more difficult to control. The 1989 tests show a removal efficiency for cadmium of 98.4%. Therefore, it is reasonable to presume a control efficiency in excess of 98.4% for beryllium.

Measurements of metals in the incoming sludge, emission rates, and control efficiencies at the Van Lare facility are shown in Table 5. The data shows no relationship between metal emissions and afterburner temperature. The results are not surprising, since volatilization of metals is most likely to occur during combustion, prior to the afterburner.

The data in Table 5 demonstrates that beryllium emissions during testing (less than 1 gm/day) were well within

TABLE 5 RESULTS OF 1993 PART 503 METALS-SLUDGE AND EMISSIONS TESTING AT VAN LARE

Pollutant	Metal Concentration in Sludge, mg/dry kg	Metal Inlet Rate, lb/hr (kg/hr)	Metal Emission Rate, lb/hr (kg/hr)	CE
1100°F (866°K)				
Mercury	1.16	5.10×10^{-3} (2.31×10^{-3})	6.47×10^{-3} (2.93×10^{-3})	0%
Beryllium	0.19	8.36×10^{-4} (3.79×10^{-4})	< 2.90×10^{-3} (< 1.32×10^{-3}) [*]	> 96.5%
Lead	129.7	0.571 (0.259)	0.0151 (0.00685)	97.4%
Arsenic	3.08	0.0135 (0.00612)	0.00136 (0.000617)	89.9%
Cadmium	7.85	0.0345 (0.0156)	0.00448 (0.00203)	87.0%
Total Chromium	68.9	0.303 (0.137)	0.00105 (0.000476)	99.7%
Nickel	40.3	0.177 (0.0803)	5.88×10^{-4} (2.67×10^{-4})	99.7%
1200°F (922°K)				
Mercury	1.56	6.30×10^{-3} (2.86×10^{-3})	7.03×10^{-3} (3.19×10^{-3})	0%
Beryllium	0.199	8.04×10^{-4} (3.65×10^{-4})	< 3.21×10^{-3} (< 1.46×10^{-3}) [*]	> 96.0%
Lead	147.0	0.594 (0.269)	0.00874 (0.00396)	98.5%
Arsenic	3.58	0.0145 (0.00658)	0.00111 (0.000503)	92.3%
Cadmium	9.51	0.0384 (0.0174)	0.00366 (0.00166)	90.5%
Total Chromium	75.4	0.305 (0.138)	8.60×10^{-4} (3.90×10^{-4})	99.7%
Nickel	46.7	0.189 (0.0857)	3.41×10^{-4} (1.55×10^{-4})	99.8%
1300°F (978°K)				
Mercury	1.65	6.56×10^{-3} (2.98×10^{-3})	6.55×10^{-3} (2.97×10^{-3})	0%
Beryllium	0.191	7.59×10^{-4} (3.44×10^{-4})	< 3.19×10^{-3} (< 1.45×10^{-3}) [*]	> 95.8%
Lead	129.0	0.513 (0.233)	0.00788 (0.00358)	98.5%
Arsenic	3.36	0.0134 (0.00608)	9.36×10^{-4} (4.25×10^{-4})	93.0%
Cadmium	9.46	0.0376 (0.0171)	0.00338 (0.00153)	91.0%
Total Chromium	72.7	0.289 (0.131)	8.21×10^{-4} (3.72×10^{-4})	99.7%
Nickel	43.9	0.174 (0.0789)	3.39×10^{-4} (1.54×10^{-4})	99.8%

* Not detected, despite greater than 2-hour sampling time; detection limit reported.

TABLE 6 PART 503 METAL CONCENTRATION LIMITS AND RECENT HIGHEST CONCENTRATIONS AT NBCUA

Pollutant	Pollutant Limits (mg/dry kg)	Recent Highest Concentrations (mg/dry kg)
Lead	8,735	140
Arsenic	16,072	4.58
Cadmium	1,245	4.78
Chromium	113,553	66.3
Nickel	499,135	25.9

TABLE 7 PART 503 METAL CONCENTRATION LIMITS AND RECENT HIGHEST CONCENTRATIONS AT VAN LARE

Pollutant	Pollutant Limits (mg/dry kg)	Recent Highest Concentrations (mg/dry kg)
Lead	2,789	265.7
Arsenic	110	9.0
Cadmium	212	38.0
Chromium	18,534	386.3
Nickel	322,327	132.4

the NESHAP limit of 10 gm/day. Measurements of mercury concentration in the sludge and emissions from the stack reveal that virtually all mercury entering the system is exhausted through the stack. Mercury emissions during testing were approximately 163 gm/day; significantly less than the NESHAP limit of 3,200 gm/day. Control efficiencies for the other five Part 503-regulated metals ranged from a low of 87% for cadmium to a high of 99.7% for total chromium and nickel. Cadmium has a relatively low volatilization temperature and melting point, while both chromium and nickel have relatively high volatilization temperatures and melting points.

Dispersion modeling was performed for both the NBCUA and the Van Lare plants to determine the dispersion factor (DF) from the stacks. The DF and the CE calculated from stack testing were used to calculate the maximum allowable concentrations for the five Part 503-regulated metals not limited by NESHAP. Results for the NBCUA and Van Lare plants are listed in Tables 6 and 7 respectively. These tables also list the highest concentration of each metal in the sludge, measured over a one year period (June 1992 through May 1993 at NBCUA; January 1992 through December 1992 at Van Lare).

Refined dispersion modeling for the NBCUA facility was performed, since the plant is located in a valley, and the heights of potential receptors are in some cases higher than the stack. The exit velocity of the exhaust measured during 1989 testing was 15.1 meters/second, and the temperature 60°F (289°K). The DF computed for the NBCUA facility was 11.35 $\mu g/m^3$ per gm/s. A maximum sludge throughput of 2000 dry lb/hr (907 dry kg/hr) was used in the calculations.

The exit velocity measured at the Van Lare plant was 2.26 meters/second, and the stack temperature was 110°F (316°K). The tall stack and flat terrain enabled the calculation of a very low DF; 1.27 $\mu g/m^3$ per gm/s, using only screening level modeling. A maximum sludge throughput of 12,916 dry lb/hr (5859 dry kg/hr) was used to determine the pollutant limits shown in Table 7.

Tables 6 and 7 show that, even though the DF calculated for NBCUA was considerably higher than the DF calculated for the Van Lare plant, the allowable sludge concentrations of all metals at the Van Lare plant are less than the allowable sludge concentrations at the NBCUA plant. The lower allowable sludge concentrations at Van-Lare are due to the higher rate of sludge throughput, and the lower control efficiencies for all metals.

Comparison of the Two Facilities

The two basic types of sludge incineration technologies are utilized at the NBCUA and Van Lare plants. Both plants, although operating under very different conditions, easily met the allowable trace metal emissions due to the high Part 503 allowable health risk of 10-4. Furthermore, testing at the NBCUA and Monroe County facilities

demonstrated that the THC emission limits of Part 503 can be met by both facilities.

Control efficiencies for metals at the NBCUA facility were higher than control efficiencies measured at the Van Lare facility, because the high pressure venturi scrubber at NBCUA has a greater tendency to capture fine particulates and remove greater quantities of trace metals than a standard two- or three-tray impingement tower, such the Van Lare plant utilizes.

The fluid bed's capability to maintain a highly efficient combustion process is demonstrated in the THC emissions from NBCUA, which were less than 10 ppmdv as propane at seven percent O_2. THC emissions at the Van Lare facility can be maintained below the Part 503 limit by operation of the zero hearth afterburner. Data shows that THC emissions can be reduced to below 20 ppmdv as propane at seven percent O_2 by maintaining the afterburner at a temperature of approximately 1200°F (922°K) or higher.

CONCLUSIONS

Under Part 503, performance testing of each municipal sewage sludge incinerator must be done to determine maximum combustion temperature, operating parameters for the air pollution control device, and control efficiencies for the seven metals of concern. Air dispersion modeling must be done to determine dispersion factors. The information generated from these two tasks will be used to determine if emissions from the incineration system is in compliance with Part 503 regulations. Facilities must demonstrate continuous compliance with Part 503 standards through regular sludge sampling and analysis of the 7 regulated metals, and continuous emissions monitoring of THC, O_2, and moisture in the stack.

The case studies presented demonstrate that older plants with multiple hearth furnaces, as well as modern incineration facilities are likely to comply with the Part 503 regulations. Compliance with the regulations will depend not only on the condition of the incineration and air pollution control equipment, but on the terrain surrounding the facility and the metal content of the incoming sludge.

Although most existing incinerators are expected to be capable of compliance with Part 503 emissions regulations, some units may need to be altered to meet the Part 503 requirements. For example, if the geographic location of an incineration system with an older design of air pollution control equipment (such as the Van Lare plant) were to result in a high DF (such as at the NBCUA facility), that plant might not pass the Part 503 requirements for metals. Likewise, an older multiple hearth furnace without an afterburner might not pass Part 503 requirements for THC emissions.

If the measured metal concentration in the sludge exceeds the allowable daily concentration, compliance may be achieved by: reducing the sludge feed rate to the incinerator; improving exhaust gas dispersion (raising the stack temperature and/or increasing the stack height); and/or increasing the control efficiency of the air pollution control system. In most cases, typical existing wet scrubber systems (high pressure venturi followed by an impingement tray scrubber) will accomplish both stages of metal emission control. A wet scrubber with a low pressure drop could be replaced with a high pressure drop wet scrubber, to increase removal efficiency. If further reductions of metal emission rates are necessary, a WESP can often be retrofitted to existing air pollution control systems, with minimal impact on energy use and space requirements. While emerging technologies in the control of metal emissions from sewage sludge incinerators may prove effective in achieving compliance with proposed regulations, existing operating data is limited.

Total hydrocarbon emissions from sewage sludge incinerators are a result of incomplete combustion. Due to their inherently higher combustion efficiency, fluid bed furnaces have an advantage in meeting new standards for THC emissions, compared to multiple hearth units. Increased temperatures at the furnace exit and increased turbulence within the combustion zone will improve the likelihood of multiple hearth furnaces complying with Part 503 regulations. An increase in furnace exhaust temperature may be achieved by increasing hearth temperatures, or by operation of either a zero-hearth, or an external afterburner. If hearth temperatures are increased, care must be taken to avoid raising the temperature beyond the furnace's design point. Even at elevated temperatures, occasional THC emissions spikes may occur. Given EPA Region V's requirement for three-hour rolling THC averages, data spikes may have a deleterious effect on compliance. Further research is required to develop an effective means to increase the gas-phase turbulence in the combustion hearths of MHFs.

A facility's approach to meeting the Part 503 regulations should take into consideration potential future federal regulations (as well as state and local requirements). Upgrades in air pollution control equipment should be made to obtain control efficiencies, or to allow upgrades to achieve control efficiencies, to meet anticipated requirements. If possible, the Best Available Control Technology (BACT) should be implemented when air pollution control equipment is modified or replaced.

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