

2.2 Sewage Sludge Incineration

There are approximately 170 sewage sludge incineration (SSI) plants in operation in the United States. Three main types of incinerators are used: multiple hearth, fluidized bed, and electric infrared. Some sludge is co-fired with municipal solid waste in combustors based on refuse combustion technology (see Section 2.1). Refuse co-fired with sludge in combustors based on sludge incinerating technology is limited to multiple hearth incinerators only.

Over 80 percent of the identified operating sludge incinerators are of the multiple hearth design. About 15 percent are fluidized bed combustors and 3 percent are electric. The remaining combustors co-fire refuse with sludge. Most sludge incinerators are located in the Eastern United States, though there are a significant number on the West Coast. New York has the largest number of facilities with 33. Pennsylvania and Michigan have the next-largest numbers of facilities with 21 and 19 sites, respectively.

Sewage sludge incinerator emissions are currently regulated under 40 CFR Part 60, Subpart O and 40 CFR Part 61, Subparts C and E. Subpart O in Part 60 establishes a New Source Performance Standard for particulate matter. Subparts C and E of Part 61--National Emission Standards for Hazardous Air Pollutants (NESHAP)--establish emission limits for beryllium and mercury, respectively.

In 1989, technical standards for the use and disposal of sewage sludge were proposed as 40 CFR Part 503, under authority of Section 405 of the Clean Water Act. Subpart G of this proposed Part 503 proposes to establish national emission limits for arsenic, beryllium, cadmium, chromium, lead, mercury, nickel, and total hydrocarbons from sewage sludge incinerators. The proposed limits for mercury and beryllium are based on the assumptions used in developing the NESHAPs for these pollutants, and no additional controls were proposed to be required. Carbon monoxide emissions were examined, but no limit was proposed.

2.2.1 Process Description^{1,2}

Types of incineration described in this section include:

- Multiple hearth,
- Fluidized bed, and
- Electric.

Single hearth cyclone, rotary kiln, and wet air oxidation are also briefly discussed.

2.2.1.1 Multiple Hearth Furnaces -

The multiple hearth furnace was originally developed for mineral ore roasting nearly a century ago. The air-cooled variation has been used to incinerate sewage sludge since the 1930s. A cross-sectional diagram of a typical multiple hearth furnace is shown in Figure 2.2-1. The basic multiple hearth furnace (MHF) is a vertically oriented cylinder. The outer shell is constructed of steel, lined with refractory, and surrounds a series of horizontal refractory hearths. A hollow cast iron rotating shaft runs through the center of the hearths. Cooling air is introduced into the shaft which extend

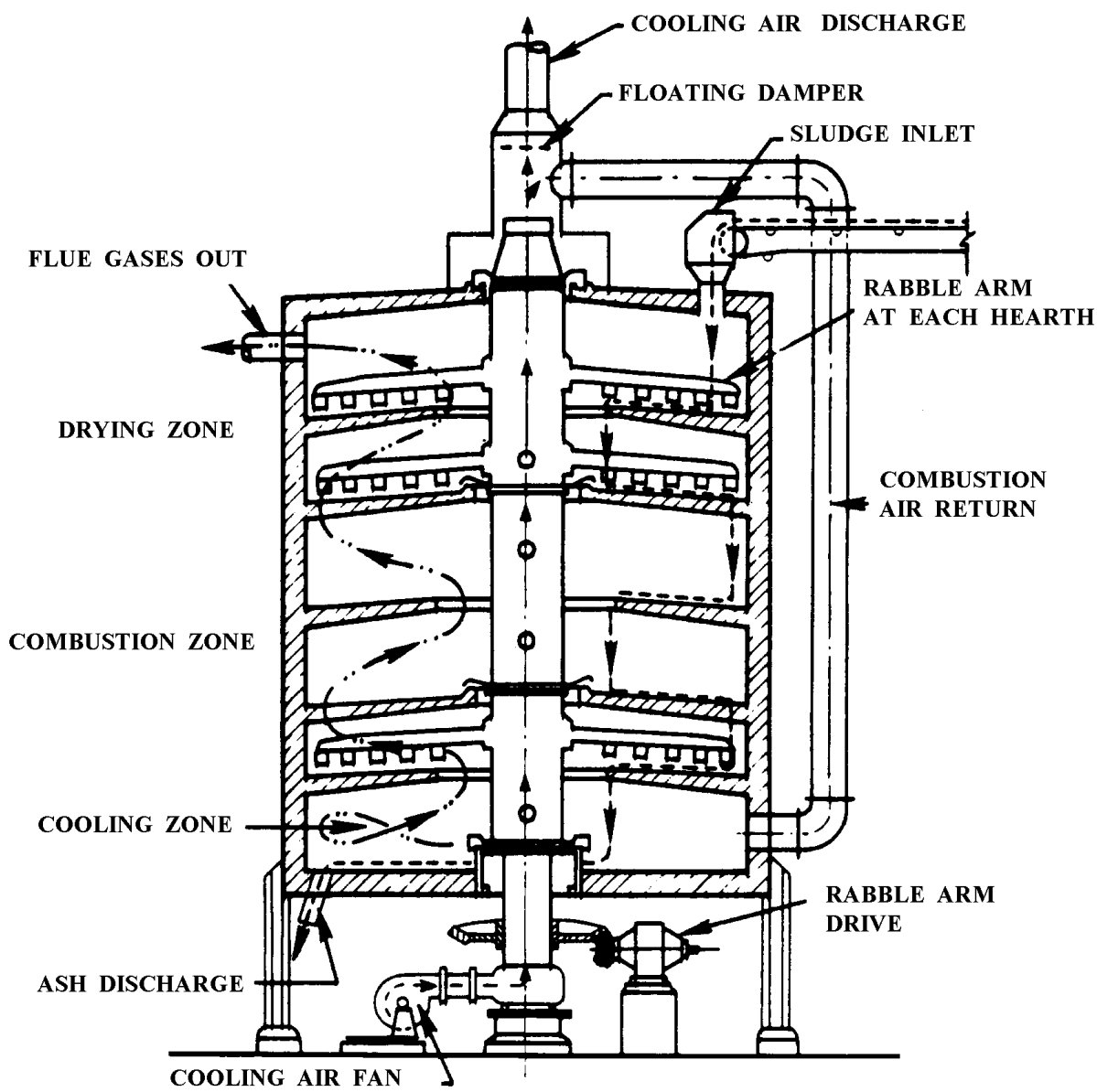


Figure 2.2-1. Cross Section of a Multiple Hearth Furnace

above the hearths. Each rabble arm is equipped with a number of teeth, approximately 6 inches in length, and spaced about 10 inches apart. The teeth are shaped to rake the sludge in a spiral motion, alternating in direction from the outside in, to the inside out, between hearths. Typically, the upper and lower hearths are fitted with four rabble arms, and the middle hearths are fitted with two. Burners, providing auxiliary heat, are located in the sidewalls of the hearths.

In most multiple hearth furnaces, partially dewatered sludge is fed onto the perimeter of the top hearth. The rabble arms move the sludge through the incinerator by raking the sludge toward the center shaft where it drops through holes located at the center of the hearth. In the next hearth the sludge is raked in the opposite direction. This process is repeated in all of the subsequent hearths. The effect of the rabble motion is to break up solid material to allow better surface contact with heat and oxygen. A sludge depth of about 1 inch is maintained in each hearth at the design sludge flow rate.

Scum may also be fed to one or more hearths of the incinerator. Scum is the material that floats on wastewater. It is generally composed of vegetable and mineral oils, grease, hair, waxes, fats, and other materials that will float. Scum may be removed from many treatment units including preaeration tanks, skimming tanks, and sedimentation tanks. Quantities of scum are generally small compared to those of other wastewater solids.

Ambient air is first ducted through the central shaft and its associated rabble arms. A portion, or all, of this air is then taken from the top of the shaft and recirculated into the lowermost hearth as preheated combustion air. Shaft cooling air which is not circulated back into the furnace is ducted into the stack downstream of the air pollution control devices. The combustion air flows upward through the drop holes in the hearths, countercurrent to the flow of the sludge, before being exhausted from the top hearth. Air enters the bottom to cool the ash. Provisions are usually made to inject ambient air directly into the middle hearths as well.

From the standpoint of the overall incineration process, multiple hearth furnaces can be divided into three zones. The upper hearths comprise the drying zone where most of the moisture in the sludge is evaporated. The temperature in the drying zone is typically between 425 and 760°C (800 and 1400°F). Sludge combustion occurs in the middle hearths (second zone) as the temperature is increased to about 925°C (1700°F). The combustion zone can be further subdivided into the upper-middle hearths where the volatile gases and solids are burned, and the lower-middle hearths where most of the fixed carbon is combusted. The third zone, made up of the lowermost hearth(s), is the cooling zone. In this zone the ash is cooled as its heat is transferred to the incoming combustion air.

Multiple hearth furnaces are sometimes operated with afterburners to further reduce odors and concentrations of unburned hydrocarbons. In afterburning, furnace exhaust gases are ducted to a chamber where they are mixed with supplemental fuel and air and completely combusted. Some incinerators have the flexibility to allow sludge to be fed to a lower hearth, thus allowing the upper hearth(s) to function essentially as an afterburner.

Under normal operating condition, 50 to 100 percent excess air must be added to an MHF in order to ensure complete combustion of the sludge. Besides enhancing contact between fuel and oxygen in the furnace, these relatively high rates of excess air are necessary to compensate for normal variations in both the organic characteristics of the sludge feed and the rate at which it enters the incinerator. When an inadequate amount of excess air is available, only partial oxidation of the carbon will occur, with a resultant increase in emissions of carbon monoxide, soot, and hydrocarbons. Too much excess air, on the other hand, can cause increased entrainment of particulate and unnecessarily high auxiliary fuel consumption.

Multiple hearth furnace emissions are usually controlled by a venturi scrubber, an impingement

tray scrubber, or a combination of both. Wet cyclones and dry cyclones are also used. Wet electrostatic precipitators (Wet ESPs) are being installed as retrofits where tighter limits on particulate matter and metals are required by State regulations.

2.2.1.2 Fluidized Bed Incinerators -

Fluidized bed technology was first developed by the petroleum industry to be used for catalyst regeneration. Figure 2.2-2 shows the cross section diagram of a fluidized bed furnace. Fluidized bed combustors (FBCs) consist of a vertically oriented outer shell constructed of steel and lined with refractory. Tuyeres (nozzles designed to deliver blasts of air) are located at the base of the furnace within a refractory-lined grid. A bed of sand, approximately 0.75 meters (2.5 feet) thick, rests upon the grid. Two general configurations can be distinguished on the basis of how the fluidizing air is injected into the furnace. In the "hot windbox" design the combustion air is first preheated by passing through a heat exchanger where heat is recovered from the hot flue gases. Alternatively, ambient air can be injected directly into the furnace from a cold windbox.

Partially dewatered sludge is fed into the lower portion of the furnace. Air injected through the tuyeres, at pressures of from 20 to 35 kilopascals (3 to 5 pounds per square inch gauge), simultaneously fluidizes the bed of hot sand and the incoming sludge. Temperatures of 750 to 925°C (1400 to 1700°F) are maintained in the bed. Residence times are typically 2 to 5 seconds. As the sludge burns, fine ash particles are carried out the top of the furnace. Some sand is also removed in the air stream; sand make-up requirements are on the order of 5 percent for every 300 hours of operation.

Combustion of the sludge occurs in two zones. Within the bed itself (Zone 1), evaporation of the water and pyrolysis of the organic materials occur nearly simultaneously as the temperature of the sludge is rapidly raised. In the second zone (freeboard area), the remaining free carbon and combustible gases are burned. The second zone functions essentially as an afterburner.

Fluidization achieves nearly ideal mixing between the sludge and the combustion air and the turbulence facilitates the transfer of heat from the hot sand to the sludge. The most noticeable impact of the better burning atmosphere provided by a fluidized bed incinerator is seen in the limited amount of excess air required for complete combustion of the sludge. Typically, FBCs can achieve complete combustion with 20 to 50 percent excess air, about half the excess air required by multiple hearth furnaces. As a consequence, FBC incinerators have generally lower fuel requirements compared to MHF incinerators.

Fluidized bed incinerators most often have venturi scrubbers or venturi/impingement tray scrubber combinations for emissions control.

2.2.1.3 Electric Infrared Incinerators -

The first electric infrared furnace was installed in 1975, and their use is not common. Electric infrared incinerators consist of a horizontally oriented, insulated furnace. A woven wire belt conveyor extends the length of the furnace and infrared heating elements are located in the roof above the conveyor belt. Combustion air is preheated by the flue gases and is injected into the discharge end of the furnace. Electric infrared incinerators consist of a number of prefabricated modules, which can be linked together to provide the necessary furnace length. A cross section of an electric furnace is shown in Figure 2.2-3.

The dewatered sludge cake is conveyed into one end of the incinerator. An internal roller mechanism levels the sludge into a continuous layer approximately one inch thick across the width of the belt. The sludge is sequentially dried and then burned as it moves beneath the infrared heating

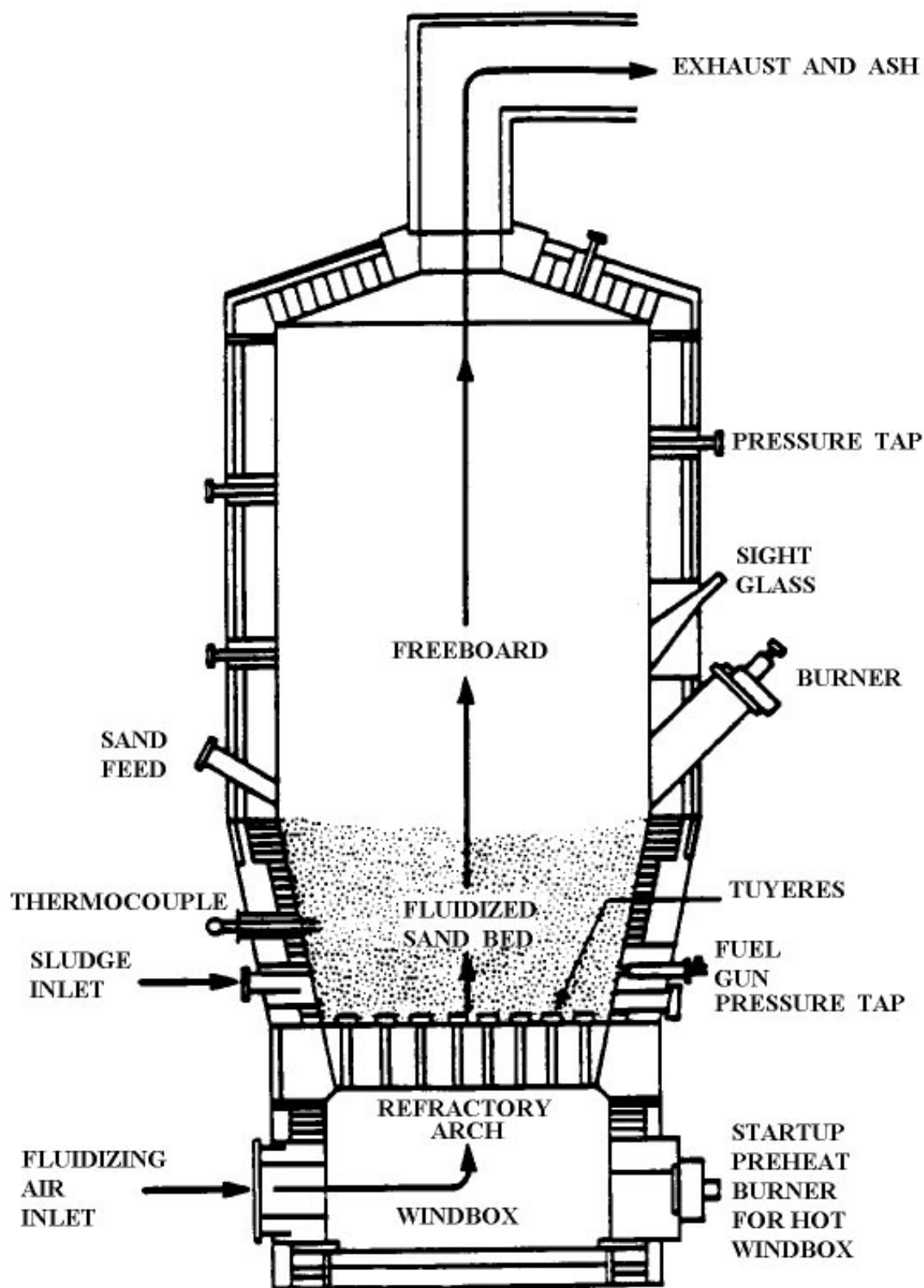


Figure 2.2-2. Cross Section of a Fluidized Bed Furnace

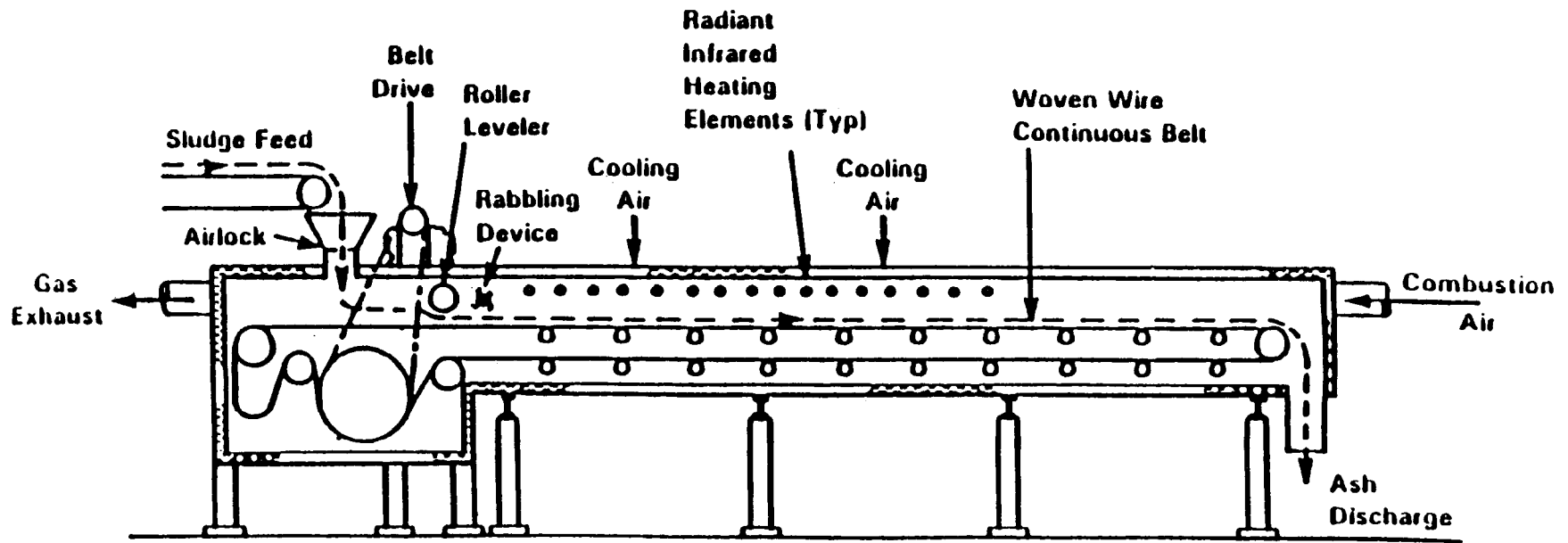


Figure 2.2-3. Cross Section of an Electric Infrared Furnace.

elements. Ash is discharged into a hopper at the opposite end of the furnace. The preheated combustion air enters the furnace above the ash hopper and is further heated by the outgoing ash. The direction of air flow is countercurrent to the movement of the sludge along the conveyor. Exhaust gases leave the furnace at the feed end. Excess air rates vary from 20 to 70 percent.

Compared to MHF and FBC technologies, the electric infrared furnace offers the advantage of lower capital cost, especially for smaller systems. However, electricity costs in some areas may make an electric furnace infeasible. One other concern is replacement of various components such as the woven wire belt and infrared heaters, which have 3- to 5-year lifetimes.

Electric infrared incinerator emissions are usually controlled with a venturi scrubber or some other wet scrubber.

2.2.1.4 Other Technologies -

A number of other technologies have been used for incineration of sewage sludge, including cyclonic reactors, rotary kilns, and wet oxidation reactors. These processes are not in widespread use in the United States and will be discussed only briefly.

The cyclonic reactor is designed for small capacity applications. It is constructed of a vertical cylindrical chamber that is lined with refractory. Preheated combustion air is introduced into the chamber tangentially at high velocities. The sludge is sprayed radially toward the hot refractory walls. Combustion is rapid: The residence time of the sludge in the chamber is on the order of 10 seconds. The ash is removed with the flue gases.

Rotary kilns are also generally used for small capacity applications. The kiln is inclined slightly from the horizontal plane, with the upper end receiving both the sludge feed and the combustion air. A burner is located at the lower end of the kiln. The circumference of the kiln rotates at a speed of about 15 centimeters (cm) per second (6 inches per second). Ash is deposited into a hopper located below the burner.

The wet oxidation process is not strictly one of incineration; it instead utilizes oxidation at elevated temperature and pressure in the presence of water (flameless combustion). Thickened sludge, at about 6 percent solids, is first ground and mixed with a stoichiometric amount of compressed air. The slurry is then pressurized. The mixture is then circulated through a series of heat exchangers before entering a pressurized reactor. The temperature of the reactor is held between 175 and 315°C (350 and 600°F). The pressure is normally 7,000 to 12,500 kilopascals (1,000 to 1,800 pounds per square inch gauge). Steam is usually used for auxiliary heat. The water and remaining ash are circulated out the reactor and are finally separated in a tank or lagoon. The liquid phase is recycled to the treatment plant. Offgases must be treated to eliminate odors: wet scrubbing, afterburning, or carbon absorption may be used.

2.2.1.5 Co-incineration and Co-firing -

Wastewater treatment plant sludge generally has a high water content and in some cases, fairly high levels of inert materials. As a result, its net fuel value is often low. If sludge is combined with other combustible materials in a co-incineration scheme, a furnace feed can be created that has both a low water concentration and a heat value high enough to sustain combustion with little or no supplemental fuel.

Virtually any material that can be burned can be combined with sludge in a co-incineration process. Common materials for co-combustion are coal, municipal solid waste (MSW), wood waste and agriculture waste. Thus, a municipal or industrial waste can be disposed of while providing an

autogenous (self-sustaining) sludge feed, thereby solving two disposal problems.

There are two basic approaches to combusting sludge with MSW: (1) use of MSW combustion technology by adding dewatered or dried sludge to the MSW combustion unit, and (2) use of sludge combustion technology by adding processed MSW as a supplemental fuel to the sludge furnace. With the latter, MSW is processed by removing noncombustibles, shredding, air classifying, and screening. Waste that is more finely processed is less likely to cause problems such as severe erosion of the hearths, poor temperature control, and refractory failures.

2.2.2 Emissions And Controls¹⁻³

Sewage sludge incinerators potentially emit significant quantities of pollutants. The major pollutants emitted are: (1) particulate matter, (2) metals, (3) carbon monoxide (CO), (4) nitrogen oxides (NO_x), (5) sulfur dioxide (SO₂), and (6) unburned hydrocarbons. Partial combustion of sludge can result in emissions of intermediate products of incomplete combustion (PIC), including toxic organic compounds.

Uncontrolled particulate emission rates vary widely depending on the type of incinerator, the volatiles and moisture content of the sludge, and the operating practices employed. Generally, uncontrolled particulate emissions are highest from fluidized bed incinerators because suspension burning results in much of the ash being carried out of the incinerator with the flue gas. Uncontrolled emissions from multiple hearth and fluidized bed incinerators are extremely variable, however. Electric incinerators appear to have the lowest rates of uncontrolled particulate release of the three major furnace types, possibly because the sludge is not disturbed during firing. In general, higher airflow rates increase the opportunity for particulate matter to be entrained in the exhaust gases. Sludge with low volatile content or high moisture content may compound this situation by requiring more supplemental fuel to burn. As more fuel is consumed, the amount of air flowing through the incinerator is also increased. However, no direct correlation has been established between airflow and particulate emissions.

Metal emissions are affected by metal content of the sludge, fuel bed temperature, and the level of particulate matter control. Since metals which are volatilized in the combustion zone condense in the exhaust gas stream, most metals (except mercury) are associated with fine particulate and are removed as the fine particulates are removed.

Carbon monoxide is formed when available oxygen is insufficient for complete combustion or when excess air levels are too high, resulting in lower combustion temperatures.

Emissions of nitrogen and sulfur oxides are primarily the result of oxidation of nitrogen and sulfur in the sludge. Therefore, these emissions can vary greatly based on local and seasonal sewage characteristics.

Emissions of volatile organic compounds (VOC) also vary greatly with incinerator type and operation. Incinerators with countercurrent airflow such as multiple hearth designs provide the greatest opportunity for unburned hydrocarbons to be emitted. In the MHF, hot air and wet sludge feed are contacted at the top of the furnace. Any compounds distilled from the solids are immediately vented from the furnace at temperatures too low to completely destruct them.

Particulate emissions from sewage sludge incinerators have historically been controlled by wet scrubbers, since the associated sewage treatment plant provides both a convenient source and a good disposal option for the scrubber water. The types of existing sewage sludge incinerator controls range

from low pressure drop spray towers and wet cyclones to higher pressure drop venturi scrubbers and venturi/impingement tray scrubber combinations. Electrostatic precipitators and baghouses are employed primarily where sludge is co-fired with municipal solid waste. The most widely used control device applied to a multiple hearth incinerator is the impingement tray scrubber. Older units use the tray scrubber alone while combination venturi/impingement tray scrubbers are widely applied to newer multiple hearth incinerators and to fluidized bed incinerators. Most electric incinerators and many fluidized bed incinerators use venturi scrubbers only.

In a typical combination venturi/impingement tray scrubber, hot gas exits the incinerator and enters the precooling or quench section of the scrubber. Spray nozzles in the quench section cool the incoming gas and the quenched gas then enters the venturi section of the control device. Venturi water is usually pumped into an inlet weir above the quencher. The venturi water enters the scrubber above the throat and floods the throat completely. This eliminates build-up of solids and reduces abrasion. Turbulence created by high gas velocity in the converging throat section deflects some of the water traveling down the throat into the gas stream. Particulate matter carried along with the gas stream impacts on these water particles and on the water wall. As the scrubber water and flue gas leave the venturi section, they pass into a flooded elbow where the stream velocity decreases, allowing the water and gas to separate. Most venturi sections come equipped with variable throats. By restricting the throat area within the venturi, the linear gas velocity is increased and the pressure drop is subsequently increased. Up to a certain point, increasing the venturi pressure drop increases the removal efficiency. Venturi scrubbers typically maintain 60 to 99 percent removal efficiency for particulate matter, depending on pressure drop and particle size distribution.

At the base of the flooded elbow, the gas stream passes through a connecting duct to the base of the impingement tray tower. Gas velocity is further reduced upon entry to the tower as the gas stream passes upward through the perforated impingement trays. Water usually enters the trays from inlet ports on opposite sides and flows across the tray. As gas passes through each perforation in the tray, it creates a jet which bubbles up the water and further entrains solid particles. At the top of the tower is a mist eliminator to reduce the carryover of water droplets in the stack effluent gas. The impingement section can contain from one to four trays, but most systems for which data are available have two or three trays.

Emission factors and emission factor ratings for multiple hearth sewage sludge incinerators are shown in Tables 2.2-1, 2.2-2, 2.2-3, 2.2-4, and 2.2-5. Tables 2.2-6, 2.2-7, and 2.2-8 present emission factors for fluidized bed sewage sludge incinerators. Table 2.2-9 presents the available emission factors for electric infrared incinerators. Tables 2.2-10 and 2.2-11 present the cumulative particle size distribution and size-specific emission factors for sewage sludge incinerators. Figure 2.2-4, Figure 2.2-5, and Figure 2.2-6 present cumulative particle size distribution and size-specific emission factors for multiple-hearth, fluidized-bed, and electric infrared incinerators, respectively.

Table 2.2-1 (Metric And English Units). CRITERIA POLLUTANT EMISSION FACTORS FOR MULTIPLE HEARTH SEWAGE SLUDGE INCINERATORS^a

Source Category ^b	Filterable Particulate Matter (PM)			Sulfur Dioxide (SO ₂)			Nitrogen Oxides (NO _x) ^c		
	kg/Mg	lb/ton	EMISSION FACTOR RATING	kg/Mg	lb/ton	EMISSION FACTOR RATING	kg/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled	5.2 E+01	1.0 E+02	B	1.4 E+01	2.8 E+01	B	2.5 E+00	5.0 E+00	C
Controlled									
Cyclone	2.0 E+00	4.0 E+00	E	2.8 E+00	5.6 E+00	E			
Cyclone/impingement	4.0 E-01	8.0 E-01	E						
Cyclone/venturi	2.5 E-01	5.0 E-01	D						
Cyclone/venturi/impingement	3.1 E-01	6.2 E-01	E						
Electrostatic precipitator									
Fabric filter	2.0 E-03	4.0 E-03	E						
Impingement	7.0 E-01	1.4 E+00	B	3.2 E-01	6.4 E-01	D			
Venturi	1.6 E+00	3.2 E+00	B	2.3 E+00	4.6 E+00	E			
Venturi/impingement/afterburner									
Venturi/impingement	1.1 E+00	2.2 E+00	A	1.0 E-01	2.0 E-01	E			
Venturi/impingement/Wet ESP	2.0 E-01	4.0 E-01	E						
Venturi/Wet ESP									

Table 2.2-1 (cont.).

Source Category	Carbon Monoxide (CO) ^c			Lead ^d			Methane			Total Nonmethane Organic Compounds		
	kg/Mg	lb/ton	EMISSION FACTOR RATING	kg/Mg	lb/ton	EMISSION FACTOR RATING	kg/Mg	lb/ton	EMISSION FACTOR RATING	kg/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled	1.55 E+01	3.1 E+01	C	5.0 E-02	1.0 E-01	B				8.4 E-01	1.7 E+00	D
Controlled												
Cyclone				3.0 E-02	6.0 E-02	E				1.5 E+00	3.0 E+00	E
Cyclone/impingement												
Cyclone/venturi				3.0 E-03	6.0 E-03	E				2.2 E-01	4.4 E-01	E
Cyclone/venturi/ impingement				1.1 E-02	2.2 E-02	E						
Electrostatic precipitator				1.0 E-03	2.0 E-03	E						
Fabric filter												
Impingement				2.0 E-02	4.0 E-02	E	3.9 E-01	7.8 E-01	E	7.8 E-01	1.6 E+00	E
Venturi				9.0 E-04	1.8 E-03	E	3.2 E+00	6.4 E+00	E			
Venturi/impingement/ afterburner				5.0 E-02	1.0 E-01	E						
Venturi/impingement				3.0 E-02	6.0 E-02	B						
Venturi/impingement/ Wet ESP												
Venturi/Wet ESP				9.0 E-05	1.8 E-04	E						

^a Units are pollutants emitted of dry sludge burned. Source Classification Code 5-01-005-15. Blanks indicate no data.

^b Wet ESP = wet electrostatic precipitator.

^c Uncontrolled emission factors for NO_x and CO apply to all air pollution control device types.

^d Hazardous air pollutants listed in the *Clean Air Act*.

Table 2.2-2 (Metric And English Units). ACID GAS EMISSION FACTORS FOR MULTIPLE HEARTH SEWAGE SLUDGE INCINERATORS^a

Source Category ^b	Sulfuric Acid (H ₂ SO ₄)			Hydrogen Chloride (HCl) ^c		
	g/Mg	lb/ton	EMISSION FACTOR RATING	kg/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled	6.0 E-01	1.2 E+00	D			
Controlled						
Cyclone	3.3 E-01	6.6 E-01	E			
Cyclone/impingement				1.0 E-02	2.0 E-02	E
Cyclone/venturi				1.0 E-02	2.0 E-02	E
Cyclone/venturi/impingement						
Electrostatic precipitator						
Fabric filter						
Impingement	5.0 E-02	1.0 E-01	E	1.0 E-02	2.0 E-02	E
Venturi				1.0 E-02	2.0 E-02	E
Venturi/impingement/afterburner						
Venturi/impingement	2.0 E-01	4.0 E-01	E			
Venturi/impingement/Wet ESP						
Venturi/Wet ESP						

^a Units are pollutants emitted of dry sludge burned. Source Classification Code 5-01-005-15. Blanks indicate no data.

^b Wet ESP = wet electrostatic precipitator.

^c Hazardous air pollutants listed in the *Clean Air Act*.

Table 2.2-3 (Metric And English Units). CHLORINATED DIBENZO-P-DIOXIN (CDD) AND CHLORINATED DIBENZOFURAN (CDF) EMISSION FACTORS FOR MULTIPLE HEARTH SEWAGE SLUDGE INCINERATORS^a

EMISSION FACTOR RATING: E

Source Category ^b	2,3,7,8-TCDD ^c		Total TCDD		Total PCDD	
	µg/Mg	lb/ton	µg/Mg	lb/ton	µg/Mg	lb/ton
Uncontrolled			6.3 E+01	1.3 E-07	2.7 E+00	5.4 E-09
Controlled						
Cyclone						
Cyclone/impingement						
Cyclone/venturi			1.4 E+00	2.8 E-09		
Cyclone/venturi/impingement	3.0 E-01	6.0 E-10				
Electrostatic precipitator						
Fabric filter						
Impingement	5.0 E-01	1.0 E-09	2.8 E+01	5.6 E-08	3.7 E+00	7.4 E-09
Venturi						
Venturi/impingement/afterburner	9.0 E-01	1.8 E-09				
Venturi/impingement	2.0 E+00	4.0 E-09				
Venturi/impingement/Wet ESP						
Venturi/Wet ESP						

Table 2.2-3 (cont.).

Source Category ^b	Total HxCDD		Total HpCDD		Total OCDD	
	µg/Mg	lb/ton	µg/Mg	lb/ton	µg/Mg	lb/ton
Uncontrolled	6.8 E+01	1.4 E-07	3.4 E+02	6.8 E-07	3.7 E+02	7.4 E-07
Controlled						
Cyclone						
Cyclone/impingement						
Cyclone/venturi			8.0 E-01	1.6 E-09	3.4 E+00	6.8 E-09
Cyclone/venturi/impingement	4.4 E+00	8.8 E-09	1.4 E+01	2.8 E-08	3.1 E+01	6.7 E-08
Electrostatic precipitator						
Fabric filter						
Impingement	2.4 E+01	4.8 E-08	7.3 E+01	1.5 E-07	5.3 E+01	1.1 E-07
Venturi						
Venturi/impingement/afterburner	6.0 E+01	1.2 E-07	2.3 E+01	4.6 E-08	1.2 E+01	2.4 E-08
Venturi/impingement	3.8 E+01	7.6 E-08	1.5 E+01	3.0 E-08	1.9 E+01	3.8 E-08
Venturi/impingement/Wet ESP						
Venturi/Wet ESP						

Table 2.2-3 (cont.).

Source Category ^b	2,3,7,8-TCDF ^c		Total TCDF ^c		Total PCDF ^c	
	µg/Mg	lb/ton	µg/Mg	lb/ton	µg/Mg	lb/ton
Uncontrolled	6.2 E+02	1.2 E-06	1.7 E+03	3.4 E-06	9.8 E+02	2.0 E-06
Controlled						
Cyclone						
Cyclone/impingement						
Cyclone/venturi	5.6 E+00	1.1 E-08	5.0 E+01	1.0 E-07	1.1 E+01	2.2 E-08
Cyclone/venturi/impingement			1.8 E+02	3.8 E-07	5.7 E+01	1.1 E-07
Electrostatic precipitator						
Fabric filter						
Impingement	1.8 E+02	3.6 E-07	7.0 E+02	1.4 E-06	3.6 E+02	7.2 E-07
Venturi						
Venturi/impingement/afterburner	5.4 E+01	1.1 E-07	3.5 E+02	7.0 E-07	1.3 E+02	2.6 E-07
Venturi/impingement	4.6 E+01	9.2 E-08	6.0 E+02	1.2 E-06	1.3 E+00	2.6 E-09
Venturi/impingement/Wet ESP						
Venturi/Wet ESP						

Table 2.2-3 (cont.).

Source Category ^b	Total HxCDF ^c		Total HpCDF ^c		Total OCDF ^c	
	µg/Mg	lb/ton	µg/Mg	lb/ton	µg/Mg	lb/ton
Uncontrolled	9.9 E+01	2.0 E-07	4.8 E+02	9.6 E-07	4.9 E+02	9.8 E-07
Controlled						
Cyclone						
Cyclone/impingement						
Cyclone/venturi	3.4 E+00	6.8 E-09	9.0 E-01	1.8 E-09	7.0 E-01	1.4 E-09
Cyclone/venturi/impingement	1.8 E+00	3.6 E-09	2.9 E+00	5.8 E-09	1.8 E+00	3.6 E-09
Electrostatic precipitator						
Fabric filter						
Impingement	1.1 E+02	2.2 E-07	2.0 E+02	4.0 E-07	1.5 E+02	3.0 E-07
Venturi						
Venturi/impingement/afterburner	7.8 E+01	1.5 E-07	4.8 E+01	9.6 E-08	7.7 E+00	1.5 E-08
Venturi/impingement	5.7 E+01	1.1 E-07	4.1 E+01	8.2 E-08	6.3 E+00	1.3 E-08
Venturi/impingement/Wet ESP						
Venturi/Wet ESP						

Table 2.2-3 (cont.).

Source Category ^b	Total Tetra- through Octa- CDD		Total Tetra- through Octa- CDF	
	µg/Mg	lb/ton	µg/Mg	lb/ton
Uncontrolled	8.5 E+02	1.7 E-06	3.8 E+03	7.6 E-06
Controlled				
Cyclone				
Cyclone/impingement				
Cyclone/venturi	5.6 E+00	1.1 E-08	6.6 E+01	1.3 E-07
Cyclone/venturi/impingement	1.1 E+02	2.2 E-07	2.5 E+02	5.0 E-07
Electrostatic precipitator				
Fabric filter				
Impingement	1.8 E+02	3.6 E-07	1.5 E+03	3.0 E-06
Venturi				
Venturi/impingement/afterburner	3.1 E+02	6.2 E-07	4.6 E+02	9.2 E-07
Venturi/impingement	2.7 E+02	5.4 E-07	9.3 E+02	1.9 E-06
Venturi/impingement/Wet ESP				
Venturi/Wet ESP				

^a Units are pollutant emitted of dry sludge burned. Source Classification Code 5-01-005-15. Blanks indicate no data.

^b Wet ESP = wet electrostatic precipitator.

^c Hazardous air pollutants listed in the *Clean Air Act*.

Table 2.2-4 (Metric And English Units). SUMMARY OF ORGANIC COMPOUND EMISSIONS FROM MULTIPLE HEARTH SEWAGE SLUDGE INCINERATORS^a

Source Category ^b	1,1,1-Trichloroethane ^c			1,1-Dichloroethane ^c			1,2-Dichloroethane ^c		
	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled	6.0 E-02	1.2 E-04	D						
Controlled									
Cyclone									
Cyclone/impingement	1.9 E+00	3.8 E-03	E	2.3 E-01	4.6 E-04	E			
Cyclone/venturi	7.0 E-02	1.4 E-04	E				4.0 E-03	8.0 E-06	E
Cyclone/venturi/impingement									
Electrostatic precipitator									
Fabric filter									
Impingement									
Venturi									
Venturi/impingement/afterburner	1.4 E+00	2.8 E-03	E				3.0 E-02	6.0 E-05	E
Venturi/impingement	6.1 E-01	1.2 E-03	D				1.0 E-02	2.0 E-05	E
Venturi/impingement/Wet ESP									
Venturi/Wet ESP									

Table 2.2-4 (cont.).

Source Category ^b	1,2-Dichlorobenzene			1,3-Dichlorobenzene			1,4-Dichlorobenzene ^c		
	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled	3.7 E-01	7.4 E-04	E				4.1 E-01	8.2 E-04	E
Controlled									
Cyclone									
Cyclone/impingement									
Cyclone/venturi				5.0 E-02	1.0 E-04	E	7.0 E-03	1.4 E-05	E
Cyclone/venturi/impingement									
Electrostatic precipitator									
Fabric filter									
Impingement									
Venturi									
Venturi/impingement/ afterburner									
Venturi/impingement	1.9 E-01	3.8 E-04	E	2.0 E-02	4.0 E-05	E	2.4 E-01	4.8 E-04	E
Venturi/impingement/Wet ESP									
Venturi/Wet ESP									

Table 2.2-4 (cont.).

Source Category ^b	2-Nitrophenol			Acetaldehyde ^c			Acetone		
	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled	6.0 E+00	1.2 E-02	E						
Controlled									
Cyclone									
Cyclone/impingement									
Cyclone/venturi	3.8 E-01	7.6 E-04	E						
Cyclone/venturi/impingement									
Electrostatic precipitator									
Fabric filter									
Impingement				1.6 E-01	3.2 E-04	E			
Venturi							3.2 E+00	6.4 E-03	E
Venturi/impingement/afterburner									
Venturi/impingement	1.2 E+00	2.4 E-03	E						
Venturi/impingement/Wet ESP									
Venturi/Wet ESP									

Table 2.2-4 (cont.).

Source Category ^b	Acetonitrile ^c			Acrylonitrile ^c			Benzene ^c		
	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled	2.5 E+01	5.0 E-02	E	2.5 E+01	5.0 E-02	E	5.8 E+00	1.2 E-02	D
Controlled									
Cyclone									
Cyclone/impingement									
Cyclone/venturi				1.5 E-01	3.0 E-04	E	3.5 E-01	7.0 E-04	E
Cyclone/venturi/impingement									
Electrostatic precipitator									
Fabric filter									
Impingement									
Venturi							1.4 E+01	2.8 E-02	E
Venturi/impingement/ afterburner	7.4 E-01	1.5 E-03	E	4.9 E-01	9.8 E-04	E	1.7 E-01	3.4 E-04	E
Venturi/impingement	9.7 E+00	2.0 E-02	E	1.7 E+01	3.4 E-02	E	6.3 E+00	1.3 E-02	D
Venturi/impingement/Wet ESP									
Venturi/Wet ESP									

Table 2.2-4. (cont.).

Source Category ^b	Bis(2-ethylhexyl)phthalate ^c			Bromodichloromethane			Carbon Tetrachloride ^c		
	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled	9.3 E-01	1.9 E-03	E	4.0 E-03	8.0 E-06	E	1.0 E-02	2.0 E-05	E
Controlled									
Cyclone									
Cyclone/impingement									
Cyclone/venturi	4.0 E-02	8.0 E-05	E				7.0 E-03	1.4 E-05	E
Cyclone/venturi/impingement									
Electrostatic precipitator									
Fabric filter									
Impingement									
Venturi				1.5 E+00	3.0 E-03	E			
Venturi/impingement/ afterburner							1.0 E-03	2.0 E-06	E
Venturi/impingement	3.2 E-01	6.4 E-04	E				3.0 E-02	6.0 E-05	D
Venturi/impingement/Wet ESP									
Venturi/Wet ESP									

Table 2.2-4 (cont.).

Source Category ^b	Chlorobenzene ^c			Chloroform ^c		
	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled	7.5 E-01	1.5 E-03	E	3.0 E-02	6.0 E-05	E
Controlled						
Cyclone						
Cyclone/impingement						
Cyclone/venturi	6.0 E-03	1.2 E-05	E	2.0 E-02	4.0 E-05	E
Cyclone/venturi/impingement						
Electrostatic precipitator						
Fabric filter						
Impingement						
Venturi	4.2 E+00	8.4 E-03	E	3.3 E+00	6.6 E-03	E
Venturi/impingement/afterburner	2.6 E-01	5.2 E-04	E	4.9 E-01	9.8 E-04	E
Venturi/impingement	6.0 E-01	1.2 E-03	E	1.3 E+00	2.6 E-03	D
Venturi/impingement/Wet ESP						
Venturi/Wet ESP						

Table 2.2-4 (cont.).

Source Category ^b	Ethylbenzene ^c			Formaldehyde ^c			Methyl Ethyl Ketone ^c		
	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled	8.0 E-01	1.6 E-03	E				6.1 E+00	1.2 E-02	E
Controlled									
Cyclone									
Cyclone/impingement									
Cyclone/venturi	3.0 E-03	6.0 E-06	E	1.3 E+00	2.6 E-03	E			
Cyclone/venturi/impingement									
Electrostatic precipitator									
Fabric filter									
Impingement									
Venturi	6.0 E+00	1.2 E-02	E	4.0 E-01	8.0 E-04	E	6.1 E+00	1.2 E-02	E
Venturi/impingement/ afterburner	2.0 E-02	4.0 E-05	E				5.0 E-02	1.0 E-04	E
Venturi/impingement	1.0 E+00	2.0 E-03	D				8.9 E+00	1.8 E-02	E
Venturi/impingement/Wet ESP									
Venturi/Wet ESP									

Table 2.2-4 (cont.).

Source Category ^b	Methyl Isobutyl Ketone ^c			Methylene Chloride ^c			Naphthalene ^c		
	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled				4.0 E-01	8.0 E-04	D	9.2 E+00	1.8 E-02	E
Controlled									
Cyclone									
Cyclone/impingement	1.0 E-02	2.0 E-05	E						
Cyclone/venturi				3.0 E-01	6.0 E-04	E	9.7 E-01	1.9 E-03	D
Cyclone/venturi/impingement									
Electrostatic precipitator									
Fabric filter									
Impingement									
Venturi									
Venturi/impingement/ afterburner				4.0 E-01	8.0 E-04	E			
Venturi/impingement				9.0 E-01	1.8 E-03	D			
Venturi/impingement/Wet ESP									
Venturi/Wet ESP									

Table 2.2-4 (cont.).

Source Category ^b	Perchloroethylene ^c			Phenol ^c			Tetrachloroethane ^c		
	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled	4.0 E-01	8.0 E-04	E	2.2 E+01	4.4 E-02	E			
Controlled									
Cyclone									
Cyclone/impingement									
Cyclone/venturi	3.0 E-01	6.0 E-04	E						
Cyclone/venturi/impingement									
Electrostatic precipitator									
Fabric filter									
Impingement									
Venturi	2.0 E-01	4.0 E-04	E				1.2 E+01	2.4 E-02	E
Venturi/impingement/ afterburner									
Venturi/impingement				1.8 E+00	3.6 E-03	E			
Venturi/impingement/Wet ESP									
Venturi/Wet ESP									

Table 2.2-4 (cont.).

Source Category ^b	Toluene ^c			Trans-1,2-Dichloroethene ^c			Trichloroethene ^c		
	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled	7.8 E+00	1.5 E-02	D	9.0 E-02	1.8 E-04	E	4.0 E-01	8.0 E-04	E
Controlled									
Cyclone									
Cyclone/impingement									
Cyclone/venturi	3.3 E+00	6.6 E-03	E						
Cyclone/venturi/impingement									
Electrostatic precipitator									
Fabric filter									
Impingement									
Venturi	1.6 E+01	3.0 E-02	E						
Venturi/impingement/ afterburner	6.6 E-01	1.3 E-03	E	4.0 E-02	8.0 E-05	D			
Venturi/impingement	6.5 E+00	1.3 E-02	D	5.0 E-02	1.0 E-04	E	4.5 E-01	9.0 E-04	E
Venturi/impingement/Wet ESP									
Venturi/Wet ESP									

Table 2.2-4. (cont.).

Source Category ^b	Vinyl Chloride ^c			Xylene, m,p ^c			Xylene (total) ^c		
	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled	6.6 E+00	1.3 E-02	E				9.5 E-01	1.9 E-03	E
Controlled									
Cyclone									
Cyclone/impingement									
Cyclone/venturi	1.0 E+00	2.0 E-03	E						
Cyclone/venturi/impingement									
Electrostatic precipitator	8.0 E-01	1.6 E-03	E						
Fabric filter									
Impingement									
Venturi				2.0 E+00	4.0 E-03	E			
Venturi/impingement/ afterburner									
Venturi/impingement	3.7 E+00	7.4 E-03	D						
Venturi/impingement/Wet ESP									
Venturi/Wet ESP									

^a Units are pollutants emitted of dry sludge burned. Source Classification Code 5-01-005-15. Blanks indicate no data.

^b Wet ESP = wet electrostatic precipitator.

^c Hazardous air pollutants in the *Clean Air Act*.

Table 2.2-5 (Metric And English Units). SUMMARY OF METAL EMISSIONS FROM MULTIPLE HEARTH SEWAGE SLUDGE INCINERATORS^a

Source Category ^b	Aluminum			Antimony ^c			Arsenic ^c		
	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled	2.4 E+02	4.8E-01	D	1.5 E+00	3.0 E-03	E	4.7 E+00	9.4 E-03	B
Controlled									
Cyclone	3.0 E-01	6.0E-04	E	3.2 E-01	6.4 E-04	E			
Cyclone/impingement									
Cyclone/venturi							1.0 E-01	2.0 E-04	E
Cyclone/venturi/impingement							8.5 E-01	1.7 E-03	E
Electrostatic precipitator	3.8 E+02	7.6 E-02	E	4.0 E-02	8.0 E-05	E	1.2 E+00	2.4 E-03	E
Fabric filter	6.8 E-01		E	4.0 E-03	8.0 E-06	E	3.0 E-03	6.0 E-06	E
Impingement									
Venturi							5.0 E-02	1.0 E-04	E
Venturi/impingement/ afterburner							4.0 E-02	8.0 E-05	E
Venturi/impingement	9.2 E+01	1.8E-01	E	2.4 E-01	4.8 E-04	E	6.1 E-01	1.2 E-03	B
Venturi/impingement/ Wet ESP									
Venturi/Wet ESP							6.0 E-01	1.2 E-03	E

Table 2.2-5. (cont.).

Source Category ^b	Barium			Beryllium ^c			Cadmium ^c		
	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled	1.5 E+01	3.0 E-02	D	1.5 E-01	3.0 E-04	E	1.6 E+01	3.7 E-02	B
Controlled									
Cyclone	1.0 E-01	2.0 E-04	E	9.0 E-03	1.8 E-05	D	1.7 E+01	3.4 E-02	D
Cyclone/impingement									
Cyclone/venturi							1.3 E+01	2.6 E-02	C
Cyclone/venturi/impingement							8.1 E+00	1.6 E-02	E
Electrostatic precipitator	7.4 E+00	1.5 E-02	E				1.7 E-01	3.4 E-04	E
Fabric filter	4.0 E-03	8.0 E-06	E				1.0 E-02	2.0 E-05	E
Impingement							1.2 E+00	2.4 E-03	E
Venturi							1.1 E-01	2.2 E-04	E
Venturi/impingement/ afterburner							3.0 E+00	6.0 E-03	E
Venturi/impingement	3.2 E+00	6.4 E-03	D	5.0 E-03	1.0 E-05	E	3.3 E+00	6.6 E-03	E
Venturi/impingement/ Wet ESP							1.0 E-01	2.0 E-04	E
Venturi/Wet ESP							4.0 E-02	8.0 E-05	E

Table 2.2-5 (cont.).

Source Category ^b	Calcium			Chromium ^c			Cobalt ^c		
	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled	7.0 E+02	1.4 E+00	C	1.4 E+01	2.9 E-02	B	9.0 E-01	1.8 E-03	C
Controlled									
Cyclone	1.2 E+00	2.4 E-03	E	1.9 E+00	3.8 E-03	D	2.0 E-01	4.0 E-04	E
Cyclone/impingement				4.0 E-02	8.0 E-05	E			
Cyclone/venturi				5.0 E-01	1.0 E-03	E			
Cyclone/venturi/impingement				1.1 E+01	2.7 E-02	E			
Electrostatic precipitator	3.5 E+02	7.0 E-01	E	1.4 E+00	2.8 E-03	E	3.8 E-01	7.6 E-04	E
Fabric filter	8.0 E-02	1.6 E-04	E	4.0 E-02	8.0 E-05	E	6.0 E-03	1.2 E-05	E
Impingement				9.8 E+00	1.9 E-02	E			
Venturi				5.0 E-01	1.0 E-03	E			
Venturi/impingement/ afterburner				4.9 E+00	9.8 E-03	E			
Venturi/impingement	2.6 E+02	5.2 E-01	D	2.1 E+00	4.2 E-03	E	4.5 E-01	9.0 E-04	D
Venturi/impingement/Wet ESP				1.1 E-01	2.2 E-04	E			
Venturi/Wet ESP				1.0 E-02	2.0 E-05	E			

Table 2.2-5 (cont.).

Source Category ^b	Copper			Gold			Iron		
	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled	4.0 E+01	8.0 E-02	B	3.0 E-02	6.0 E-05	E	5.6 E+02	1.1 E+00	C
Controlled									
Cyclone	2.7 E+00	5.4 E-03	E				1.7 E+00	3.4 E-03	E
Cyclone/impingement									
Cyclone/venturi	1.0 E+00	2.0 E-03	E						
Cyclone/venturi/impingement									
Electrostatic precipitator	2.0 E-01	4.0 E-04	E	9.0 E-03	1.8 E-05	E	2.5 E+01	5.0 E-02	E
Fabric filter	2.0 E-03	4.0 E-06	E	2.0 E-03	4.0 E-06	E	2.3 E-01	4.6 E-04	E
Impingement									
Venturi	4.0 E-01	8.0 E-04	E						
Venturi/impingement/afterburner	5.8 E+00	1.2 E-02	E						
Venturi/impingement	5.5 E+00	1.1 E-02	D	1.0 E-02	2.0 E-05	E	4.8 E+01	9.6 E-02	D
Venturi/impingement/Wet ESP									
Venturi/Wet ESP	1.0 E-02	2.0 E-05	E						

Table 2.2-5 (cont.).

Source Category ^b	Manganese ^c			Magnesium			Mercury ^c		
	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled	9.4 E+00	1.9 E-02	C	1.4 E+02	2.8 E-01	C			
Controlled									
Cyclone	3.3 E-01	6.6 E-04	E	1.4 E+00	2.8 E-03	E	2.3 E+00	4.6E-03	E
Cyclone/impingement									
Cyclone/venturi							1.6 E+00	3.2E-03	E
Cyclone/venturi/impingement									
Electrostatic precipitator	3.2 E-01	6.4 E-04	E	8.8 E+00	1.8 E-02	E			
Fabric filter	5.0 E-03	1.0 E-05	E	3.0 E-02	6.0 E-05	E			
Impingement							9.7 E-01	1.9E-03	E
Venturi									
Venturi/impingement/afterburner									
Venturi/impingement	8.5 E-01	1.7 E-03	D	4.2 E+00	8.4 E-03	D	5.0 E-03	1.0E-05	E
Venturi/impingement/Wet ESP									
Venturi/Wet ESP									

Table 2.2-5 (cont.).

Source Category ^b	Nickel ^c			Phosphorus ^c			Potassium		
	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled	8.0 E+00	1.6 E-02	B	3.8 E+02	7.6 E-01	D	5.3 E+01	1.1 E-01	E
Controlled									
Cyclone	8.0 E-02	1.6 E-04	E	8.9 E+00	1.8 E-02	E	9.0 E-01	1.8 E-03	E
Cyclone/impingement	1.3 E+00	2.6 E-03	D						
Cyclone/venturi	3.5 E-01	7.0 E-04	E						
Cyclone/venturi/impingement	4.5 E+00	9.0 E-03	E						
Electrostatic precipitator	2.0 E+00	4.0 E-03	E	6.9 E+00	1.4 E-02	E			
Fabric filter	1.4 E-02	2.8 E-05	E	2.0 E-01		E			
Impingement	4.1 E+00	8.2 E-03	E						
Venturi	6.0 E-02	1.2 E-04	E	9.6 E-01	1.9 E-03	E			
Venturi/impingement/afterburner	9.0 E-01	1.8 E-03	E						
Venturi/impingement	9.0 E-01	1.8 E-03	A	1.2 E+01	2.4 E-02	D	7.3 E+00	1.4 E-02	E
Venturi/impingement/Wet ESP									
Venturi/Wet ESP	3.0 E-03	6.0 E-06	E						

Table 2.2-5 (cont.).

Source Category ^b	Selenium ^c			Silicon			Silver		
	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled	1.5 E-01	3.0 E-04	D	3.4 E+02	6.8 E-01	E	6.5 E-01	1.3 E-03	E
Controlled									
Cyclone				4.6 E+00	9.2 E-03	E			
Cyclone/impingement									
Cyclone/venturi									
Cyclone/venturi/impingement									
Electrostatic precipitator							6.0 E-03	1.2 E-05	E
Fabric filter	1.2 E-01	2.4 E-04	E				1.0 E-04	2.0 E-07	E
Impingement									
Venturi	6.0 E-02	1.2 E-04	E				4.0 E-01	8.0 E-04	E
Venturi/impingement/afterburner									
Venturi/impingement				4.4 E+01	8.8 E-02	E	9.0 E-02	1.8 E-04	E
Venturi/impingement/Wet ESP									
Venturi/Wet ESP									

Table 2.2-5 (cont.).

Source Category ^b	Sodium			Sulfur			Tin		
	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled	4.7 E+01	9.4 E-02	C	3.6 E+03	7.2 E-00	D	1.3 E+01	2.6 E-02	C
Controlled									
Cyclone	1.8 E+00	3.6 E-03	E	1.9 E+01	3.9 E-02	E	5.9 E+00	1.2 E-02	E
Cyclone/impingement									
Cyclone/venturi									
Cyclone/venturi/impingement									
Electrostatic precipitator	5.5 E-01	1.1 E-03	E				2.0 E-01	4.0 E-04	E
Fabric filter	1.0 E-02	2.0 E-05	E	6.0 E+01	1.2 E-01	E	2.0 E-02	4.0 E-05	E
Impingement									
Venturi									
Venturi/impingement/afterburner									
Venturi/impingement	1.4 E+01	2.8 E-02	D	1.1 E+02	2.2 E-01	E	7.9 E+00	1.6 E-02	D
Venturi/impingement/Wet ESP									
Venturi/Wet ESP									

Table 2.2-5 (cont.).

Source Category ^b	Titanium			Vanadium			Zinc		
	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING	g/Mg	lb/ton	EMISSION FACTOR RATING
Uncontrolled	5.1 E+01	1.0 E-01	C	3.3 E+00	6.6 E-03	C	6.6 E+01	1.3 E-01	C
Controlled							1.1 E+01	2.2 E-02	E
Cyclone	1.0 E-01	2.0 E-04	E	3.0 E-01	6.0 E-04	E			
Cyclone/impingement									
Cyclone/venturi							3.8 E+01	7.6 E-02	E
Cyclone/venturi/impingement									
Electrostatic precipitator	9.0 E-01	1.8 E-03	E	9.9 E-01	2.0 E-03	E	3.9 E-01	7.8 E-04	E
Fabric filter	6.0 E-03	1.2 E-05	E	2.0 E-03	4.0 E-06	E	4.0 E-02	8.0 E-05	E
Impingement									
Venturi							4.4 E+00	8.8 E-03	E
Venturi/impingement/ afterburner							3.3 E+01	6.6 E-02	E
Venturi/impingement	3.1 E+00	6.2 E-03	D	8.0 E-01	1.6 E-03	E	2.4 E+01	4.8 E-02	C
Venturi/impingement/Wet ESP									
Venturi/Wet ESP							2.0 E-01	4.0 E-04	E

^a Units are pollutants emitted of dry sludge burned. Source Classification Code 5-01-005-15. Blanks indicate no data.

^b Wet ESP = wet electrostatic precipitator.

^c Hazardous air pollutants listed in the *Clean Air Act*.

Table 2.2-6 (Metric And English Units). CRITERIA POLLUTANT EMISSION FACTORS FOR FLUIDIZED BED SEWAGE SLUDGE INCINERATORS^a

EMISSION FACTOR RATING: E

Source Category ^b	Particulate Matter		Sulfur Dioxide		Nitrogen Oxides ^c	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Uncontrolled	2.3 E+02	4.6 E+02	1.5 E-01	3.0 E-01	8.8 E-01	1.7 E+00
Controlled						
Cyclone						
Cyclone/impingement						
Cyclone/venturi						
Cyclone/venturi/impingement	5.0 E-01	1.0 E+00				
Electrostatic precipitator						
Fabric filter						
Impingement	1.3 E-01	2.6 E-01	3.0 E-01	6.0 E-01		
Venturi	5.7 E-01		9.2 E+00	1.8 E+01		
Venturi/impingement/afterburner						
Venturi/impingement	2.7 E-01	1.1 E+00	4.0 E-01	8.0 E-01		
Venturi/impingement/Wet ESP	1.0 E-01	2.0 E-01				
Venturi/Wet ESP						

Table 2.2-6 (cont.).

Source Category ^b	Carbon Monoxide ^c (CO)		Lead ^d		Methane VOC	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Uncontrolled	1.1 E+00	2.1 E+00	2.0 E-02	4.0 E-02		
Controlled						
Cyclone						
Cyclone/impingement						
Cyclone/venturi						
Cyclone/venturi/impingement						
Electrostatic precipitator						
Fabric filter			5.0 E-06	1.0 E-05		
Impingement			3.0 E-03	6.0 E-03		
Venturi					1.6 E+00	3.2 E+00
Venturi/impingement/afterburner						
Venturi/impingement			8.0 E-02	1.6 E-01	4.0 E-01	8.0 E-01
Venturi/impingement/Wet ESP			1.0 E-06	2.0 E-06		
Venturi/Wet ESP						

^a Units are pollutants emitted of dry sludge burned. Source Classification Code 5-01-005-16.

^b Wet ESP = wet electrostatic precipitator.

^c Uncontrolled Emission Factors for NO_x and CO apply to all Air Pollution Control Device Types.

^d Hazardous air pollutants listed in the *Clean Air Act*.

Table 2.2-7 (Metric And English Units). ACID GAS AND ORGANIC COMPOUND EMISSION FACTORS FOR FLUIDIZED BED SEWAGE SLUDGE INCINERATORS^a

EMISSION FACTOR RATING: E

Pollutant	Uncontrolled		Impingement		Venturi/Impingement		Cyclone/Impingement	
	g/Mg	lb/ton	g/Mg	lb/ton	g/Mg	lb/ton	g/Mg	lb/ton
Sulfuric Acid (H ₂ SO ₄)			3.0 E+01	6.0 E-02	6.0 E+01	1.2 E-01		
Hydrogen Chloride (HCl) ^b					5.0 E+01	1.0 E-01		
2,3,7,8-TCDD ^b					3.0 E-07	6.0 E-10		
Total TCDD					2.2 E-06	4.4 E-09		
Total PCDD	1.1 E-06	2.2 E-09						
Total HxCDD					9.0 E-07	1.8 E-09		
Total HpCDD					9.0 E-07	1.8 E-09		
Total OCDD					4.3 E-06	8.6 E-09		
2,3,7,8-TCDF ^b					2.0 E-07	4.0 E-10		
Total TCDF ^b					6.2 E-06	1.2 E-08		
Total PCDF ^b					5.2 E-06	1.0 E-08		
Total HxCDF ^b					4.1 E-06	8.2 E-09		
Total HpCDF ^b					1.6 E-06	3.2 E-09		
Total OCDF ^b					1.3 E-06	2.6 E-09		
1,1,1-Trichloroethane ^b					2.6 E-01	5.2 E-04		
1,2-Dichlorobenzene					6.4 E+01	1.3 E-01		
1,4-Dichlorobenzene ^b					2.4 E+02	4.8 E-01		
Benzene ^b					2.0 E-01	4.0 E-04		
Bis(2-ethylhexyl)phthalate ^b					4.1 E+01	8.2 E-02		
Carbon Tetrachloride ^b					1.2 E-02	2.4 E-05		
Chlorobenzene ^b					5.0 E-03	1.0 E-05		

Table 2.2-7 (cont.).

Pollutant	Uncontrolled		Impingement		Venturi/Impingement		Cyclone/Impingement	
	g/Mg	lb/ton	g/Mg	lb/ton	g/Mg	lb/ton	g/Mg	lb/ton
Chloroform ^b					2.0 E+00	4.0 E-03		
Ethylbenzene ^b					2.5 E-02	5.0 E-05		
Methylene Chloride ^b					7.0 E-01	1.4 E-03		
Naphthalene ^b					9.7 E+01	1.9 E-01		
Perchloroethylene ^b					1.2 E-01	2.4 E-04		
Toluene ^b							3.5 E-01	7.0 E-04
Trichloroethene ^b					3.0 E-02	6.0 E-05		

^a Units are pollutants emitted of dry sludge burned. Source Classification Code 5-01-005-16. Blanks indicate no data.

^b Hazardous air pollutants listed in the *Clean Air Act*.

Table 2.2-8 (Metric And English Units). METAL EMISSION FACTORS FOR FLUIDIZED BED SEWAGE SLUDGE INCINERATORS^a

EMISSION FACTOR RATING: E

EMISSION FACTORS

Pollutant	Uncontrolled		Impingement		Venturi/Impingement		Venturi/Impingement/ Wet ESP ^b	
	g/Mg	lb/ton	g/Mg	lb/ton	g/Mg	lb/ton	g/Mg	lb/ton
Aluminum					1.9 E+00	3.8 E-03		
Arsenic ^c	2.2 E+00	4.4 E-03			1.5 E-02	3.0 E-05	5.0 E-03	1.0 E-05
Barium					2.4 E-01	4.8 E-04		
Beryllium ^c					2.0 E-04	4.0 E-07	2.0 E-04	4.0 E-07
Cadmium ^c	2.2 E+00	4.4 E-03	4.0 E-01	8.0 E-04	5.7 E-01	1.1 E-03	1.0 E-03	2.0 E-06
Calcium ^c					5.2 E+00	1.0 E-02		
Chromium ^c			3.2 E-01	6.4 E-04	2.5 E-01	5.0 E-04	3.0 E-02	6.0 E-05
Copper					3.0 E-01	6.0 E-04		
Manganese ^c					3.0 E-01	6.0 E-04		
Magnesium					6.0 E-01	1.2 E-03		
Mercury ^c					3.0 E-02	6.0 E-05		
Nickel ^c	1.78 E+01	3.5 E-02			1.7 E+00	3.4 E-03	5.0E-03	1.0E-05
Potassium					6.0 E-01	1.2 E-03		
Selenium ^c					2.0 E-01	4.0 E-04		
Silicon					3.2 E+00	6.4 E-03		
Sulfur					8.6 E+00	1.7 E-02		
Tin					3.5 E-01	7.0 E-04		
Titanium					4.0 E-01	8.0 E-04		
Zinc					1.0 E+00	2.0 E-03		

^a Units are pollutants emitted of dry sludge burned. Source Classification Code 5-01-005-16.^b Wet ESP = wet electrostatic precipitator.^c Hazardous air pollutants listed in the *Clean Air Act*.

Table 2.2-9 (Metric And English Units). SUMMARY OF EMISSION FACTORS FOR ELECTRIC INFRARED SEWAGE SLUDGE INCINERATORS^a

EMISSION FACTOR RATING: E

Source Category ^b	Particulate Matter		Sulfur Dioxide		Nitrogen Oxides	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Uncontrolled	3.7 E+00	7.4 E+00	9.2 E+00	1.8 E+01	4.3 E+00	8.6 E+00
Controlled						
Cyclone						
Cyclone/impingement						
Cyclone/venturi	1.9 E+00	3.8 E+00				
Cyclone/venturi/impingement						
Electrostatic precipitator						
Fabric filter						
Impingement	8.2 E-01	1.6 E+00				
Venturi						
Venturi/impingement/ afterburner						
Venturi/impingement	9.5 E-01	1.9 E+00	2.3 E+00	4.6 E+00	2.9 E+00	5.8 E+00
Venturi/impingement/ Wet ESP						
Venturi/Wet ESP						

^a Units are pollutants emitted of dry sludge burned. Source Classification Code 5-01-005-17.

^b Wet ESP = wet electrostatic precipitator.

Table 2.2-10 (Metric And English Units). CUMULATIVE PARTICLE SIZE DISTRIBUTION FOR SEWAGE SLUDGE INCINERATORS^a

EMISSION FACTOR RATING: E

Particle Size (μm)	Cumulative Mass % Stated Size				
	Uncontrolled		Controlled (Scrubber)		
	MH ^b	EI ^c	MH	FB ^d	EI
15	15	43	30	7.7	60
10	10	30	27	7.3	50
5.0	5.3	17	25	6.7	35
2.5	2.8	10	22	6.0	25
1.0	1.2	6.0	20	5.0	18
0.625	0.75	5.0	17	2.7	15

^a Reference 5.

^b MH = multiple hearth incinerator. Source Classification Code (SCC) 5-01-005-15.

^c EI = electric infrared incinerator. SCC 5-01-005-17.

^d FB = fluidized bed incinerator. SCC 5-01-005-16.

Table 2.2-11 (Metric And English Units). CUMULATIVE PARTICLE SIZE-SPECIFIC EMISSION FACTORS FOR SEWAGE SLUDGE INCINERATORS^a

EMISSION FACTOR RATING: E

Particle Size (µm)	Cumulative Emission Factor									
	Uncontrolled				Controlled (Scrubber)					
	MH ^b		EI ^c		MH		FB ^d		EI	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
15	6.0 E+00	1.2 E+01	4.3 E+00	8.6 E+00	1.2 E-01	2.4 E-01	2.3 E-01	4.6 E-01	1.2 E+00	2.4 E+00
10	4.1 E+00	8.2 E+00	3.0 E+00	6.0 E+00	1.1 E-01	2.2 E-01	2.2 E-01	4.4 E-01	1.0 E+00	2.0 E+00
5.0	2.1 E+00	4.2 E+00	1.7 E+00	3.4 E+00	1.0 E-01	2.0 E-01	2.0 E-01	4.0 E-01	7.0 E-01	1.4 E+00
2.5	1.1 E+00	2.2 E+00	1.0 E+00	2.0 E+00	9.0 E-02	1.8 E-01	1.8 E-01	3.6 E-01	5.0 E-01	1.0 E+00
1.0	4.7 E-01	9.4 E-01	6.0 E-01	1.2 E+00	8.0 E-02	1.6 E-01	1.5 E-01	3.0 E-01	3.5 E-01	7.0 E-01
0.625	3.0 E-01	6.0 E-01	5.0 E-01	1.0 E+00	7.0 E-02	1.4 E-01	8.0 E-02	1.6 E-01	3.0 E-01	6.0 E-01

^a Reference 5.

^b MH = multiple hearth incinerator. Source Classification Code (SCC) 5-01-005-15.

^c EI = electric infrared incinerator. SCC 5-01-005-17.

^d FB = fluidized bed incinerator. SCC 5-01-005-16.

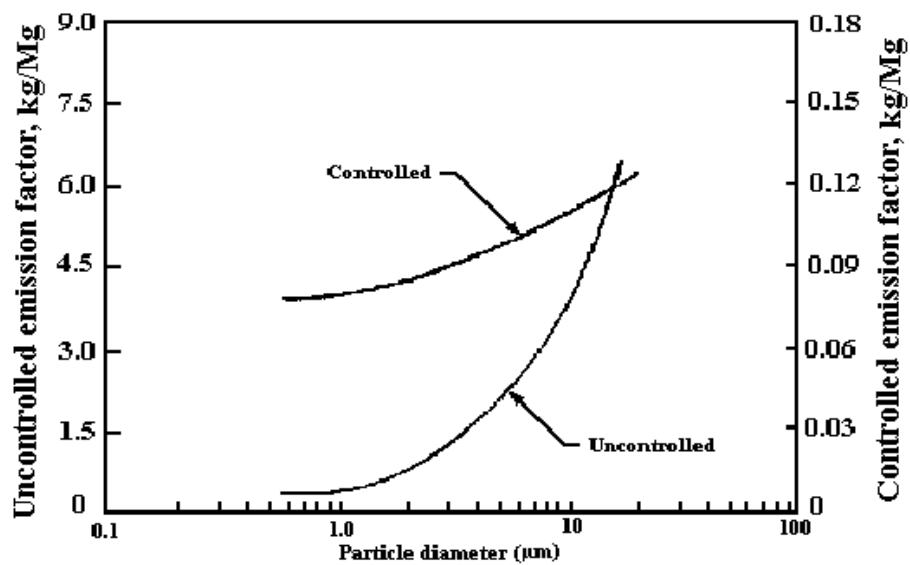


Figure 2.2-4. Cumulative Particle Size Distribution and Size-Specific Emission Factors for Multiple-Health Incinerators

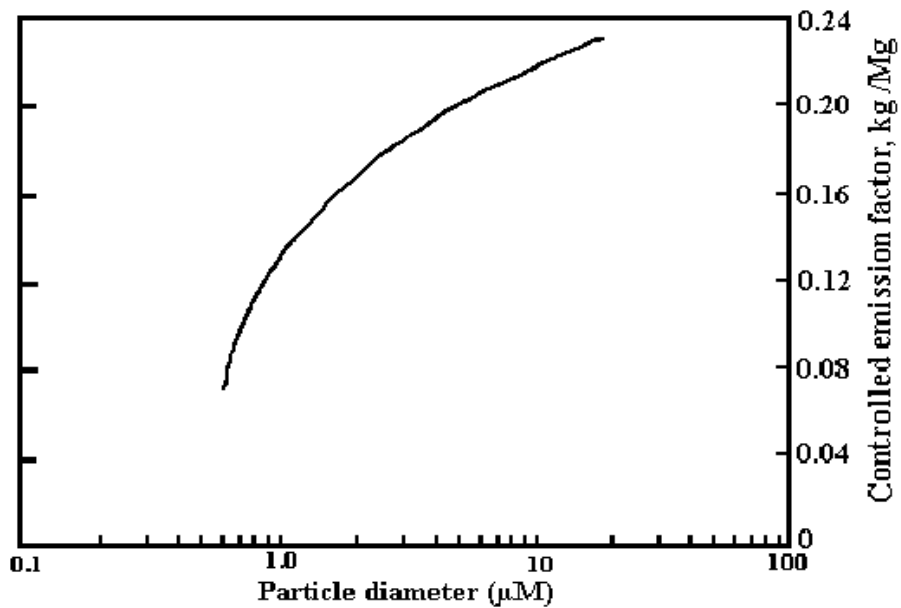


Figure 2.2-5. Cumulative Particle Size Distribution and Size-Specific Emission Factors for Fluidized-Bed Incinerators

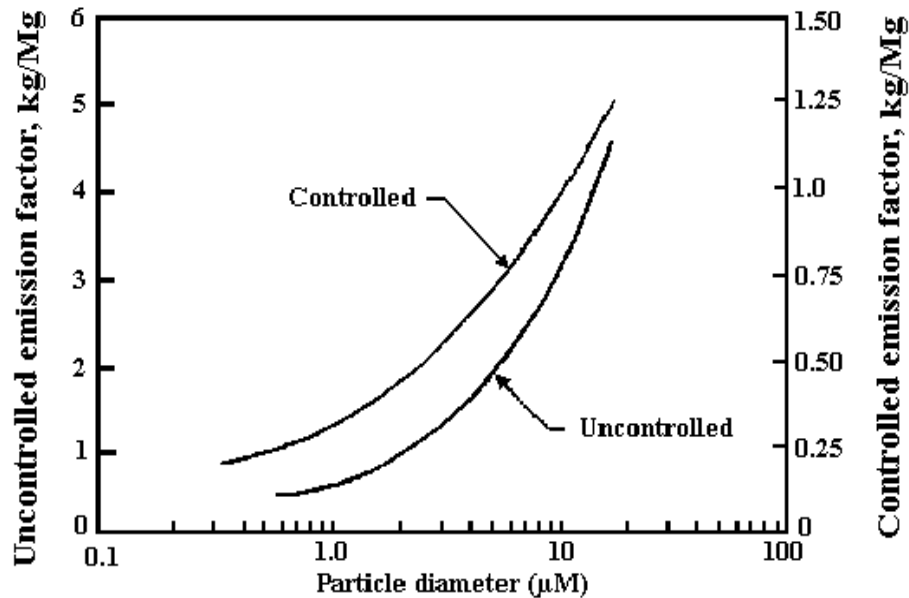


Figure 2.2-6. Cumulative Particle Size Distribution and Size-Specific Emission Factors for Electric (infrared) Incinerators

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