EMISSION FACTOR DOCUMENTATION FOR

AP-42 SECTION 2.2

SEWAGE SLUDGE INCINERATION

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Office of Air and Radiation
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1.0 INTRODUCTION

The document "Compilation of Air Pollutant Emission Factors" (AP-42) has been published by the U.S. Environmental Protection Agency (EPA) since 1972. Supplements to AP-42 have been routinely published to add new emission source categories and to update existing emission factors. AP-42 is routinely updated by EPA to respond to new emission factor needs of EPA, state, and local air pollution control programs and industry.

An emission factor relates the quantity (weight) of pollutants emitted to a unit of activity of the source. The uses for the emission factors reported in AP-42 include:

1. Estimates of area-wide emissions;
2. Emission estimates for a specific facility; and
3. Evaluation of emissions relative to ambient air quality.

The purpose of this report is to provide background information from test reports to support calculation of emission factors for sewage sludge incinerators (SSI). Including the introduction (Chapter 1.0), this report contains five chapters. Chapter 2.0 gives a description of the sewage sludge incineration industry. It includes a characterization of the industry, an overview of the different process types, a description of emissions, and a description of the technology used to control emissions resulting from sewage sludge incineration. Chapter 3.0 is a review of emissions data collection and analysis procedures. It describes the method used to locate and collect test data, the screening of emission data reports, and the quality rating system for both emissions data and emission factors. Chapter 4.0 details pollutant emission factor development. It includes the review of specific data sets, the results of data analysis, and the data base protocol. Chapter 5.0 presents the AP-42 Section 2.5.

2.0 INDUSTRY DESCRIPTION

Incineration is a means of disposing of sewage sludge generated by the treatment of wastewater from residential, commercial, and industrial establishments. When compared to other forms of disposal, incineration has the advantages of reducing the solid mass, destroying or reducing the organic matter present in the sludge, and the potential for recovering energy through combustion. Disadvantages include the necessity of ash disposal and the potential for air emissions of pollutants.

This section provides background information on the current status of sewage sludge incineration. In Section 2.1, the sewage sludge incineration industry is briefly overviewed. Incinerator and emission control design are described in detail in Sections 2.2 and 2.3, respectively.

2.1 CHARACTERIZATION OF THE INDUSTRY

There are currently about 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.[1] Some sludge is co-fired with municipal solid waste in combustors based on refuse combustion technology. Unprocessed refuse co-fired with sludge in combustors based on sludge incinerating technology is limited to multiple hearth incinerators. Over 80 percent of the identified operating sludge incinerators are of the multiple hearth design. About 15 percent are fluidized bed combustors and about 3 percent are electric. The remaining combustors co-fire refuse with sludge.

Most SSI facilities 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 21 and 19 sites, respectively.

Approximately 5.9 million dry megagrams (Mg) (6.5 million dry tons) of sludge are generated in U.S. municipal wastewater plants each year.[2] It is estimated that 25 percent of this sludge is incinerated.[3] This means that about 1.5 million dry Mg (1.6 million dry tons) of sludge is incinerated annually. A database containing results of the National Sewage Sludge Use and Disposal Survey conducted in 1988, and sponsored by the U.S. EPA, is available to the public from the National Technical Information Service (NTIS). The database contains general operating, financial, and use disposal practice data, as well as chemical concentrationss from sludge samples collected prior to disposal.

2.2 SLUDGE INCINERATION TECHNOLOGIES

Sewage sludge incineration refers to the oxidation of combustible materials generated by wastewater sewage treatment plants to reduce the volume of solid waste. The first step in the process of sewage sludge incineration is the dewatering of the sludge. Sludge is generally dewatered until it is about 15 to 30 percent solids. Above 25 percent solids, the sludge will usually burn without auxiliary fuel. After dewatering, the sludge is sent to the incinerator where thermal oxidation occurs. The unburned residual ash is removed from the incinerator, usually on a continuous basis, and is disposed. A portion of the noncombustible waste, as well as unburned volatile organic compounds, is carried out of the combustor through entrainment in the exhaust gas stream. Air pollution control devices, primarily wet scrubbers, are used to remove the entrained pollutants from the exhaust gas stream. The cleaned gas stream is then exhausted to the ambient air, and the collected pollutants, now suspended in the scrubber water, are sent back to the head of the wastewater treatment plant.

Several different incineration technologies are used for sewage sludge incineration. They include 1) multiple hearth, 2) fluidized bed, 3) electric, 4) co-incineration with refuse, 5) single hearth cyclone, 6) rotary kiln, and 7) high pressure, wet air oxidation. In this section, only the first four will be discussed in detail; multiple hearth and fluidized bed are most commonly used. The other technologies are not widely used in the United States.[4]

2.2.1 Multiple Hearth Furnaces

The multiple hearth furnace (MHF) 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. The basic multiple hearth furnace is a verticlly 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. Attached to the central shaft are the rabble arms, which extend above the hearths. Cooling air for the center shaft and rabble arms is introduced into the shaft by a fan located at its base. 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, then inside out, between hearths. Typically, the upper and lower hearths are fitted with 4 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 by conveyors or pumps. 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. On the next hearth, the sludge is raked in the opposite direction. This process is repeated in 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 one 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, and it usually has a higher heating value and a larger volatile fraction than sludge. Scum may be removed from many treatment units including pre-aeration 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 1,400°F). Sludge combustion occurs in the middle hearths (second zone) as the temperature is increased between 815 and 925°C (1,500 and 1,700°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 the afterburn process, furnace exhaust gases are ducted to a chamber where they are mixed with supplemental fuel and air and are 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 conditions, 50 to 100 percent excess air must be added to a 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 in order 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 are also used. Wet electrostatic precipitators (ESPs) are being installed as retrofits where tighter limits on particulates and metals are required by State regulations.

2.2.2 Fluidized Bed Incinerators

Fluidized bed technology was first developed by the petroleum industry to be used for catalyst regeneration. Fluidized bed technology was first used for municipal sludge incineration in 1962. Fluidized bed combustors (FBCs) consist of a verically 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 and ash, approximately 0.75 meters (2.5 feet) thick, rests upon the grid. Two general configurations are distinguished based on 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 bed of the furnace. Air injected through the tuyeres, at pressures from 20 to 35 kPa (3 to 5 psig), fluidizes the bed of hot sand and the incoming sludge. Temperatures of 750 to 925°C (1,380 to 1,700°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 1 percent for every 60 hours of operation.[4]

The overall process of 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 rapidly increases. In the second zone (freeboard area), the remaining free carbon and combustible gases are burned. The second zone functions essentially as an afterburner.

Fluidization of the bed 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 improved mixing and combustion provided by a fluidized bed incinerator is the lower 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.

2.2.3 Electric Incinerators

The first electric furnace was installed in 1975, and their use is not common. An electric incinerator consists 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 incinerators consist of a number of prefabricated modules that are linked together to provide the necessary furnace length.

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

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

2.2.4 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 one or more combustible waste materials are combined with sludge in a co-incineration scheme (i.e., municipal solid waste and sewage sludge), 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 waste material that can be burned can be combined with sludge in a co-incineration process. Common materials for co-incineration are municipal solid waste, wood waste, and agricultural 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 burning sludge with municipal solid waste (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 raw or 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.[5]

Sewage sludge can also be co-fired with a non-waste material such as coal in order to produce sustained combustion.

2.3 SEWAGE SLUDGE INCINERATION EMISSIONS AND CONTROL TECHNOLOGIES

2.3.1 Pollutant Emissions

Sewage sludge incinerators can 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 (SO_2), and 6) unburned hydrocarbons. Partial combustion of sludge can result in emissions of intermediate products of incomplete combustion (PICs) including toxic organic compounds.

Uncontrolled particulate emission rates vary widely depending on the type of incinerator, the volatile compound and moisture contents 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 air flow and particulate emissions.

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

Carbon monoxide is formed when available oxygen is insufficient for complete combustion or when combustion temperatures are too low. When incomplete combustion occurs, CO is formed in place of CO_2.

Nitrogen and sulfur oxide emissions 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 also vary greatly with incinerator type and operation. Incinerators with countercurrent air flow 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 easily volatalized from the solids are immediately vented from the furnace at temperatures too low to completely destruct them.

2.3.2 Control Technologies

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 also employed, primarily where sludge is co-fired with municipal solid waste.

There are three basic types of wet scrubbers:

1. Low energy (spray tower), primarily for acid gas control;
2. Medium energy (impingement scrubbers such as packed column, baffle plate, and liquid impingement) for PM and/or acid gas control; and
3. High energy (venturi), primarily for PM control.

Low energy scrubbers (spray towers) are usually circular in cross-section. The liquid is sprayed down the tower as the gases rise. Acid gases are absorbed/neutralized by the scrubbing liquid. Large particles are removed by impingement on the liquor pool, and finer particles are removed as the flue gas rises through the tower. Low energy scrubbers mainly remove particles larger than 5-10 microns.[7]

Medium energy devices mostly rely on impingement to facilitate removal of PM. This can be accomplished through a variety of configurations, such as packed columns, baffle plates, and liquid impingement scrubbers.

High energy venturi scrubbers are designed for applications requiring high removal efficiencies of submicron particles. They are often used for PM removal. A typical venturi scrubber consists of a converging section, a throat, and a diverging section.

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 some 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. In some cases, hot flue gas from the incinerator passes through a waste heat boiler for steam generation before going to the gas 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 surface. 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 and pressure drop increase. Up to a certain point, increasing the venturi pressure drop increases the removal efficiency.

Venturi scrubbers typically attain 60 to 99 percent removal efficiency for particulate matter, depending on pressure drop and particle size distribution.[6]

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. A mist eliminator at the top of the tower reduces 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.

Control devices such as fabric filters and dry ESPs are generally not used to control emissions from sewage sludge incinerators due to the high moisture content of the emission stream.

REFERENCES FOR CHAPTER 2.0

1. U.S. Environmental Protection Agency. Second Review of Standards of Performance for Sewage Sludge Incinerators, EPA-450/3-84-010, Research Triangle Park, NC, March 1984.

2. Environmental Regulations and Technology: Use and Disposal of Municipal Wastewater Sludge, EPA 625/10-84-003, U.S. Environmental Protection Agency Technology Transfer, September 1984.

3. U.S. Environmental Protection Agency. Seminar Publication: Municipal Wastewater Sludge Combustion Technology, EPA/626/4-85/015, Cincinnati, OH, September 1985.

4. Radian Corporation. Locating and Estimating Air Toxics Emissions from Sewage Sludge Incinerators, Research Triangle Park, NC, April 30, 1989.

5. U.S. Environmental Protection Agency. Process Design Manual for Sludge Treatment and Disposal, EPA-625/1-79-011, Cincinnati, OH, September 1979.

6. U.S. Environmental Protection Agency. Control Techniques for Particulate Emissions from Stationary Sources--Volume 1, EPA-450/3-81-005a, Research Triangle Park, NC, September 1982.

7. Radian Corporation. Hospital Waste Combustion Study: Data Gathering Phase. Prepared for the U.S. Environmental Protection Agency, Research Triangle Park, NC, EPA-450/3-88-017, December 1988.

8. Parish, M.G., Cleaver Brooks. Incinerator Heat Recovery and Its Effect on Air Pollution Control Selection. Presented at the 3rd National Symposium on Infectious Waste Management, Chicago, IL, April 18, 1989.

3.0 GENERAL DATA REVIEW AND ANALYSIS PROCEDURES

3.1 LITERATURE SEARCH AND SCREENING

The first step of this investigation involved a search primarily to identify recently-published literature relating to criteria and noncriteria pollutant emissions associated with sewage sludge incineration. This task included an extensive literature search, contacts to identify ongoing projects within EPA, and electronic database searches. Source test reports and background documents for the previous AP-42 section on sewage sludge incinerators were also retrieved from the EPA.

The literature search conducted for the update of this section included on-line library system searches of the Office of Research and Development/National Technical Information Service (ORD/NTIS) Database and the NSPS/CTG/CTC database. The Crosswalk/Air Toxics Emission Factors (XATEF), VOC/PM Chemical Speciation (SPECIATE), and the Aerometric Information Retrieval System (AIRS)/Facility Subsystem Emission Factors (AFSEF) electronic databases were also searched.

Contact was also made with the EPA's Office of Water (Alan Rubin), Risk Reduction Engineering Laboratory (Harry Bostian), and Emission Standards Division (Gene Crumpler), and the author of the AP-40 sewage sludge incineration chapter (Cal Brunner).

3.2 LITERATURE AND DATA REVIEW

To reduce the large amount of literature collected to a final group of references pertinent to this report, the following general criteria were used:

- Only primary references of emissions data were used.
- Test study source processes were clearly identified.
- Test studies specified whether emissions were controlled or uncontrolled.
- Studies referenced for controlled emissions specify the control device.
- Data support (i.e., calculation sheets, sampling and analysis description) was supplied.

- Test study units were convertible to selected reporting units.
- Test studies that were positively biased to a particular situation were excluded.

A final set of reference materials was compiled after a thorough review of the pertinent reports, documents, and information according to these criteria.

3.2 EMISSION DATA QUALITY RATING SYSTEM

As delineated by the Emission Inventory Branch (EIB), the reduced data set was ranked for quality. The ranking of the data was used to identify questionable data. Each data set was ranked as follows:

A - When tests were performed by sound methodology and reported in enough detail for adequate validation. These tests are not necessarily EPA reference test methods, although such reference methods are preferred.

B - When tests were performed by a generally sound methodology, but lack enough detail for adequate validation.

C - When tests were based on an untested or new methodology or are lacking a significant amount of background data.

D - When tests were based on a generally unacceptable method but the method may provide an order-of-magnitude value for the source.[1]

The selected rankings were based on the following criteria:

- Source operation. The manner in which the source was operated is well documented in the report. The source was operating within typical parameters during the test.
- Sampling procedures. The sampling procedures conformed to a generally acceptable methodology. If actual procedures deviated from accepted methods, the deviations are well documented. When this occurs an evaluation is made of the extent such alternative procedures could influence the test results.
- Sampling and process data. Many variations can occur unnoticed and without warning during testing. Such variations can induce wide deviations in sampling results. If a large spread between test results cannot be explained by information contained in the test report, the data are suspect and are given a lower rating.

- Analysis and calculations. The test reports contain original raw data sheets. The nomenclature and equations used were compared to those (if any) specified by EPA to establish equivalency. The depth of review of the calculations was dictated by the reviewer's confidence in the ability and conscientiousness of the tester, which in turn was based on factors such as consistency of results and completeness of other areas of the test report.

3.3 PARTICLE SIZE DETERMINATION

There is no one method which is universally accepted for the determination of particle size. A number of different techniques can be used which measure the size of particles according to their basic physical properties. Since there is no "standard" method for particle size analysis, a certain degree of subjective evaluation was used to determine if a test series was performed using a sound methodology for particle sizing.

For pollution studies, the most common types of particle sizing instruments are cyclones and cascade impactors. Traditionally, cyclones have been used as a precipitator ahead of a cascade impactor to remove the larger particles. These cyclones are of the standard reverse-flow design whereby the flue gas enters the cyclone through a tangential inlet and forms a vortex flow pattern. Particles move outward toward the cyclone wall with a velocity that is determined by the geometry, size and flow rate of the cyclone. Large particles are propelled by centrifugal force towards the wall and are collected. A series of cyclones with progressively decreasing cut-points can be used to obtain particle size distributions.

Cascade impactors used for the determination of particle size in process streams consist of a series of plates or stages containing either small holes or slits with the size of the openings decreasing from one plate to the next. In each stage of an impactor, the gas stream passes through the orifice or slit to form a jet that is directed toward an impaction plate. For each stage, there is a characteristic particle diameter that has a 50 percent probability of impaction. This characteristic diameter is called the cut-point (D50) of the stage. Typically, commercial instruments have six to eight impaction stages with a backup filter to collect those particles which are either too small to be collected by the last stage or which are retrained off the various impaction surfaces by the moving gas stream.

3.4 PARTICULATE SIZE DATA ANALYSIS METHODOLOGY

The particulate emission information contained in the various reference documents was reduced to a common format using a family of computer programs developed especially for this purpose. These programs use the so-called "spline" fits. Spline fits result in cumulative mass size distributions very similar to those which would be drawn using a French curve and fully logarithmic graph paper. In effect, the logarithm of cumulative mass is plotted as a function of the logarithm of the particle size, and a smooth curve with a continuous, non-negative derivative is drawn.

The process by which this smooth cumulative distribution is constructed involves passing an interpolation parabola through three measured data points at a time. The parabola is then used to interpolate additional points between measured values. When the set of interpolated points are added to the original set of data, a more satisfactory fit is obtained than would be the case using only the measured data. The size-specific emission factors are determined once the size distribution is obtained by a spline fit.

3.5 EMISSION FACTOR QUALITY RATING SYSTEM

The quality of the emission factors developed from analysis of the test data was rated utilizing the following general criteria:

A - Excellent. Developed only from A-rated test data taken from many randomly chosen facilities in the industry population. The source category is specific enough to minimize the variability within the source population.

B - Above average. Developed only from A-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industries. As with the A rating, the source category is specific enough to minimize the variability within the source population.

C - Average. Developed only from A- and B-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As with the A rating, the source category is specific enough to minimize the variability within the source population.

D - Below average. The emission factor was developed only from A- and B-rated test data from a small number of facilities, and there is reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Any limitations on the use of the emission factor are noted in the emission factor table.

E - Poor. The emission factor was developed from C- and D-rated test data, and there is reason to suspect that the facilities tested do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of these factors are always clearly noted.[1]

The use of these criteria is somewhat subjective and depends to an extent on the individual reviewer. Details of the rating of each candidate emission factor are provided in Chapter 4 of this report.

REFERENCES FOR CHAPTER 3.0

1. Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections. Draft, Emission Inventory Branch, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. March 6, 1992.

2. Interim Report to State/Local APC Agencies of Particle Size Distributions and Emission Factors (Including PM10), Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. July 1986.

3. Lime and Cement Industry--Source Category Report. Volume II--Cement Industry, EPA Contract No. 68-02-3891, Midwest Research Institute, Kansas City, Missouri. August 1986.

4.0 POLLUTANT EMISSION FACTOR DEVELOPMENT

This chapter describes the test data and methodology used to develop pollutant emission factors for the sewage sludge incineration industry.

4.1 REVIEW OF SPECIFIC DATA SETS

A total of 108 references were documented and reviewed during the literature search. These references are listed at the end of this chapter.

The following efforts were made to ensure that the selection and rating of reference documents did not introduce a bias in the data. The majority of references used were compliance test reports. Given the impetus for compliance testing, these reports would be expected to characterize facilities with various levels of maintenance, operation, and control. The remaining references were classified as research or special study tests. In some cases, it could be reasoned that such studies would involve testing of facilities with above average maintenance, operation, and control and would, therefore, not be representative of the industry. Rather than downgrade the ratings for these references, each reference was considered on its own merit. The original group of 108 documents was reduced to a final set of primary references utilizing the criteria outlined in Chapter 3.0. For the reference documents not used, the reason(s) for rejection are summarized below:

Reference	Reason for Rejection
8	Back-half collection included in results
23	Control device not specified
31	Insufficient lab, process, analytical data
35b	Duplicate of test in References 34 n and s
36	Not primary data
37a,b	Insufficient lab, process, analytical data
38	Duplicate of test in Reference 4
41a-j	Test results based on only one run
46	Duplicate of test in Reference 42
50	Not primary data
51	Test results based on only one run
52	Insufficient process, control data

Reference	Reason for Rejection
55	Duplicate of test in Reference 30
56	Insufficient lab, process, analytical data
57	Insufficient lab, process, analytical data
58	Insufficient lab, process, analytical data
59	Test results on only one run
60	Test results on only one run
61	Test results on only one run
62	Insufficient lab, process, analytical data
63	Insufficient lab, process, analytical data
64	Insufficient lab, process, analytical data
65	Insufficient process data
66	Insufficient lab, process, analytical data
73	Control device not specified
74	Averages cannot be converted into selected reporting units
76	Scale-reading problems during test
82	Insufficient lab, process, analytical data
83	Duplicate of tests in Reference 5
94	Insufficient process data
100	Summary of tests in Referencees 104, 106, 107
103	Insufficient process data
105	Insufficient process data

The following is a discussion of the data contained in each of the primary references used to develop candidate emission factors.

4.1.1 References 1 Through 3

References 1 through 3 are tests performed on three different sludge incinerators by an EPA contractor. These tests were performed to gather emission data for a study conducted under Tier 4 of the National Dioxin Study. The primary objective of the tests was to determine the presence of dioxins and/or furan emissions from the incineration process. Controlled data for these emissions are provided in References 1 and 2. Reference 3 contains controlled and uncontrolled emissions data. In References 1 and 3, testing results were also presented for uncontrolled emissions of oxides of nitrogen (NO_x), sulfur dioxide (SO_2), and carbon monoxide (CO). Uncontrolled nonmethane volatile organic compound (VOC) emissions results were provided in References 1 and 2. These values were obtained from continuous monitoring of the combustion gases during the dioxin/furan tests.

A rating of A was assigned to the data in each of the tests for criteria pollutants.

4.1.2 Reference 4

This report comprises emission tests performed on a fluidized-bed incinerator to demonstrate the relationship between the temperature of incineration and the emissions of certain trace metals. The tests were performed at three different operating temperatures. Results were obtained for controlled emissions of total particulate matter and metals (arsenic [As], cadmium [Cd], chromium [Cr], lead [Pb], and nickel [Ni]). Modified Method 5 and source assessment sampling system (SASS) train results were presented for each test, but the report states that SASS train results were used in preference to the Modified Method 5 results because approximately 10 times as much flow was sampled by the SASS train method. Metal emissions did increase with increasing incineration temperature. Operating temperatures for a fluidized-bed incinerator usually range from 680 to 820^oC (1250 to 1500^oF). These tests were conducted at 704, 816, and 927^oC (1300, 1500, and 1700^oF). The data in this report were assigned a rating of B. Particle size determinations for controlled emissions were made by sampling with an Andersen Cascade Impactor.

4.1.3 References 5o through 5r

These references contain data from particulate and gaseous emissions tests conducted at four sludge incinerators. Each test provides controlled particulate matter emission data, and, except for incinerator "q," uncontrolled data are also presented. Controlled emission factors for Cd, Cr, Pb, SO_2, and H_2SO_4 are presented for each incinerator. Data from incinerator "p" include controlled results for Ni. Uncontrolled emission factors for SO_2 and H_2SO_4 are presented for incinerators "o," "p," and "r."

A rating of A was assigned to the data for incinerators "o" and "p." These reports provided adequate detail for validation, and the methodology appeared to be sound. The report for incinerator "q" did not contain sufficient process information to determine whether the incinerator was operating within design specifications. The report for incinerator "r" showed a wide, unexplained deviation in test results. For these reasons, References 5q and 5r were given a B rating.

4.1.4 References 6 and 7

These are chromium and organics screening study test reports. The tests were conducted by an EPA contractor on two incinerators located at the same site. Tests were conducted at the inlet and outlet of the scrubber to determine the concentration and mass emission rates of total particulate matter, semivolatile organic compounds and VOCs. Results were also obtained for controlled methane VOC emissions.

Total particulate matter emissions were determined using EPA Method 5. Volatile organic compounds were measured with a Volatile Organic Sampling Train (VOST) and semivolatile organic compound emissions were determined using Modified Method 5 with an XAD-2 resin trap. The data for metals, semivolatile organic compounds, and total particulate matter presented in Reference 7 were assigned a rating of A. The report states that the VOC results must be considered as "estimates" because the samples saturated the analytical systems during analysis. Further, the inlet results were obtained from one incinerator and the outlet results from another. Therefore, the volatile organic emission results were assigned a rating of D and will be used for "order-of-magnitude" values only.

Particle size distribution measurements were made at the scrubber inlet and outlet. Four samples were collected at the scrubber inlet and five at the scrubber outlet. Particle size fractions were analyzed gravimetrically. Because the Method 5 particulate matter tests were conducted at the same time the particle size determinations were made, the results can be used in the development of particle size-specific emission factors.

4.1.5 References 9 through 13

These are the results of five particulate matter emissions compliance tests performed on five different sludge incinerators located at one treatment plant. Each test was conducted in accordance with EPA Methods 1 through 5 and provided controlled emissions data.

It was determined that the tests were generally of good quality. However, original raw field data sheets, laboratory data sheets, and sampling train calibration data were not included with the reports. For this reason, a rating of B was assigned to the test data in these references.

4.1.6 References 14 and 15

These are reports of compliance tests conducted to determine particulate matter emissions from two different sludge incinerators. Each test was performed in accordance with EPA Methods 1 through 5 and provided controlled emissions data. The quality of each test was generally good. However, in each case, information pertaining to design operating parameters (e.g., sludge feed rate) was not provided; thus, it could not be determined if the sources were operating within typical ranges of these parameters. Therefore, the test data from these references were assigned a rating of B.

4.1.7 Reference 16

Reference 16 is a particulate matter emissions compliance test report that provides controlled emissions data. The tests were performed in accordance with EPA Methods 1 through 5. The quality of the tests and process description provided were good, and the information required was complete. A rating of A was assigned to the test data.

4.1.8 References 17 through 20

References 17 and 18 contain the results of two compliance tests for one incinerator. References 19 and 20 contain information from compliance tests for two incinerators at another site. For each test, EPA Methods 1, 2, 3, and 5 were used to provide controlled particulate matter emissions data.

The quality of each test was good, and enough detail was provided for adequate validation. The test data from each reference were assigned a rating of A.

4.1.9 Reference 21

Reference 21 is a source sampling report of testing performed concurrently at the sludge incinerator scrubber inlet and scrubber stack to determine particulate matter emissions and particle size distributions. The results of the EPA Method 5 tests provided controlled and uncontrolled particulate matter emissions data.

The tests were of good quality and all necessary data pertaining to process descriptions and sampling and analytical data were provided. However, because design parameters for the incinerator were missing, it is not known if the source was operating within typical ranges for these parameters during the test. Because of this, the data were rated B. Particle sizing was performed using a cascade impactor attached to a probe on the Method 5 sampling train. The report presents the scrubber collection efficiencies by particle size range.

4.1.10 References 22a through 22d

These compliance test reports present controlled particulate emissions data for incinerators within the same metropolitan sewer district. The tests were performed using EPA Methods 1 through 5. While the testing methodology appears to be sound, all four reports lacked enough detail for adequate validation. Field, laboratory, and calibration data were not provided in the reports. In addition, the conditions under which the source was operated were not well documented. For these reasons, each of the four tests was assigned a C rating.

4.1.11 References 24 and 25

These are reports of two particulate matter emissions compliance tests performed on the same incinerator at different times. The testing methodology was sound, and the level of detail of the documentation was adequate (except for missing design parameters). However, the results of the tests, taken only 1 month apart, show a wide deviation. Particulate matter emissions averaged 1.62 kilograms per dry megagram of sludge (3.25 pounds per dry ton of sludge) in the first test and 0.36 kilograms per dry megagram of sludge (0.73 pounds per dry ton of sludge) in the second test. While there may be a reasonable technical explanation for the deviation, none was provided. Therefore, each test was assigned a C rating.

4.1.12 <u>References 26 through 29</u>

These are reports of compliance tests conducted on four different sludge incinerators. Results are presented for controlled emissions of total particulate matter, NO_x (for References 26 through 28), SO_2, acid gases (HCl for References 26 through 28, and H_2SO_4 for Reference 27), and methane VOC. Reference 29 also contains controlled CO emission data. Reference 28 contains controlled Pb and Hg emissions data. Controlled metal emissions data are included in References 26 and 28 for As, Cd, Cr, and Ni. Metal emissions data from Reference 27 were not used because, according to information obtained from the State agency, the results were based on sludge analysis.

The testing methodology for each test appeared to be generally sound. Each of the reports lacked sufficient detail for adequate validation of the results. Also, this State requires front- and back-half collections to be included in particulate matter emission results, and the reports did not include a breakdown of the collections. The State agency was contacted for additional information including dry feed rates for each of the test runs and weights for the front-half collections of particulate matter.

Because raw data sheets, design feed rates, and other process data were missing from the reports, each data set was rated B.

4.1.13 <u>Reference 30</u>

Reference 30 is a particulate matter emissions compliance test report. Sufficient documentation was provided for validation and the testing methodology was generally sound. However, the first run of the test was made with the percentage of isokinetic nozzle velocity less than the desired minimum of 90. The report discussion mentions this deviation and states that corrections were made for this in the report. Nevertheless, it was decided that only the second and third runs would be used in determining the average emission value for this test. A rating of B was assigned to the data.

4.1.14 Reference 32

This compliance report presented the results for particulate matter emissions testing of one sludge incinerator. The testing methodology was sound and the level of documentation was sufficient for validation purposes. However, background data pertaining to the source operation and design parameters were not provided. For this reason, the data were assigned a B rating.

4.1.15 Reference 33

Reference 33 is a particulate matter emissions compliance report for one sludge incinerator. The tests were performed in accordance with EPA Method 5 and provided controlled emissions data. Complete background information and testing details were provided. The data were given an A rating.

4.1.16 Reference 34n and s

This report presents the results of a source emissions survey conducted for an incineration systems manufacturer. Testing was performed on two incinerators at one site to determine particulate matter concentrations at both the scrubber inlet and outlet. Tests at the scrubber inlet consisted of one run for each incinerator and both back- and front-half collections were used. Three runs were used for each outlet test, and the results were based on the front-half collections only.

The testing methodology was sound and the source process was described adequately. Original field data, calibration information, and laboratory analysis sheets were not included in the report. For this reason, the controlled (outlet) data for each test were given a B rating. Uncontrolled (inlet) data were assigned a D rating because the results were based on a single run. These data (using the front-half collection results only) may provide an order-of-magnitude value for the source.

Particle size distribution for uncontrolled emissions was determined using a Coulter Counter. Results of particle sizing are presented in Reference 35b (a duplicate of the particulate emissions test described in Reference 34).

4.1.17 References 35a, 35c, 35d, and 35e

These are reports presenting emission data for four infrared sludge incinerators. Each of the reports provides controlled particulate matter emission data, and Reference 35e provides uncontrolled data as well. Reference 35e also presents emissions data for NO_x and SO_2 before and after the control device.

The data are part of summary reports compiled for an incinerator manufacturer, and background information was not included. Raw data, analytical reports, sampling procedures, calibration information, and process descriptions were missing. Because of these deficiencies, each of the tests was assigned a C rating.

References 35a and 35e provided controlled and uncontrolled particle size data. In the case of Reference 35a, the uncontrolled particulate size distribution data were established 5 months after the particulate loading tests. Therefore, these data cannot be used.

4.1.18 References 39 and 40

These reports are part of research projects designed to investigate the performance of air pollutant abatement systems for controlling metals and organics emitted from sewage sludge incinerators. The tests were conducted by an EPA contractor to determine the efficiency of an ESP and a baghouse, respectively. In each case, testing was done on incinerators with existing scrubber systems, and slipstreams were used for experimental testing of the control devices. Because comparative data were needed, the reports contain scrubber inlet and outlet data representing emissions not controlled by the ESP or the baghouse. Controlled and uncontrolled emissions data are provided in Reference 39 for particulate matter, As, Cd, Cr, Pb, and Ni. Uncontrolled emissions data are presented for nonmethane VOC's in both reports and for NO_x, CO, and SO_2 in Reference 39.

The methodologies were sound, and background information and documentation provided were complete in both reports. Therefore, both reports were assigned A ratings.

Each report provides controlled and uncontrolled particulate matter mass concentrations by SASS size fractions.

4.1.19 <u>References 42 through 44</u>

These are particulate matter emission compliance reports for sludge incinerators at three different sites. In each case, the methodologies were sound, and appropriate background information and documentation were provided. Each data set was given an A rating.

4.1.20 <u>Reference 45</u>

This is a particulate matter and sulfur dioxide emissions test report for a sludge incinerator. The report provides controlled emissions data for each of these pollutants. While the methodology used was sound, the report did not include sufficient background information to establish the design feed rate value. Therefore, a B rating was assigned to the data.

4.1.21 <u>Reference 47</u>

Reference 47 is a particulate matter emission compliance report for one sludge incinerator. Method 5 procedure was used for the test. The report did not include complete documentation for validation purposes, nor did it provide design parameters for the source. Therefore, the data were given a rating of B.

4.1.22 <u>References 48 and 49</u>

These references are reports of two particulate matter emission compliance tests for the same incinerator. The tests were done in 1982 and 1984. Each report contained documentation adequate for validation, and the test methodologies were deemed to be sound. An A rating was assigned to each.

4.1.23 <u>References 53 and 54</u>

These are reports of compliance tests performed on two different sludge incinerators. The reports contain controlled emissions data for particulate matter. Reference 53 also contains data for Hg emissions after the control device.

In each case, sound testing methodologies were used. However, each report lacked enough detail for adequate validation, e.g., source manner of operation was not well documented. The State agency was contacted to determine dry feed rates for use in emission factor calculations. Both reports were assigned a B rating.

4.1.24 References 67 through 72

References 67 through 72 comprise seven compliance tests on seven different sludge incinerators. Each of the reports presents controlled particulate matter emissions data. Other controlled emissions data reported include: Reference 68--NO_x, CO, and nonmethane VOC's; Reference 69--NO_x, SO_2, and methane VOC's; References 71 and 72--NO_x, and SO_2.

Each of the tests was considered to have used sound testing methodologies, and the reports included enough detail for adequate validation. The data were assigned an A rating in each case.

4.1.25 Reference 75

This is a report of a compliance test performed on one incinerator and provides controlled particulate matter emissions data. Sufficient process information and field data were provided for validation of the results. However, no information regarding the sampling procedures and test methodology was included with the report. The State agency was contacted for this information and confirmed that EPA Method 5 was used. The data were assigned a rating of A.

4.1.26 References 77 through 79

References 77 through 79 are reports of compliance tests performed on three different sludge incinerators. Each test report provides controlled particulate matter emissions data, and Reference 79 also provides controlled emissions data for nonmethane VOC's. For each test report, the methodology was judged to be sound. Each report included appropriate and complete background information with details sufficient for validation. The reports were assigned A ratings.

4.1.27 Reference 80

This is a report of a compliance test performed on one sludge incinerator. Controlled particulate matter emissions results are presented. Laboratory, calibration, and field data sheets were provided, but information pertaining to the source process was not included. The State agency was contacted to obtain this information. The data were assigned an A rating.

4.1.28 Reference 81

This compliance test report provides controlled emissions data for total particulate matter. The testing methodology was judged to be sound, and adequate detail was provided for validation. A rating of A was assigned to the data.

4.1.29 Reference 84

This test report provides controlled emissions data for noncriteria pollutants. The report included original raw field data sheets, laboratory data sheets, sampling train calibration data, and process data. The quality of each test was good. The data from the reference were assigned a rating of A.

4.1.30 References 85, 86, 87, and 88

These four reports (Sites 1 through 4) were all prepared under the same group of authors for the U.S. EPA Water Engineering Research Laboratory. Sites 1 and 2 are MHF facilities with venturi and impingement scrubber pollution controls. During testing, Site 1 handled 0.45 to 0.91 megagrams (Mg) per hour [0.5 to 1 ton per hour (tph)] of dry sludge feed, and Site 2 handled about 1.3 Mg/hr (1.5 tph). Controlled data only were available for Site 1, while both uncontrolled and controlled data were reported for Site 2. At Site 1, data collected were for 18 organic compounds, 5 metals, and total PM. At Site 2, data collected covered 20 organic compounds and 6 metals. Emission tests for metals were conducted for short-term and long-term conditions. Results of long-term tests were given an A rating. Results of short-term testing were assigned a B rating due to likelihood that fluctuations of results would occur. All other thes results were assigned an A rating.

Site 3 is a FBC with venturi and impingement scrubber pollution control devices. The facility processed an average of 0.9 Mg/hr (1 tph) of dry sludge during testing, and emissions data collected were for controlled emissions. Data collected covered 10 semivolatiles and 5 metals and were rated A.

Site 4 is another MHF. This facility used an afterburner, as well as venturi and impingement scrubbers for air pollution control. The MHF was fed approximately 0.5 Mg/hr (0.6 tph) dry sludge during testing. Pollutants were sampled at 3 different locations: (1) uncontrolled emissions after the incinerator, (2) emissions after the high energy scrubbers, and (3) emissions after the afterburner and high energy scrubbers. Semivolatiles and metals data were collected for all three operating conditions, and dioxins and furans data was collected for the third operating condition. All data were rated A.

4.1.31 References 89, 90, and 91

All three of these reports present information on the same MHF facility under a variety of test conditions. The facility is equipped with venturi and impingement scrubbers.

Reference 89 presents two sets of tests on inlet and outlet emissions from the venturi and impingement scrubbers during pilot-scale testing of a wet ESP and a baghouse. Information was reported for 9 organic compounds during one set of tests during the baghouse pilot-scale testing. Information was also reported for 19 organic compounds during one set of tests during the other set of tests conducted during the ESP pilot-scale testing. The data from Reference 89 were assigned a rating of A.

Reference 90 presents information on uncontrolled emissions from the incinerator, and outlet emissions from the venturi and impingement scrubbers and a wet ESP running in parallel. Information was reported for 24 metals in the uncontrolled and controlled emission samples. The information from this reference is rated B because some of the flue gas flow rates were calculated.

Reference 91 presents information on uncontrolled emissions from the incinerator, and outlet emissions from the venturi and impingement scrubberss an a fabric filter running in parallel. Information was reported for 24 metals in the uncontrolled and controlled emission samples. The information from this sample is rated A.

4.1.32 Reference 92

This report summarizes tests done at the Crenston facility on a multiple hearth furnace equipped with a venturi/impingement/afterburner for control. The report included information on dioxin/furan emissions and emissions of five metals. Because of the lack of background information, the data were rated C.

4.1.33 Reference 93

This report summarizes tests for dioxins and furans done on a multiple hearth incinerator. However, emissions were not measured at detectible levels. Therefore, results of this test report were not used.

4.1.34 Reference 95

Reference 95 presents information on tests done at a MHF using a venturi scrubber for control. The report presents information on 27 metals, dioxins/furans, and polycyclic aromatic hydrocarbons (PAH's) sampled at the venturi scrubber outlet. The information from Reference 95 was assigned a rating of B because field and analytical data sheets were not provided.

4.1.35 Reference 96

Reference 96 presents information on tests done at a MHF using a venturi scrubber for air pollution control. Emissions from the venturi outlet were sampled for 7 PAH's. The data from this report were assigned a rating of C because field and analytical data sheets were not included, and inadequate detail of sampling procedures was provided.

4.1.36 Reference 97

Reference 97 presents information on tests conducted at an FBC using venturi and impingement scrubbers for air pollution control. Emissions of 5 metals were tested at the outlet of the venturi/impingement control system. The data from this report were assigned a rating of C because field and analytical data sheets were not included in the report.

4.1.37 Reference 98

Reference 98 contains data for three MHFs and one FBC. Two of the MHF's and the FBC are controlled with an impingement scrubber. The remaining MHF is controlled with a cyclone scrubber. A total of 24 metals were tested at the inlet to and outlet from the control devices for the MHF's. Only outlet emissions from the FBC were reported. The information from this reference was assigned a rating of A.

4.1.38 Reference 99

Reference 99 contains data from tests done on one MHF using a venturi/impingement system for air pollution control. The report presents information on dioxins/ furans, 11 metals, 15 semi-volatile compounds, CO, HCl, and total PM exiting the scrubber system. The data were rated A.

4.1.39 Reference 101

Reference 101 is a test report on a MHF equipped with a cyclone/venturi system for air pollution control. Testing on the outlet emissions from the cyclone/venturi system was performed to determine the emissions of HCl, PM, 12 metals, dioxins/furans, PAH compounds, and 3 organics. Testing was performed during normal incinerator operation conditions with sludge feed rates between 1.5 and 1.7 tph (dry basis). The data are rated A.

4.1.40 Reference 102

Reference 102 contains data from tests conducted at a MHF equipped with a venturi/impingement control system followed by a wet ESP. Emissions of 9 metals were tested at the exit from the venturi/impingement system and after the wet ESP. Data from this report are rated C because no field or analytical data sheets were provided to validate the numbers reported.

4.1.41 References 104, 106, 107, and 108

These four reports (sites 6, 8, 9 and 10) are a continuation of those conducted in References 85-88 (sites 1-4). Sites 6, 9, and 10 are MHF facilities. Site 8 is an FBC facility.

Reference 104 presented data on 5 metals, PM and CO sampled at the inlet and outlet of a venturi/impingement air pollution control system. Two sets of results are reported: sampling during low CO operation and sampling during normal CO operation. The data from this reference are rated A.

Site 8 is equipped with venturi/impingement scrubbers followed by a wet ESP for air pollution control. Reference 106 presented data on 5 metals, SO_2, NO_X, and CO sampled at the inlet to the venturi/impingement scrubbers, inlet to the ESP (outlet from venturi/impingement), and outlet from the wet ESP. Also tested at the inlet to the wet ESP were 14 organic compounds and dioxins/furans. The data from this reference are rated A.

Site 9 is equipped with venturi/impingement scrubbers followed by a wet ESP for air pollution control. Reference 107 presented data on 6 metals, PM, SO_2, NO_X, CO, and organic compounds sampled at the inlet to the scrubbers, inlet to the ESP, and outlet from the ESP. However, data on the organic compounds could not be converted to an emission rate value because stack flow rates were not reported for this sampling run. Two sets of results were reported: sampling during low CO operation and sampling during normal CO operation. All other test data are rated A.

Site 10 is equipped with a cyclone and venturi for air pollution control. Reference 108 presented data on 21 organic compounds sampled at the outlet of the control system. Three sets of data were reported: tests conducted at low, medium and high THC levels. The data from this reference are rated B because field and analytical data sheets were not included.

4.2 RESULTS OF DATA ANALYSIS

Emission factor calculations were made in terms of weight of pollutant per weight of dry sludge incinerated. It should be noted that the terms "controlled" and "uncontrolled" in this discussion are indicative only of the location at which the measurements were made.

A summary of the particulate emission data discussed below is contained in Tables 4-1 and 4-2. Tables 4-3 through 4-7 present summaries of criteria pollutant (other than particulate matter) data, and Tables 4-8 through 4-55 contain summaries of noncriteria pollutant data. Table 4-56 summarizes the data presented in Tables 4-1 through 4-55.

TABLE 4-1. SUMMARY OF EMISSION FACTORS FOR PARTICULATE MATTER FROM SEWAGE SLUDGE INCINERATORS

Source category/ reference/rating	Uncontrolled, kg/Mg (lb/ton)	After control device kg/Mg (lb/ton)	Efficiency, percent
Multiple hearth			
Cyclone			
5r,b	23.1 (46.2)	1.17 (2.34)	94.9
79,a		2.930 (5.86)	
98,q	51 (102)	1.86 (3.6)	96.4
Cyclone/impingement			
78,a		0.404 (0.808)	
Cyclone/venturi			
10,b		0.240 (0.480)	
11,b		0.280 (0.560)	
13,b		0.150 (0.300)	
13,b		0.368 (0.736)	
101,a		0.21 (0.42)	
Cyclone/venturi/impingement			
39,a	15.9 (31.8)	0.309 (0.618)	98.1
Impingement			
5o,a	178 (356)	0.458 (0.916)	99.7
5p,a	13.4 (26.8)	1.72 (3.44)	87.2
7,a	7.7 (15.4)	0.108 (0.216)	98.6
9,b		0.916 (1.832)	
12,b		0.937 (1.874)	
22d,c		0.375 (0.750)	
30,b		0.233 (0.466)	
53,b		0.574 (1.148)	
54,b		0.521 (1.042)	
67,a		1.116 (2.232)	
68,a		1.16 (2.32)	
71,a		0.179 (0.358)	
72,a		0.726 (1.452)	
75,a		0.233 (0.466)	

TABLE 4-1. SUMMARY OF EMISSION FACTORS FOR PARTICULATE MATTER FROM SEWAGE SLUDGE INCINERATORS
(Continued)

Source category/ reference/rating	Uncontrolled, kg/Mg (lb/ton)	After control device kg/Mg (lb/ton)	Efficiency, percent
Venturi			
21,b	12.4 (24.8)	1.73 (3.46)	86.1
24,c		0.365 (0.730)	
25,c		1.625 (3.250)	
26,b		0.274 (0.548)	
27,b		7.065 (14.13)	
32,b		1.60 (3.20)	
47,b		0.540 (1.08)	
70,a		0.429 (0.859)	
77,a		0.880 (1.76)	
Venturi/impingement			
15,b		0.235 (0.470)	
16,a		0.411 (0.822)	
17,a		0.105 (0.210)	
18,a		0.270 (0.540)	
19,a		0.370 (0.740)	
20,a		0.290 (0.580)	
22a,c		0.925 (1.850)	
22b,c		0.460 (0.920)	
22c,c		0.865 (1.730)	
33,a		0.255 (0.510)	
42,a		0.165 (0.330)	
45,b		0.509 (1.018)	
48,a		0.910 (1.820)	
49,a		5.60 (11.2)	
80,a		0.636 (1.272)	
81,a		0.170 (0.340)	
91,a	6.50 (13.0)	0.35 (0.70)	94.6
98,a	211 (422)	2.5 (5.0)	93.2
104,a	103.01 (206.3)	1.64 (3.3)	98
104,a	97.8 (195.7)	1.45 (2.9)	96.5
107,a	13.2 (26.4)	1.74 (3.47)	86.8
107,a	115.5 (230.9)	1.57 (3.14)	99

TABLE 4-1. SUMMARY OF EMISSION FACTORS FOR PARTICULATE MATTER FROM SEWAGE SLUDGE INCINERATORS (Continued)

Source category/ reference/rating	Uncontrolled, kg/Mg (lb/ton)	After control device kg/Mg (lb/ton)	Efficiency, percent
Venturi/impingement/WESP			
107,a	115.5 (230.9)	0.18 (0.36)	99.8
Fabric filter			
91,a	0.20 (0.40)	0.002 (0.004)	99
Fluidized bed			
Cyclone/venturi/impingement			
43,a		0.431 (0.862)	
44,a		0.55 (1.10)	
Impingement			
5q,b		0.114 (0.228)	
14,b		0.149 (0.298)	
Venturi			
69,a		0.570 (1.140)	
Venturi/impingement			
4,b		0.090 (0.180)	
28,b		0.292 (0.584)	
29,b		0.427 (0.854)	
Venturi/impingement/WESP			
98,a		0.25 (0.5)	
106,a	230.5 (461.1)*	0.04 (0.08)	99.9
106,a	230.5 (461.1)*	0.01 (0.02)	100
Electric infrared			
Cyclone/venturi			
35c,c		1.93 (3.86)	
Impingement			
35a,c		0.821 (1.642)	

TABLE 4-1. SUMMARY OF EMISSION FACTORS FOR PARTICULATE MATTER FROM SEWAGE SLUDGE INCINERATORS
(Continued)

Source category/ reference/rating	Uncontrolled, kg/Mg (lb/ton)	After control device kg/Mg (lb/ton)	Efficiency, percent
Venturi/impingement			
34n,d,b	2.50 (5.00)	0.472 (0.944)	81.1
34s,d,ba	4.05 (8.10)	0.640 (1.28)	
35d,c		0.875 (1.750)	
35e,c	4.55 (9.10)	1.818 (3.636)	60.0

TABLE 4-2. SUMMARY OF EMISSION FACTORS FOR PARTICLE SIZE (PM_{10}) DATA FROM SEWAGE SLUDGE INCINERATORS

Source category/ reference/rating	Cut diameter, microns	Uncontrolled		Controlled		Control efficiency, %
		Cum. % < cut	Emission factor lb/ton feed	Cum. $ < cut	Emission factor, lb/ton feed	
<u>Multiple hearth</u>						
Impingement						
7,a	0.625	4.11	0.61	59.3	0.15	75
	1.00	6.37	0.94	62.4	0.16	83
	2.50	15.0	2.22	68.9	0.17	92
	5.00	28.7	4.24	74.3	0.19	96
	10.0	54.8	8.11	80.1	0.20	98
	15.0	80.0	11.8	83.7	0.21	98
Venturi						
21,b	0.625	12.7	3.17	73.9	2.59	18
	1.00	13.6	3.38	77.2	2.71	20
	2.50	15.4	3.82	84.3	2.96	23
	5.300	16.9	4.19	90.1	3.16	25
	10.0	18.5	4.61	96.2	3.38	27
	15.0	19.6	4.87	99.3	3.49	28
<u>Fluidized bed</u>						
Venturi						
4,b	0.625			32	0.16	
	1.0			60	0.30	
	2.50			71	0.35	
	5.00			78	0.39	
	10.0			86	0.43	
	15.0			92	0.46	

TABLE 4-2. SUMMARY OF EMISSION FACTORS FOR PARTICLE SIZE (PM_{10}) DATA FROM SEWAGE SLUDGE INCINERATORS (Concluded)

Source category/ reference/rating	Cut diameter, microns	Uncontrolled		Controlled		Control efficiency, %
		Cum. % < cut	Emission factor lb/ton feed	Cum. $ < cut	Emission factor, lb/ton feed	
Electric infrared Impingement						
35a,c	0.625			3.41	0.059	
	1.0			5.32	0.092	
	2.50			12.6	0.22	
	5.00			24.3	0.42	
	10.0			46.8	0.81	
	15.0			68.9	1.19	
Venturi/impingement						
34n,d	0.625	59.4	0.17			
	1.0	65.3	0.19			
	2.50	78.5	0.23			
	5.00	90.3	0.26			
	10.0	99.0	0.29			
	15.0	100.0	0.29			
34g,d	0.625	59.8	0.88			
	1.0	65.7	0.97			
	2.50	78.9	1.16			
	5.00	90.6	1.33			
	10.0	99.0	1.46			
	15.0	100.00	1.47			
35e,c	0.625	11.1	1.01	31.1	1.13	--
	1.0	13.9	1.526	36.2	1.32	--
	2.50	23.2	2.11	49.4	1.80	15
	5.00	36.9	3.36	63.9	2.33	31
	10.0	64.4	5.86	85.5	3.11	47
	15.0	93.7	8.53	100.0	3.64	57

TABLE 4-3. SUMMARY OF EMISSION FACTORS FOR VOLATILE ORGANIC COMPOUNDS FROM SEWAGE SLUDGE INCINERATORS

Source category/ reference/rating	Uncontrolled, kg/Mg (lb/ton)		After control device, kg/Mg (lb/ton)		Efficiency, percent
	methane	nonmethane	methane	nonmethane	
Multiple hearth					
Cyclone					
79,a				1.53 (3.06)	
Cyclone/venturi					
2,a		0.510 (1.02)			
84,a				0.220 (0.440)	
Cyclone/venturi/impingement					
1,a		2.620 (5.24)			
39,a		0.146 (0.292)			
40,a		0.108 (0.216)			
Impingement					
6,d			0.39 (0.78)		
68,a				0.785 (1.57)	
Venturi					
26,a			0.027 (0.054)		
27,b			6.45 (12.9)		
Fluidized Bed					
Venturi					
69,a			1.65 (3.30)		
Venturi/impingement					
28,b			0.189 (0.378)		
29,b			0.610 (1.220)		

TABLE 4-4. SUMMARY OF EMISSION FACTORS FOR LEAD FROM SEWAGE SLUDGE INCINERATORS

Source category/ reference/rating	Uncontrolled, kg/Mg (lb/ton)	Controlled, kg/Mg (lb/ton)	Efficiency, percent
Multiple hearth			
Cyclone			
5r,b		0.037 (0.074)	
98,a	0.044 (0.088)	0.016 (0.032)	64
Cyclone/venturi			
84,a		0.0052 (0.0104)	
101,a		0.0006 (0.0011)	
Cyclone/venturi/impingement			
39,a	0.047 (0.094)	0.011 (0.022)	77.2
Impingement			
50,a		0.019 (0.038)	
5p,a		0.039 (0.078)	
99,b		0.0031 (0.0063)	
Venturi/impingement			
90,b	0.05 (0.10)	0.017 (0.0214)	66
102,c		0.00105 (0.0021)	
91,a	0.03 (0.06)	0.003 (0.006)	90
85,b		0.011 (0.022)	
85,a		0.02 (0.04)	
95,a	0.064 (0.128)	0.018 (0.036)	71.6
86,b	0.013 (0.026)		
88,a	0.068 (0.136)	0.037 (0.074)	45.6
104,a	0.14 (0.28)	0.04 (0.08)	71.2
104,a	0.23 (0.46)*	0.05 (0.11)	77
107,a	0.04 (0.08)	0.03 (0.05)	32.8
107,a	0.08 (0.17)*	0.04 (0.08)	54
Venturi/WESP			
102,c	0.00121 (0.00242)	0.00009 (0.00018)	92.7

TABLE 4-4. SUMMARY OF EMISSION FACTORS FOR LEAD FROM SEWAGE SLUDGE INCINERATORS (Continued)

Source category/ reference/rating	Uncontrolled, kg/Mg (lb/ton)	Controlled, kg/Mg (lb/ton)	Efficiency, percent
Venturi			
95,b		0.0009 (0.0018)	
Venturi/impingement/ afterburner			
92,c		0.031 (0.062)	
88,a	0.068 (0.136)	0.066 (0.132)	
Venturi/impingement/WESP			
107,a	0.08 (0.17)*		
Wet ESP			
90,b	0.05 (0.10)	0.00165 (0.0033)	95
<u>Fluidized Bed</u>			
Impingement			
5q,b		0.003 (0.006)	
Venturi/impingement			
4,b		0.005 (0.010)	
28,b		0.002 (0.004)	
97,c		0.001 (0.002)	
87,a		0.46 (0.92)	
98,a		0.001 (0.002)	
106,a	0.03 (0.06)	0.00002 (0.00004)	99.9
Venturi/impingement/WESP			
106,a	0.03 (0.06)	0.000001 (0.00)	100
Fabric Filter			
91,a	0.0008 (0.0016)	0.000005 (0.000010)	99.4

*Low CO.

TABLE 4-5. SUMMARY OF EMISSION FACTORS FOR SULFUR DIOXIDE FROM SEWAGE SLUDGE INCINERATORS

Source category/ reference/rating	Uncontrolled, kg/Mg (lb/ton)	Controlled, kg/Mg (lb/ton)	Efficiency, percent
<u>Multiple hearth</u>			
Cyclone			
5r,b	8.34 (16.68)	1.77 (3.54)	78.7
98,a	18.6 (37.2)	3.90 (7.80)	79.0
Cyclone/venturi/impingement			
1,a	19.7 (39.4)		
39,a	25.1 (50.2)		
Impingement			
3,a	9.98 (19.96)		
5o,a	14.4 (28.8)	0.031 (0.062)	99.7
5p,a	4.686 (9.372)	0.107 (0.214)	99.7
71,a		0.360 (0.720)	
72,a		0.807 (1.614)	
99,a		0.3 (0.6)	
Venturi			
26,b		0.78 (1.56)	
27,b		3.84 (7.68)	
Venturi/impingement			
45,b		0.001 (0.002)	
98,a	21.1 (42.2)	0.20 (0.40)	98.3
<u>Fluidized Bed</u>			
Impingement			
5q,b		0.347 (0.694)	
Venturi			
69,a		9.25 (18.5)	
Venturi/impingement			
28,b		0.10 (0.20)	
29,b		0.78 (1.56)	
98,a		0.76 (1.42)	
106,a	0.15 (0.30)	0.01 (0.03)	91.2
<u>Electric infrared</u>			
Venturi/impingement			
35e,c	9.2 (18.4)	2.32 (4.64)	74.7

TABLE 4-6. SUMMARY OF EMISSION FACTORS FOR OXIDES OF NITROGEN FROM SEWAGE SLUDGE INCINERATORS

Source category/ reference/rating	Uncontrolled, kg/Mg (lb/ton)	After control device kg/Mg (lb/ton)	Efficiency, percent
Multiple hearth			
Cyclone			
98,a		0.004 (0.008)	
Cyclone/venturi/impingement			
1,a	4.37 (8.74)		
39,a	6.73 (13.46)		
Impingement			
3,a	5.965 (11.930)		
68,a		5.65 (11.30)	
71,a		0.888 (1.776)	
72,a		3.77 (7.54)	
99,a		0.44 (0.88)	
Venturi			
26,b		0.248 (0.496)	
27,b		1.705 (3.410)	
Venturi/impingement			
98,a		0.08 (0.16)	
107,a	0.3 (0.5)*		
107,a	0.2 (0.4)		
Fluidized Bed			
Venturi			
69,a		2.92 (5.84)	
Venturi/impingement			
28,b		1.41 (2.82)	
98,a		0.06 (0.12)	
106,a	0.04 (0.09)	0.01 (0.02)	
Electric infrared			
Venturi/impingement			
35e,c	4.32 (8.64)	2.90 (5.80)	

TABLE 4-7. SUMMARY OF EMISSION FACTORS FOR CARBON MONOXIDE FROM SEWAGE SLUDGE INCINERATORS

Source category/ reference/rating	Uncontrolled, kg/Mg (lb/ton)	After control device kg/Mg (lb/ton)	Efficiency, percent
Multiple hearth			
Cyclone			
84,a	53 (106)		
Cyclone/venturi			
101,a		1.35 (2.7)	
Cyclone/venturi/impingement			
1,a	19.5 (39.0)		
39,a	44.1 (88.2)		
Impingement			
3,a	27.0 (54.0)		
68,a		1.65 (3.30)	
72,a		1.78 (3.56)	
99,a		3.26 (6.53)	
Venturi/impingement			
104,a		1.05 (2.11)*	
104,a		2.04 (4.09)	
107,a		1.42 (2.83)	
107,a		0.65 (1.30)*	
Fluidized Bed			
Venturi/impingement			
29,b		2.13 (4.26)	
106,a	0.005 (0.01)	0.003 (0.01)	27.7

* Low CO.

TABLE 4-8. SUMMARY OF SULFURIC ACID AND HYDROGEN CHLORIDE, FACTORS FROM SEWAGE SLUDGE INCINERATORS

	H_2SO_4			HCl		
Source category/ reference/rating	Uncontrolled kg/Mg (lb/ton)	After control device kg/Mg (lb/ton)	Efficiency, percent	Uncontrolled kg/Mg (lb/ton)	After control device kg/Mg (lb/ton)	Efficiency, percent
<u>Multiple hearth</u>						
Cyclone						
5r,b	0.580 (1.16)	0.207 (0.414)	64.3			
98,a	1.27 (2.54)	0.46 (0.92)	64.2			
Impingement						
5o,a	0.491 (0.982)	0.042 (0.084)	91.4			
5p,a	0.047 (0.094)	0.072 (0.144)				
99,a						
Venturi						
26,b					0.014 (0.028)	
27,d		1.15 (2.30)			0.910 (1.820)	
Venturi/impingement						
98,a	0.60 (1.20)	0.17 (0.34)	82.4			
Cyclone/venturi						
101,a					0.012 (0.024)	
Cyclone/impingement						
99,a					0.01 (0.03)	
<u>Fluidized bed</u>						
Impingement						
5q,b		0.027 (0.054)				
Venturi/impingement						
28,b					0.055 (0.110)	
98,a		0.06 (0.12)				

4-9. SUMMARY OF 2,3,7,8 TETRA-, TOTAL TETRA- AND TOTAL PENTACHLORINATED DIBENZO-P-DIOXIN EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS[a]

Source category/ reference/rating	2,3,7,8 tetra			Tetra		
	Uncontrolled μg/Mg (10^{-9} lb/ton)	After control device μg/Mg (10^{-9} lb/ton)	Efficiency, percent	Uncontrolled μg/Mg (10^{-9} lb/ton)	After control device μg/Mg (10^{-9} lb/ton)	Efficiency, percent
<u>Multiple Hearth</u>						
Cyclone/venturi						
2,a					1.40 (2.80)	
Cyclone/venturi/ impingement 1,a		0.263 (0.526)			63.8 (127.6)	
Impingement						
3,a		0.971 (1.942)		62.7 (125.4)	56.5 (113)	9.9
99,a		0.052 (0.105)			0.35 (0.69)	
Venturi/impingement						
92,c		2.4 (4.8)			134 (268)	
88,a		1.63 (3.26)				
Venturi/impingement/ afterburner 92,c		0.9 (1.8)			139 (278)	
<u>Fluidized Bed</u>						
Venturi/impingement						
106,a						

Units in μg/Mg (10^{-9} lb/ton) dry sludge.

TABLE 4-10. SUMMARY OF TOTAL PENTA- AND TOTAL HEXACHLORINATED DIBENZO-P-DIOXIN EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS[a]

	Penta			Hexa		
Source category/ reference/rating	Uncontrolled μg/Mg (10^{-9} lb/ton)	After control device μg/Mg (10^{-9} lb/ton)	Efficiency, percent	Uncontrolled μg/Mg (10^{-9} lb/ton)	After control device μg/Mg (10^{-9} lb/ton)	Efficiency, percent
Multiple Hearth						
Cyclone/venturi/ impingement 1,a		1.51 (3.02)			4.38 (8.76)	
Impingement						
3,a		7.32 (14.64)		67.7 (135.4)	47.8 (95.6)	29.4
99,a	2.74 (5.48)	0.14 (0.29)			0.39 (0.80)	
Venturi/impingement						
92,c		50.6 (101.2)			39.5 (80)	
88,a		55.6 (112)			37 (74)	
Venturi/impingement/ afterburner 92,c		151.4 (300.8)			60 (120)	
Fluidized Bed						
Venturi/impingement 106,a		1.1 (2.2)			0.9 (1.8)	

Units in μg/Mg (10^{-9} lb/ton) dry sludge.

TABLE 4-11. SUMMARY OF TOTAL HEPTA- AND TOTAL OCTACHLORINATED DIBENZO-P-DIOXIN EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS[a]

	Hepta			Octa		
Source category/ reference/rating	Uncontrolled μg/Mg (10^{-9} lb/ton)	After control device μg/Mg (10^{-9} lb/ton)	Efficiency, percent	Uncontrolled μg/Mg (10^{-9} lb/ton)	After control device μg/Mg (10^{-9} lb/ton)	Efficiency, percent
Multiple Hearth						
Cyclone/venturi						
2,a		0.774 (1.548)			3.439 (6.878)	
Cyclone/venturi/ impingement		14.1 (28.2)			30.7 (61.4)	
1,a						
Impingement						
3,a	340 (680)	144 (288)	57.6	375 (750)	105 (210)	72.2
99,a		1.6 (3.2)			1.50 (2.93)	
Venturi/impingement						
92,c		19.4 (38.8)			24.3 (48.6)	
88,a		9.9 (20)			13.7 (27.4)	
Venturi/impingement/ afterburner		23.3 (46.6)			12.1 (24.2)	
92,c						
Fluidized Bed						
Venturi/impingement						
106,a		0.9 (1.8)			4.3 (8.6)	

Units in μg/Mg (10^{-9} lb/ton) dry sludge.

TABLE 4-12. SUMMARY OF TOTAL TETRA- THROUGH OCTACHLORINATED DIBENZO-P-DIOXIN EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS[a]

Source category/ reference/rating	Uncontrolled μg/Mg (10^{-9} lb/ton)	After control device μg/Mg (10^{-9} lb/ton)	Efficiency, percent
Multiple Hearth			
Cyclone/venturi			
2,a		5.63 (11.26)	
Cyclone/venturi/ impingement		113 (226)	
1,a			
Impingement			
3,a	847 (1,694)	360 (720)	57.4
99,a		4 (8)	
Venturi/impingement			
92,c		271 (542)	
Venturi/impingement/ afterburner		310 (620)	
92,c			

Units in μg/Mg (10^{-9} lb/ton) dry sludge.

TABLE 4-13. SUMMARY OF 2,3,7,8 TETRA- AND TOTAL TETRAACHLORINATED DIBENZOFURAN EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS[a]

Source category/ reference/rating	2,3,7,8 tetra Uncontrolled μg/Mg (10^{-9} lb/ton)	2,3,7,8 tetra After control device μg/Mg (10^{-9} lb/ton)	2,3,7,8 tetra Efficiency, percent	Tetra Uncontrolled μg/Mg (10^{-9} lb/ton)	Tetra After control device μg/Mg (10^{-9} lb/ton)	Tetra Efficiency, percent
Multiple Hearth						
Cyclone/venturi						
2,a		7.50 (15.0)			74 (148)	
84,a		3.8 (7.6)			26.1 (52.2)	
Cyclone/venturi/ impingement 1,a					188 (376)	
Impingement						
3,a	620 (1,240)	371 (742)	40.2	1,708 (3,416)	1,395 (2,790)	18.3
99,a		0.79 (1.58)			7.1 (14.2)	
Venturi/impingement						
92,c		80.4 (160)			600 (1,200)	
88,a		12.4 (24.8)				
Venturi/impingement/ afterburner 92,c		53.7 (107.4)			350 (700)	
Fluidized Bed						
Venturi/impingement						
106,a		0.23 (0.46)			6.2 (12.5)	

Units in μg/Mg (10^{-9} lb/ton) dry sludge.

TABLE 4-14. SUMMARY OF TOTAL PENTA- AND TOTAL HEXACHLORINATED DIBENZOFURAN EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS[a]

Source category/ reference/rating	Penta			Hexa		
	Uncontrolled μg/Mg (10^{-9} lb/ton)	After control device μg/Mg (10^{-9} lb/ton)	Efficiency, percent	Uncontrolled μg/Mg (10^{-9} lb/ton)	After control device μg/Mg (10^{-9} lb/ton)	Efficiency, percent
Multiple Hearth						
Cyclone/venturi						
2,a		16.8 (33.6)			5.67 (11.34)	
84,a		6.0 (12.0)			1.2 (2.4)	
Cyclone/venturi/ impingement 1,a		57.5 (115)			1.777 (3.554)	
Impingement						
3,a	980 (1,960)	718 (1,436)	26.6	99.5 (199)	219 (438)	
99,a		2.1 (4.2)			2.50 (5.04)	
Venturi/impingement						
92,c		1.3 (2.6)			74.1 (148.2)	
88,a					39.7 (79.4)	
Venturi/impingement/ afterburner 92,c		130 (260)			77.7 (155.4)	
Fluidized Bed						
Venturi/impingement						
106,a		5.2 (10.4)			4.1 (8.1)	

[a]Units in μg/Mg (10^{-9} lb/ton) dry sludge.

TABLE 4-15. SUMMARY OF TOTAL HEPTA- AND TOTAL OCTACHLORINATED DIBENZOFURAN EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS[a]

	Hepta			Octa		
Source category/ reference/rating	Uncontrolled μg/Mg (10^{-9} lb/ton)	After control device μg/Mg (10^{-9} lb/ton)	Efficiency, percent	Uncontrolled μg/Mg (10^{-9} lb/ton)	After control device μg/Mg (10^{-9} lb/ton)	Efficiency, percent
Multiple Hearth						
Cyclone/venturi						
2,a					0.257 (0.514)	
84,a		0.9 (1.8)			1.2 (2.4)	
Cyclone/venturi/ impingement		2.89 (5.78)			1.79 (3.58)	
1,a						
Impingement						
3,a	481 (820)	410 (820)	14.9	491 (982)	310 (620)	36.9
99,a		0.34 (0.68)			0.12 (0.24)	
Venturi/impingement						
92,c		71.1 (142.2)			6.2 (12.4)	
88,a		11.2 (22.4)			6.4 (12.8)	
Venturi/impingement/ afterburner		48 (96)			7.7 (15.4)	
92,c						
Fluidized Bed						
Venturi/impingement						
106,a		1.6 (3.3)			1.3 (2.6)	

Units in μg/Mg (10^{-9} lb/ton) dry sludge.

TABLE 4-16. SUMMARY OF TOTAL TETRA- THROUGH OCTACHLORINATED DIBENZOFURAN EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS[a]

Source category/ reference/rating	Uncontrolled μg/Mg (10^{-9} lb/ton)	After control device μg/Mg (10^{-9} lb/ton)	Efficiency, percent
Multiple Hearth			
Cyclone/venturi			
2,a		97 (194)	
84,a		35.5 (71.0)	
Cyclone/venturi/impingement			
1,a		250 (500)	
Impingement			
3,a	3,766 (7,532)	3,050 (6,100)	18.9
99,a		12 (24)	
Venturi/impingement			
92,c		931 (1,862)	
Venturi/impingement/afterburner			
88,a		318 (636)	
92,c		613 (1,226)	

Units in μg/Mg (10^{-9} lb/ton) dry sludge.

TABLE 4-17. SUMMARY OF 1,1,1 TRICHLOROETHANE AND 1,1 DICHLOROETHANE EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS[a]

Source category/ reference/rating	1,1,1 Trichloroethane			1,1 Dichloroethane		
	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device g/Mg (10^{-3} lb/ton)	Efficiency, percent	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device g/Mg (10^{-3} lb/ton)	Efficiency, percent
Multiple Hearth						
Cyclone/impingement						
89,a	0.13 (0.26)	3.22 (6.45)			0.23 (0.46)	
89,a		0.66 (1.42)				
Venturi/impingement						
85,a		0.19 (0.38)				
86,a	0.007 (0.014)	0.016 (0.032)				
88,a	0.048 (0.096)	1.64 (3.28)				
Venturi/impingement/ afterburner	0.048 (0.096)	1.38 (2.76)				
88,a						
Cyclone/venturi						
108,b		0.43 (0.87)*				
108,b		0.07 (0.14)				
Fluidized Bed						
Venturi/impingement						
87,a		0.44 (0.87)				
106,a		0.08 (0.16)				

Units in μg/Mg (10^{-9} lb/ton) dry sludge.

TABLE 4-18. SUMMARY OF 1,2-DICHLOROETHANE EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS[a]

Source category/ reference/rating	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device g/Mg (10^{-3} lb/ton)	Efficiency, percent
Multiple Hearth			
Venturi/impingement 85,a		0.014 (0.028)	
Venturi/impingement/ afterburner 88,a		0.031 (0.062)	
Cyclone/venturi 108,b		0.004 (0.01)	

TABLE 4-19. SUMMARY OF 1,2-DICHLOROBENZENE AND 1,3-DICHLOROBENZENE EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category reference/rating	1,2-Dichlorobenzene			1,3-Dichlorobenzene		
	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
Multiple hearth						
Venturi/impingement						
85,a		0.001 (0.002)			0.0009 (0.0018)	
86,a	0.37 (0.74)	0.39 (0.78)			0.04 (0.08)	
Cyclone/venturi						
108,b		0.04 (0.07)*			0.3 (0.6)*	
108,b					0.05(0.10)	
Fluidized Bed						
Venturi/impingement						
106,a		67.4 (134.7)				

*High THC levels

TABLE 4-20. SUMMARY OF 1,4-DICHLOROBENZENE EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category reference/rating	1,4-Dichlorobenzene Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
Multiple hearth			
Venturi/impingement			
85,a		0.003 (0.006)	
86,a	0.41 (0.82)	0.48 (0.96)	
Cyclone/venturi			
108,b		0.24 (0.49)*	
108,b		0.007 (0.01)	
Fluidized Bed			
Venturi/impingement			
106,a		239 (479.4)	

*High THC levels

TABLE 4-21. SUMMARY OF 2-NITROPHENOL AND ACETALDEHYDE EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category reference/rating	2-Nitrophenol			Acetaldehyde		
	Uncontrolled g/Mg (10^{-3} lb/ton)	After control, device, g/Mg (10^{-3} lb/ton)	Efficiency, percent	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
<u>Multiple hearth</u>						
Venturi/impingement						
86,a	6.0 (12.0)	1.18 (2.36)	80.0			
Cyclone/impingement						
99,a					0.16 (0.31)	
Cyclone/venturi						
108,b		0.76 (1.52)*				
108,b		0.38 (0.75)				

* High THC levels

TABLE 4-22. SUMMARY OF ACETONE EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category reference/rating	Acetone: Uncontrolled g/Mg (10^{-3} lb/ton)	Acetone: After control device, g/Mg (10^{-3} lb/ton)	Acetone: Efficiency, percent
Multiple hearth			
venturi			
89,a		3.16 (6.32)	

TABLE 4-23. SUMMARY OF ACETONITRILE AND ACYLONITRILE EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category reference/rating	Acetonitrile Uncontrolled g/Mg (10^{-3} lb/ton)	Acetonitrile After control device, g/Mg (10^{-3} lb/ton)	Acetonitrile Efficiency, percent	Acylonitrile Uncontrolled g/Mg (10^{-3} lb/ton)	Acylonitrile After control device, g/Mg (10^{-3} lb/ton)	Acylonitrile Efficiency, percent
<u>Multiple hearth</u>						
Venturi/impingement						
88,a	25.4 (50.8)	9.76 (19.6)	61.6	25.4 (50.8)	33.5 (67.0)	
85,a					8.20 (16.4)	
86,a				25.3 (50.6)	10.1 (20.2)	
Venturi/impingement/ afterburner						
88,a	25.4 (50.8)	0.74 (1.44)	97.1	25.4 (50.8)	0.49 (0.97)	98.1
Cyclone/venturi						
108,b					11.9 (23.8)*	
108,b					0.15 (0.29)	

* High THC levels.

TABLE 4-24. SUMMARY OF BENZENE, AND BIS(2-ETHYLHEXYL) PHTHALATE EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category reference/rating	Benzene: Uncontrolled g/Mg (10^{-3} lb/ton)	Benzene: After control device, g/Mg (10^{-3} lb/ton)	Benzene: Efficiency, percent	Bis(2-ethylhexyl)phthalate: Uncontrolled g/Mg (10^{-3} lb/ton)	Bis(2-ethylhexyl)phthalate: After control device, g/Mg (10^{-3} lb/ton)	Bis(2-ethylhexyl)phthalate: Efficiency, percent
Multiple hearth						
Venturi/impingement						
86,a	2.3 (4.6)	3.55 (7.10)		0.93 (1.86)	0.64 (1.28)	31.1
85,a		10.5 (21.1)			0.001 (0.002)	
88,a	3.54 (7.04)	6.8 (13.6)				
86,a	11.3 (22.6)	4.28 (8.56)	62.1			
Venturi/impingement/ afterburner						
88,a	3.54 (7.09)	0.17 (0.34)	95.2			
Venturi						
89,a	6.1 (12.2)	14.0 (28.1)				
Cyclone/venturi						
101,c		0.33 (0.66)				
108,b		15.4 (30.8)*			1.0 (2.0)*	
108,b		0.38 (0.75)			0.04 (0.08)	
Fluidized bed						
Venturi/impingement						
87,a		0.40 (0.80)			0.26 (0.52)	
106,a		0.07 (0.14)			82.1 (164.2)	

* High THC levels.

TABLE 4-25. SUMMARY OF BROMODICHLOROMETHANE AND CARBON TETRACHLORIDE EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category reference/rating	Bromodichloromethane			Carbon Tetrachloride		
	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
<u>Multiple hearth</u>						
Venturi						
89,a	0.0041 (0.0082)	1.48 (2.96)				
Venturi/impingement afterburner				0.024 (0.048)	0.001 (0.002)	95.8
88,a						
Venturi/impingement						
85,a					0.07 (0.14)	
86,a				0.0031 (0.0063)	0.002 (0.004)	35.5
88,a				0.024 (0.048)	0.011 (0.023)	54.2
Cyclone/venturi						
108,b					0.007 (0.01)	
<u>Fluidized Bed</u>						
Venturi/impingement						
87,a					0.012 (0.024)	

TABLE 4-26. SUMMARY OF CHLOROBENZENE AND CHLOROMETHANE EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category reference/rating	Chlorobenzene Uncontrolled g/Mg (10^{-3} lb/ton)	Chlorobenzene After control device, g/Mg (10^{-3} lb/ton)	Chlorobenzene Efficiency, percent	Chloromethane Uncontrolled g/Mg (10^{-3} lb/ton)	Chloromethane After control, device, g/Mg (10^{-3} lb/ton)	Chloromethane Efficiency, percent
Multiple hearth						
Venturi						
89,a	1.3 (2.6)	3.1 (1.11)		0.384 (0.768)	5.3 (10.4)	
100,a		5.4 (10.8)				
Venturi/impingement/ afterburner						
88,a	0.66 (1.32)	0.26 (0.53)	60.6			
Venturi/impingement						
85,a		0.67 (1.34)				
86,a	0.31 (0.62)	0.29 (0.59)	6.45			
88,a	0.66 (1.32)	0.83 (1.65)				
Cyclone/venturi						
89,a		0.24 (0.48)*				
		0.006 (0.01)				
Fluidized bed						
Venturi/impingement						
87,a		0.005 (0.01)				

* High THC levels.

TABLE 4-27. SUMMARY OF CHLOROFORM EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

	Chloroform		
Source category reference/rating	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
Multiple hearth			
Venturi			
89,a	0.024 (0.048)	4.2 (8.3)	
100,a		2.4 (4.7)	
Venturi/impingement afterburner			
88,a	0.063 (0.126)	0.49 (0.98)	
Venturi/impingement			
85,a	0.005 (0.01)	3.03 (6.05)	
86,a		0.49 (1.0)	
88,a	0.063 (0.126)	0.38 (0.76)	
Cyclone/venturi			
108,b		0.21 (0.43)*	
108,b		0.024 (0.05)	
Fluidized bed			
Venturi/impingement			
87,a		3.76 (7.52)	
106,a		0.20 (0.40)	

* High THC levels.

TABLE 4-28. SUMMARY OF ETHYLBENZENE AND FORMALDEHYDE EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category reference/rating	Ethylbenzene			Formaldehyde		
	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency. percent	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
<u>Multiple hearth</u>						
Venturi/impingement						
85,a		0.94 (1.88)				
86,a	0.30 (0.60)	0.41 (0.82)				
88,a	1.32 (2.64)	1.68 (3.37)				
Venturi/impingement/ afterburner						
88,a	1.32 (2.64)	0.02 (0.04)	98.5			
Cyclone/venturi						
101,a					1.32 (2.64)	
108,b		1.27 (2.54)				
108,b		0.003 (0.01)				
Venturi						
89,a		9.76 (19.5)				
89,a	0.68 (1.36)	2.29 (4.59)			0.40 (0.81)	
<u>Fluidized bed</u>						
Venturi/impingement						
106,a		0.03 (0.06)				
87,a		0.02 (0.04)				

* High THC levels.

TABLE 4-29. SUMMARY OF METHYL ETHYL KETONE EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category reference/rating	Methyl Ethyl Ketone		
	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
Multiple hearth			
Venturi/impingement			
88,a	6.1 (12.2)	8.88 (17.7)	
Venturi			
89,a		6.12 (12.24)	
Venturi/impingement/ afterburner			
88,a	6.1 (12.2)	0.05 (0.1)	99.2

TABLE 4-30. SUMMARY OF METHYL ISOBUTYL KETONE AND METHYLENE CHLORIDE EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

	Methyl Isobutyl Ketone			Methylene Chloride		
Source category reference/rating	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
<u>Multiple hearth</u>						
Cyclone/impingement						
98,a		0.01 (0.03)				
Venturi						
89,a				0.016 (0.032)	2.15 (4.30)	
Venturi/impingement						
85,a					0.11 (0.22)	
86,a				1.15 (2.30)	0.45 (0.89)	60.9
88,a				0.073 (0.146)	2.22 (4.44)	
Venturi/impingement/ afterburner						
88,a				0.073 (0.146)	0.42 (0.84)	
Cyclone/venturi						
108,b					0.27 (0.54)*	
108,b					0.35 (0.71)	
<u>Fluidized bed</u>						
Venturi/impingement						
87,a					0.076 (0.152)	
106,a					1.3 (2.6)	

* High THC levels.

TABLE 4-31. SUMMARY OF NAPHTHALENE EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category reference/rating	Naphthalene Uncontrolled g/Mg (10^{-3} lb/ton)	Naphthalene After control device, g/Mg (10^{-3} lb/ton)	Naphthalene Efficiency, percent
<u>Multiple hearth</u>			
Venturi/impingement			
88,a	0.024 (0.048)		
86,a	18.3 (36.6)	0 (0)	100
Cyclone/venturi			
101,a		0.0004 (0.0007)	
108,b		2.83 (5.66)*	
108,b		0.093 (0.19)	
<u>Fluidized bed</u>			
Venturi/impingement			
106,a		97.3 (194.5)	

* High THC levels.

TABLE 4-32. SUMMARY OF PERCHLOROETHYLENE AND PHENOL EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

	Perchloroethylene			Phenol		
Source category reference/rating	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
<u>Multiple hearth</u>						
Venturi						
89,a	0.29 (0.60)	0.21 (0.42)				
Venturi/impingement/ afterburner						
88,a	0.51 (1.02)	0.95 (1.90)				
Venturi/impingement						
85,a		8.4 (16.7)				
86,a	0.38 (0.76)	0.67 (1.34)		44.8 (89.6)	1.79 (3.58)	96.0
88,a	0.51 (1.02)	1.37 (2.74)		0.051 (0.10)		
Cyclone/venturi						
108,b		0.62 (1.24)*				
108,b		0.014 (0.03)				
<u>Fluidized bed</u>						
Venturi/impingement						
106,a		0.12 (0.22)				

* High THC levels.

TABLE 4-33. SUMMARY OF TETRACHLOROETHANE AND TOLUENE EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

	Tetrachloroethane			Toluene		
Source category reference/rating	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
<u>Multiple hearth</u>						
Venturi						
89,a		21.4 (42.8)*		4.7 (9.4)	14.9 (29.8)*	
89,a		2.2 (4.5)			16.2 (32.4)	
Venturi/impingement						
85,a					3.1 (6.3)	
86,a				16.7 (33.4)	9.9 (19.8)	41.0
88,a				2 (4)	6.4 (12.8)	
Venturi/impingement/ afterburner						
88,a				2 (4)	0.66 (1.33)	67.0
Cyclone/venturi						
108,b					6.5 (12.9)	
108,b					0.008 (0.16)	
Fluidized Bed						
Cyclone/impingement						
87,a					0.62 (1.24)	
106,a					0.09 (0.17)	

* High THC levels.

TABLE 4-34. SUMMARY OF t-1,2-DICHLOROETHENE EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

	t-1,2-Dichloroethene		
Source category reference/rating	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
<u>Multiple hearth</u>			
Venturi			
89,a	0.09 (0.18)	5.2 (10.4)	
Venturi/impingement			
88,a		0.047 (0.095)	
Venturi/impingement/ afterburner		0.12 (0.25)	
85,a		0.007 (0.013)	
86,a		0.002 (0.004)	
88,a			
Cyclone/venturi			
108,b		0.01 (0.02)	

TABLE 4-35. SUMMARY OF M/P-XYLENE, AND TOTAL XYLENES EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

	M/P-Xylene			Total Xylenes		
Source category reference/rating	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
<u>Multiple hearth</u>						
Venturi						
89,a				0.95 (1.90)	2.0 (4.0)	
89,a	0.67 (1.34)	2.0 (4.0)			0.83 (1.66)	

TABLE 4-36. SUMMARY OF ARSENIC EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category reference/rating	Arsenic: Uncontrolled g/Mg (10^{-3} lb/ton)	Arsenic: After control device, g/Mg (10^{-3} lb/ton)	Arsenic: Efficiency, percent
Multiple hearth			
Cyclone/venturi			
101,c		0.10 (0.20)	
Cyclone/venturi/impingement	14.7 (29.4)	0.849 (1.698)	94.2
39,a			
Venturi			
26,b		0.004 (0.008)	
92,c		0.09 (0.18)	
Venturi/impingement			
102,c	5.90 (11.80)	0.26 (0.52)	95.5
91,a		0.19 (0.38)	
107,a	1.68 (3.36)*	2.01 (4.03)	
107,a	1.03 (2.06)	1.54 (3.08)	
86,a			
90,a	14 (28.1)	0.906 (1.81)	93.5
88,a	0.30 (0.60)	0.005 (0.010)	98.3
85,a		0.07 (0.14)	
85,a		0.04 (0.08)	
86,a	1.80 (3.6)	0.34 (0.68)	81.1
86,a	1.31 (2.62)	0.39 (0.78)	70.2
Venturi/WESP			
102,c	0.12 (0.24)	0.013 (0.024)	89.2
107,a	1.68 (3.36)*	1.21 (2.42)	28
Venturi/impingement afterburner			
88,a	0.030 (0.60)	0.04 (0.08)	86.7
92,c		0.04 (0.08)	
ESP			
90,b	14 (28)	1.20 (2.40)	92.4
Fabric Filter			
91,a	0.16 (0.32)	0.003 (0.006)	98.1
Fluidized bed			
Venturi/impingement			
4,b		0.003 (0.006)	
28,b		0.019 (0.038)	
87,a		0.028 (0.056)	
106,a	2.22 (4.45)	0.01 (0.02)	99.5
Venturi/impingement/WESP			
106,a	2.22 (4.5)	0.005 (0.009)	99.8

* Low CO.

TABLE 4-37. SUMMARY OF BERYLLIUM EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

	Beryllium		
Source category reference/rating	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
Multiple hearth			
Venturi/impingement			
86,a	0.008 (0.016)	0.0007 (0.0014)	91.3
104,a	0.04 (0.08)*	0.005 (0.01)	89
104,a	0.04 (0.07)	0.01 (0.02)	85.4
Fluidized bed			
Venturi/impingement			
106,a	0.4 (0.8)	0.0002 (0.0003)	99.95
Venturi/impingement/WESP 106,a	0.4 (0.8)	0.0002 (0.0004)	99.95

* Low CO.

TABLE 4-39. SUMMARY OF CHROMIUM AND MERCURY EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category/ reference/rating	Chromium			Mercury		
	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
Multiple hearth						
Cyclone						
5r,b		3.86 (7.72)				
98,a	12.1 (24.2)	1.72 (3.44)	85.8			
99,a		0.27 (0.552)			2.31 (4.63)	
Cyclone/venturi						
84,a		0.8 (1.6)				
101,a		0.26 (0.53)			1.65 (3.30)	
Impingement						
5o,a		3.52 (7.04)				
5p,a		16.1 (32.2)				
53,b					0.968 (1.936)	
Cyclone/impingement						
99,a		0.039 (0.077)				
Venturi						
26,b		0.062 (0.124)				
95,b		0.048 (0.086)			0.0051 (0.0101)	
Cyclone/venturi/ impingement						
39,a	16.5 (33)	11.2 (22.4)	32.0			
Venturi/impingement						
85,b		0.35 (0.70)				
90,b		10.4 (20.8)	57			
88,a	1.26 (2.52)					
102,c		0.082 (0.164)				
91,a	52.5 (105.0)	1.11 (2.22)	97.9			
85,a		0.21 (0.42)				
86,b	2.54 (5.08)	0.44 (0.88)	82.7			
86,a	3.02 (6.04)	0.30 (0.60)	90.1			
98,a	22.1 (44.2)	5.57 (11.14)	75.1			
107,a	4.35 (8.69)	3.85 (7.70)	11.45			
107,a	8.93 (17.85)*	0.99 (1.96)	89			
104,a	28.68 (57.36)	0.2 (0.4)	99.3			
104,a	33.8 (67.6)	0.09 (0.19)	99.7			

TABLE 4-39. SUMMARY OF CHROMIUM AND MERCURY EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS (Continued)

Source category/ reference/rating	Chromium			Mercury		
	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
Venturi/impingement/ afterburner						
92,b		4.89 (9.8)				
ESP						
90,b	16.3 (33.3)	1.45 (2.90)	91.1			
Venturi/WESP						
102,c	0.011 (0.022)	0.011 (0.022)	0			
Fabric Filter						
91,a	0.34 (0.68)	0.04 (0.08)	88.8			
Venturi/impingement/ WESP						
107,a	4.35 (8.7)*	0.11 (0.23)	97			
<u>Fluidized bed</u>						
Impingement						
5q,b		0.319 (0.638)				
Venturi/impingement						
4,b		0.091 (0.182)				
28,b		0.575 (1.15)			0.03 (0.06)	
97,a		0.002 (0.005)				
87,a		0.71 (1.42)				
98,a	32.3 (64.5)	0.16 (0.32)	99.5			
106,a		0.0008 (0.17)				
Venturi/impingement/ WESP						
107,a	32.3 (64.5)	0.026 (0.05)	99.92			

* Low CO.

TABLE 4-40. SUMMARY OF NICKEL EMISSION FACTORS
FROM SEWAGE SLUDGE INCINERATORS

	Nickel		
Source category reference/rating	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
~~Multiple hearth~~			
Cyclone			
98,a	3.5 (7.0)	0.079 (0.158)	99
99,a		0.074 (0.148)	
Cyclone/venturi			
84,a		0.65 (1.3)	
101,c		0.044 (0.088)	
Cyclone/venturi/ impingement	5.4 (10.8)	4.51 (9.02)	16.5
39,a			
Impingement			
5p,a		4.12 (8.24)	
Venturi			
26,b		0 037 (0 074)	
95,b		0.096 (0.192)	
Venturi/impingement			
85,a		0.11 (0.22)	
90,b		4.95 (64.4)	
88,a	6.2 (12.4)	0.38 (0.76)	93.9
91,a	27.3 (54.6)	1.52 (3.04)	94.4
98,a	9.51 (19.0)	1.40 (2.80)	86.0
85,b		0.18 (0.36)	
86,a	4.52 (9.04)	1.02 (2.04)	77.4
86,b	2.90 (5.80)	0.76 (1.52)	73.8
98,a		0.26 (0.52)	
104,a	3.1 (6.1)*	0.1 (0.2)	97
104,a	2.9 (5.8)	0.2 (0.4)	93.4
107,a	8.2 (16.4)	0.6 (0.13)	92.2
107,a	20.5 (41.0)	0.08 (0.16)	100
Venturi/impingement/ afterburner			
88,a	6.2 (12.4)	1.31 (2.62)	78.9
92,a		0.44 (0.88)	
Cyclone/impingement			
98,a		0.79 (1.58)	
99,a		2.91 (5.83)	
100,a		0.11 (0.22)	

TABLE 4-40. SUMMARY OF NICKEL EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS (Continued)

Source category reference/rating	Nickel Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
Electroctatic precipitator			
90,a	5.5 (11.0)	1.96 (3.92)	62.7
Venturi/WESP			
102,c	0.0058 (0.011)	0.003 (0.006)	50
Fabric filter			
91,a	0.19 (0.38)	0.014 (0.028)	92.64
Fluidized bed			
Venturi/impingement			
28,b		0.848 (1.696)	
97,a		0.059 (0.117)	
87,a		6 (12)	
106,a	17.8 (35.5)	0.017 (0.03)	99.9
Venturi/impingement/ WESP	17.8 (35.5)	0.005 (0.01)	99.9
106,a			

* Low CO.

TABLE 4-41. SUMMARY OF ALUMINUM AND ANTIMONY EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category reference/rating	Aluminum			Antimony		
	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
<u>Multiple hearth</u>						
Cyclone						
98,a	93.9 (187.8)	0.28 (0.56)	99.7	0.77 (1.54)	0.32 (0.64)	58.4
Electrostatic precipitator						
90,b	898 (1,796)	141 (282)			0.037 (0.073)	98.6
Fabric filter						
91,a	0.59 (1.20)	0.68 (1.35)		0.047 (0.094)	0.004 (0.008)	92.4
Venturi/impingement						
90,b	898 (1797)	323 (646)	64.0	2.84 (5.70)	0.21 (0.42)	92.6
91,a	39.4 (78.8)	25.7 (51.4)	34.7	1.86 (3.72)	0.23 (0.46)	87.9
98,a	183 (366)	15.1 (30.2)	86.7	1.82 (3.64)	0.30 (0.60)	61.4
<u>Fluidized Bed</u>						
Venturi/impingement						
98,a		1.89 (2.78)				

TABLE 4-42. SUMMARY OF BARIUM EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category reference/rating	Barium Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
Multiple hearth			
Cyclone			
98,a	7.86 (15.74)	0.10 (0.20)	98.7
Electrostatic precipitator			
90,b		7.43 (14.9)	83.8
Fabric filter			
91,a	0.043 (0.086)	0.004 (0.008)	90.6
Venturi/impingement			
90,b	49.2 (98.4)	6.71 (13.4)	86.4
91,a	1.66 (3.32)	0.24 (0.48)	85.5
98,a	18.3 (36.6)	2.57 (5.14)	84.1
Fluidized Bed			
Venturi/impingement			
98,b		0.24 (0.48)	

TABLE 4-43. SUMMARY OF CALCIUM, AND COBALT EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category/ reference/rating	Calcium			Cobalt		
	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
Multiple hearth						
Cyclone/impingement						
98,a	287 (574)	1.19 (2.38)	99.6	0.57 (1.14)	0.02 (0.04)	99
Electrostatic precipitator						
90,a		351 (631)			0.38 (0.77)	
Fabric filter						
91,a	10.3 (20.6)	0.08 (0.16)		0.052 (0.104)	0.006 (0.011)	87.1
Venturi/impingement						
88,a	1440 (2880)	519 (1038)	64	1.01 (2.03)	0.06 (0.13)	94.1
90,a		493 (986)	64.9		0.06 (0.12)	93.7
91,a	947 (1,894)	5.78 (11.56)	99.4	1.28 (2.56)	1.25 (2.50)	2.4
98,a	828 (1,656)	34.5 (69.0)	85.4	1.60 (3.20)	0.42 (0.84)	76.4
Fluidized bed						
Venturi/impingement						
98,a		5.20 (10.4)				

TABLE 4-44. SUMMARY OF COPPER EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category reference/rating	Copper: Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
Multiple hearth			
Cyclone			
98,a	27.1 (54.2)	3.9 (7.8)	85.7
99,a		1.46 (2.92)	
Electrostatic precipitator			
90,b	101	0.2 (0.4)	99.8
Fabric filter			
91,a	1.08 (2.16)	0.002 (0.004)	99.8
Cyclone/venturi			
l0l,a		1.04 (2.07)	
Venturi			
95,b		0.44 (0.88)	
Venturi/esp			
92,c	0.42 (0.84)	0.013 (0.026)	96.8
Venturi/impingement			
90,b		11.2 (22.4)	88.5
102,c		0.49 (1.00)	
91,a	35.8 (71.6)	2.22 (4.44)	93.8
98,a	37.8 (75.6)	8.12 (16.2)	81.0
Venturi/impingement/ afterburner			
88,a		6.22 (12.44)	
92,c		5.44 (10.88)	
Fluidized bed			
Venturi/impingement			
97,a		0.48 (0.96)	
98,a		0.16 (0.32)	

TABLE 4-45. SUMMARY OF IRON AND GOLD EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category reference/rating	Iron: Uncontrolled g/Mg (10^{-3} lb/ton)	Iron: After control device, g/Mg (10^{-3} lb/ton)	Iron: Efficiency, percent	Gold: Uncontrolled g/Mg (10^{-3} lb/ton)	Gold: After control device, g/Mg (10^{-3} lb/ton)	Gold: Efficiency, percent
Multiple hearth						
Cyclone						
98,a	180 (360)	1.72 (3.44)	99.0			
Electrostatic precipitator						
90,a	1,382 (2,763)	25.2 (49.9)	98.0	0.009 (0.018)	0.002 (0.004)	85.4
Fabric filter						
91,a	13.4 (26.8)	0.23 (0.46)		0.002 (0.004)	0.0008 (0.0016)	97.9
Venturi/impingement						
90,b	1,382 (2,763)	71.8 (144)	94.8		0.001 (0.002)	
91,a	622 (1,244)	6.20 (12.4)	99	0.08 (0.16)	0.00	100
98,a	619 (1,240)	64.8 (129.6)	87.1			
Venturi						
95,b		0.52 (1.04)				
Fluidized Bed						
Venturi/impingement						
98,a		2.70 (5.40)				

TABLE 4-46. SUMMARY OF MANGANESE EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category/ reference/rating	Manganese: Uncontrolled g/Mg (10^{-3} lb/ton)	Manganese: After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
<u>Multiple hearth</u>			
Cyclone			
98,a		0.63 (1.27)	
99,a		0.49 (0.98)	
Electrostatic precipitator			
90,b			
		0.32 (0.65)	
Fabric filter			
91,a		0.0002 (0.0005)	
Venturi/impingement			
90,a	10 (20)	1.24 (2.41)	88.2
91,a	7.65 (15.30)	0.20 (0.40)	97.4
98,a	26.0 (52.0)	1.12 (2.24)	75.4
Cyclone/venturi			
101,a		2.97 (5.95)	
<u>Fluidized Bed</u>			
Venturi/impingement			
98,a		0.27 (0.54)	

TABLE 4-47. SUMMARY OF MAGNESIUM AND PHOSPHORUS EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category reference/rating	Magnesium			Phosphorus		
	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
<u>Multiple hearth</u>						
Cyclone						
99,a		2.69 (5.39)			13.5 (27.1)	
98,a	21.1 (42.2)	0.16 (0.32)	99.3	89.6 (179.2)	4.26 (8.52)	95.3
Electrostatic precipitator						
90,a	446 (892)	8.83 (17.7)	97.7		6.9 (13.8)	99.3
Fabric filter						
91,a	3.85 (7.70)	0.03 (O.O5)	99.3	l0.5 (21)	0.21 (0.42)	98.0
Venturi/impingement						
90,b	446 (892)	6.26 (12.52)	98.7	1,047 (2,093)	10 (20)	98.9
91,a	141 (282)	1.34 (2.68)	99.1	422 (844)	3.45 (6.90)	99.2
98,a	88.7 (177.4)	5.13 (10.2)	86.6	332 (664)	24.0 (48.0)	83.7
Venturi						
95,b					0.96 (1.92)	
<u>Fluidized Bed</u>						
Venturi/impingement						
98,a		0.60 (1.20)			2.47 (4.94)	

TABLE 4-48. SUMMARY OF SELENIUM EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category/ reference/rating	Selenium Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
Multiple hearth			
Cyclone			
98,a		0.19 (0.38)	
Electrostatic precipitator			
90,b	0.395 (0.79)	0.84 (1.64)	
Fabric filter			
91,a	0.033 (0.066)	0.12 (0.24)	
Venturi/impingement		5.47 (10.54)	
90,b	0.02 (0.04)	0.26 (0.52)	
91,a		0.90 (1.80)	
98,a			
Cyclone/venturi			
101,a		0.26 (0.53)	
Venturi			
102,c		0.064 (0.128)	
Fluidized Bed			
Venturi/impingement			
98,a		0.21 (0.42)	

TABLE 4-49. SUMMARY OF SILICON AND SILVER EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category reference/rating	Silicon Uncontrolled g/Mg (10^{-3} lb/ton)	Silicon After control device, g/Mg (10^{-3} lb/ton)	Silicon Efficiency, percent	Silver Uncontrolled g/Mg (10^{-3} lb/ton)	Silver After control device, g/Mg (10^{-3} lb/ton)	Silver Efficiency, percent
Multiple hearth						
Cyclone						
98,a	218 (436)	4.63 (9.26)	97.9			
Fabric filter						
91,a				0.01 (0.02)	0.0001 (0.0002)	96.1
Electrostatic precipitator						
90,a				1.27 (2.54)	0.0064 (0.0128)	99.5
Venturi/impingement						
90,b				1.27 (2.54)	0.0983 (0.196)	91.9
91,a				0.67 (1.34)	0.09 (0.18)	86.6
98,a	474 (948)	44.4 (88.8)	85.8			
Venturi						
95,b					0.36 (0.72)	
Fluidized Bed						
Venturi/impingement						
98,a		3.18 (6.36)				

TABLE 4-50. SUMMARY OF SODIUM EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category/ reference/rating	Sodium Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
Multiple hearth			
Cyclone			
98,a	13.1 (26.2)	1.79 (3.60)	86.2
Electrostatic precipitator			
90,b	141 (282)	0.55 (1.10)	99.6
Fabric filter			
91,a	1.07 (2.14)	0.01 (0.02)	99.1
Venturi/impingement			
90,d	141 (282)	17.5 (35.0)	85.7
91,a	43.3 (86.6)	17.4 (34.8)	59.9
98,a	36.8 (73.6)	8.13 (16.2)	75.8
Fluidized Bed			
Venturi/impingement			
98,a		1.18 (2.36)	

TABLE 4-51. SUMMARY OF SULFUR AND TIN EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

	Sulfur			Tin		
Source category reference/rating	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
<u>Multiple hearth</u>						
Cyclone						
98,a	22.9 (45.0)	19.5 (39.0)	15	10.3 (20.6)	5.90 (11.8)	42.6
Electrostatic precipitator						
90,a	15,850 (31,700)	7,846 (15,693)	50.5	19.3 (38.5)	0.20 (0.41)	99.15
Fabric filter						
91,a	44.1 (88.2)	60.4 (120.8)		0.26 (0.52)	0.016 (0.032)	93.9
Venturi/impingement						
90,b	15,850 (31,700)	202 (403)	97.97	19.3 (38.5)	9.42 (18.8)	37.0
91,a	2,172 (4,344)	103 (206)	95.3	8.66 (17.32)	1.11 (2.22)	87.21
98,a	62.3 (124.6)	18.5 (37.0)	47.5	27.9 (55.8)	13.2 (26.4)	49.1
Venturi						
95,b					0.36 (0.72)	
<u>Fluidized Bed</u>						
Venturi/impingement						
98,a		8.6 (17.2)			0.35 (0.70)	

TABLE 4-52. SUMMARY OF TITANIUM EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category/ reference/rating	Titanium: Uncontrolled g/Mg (10^{-3} lb/ton)	Titanium: After control device, g/Mg (10^{-3} lb/ton)	Titanium: Efficiency, percent
<u>Multiple hearth</u>			
Cyclone			
98,a	32.1 (64.2)	0.12 (0.24)	99.6
Electrostatic precipitator			
90,b	132 (263)	0.88 (1.76)	99.3
Fabric filter			
91,a	1.41 (2.82)	0.006 (0.012)	99.6
Venturi/impingement			
90,d	132 (263)	4.95 (10.0)	95.6
91,a	44.4 (88.8)	0.19 (0.38)	99.6
98,a	46.8 (93.6)	4.2 (8.40)	84.5
<u>Fluidized Bed</u>			
Venturi/impingement			
98,a		0.39 (0.80)	

TABLE 4-53. SUMMARY OF VANADIUM AND ZINC EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category reference/rating	Vanadium			Zinc		
	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
Multiple hearth						
Cyclone						
98,a	1.18 (2.34)	0.04 (0.08)		90.7 (181)	13.7 (27.4)	85.0
99,a		0.48 (0.95)			8.54 (17.1)	
Venturi						
95,b					4.4 (8.8)	
Electrostatic precipitator						
90,b	4.9 (9.8)	0.99 (0.38)	95.4	145 (290)	0.39 (0.78)	99.7
Fabric filter						
91,a	0.26 (0.52)	0.002 (0.004)	99.2	1.54 (3.08)	0.04 (0.08)	97.2
Venturi/impingement						
90,b	4.9 (9.8)	0.511 (1.02)	90	145 (290)	14.3 (20.6)	89
88,a					46.8 (93.6)	
91,a	9.57 (19.14)	1.09 (2.18)	88.6	53.4 (106.8)	7.21 (14.42)	86.5
98,a	0.70 (1.40)	0.90 (1.80)		102 (204)	28.5 (47.0)	72.0
Cyclone /venturi						
101,a					38.5 (77.1)	
Venturi/impingement/ Afterburner						
92,c					47.2 (94.4)	
88,a					18.8 (37.6)	
Venturi/WESP						
102,b				2.76 (5.52)	0.2 (0.4)	92.7
Fluidized Bed						
Venturi/impingement						
98,a		0.11 (0.22)			1.03 (2.06)	

TABLE 4-54. SUMMARY OF VINYL CHLORIDE EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

	Vinyl chloride		
Source category/ reference/rating	Uncontrolled g/Mg (10^{-3} lb/ton)	After control device, g/Mg (10^{-3} lb/ton)	Efficiency, percent
Multiple hearth		177 (353)	
Cyclone			
98,a			
Electrostatic precipitator		0.8 (1.61)	
90,b			
Venturi/impingement			
90,d		3.3 (6.6)	
91,a	9.6 (19.1)	6.2 (12.3)	35.4
98,a	3.6 (7.2)	1.6 (3.1)	55.6
Cyclone/venturi			
108,b		0.04 (0.07)	
108,b		2.02 (4.04)*	

* High THC levels.

TABLE 4-56. SUMMARY OF SEWAGE SLUDGE INCINERATOR EMISSION DATA FOR CRITERIA POLLUTANTS AND ACID GASES

Pollutant/source	Average emission factor, kg/Mg	Emission factor rating
Particulate matter		
Multiple hearth		
Uncontrolled	52.5	B
Controlled		
Impingement	0.7	B
Venturi	1.6	B
Venturi/impingement	1.1	A
Cyclone	2	E
Cyclone/impingement	0.4	E
Cyclone/venturi	0.25	D
Cyclone/venturi/impingement	0.31	E
Venturi/impingement/WESP	0.2	E
Fabric Filter	0.002	E
Fluidized bed		
Uncontrolled	230.5	E
Controlled		
Cyclone/venturi/impingement	0.5	E
Impingement	0.13	E
Venturi	0.57	E
Venturi/impingement	0.27	E
Venturi/impingement/WESP	0.1	E
Electric infrared		
Uncontrolled	3.7	E
Controlled		
Cyclone/venturi	1.93	E
Impingement	0.82	E
Venturi/impingement	0.95	E
Methane VOC		
Multiple hearth		
Controlled		
Impingement	0.39	E
Venturi	3.24	E
Fluidized bed		
Controlled		
Venturi	1.65	E
Venturi/impingement	0.40	E

TABLE 4-56. SUMMARY OF SEWAGE SLUDGE INCINERATOR EMISSION DATA FOR CRITERIA POLLUTANTS AND ACID GASES
(Continued)

Pollutant/source	Average emission factor, kg/Mg	Emission factor rating
Nonmethane VOC		
Multiple hearth		
Uncontrolled	0.846	D
Controlled		
Cyclone	1.530	E
Cyclone/venturi	0.220	E
Impingement	0.785	E
Lead (Pb)		
Multiple hearth		
Uncontrolled	0.05	B
Controlled		
Cyclone	0.03	E
Cyclone/venturi	0.003	E
Cyclone/venturi/impingement	0.011	E
Impingement	0.02	E
Venturi/impingement/afterburner	0.05	E
Venturi	0.0009	E
Venturi/WESP	0.00009	E
Venturi/impingement	0.03	B
Wet ESP	0.001	E
Fluidized bed		
Uncontrolled	0.02	E
Controlled		
Impingement	0.003	E
Venturi/impingement	0.08	D
Venturi/impingement/WESP	0.000001	E
Fabric filter	0.000005	E

TABLE 4-56. SUMMARY OF SEWAGE SLUDGE INCINERATOR EMISSION DATA FOR CRITERIA POLLUTANTS AND ACID GASES
(Continued)

Pollutant/source	Average emission factor, kg/Mg	Emission factor rating
Sulfur dioxide (SO_2)		
Multiple hearth		
Uncontrolled	13.6	B
Controlled		
Cyclone	2.8	E
Venturi/impingement	0.1	E
Venturi	2.3	E
Impingement	0.32	D
Fluidized bed		
Uncontrolled	0.15	E
Controlled		
Venturi/impingement	0.4	E
Impingement	0.3	E
Venturi	9.2	E
Electric infrared		
Uncontrolled	9.2	E
Controlled		
Venturi/impingement	2.3	E
Nitrogen oxides (NO_x)		
Multiple hearth		
Uncontrolled	2.5	C
Controlled		
Impingement		
Venturi		
Venturi/impingement		
Cyclone		
Fluidized bed		
Uncontrolled	0.88	E
Controlled		
Venturi/impingement		
Venturi		
Electric infrared		
Uncontrolled	4.3	E
Controlled		
Venturi/impingement	2.9	E

TABLE 4-56. SUMMARY OF SEWAGE SLUDGE INCINERATOR EMISSION DATA FOR CRITERIA POLLUTANTS AND ACID GASES
(Continued)

Pollutant/source	Average emission factor, kg/Mg	Emission factor rating
Carbon monoxide (CO)		
Multiple hearth		
Uncontrolled	15.5	C
Controlled		
Cyclone/venturi		
Impingement		
Venturi/impingement		
Fluidized bed		
Uncontrolled	1.1	E
Controlled		
Venturi/impingement		
Sulfuric acid (H_2SO_4)		
Multiple hearth		
Uncontrolled	0.6	D
Controlled		
Cyclone	0.33	E
Impingement	0.05	E
Venturi/impingement	0.2	E
Fluidized bed		
Controlled		
Impingement	0.03	E
Venturi/impingement	0.06	E
Hydrogen chloride (HCl)		
Multiple hearth		
Controlled		
Impingement	0.01	E
Venturi	0.01	E
Cyclone/venturi	0.01	E
Cyclone/impingement	0.01	E
Fluidized bed		
Controlled		
Venturi/impingement	0.05	E

TABLE 4-57. SUMMARY OF DIOXIN/FURAN EMISSION DATA

Pollutant/source	Average emission factor, μg/Mg	Emission factor rating
2,3,7,8 Tetrachlorodibenzo-p-dioxin		
Multiple hearth		
Controlled		
Cyclone/venturi/impingement	0.3	E
Impingement	0.5	E
Venturi/impingement	2	E
Venturi/impingement/afterburner	0.9	E
Fluidized bed		
Controlled		
Venturi/impingement	0.3	E
Total tetrachlorodibenzo-p-dioxin		
Multiple hearth		
Uncontrolled	63	E
Controlled		
Cyclone/venturi	1.4	E
Cyclone/venturi/impingement	63.8	E
Impingement	28	E
Venturi/impingement	134	E
Venturi/impingement/afterburner	139	E
Fluidized bed		
Controlled		
Venturi/impingement	2.2	E
Total pentachlorodibenzo-p-dioxin		
Multiple hearth		
Uncontrolled	2.7	E
Controlled		
Cyclone/venturi/impingement	1.5	E
Impingement	3.7	E
Venturi/impingement	53.1	E
Venturi/impingement/afterburner	151.4	E
Fluidized bed		
Uncontrolled	1.1	E

TABLE 4-57. SUMMARY OF DIOXIN/FURAN EMISSION DATA
(Continued)

Pollutant/source	Average emission factor, μg/Mg	Emission factor rating
Total hexachlorodibenzo-p-dioxin		
Multiple hearth		
Uncontrolled	67.7	E
Controlled		
Cyclone/venturi/impingement	4.4	E
Impingement	24.1	E
Venturi/impingement	38.2	E
Venturi/impingement/afterburner	60.0	E
Fluidized bed		
Controlled		
Venturi/impingement	0.9	E
Total heptachlorodibenzo-p-dioxin		
Multiple hearth		
Uncontrolled	340	E
Controlled		
Cyclone/venturi	0.8	E
Cyclone/venturi/impingement	14.1	E
Impingement	72.8	E
Venturi/impingement	14.6	E
Venturi/impingement/afterburner	23.3	E
Fluidized bed		
Controlled		
Venturi/impingement	0.9	E

TABLE 4-57. SUMMARY OF DIOXIN/FURAN EMISSION DATA
(Continued)

Pollutant/source	Average emission factor, μg/Mg	Emission factor rating
Total octachlorodibenzo-p-dioxin		
Multiple hearth		
Uncontrolled	375	E
Controlled		
Cyclone/venturi	3.4	E
Cyclone/venturi/impingement	30.7	E
Impingement	53.2	E
Venturi/impingement	19.0	E
Venturi/impingement/afterburner	12.1	E
Fluidized bed		
Controlled		
Venturi/impingement	4.3	E
Total tetra- through octachlorodibenzo-p-dioxin		
Multiple hearth		
Uncontrolled	847	E
Controlled		
Cyclone/venturi	5.6	E
Cyclone/venturi/impingement	113	E
Impingement	182	E
Venturi/impingement	271	E
Venturi/impingement/afterburner	310	E
2,3,7,8-Tetrachlorodibenzofuran		
Multiple hearth		
Uncontrolled	620	E
Controlled		
Cyclone/venturi	5.6	E
Impingement	186	E
Venturi/impingement	46.4	E
Venturi/impingement/afterburner	53.7	E
Fluidized bed		
Controlled		
Venturi/impingement	0.2	E

TABLE 4-57. SUMMARY OF DIOXIN/FURAN EMISSION DATA
(Continued)

Pollutant/source	Average emission factor, μg/Mg	Emission factor rating
Total tetrachlorodibenzofuran		
Multiple hearth		
Uncontrolled	1,708	E
Controlled		
Cyclone/venturi	50	E
Cyclone/venturi/impingement	188	E
Impingement	701	E
Venturi/impingement	600	E
Venturi/impingement/afterburner	350	E
Fluidized bed		
Controlled		
Venturi/impingement	6.2	E
Total pentachlorodibenzofuran		
Multiple hearth		
Uncontrolled	980	E
Controlled		
Cyclone/venturi	11.4	E
Cyclone/venturi/impingement	57.5	E
Impingement	360	E
Venturi/impingement	1.3	E
Venturi/impingement/afterburner	130	E
Fluidized bed		
Controlled		
Venturi/impingement	5.2	E

TABLE 4-57. SUMMARY OF DIOXIN/FURAN EMISSION DATA
(Continued)

Pollutant/source	Average emission factor, μg/Mg	Emission factor rating
Total hexachlorodibenzofuran		
Multiple hearth		
Uncontrolled	99.5	E
Controlled		
Cyclone/venturi	3.4	E
Cyclone/venturi/impingement	1.8	E
Impingement	110.7	E
Venturi/impingement	56.8	E
Venturi/impingement/afterburner	77.7	E
Fluidized bed		
Controlled		
Venturi/impingement	4.1	E
Total heptachlorodibenzofuran		
Multiple hearth		
Uncontrolled	481	E
Controlled		
Cyclone/venturi	0.9	E
Cyclone/venturi/impingement	2.9	E
Impingement	205	E
Venturi/impingement	41.1	E
Venturi/impingement/afterburner	48	E
Fluidized bed		
Controlled		
Venturi/impingement	1.6	E

TABLE 4-57. SUMMARY OF DIOXIN/FURAN EMISSION DATA
(Continued)

Pollutant/source	Average emission factor, μg/Mg	Emission factor rating
Total octachlorodibenzofuran		
Multiple hearth		
Uncontrolled	491	E
Controlled		
Cyclone/venturi	0.7	E
Cyclone/venturi/impingement	1.8	E
Impingement	155	E
Venturi/impingement	6.3	E
Venturi/impingement/afterburner	7.7	E
Fluidized bed		
Controlled		
Venturi/impingement	1.3	E
Total tetra- through octachlorodibenzofuran		
Multiple hearth		
Uncontrolled	3,766	E
Controlled		
Cyclone/venturi	66.2	E
Cyclone/venturi/impingement	250	E
Impingement	l,531	E
Venturi/impingement	931	E
Venturi/impingement/afterburner	465	E

TABLE 4-58. SUMMARY OF ORGANIC AND METAL EMISSION DATA

Pollutant/source	Average emission factor, g/Mg	Emission factor rating
1,1,1-Trichloroethane		
Multiple hearth		
Uncontrolled	0.06	D
Controlled		
Cyclone/impingement	1.94	E
Cyclone/venturi	0.07	E
Venturi/impingement/afterburner	1.38	E
Venturi/impingement	0.61	D
Fluidized bed		
Controlled		
Venturi/impingement	0.26	E
1,3-Dichlorobenzene		
Multiple hearth		
Controlled		
Venturi/impingement	0.02	E
Cyclone/venturi	0.05	E
l,l-Dichloroethane		
Multiple hearth		
Controlled		
Cyclone/impingement	0.23	E
1,2-Dichlorobenzene		
Multiple hearth		
Uncontrolled	0.37	E
Controlled		
Venturi/impingement	0.19	E
Fluidized bed		
Controlled		
Venturi	67.4	E

TABLE 4-58. SUMMARY OF ORGANIC AND METAL EMISSION DATA
(Continued)

Pollutant/source	Average emission factor, g/Mg	Emission factor rating
1,2-Dichloroethane		
Multiple hearth		
Controlled		
Venturi/impingement/afterburner	0.03	E
Venturi/impingement	0.01	E
Cyclone/venturi	0.004	E
1,4-Dichlorobenzene		
Multiple hearth		
Uncontrolled	0.41	E
Controlled		
Venturi/impingement	0.24	E
Cyclone/venturi	0.007	E
Fluidized bed		
Controlled		
Venturi/impingement	239.7	E
2-Nitrophenol		
Multiple hearth		
Uncontrolled	6.0	E
Controlled		
Venturi/impingement	1.18	E
Cyclone/venturi	0.38	E
Acetaldehyde		
Multiple hearth		
Controlled		
Impingement	0.16	E
Acetone		
Multiple hearth		
Controlled		
Venturi	3.16	E

TABLE 4-58. SUMMARY OF ORGANIC AND METAL EMISSION DATA (Continued)

Pollutant/source	Average emission factor, g/Mg	Emission factor rating
Acetonitrile		
Multiple hearth		
Uncontrolled	25.4	E
Controlled		
Venturi/impingement/afterburner	0.74	E
Venturi/impingement	9.76	E
Acrylonitrile		
Multiple hearth		
Uncontrolled	25.4	E
Controlled		
Cyclone/venturi	0.15	E
Venturi/impingement/afterburner	0.49	E
Venturi/impingement	17.3	D
Aluminum		
Multiple hearth		
Uncontrolled	243	D
Controlled		
Cyclone	0.3	E
Electrostatic precipitator	141	E
Venturi/impingement	0.68	E
	124	E
Fluidized bed		
Controlled		
Venturi/impingement	1.9	E
Antimony		
Multiple hearth		
Uncontrolled	1.5	E
Controlled		
Cyclone	0.32	E
Electrostatic precipitator	0.04	E
Fabric filter	0.004	E
Venturi/impingement	0.24	E

TABLE 4-58. SUMMARY OF ORGANIC AND METAL EMISSION DATA (Continued)

Pollutant/source	Average emission factor, g/Mg	Emission factor rating
Arsenic		
Multiple hearth		
Uncontrolled	4.7	B
Controlled		
Cyclone/venturi/impingement	0.85	E
Cyclone/venturi	0.10	E
Electrostatic precipitator	1.2	E
Fabric filter	0.003	E
Venturi/impingement	0.61	B
Venturi	0.05	E
Venturi/WESP	0.6	E
Venturi/impingement/afterburner	0.04	E
Fluidized bed		
Uncontrolled	2.2	E
Controlled		
Venturi/impingement	0.015	D
Venturi/impingement/WESP	0.005	E
Barium		
Multiple hearth		
Uncontrolled	15.4	D
Controlled		
Cyclone	0.1	E
Electrostatic precipitator	7.43	E
Fabric filter	0.004	E
Venturi/impingement	3.2	D
Fluidized bed		
Controlled		
Venturi/impingement	0.24	E

TABLE 4-58. SUMMARY OF ORGANIC AND METAL EMISSION DATA
(Continued)

Pollutant/source	Average emission factor, g/Mg	Emission factor rating
Benzene		
Multiple hearth		
Uncontrolled	5.8	D
Controlled		
Cyclone/venturi	0.35	E
Venturi	14.0	E
Venturi/impingement/afterburner	0.17	E
Venturi/impingement	6.3	D
Fluidized bed		
Controlled		
Venturi/impingement	0.2	E
Beryllium		
Multiple hearth		
Uncontrolled	0.15	E
Controlled		
Cyclone	0.009	D
Venturi/impingement	0.005	E
Fluidized bed		
Controlled		
Venturi/impingement	0.0002	E
Venturi/impingement/WESP	0.0002	E
Bis(2-ethylhexyl)phthalate		
Multiple hearth		
Uncontrolled	0.93	E
Controlled		
Cyclone/venturi	0.04	E
Venturi/impingement	0.32	E
Fluidized bed		
Controlled		
Venturi/impingement	41.2	E

TABLE 4-58. SUMMARY OF ORGANIC AND METAL EMISSION DATA
(Continued)

Pollutant/source	Average emission factor, g/Mg	Emission factor rating
Bromodichloromethane		
Multiple hearth		
Uncontrolled	0.004	E
Controlled		
Venturi	1.48	E
Cadmium		
Multiple hearth		
Uncontrolled	15.7	B
Controlled		
Cyclone	17.0	D
Cyclone/venturi	12.6	C
Cyclone/venturi/impingement	8.1	E
Electrostatic precipitator	0.17	E
Fabric filter	0.01	E
Impingement	1.23	E
Venturi	0.11	E
Venturi/impingement/afterburner	3.04	E
Venturi/impingement	3.3	B
Venturi/impingement/WESP	0.1	E
Venturi/WESP	0.04	E
Fluidized bed		
Uncontrolled	2.25	E
Controlled		
Venturi/impingement	0.57	D
Impingement	0.4	E
Venturi/impingement	0. 001	E

TABLE 4-58. SUMMARY OF ORGANIC AND METAL EMISSION DATA
(Continued)

Pollutant/source	Average emission factor, g/Mg	Emission factor rating
Calcium		
Multiple hearth		
Uncontrolled	702	C
Controlled		
Cyclone	1.2	E
Electrostatic precipitator	351	E
Fabric filter	0.08	E
Venturi/impingement	263	D
Fluidized bed		
Controlled		
Venturi/impingement	5.2	E
Carbon tetrachloride		
Multiple hearth		
Uncontrolled	0.01	E
Controlled		
Venturi/impingement/afterburner	0.001	E
Venturi/impingement	0.03	D
Cyclone/venturi	0.007	E
Fluidized bed		
Controlled		
Venturi/impingement	0.012	E
Chlorobenzene		
Multiple hearth		
Uncontrolled	0.75	E
Controlled	4.2	E
Venturi	0.006	E
Cyclone/venturi	0.26	E
Venturi/impingement/afterburner	0.60	E
Venturi/impingement		
Fluidized bed		
Controlled		
Venturi/impingement	0.005	E

TABLE 4-58. SUMMARY OF ORGANIC AND METAL EMISSION DATA (Continued)

Pollutant/source	Average emission factor, g/Mg	Emission factor rating
Chloromethane		
Multiple hearth		
Uncontrolled	0.4	E
Controlled		
Venturi	5.3	E
Chloroform		
Multiple hearth		
Uncontrolled		
Controlled	0.03	E
Venturi		
Cyclone/venturi	3.3	E
Venturi/impingement/afterburner	0.02	E
Venturi/impingement	0.49	E
	1.30	E
Fluidized bed		
Controlled		
Venturi/impingement	1.98	D

TABLE 4-58. SUMMARY OF ORGANIC AND METAL EMISSION DATA (Continued)

Pollutant/source	Average emission factor, g/Mg	Emission factor rating
Chromium		
Multiple hearth		
Uncontrolled	14.5	B
Controlled		
Cyclone	1.95	D
Cyclone/venturi	0.5	E
Cyclone/venturi/impingement	11.2	E
Impingement	9.8	E
Venturi	0.5	E
Electrostatic precipitator	1.45	E
Fabric filter	0.04	E
Venturi/impingement	2.14	B
Venturi/impingement/afterburner	4.9	E
Cyclone/impingement	0.04	E
Venturi/WESP	0.01	E
Venturi/impingement/WESP	0.11	E
Fluidized bed		
Controlled	0.25	C
Venturi/impingement	0.32	E
Impingement	0.03	E
Venturi/impingement/WESP		
Cobalt		
Multiple hearth		
Uncontrolled	0.9	C
Controlled		
Cyclone	0.2	E
Electrostatic precipitator	0.38	E
Fabric filter	0.006	E
Venturi/impingement	0.45	D

TABLE 4-58. SUMMARY OF ORGANIC AND METAL EMISSION DATA
(Continued)

Pollutant/source	Average emission factor, g/Mg	Emission factor rating
Copper		
Multiple hearth		
Uncontrolled	40.5	B
Controlled		
Cyclone	2.7	E
Electrostatic precipitator	0.20	E
Fabric filter	0.002	E
Venturi/impingement/afterburner	5.8	E
Venturi/impingement	5.5	D
Venturi	0.4	E
Cyclone/venturi	1.0	E
Venturi/WESP	0. 01	E
Fluidized bed		
Controlled		
Venturi/impingement	0.3	E
Ethylbenzene		
Multiple hearth		
Uncontrolled	0.8	E
Controlled		
Cyclone/venturi	0.003	E
Venturi	6.02	E
Venturi/impingement/afterburner	0.02	E
Venturi/impingement	1.01	D
Fluidized bed		
Controlled		
Venturi/impingement	0.025	E
Formaldehyde		
Multiple hearth		
Controlled		
Cyclone/venturi	1.32	E
Venturi	0.40	E

TABLE 4-58. SUMMARY OF ORGANIC AND METAL EMISSION DATA
(Continued)

Pollutant/source	Average emission factor, g/Mg	Emission factor rating
Gold		
<u>Multiple hearth</u>		
Uncontrolled	0.03	E
Controlled		
Electrostatic precipitator	0.009	E
Fabric filter	0.002	E
Venturi/impingement	0.001	E
Iron		
<u>Multiple hearth</u>		
Uncontrolled	563.3	C
Controlled		
Cyclone	1.72	E
Electrostatic precipitator	25.2	E
Fabric filter	0.23	E
Venturi/impingement	48.4	D
Manganese		
<u>Multiple hearth</u>		
Uncontrolled		
Controlled	9.4	C
Cyclone		
Electrostatic precipitator	0.33	E
Fabric filter	0.32	E
Venturi/impingement	0.005	E
	0.85	D
<u>Fluidized bed</u>		
Controlled		
Venturi/impingement	0.3	E

TABLE 4-58. SUMMARY OF ORGANIC AND METAL EMISSION DATA (Continued)

Pollutant/source	Average emission factor, g/Mg	Emission factor rating
Magnesium		
Multiple hearth		
Uncontrolled	140.1	C
Controlled		
Cyclone	1.4	E
Electrostatic precipitator	8.83	E
Fabric filter	0.03	E
Venturi/impingement	4.24	D
Fluidized bed		
Controlled		
Venturi/impingement	0.6	E
Mercury (Hg)		
Multiple Hearth		
Controlled		
Cyclone	2.3	E
Cyclone/venturi	1.6	E
Venturi/impingement	0.005	E
Impingement	0.97	E
Fluidized bed		
Control		
Venturi/impingement	0.03	E
Methyl ethyl ketone		
Multiple hearth		
Uncontrolled	6.1	E
Controlled		
Venturi	6.12	E
Venturi/impingement/afterburner	0.050	E
Venturi impingement	8.87	E
Methyl isobutyl ketone		
Multiple hearth		
Controlled		
Cyclone/impingement	0.01	E

TABLE 4-58. SUMMARY OF ORGANIC AND METAL EMISSION DATA
(Continued)

Pollutant/source	Average emission factor, g/Mg	Emission factor rating
Methylene chloride		
Multiple hearth		
Uncontrolled	0.4	D
Controlled		
Venturi	2.1	E
Cyclone/venturi	0.3	E
Venturi/impingement/afterburner	0.4	E
Venturi/impingement	0. 9	D
Fluidized bed		
Controlled		
Venturi/impingement	0.7	E
Naphthalene		
Multiple hearth		
Uncontrolled	9.2	E
Controlled		
Cyclone/venturi	0.97	D
Fluidized bed		
Controlled		
Venturi/impingement	97.3	E

TABLE 4-58. SUMMARY OF ORGANIC AND METAL EMISSION DATA
(Continued)

Pollutant/source	Average emission factor, g/Mg	Emission factor rating
Nickel		
Multiple hearth		
Uncontrolled	8.0	B
Controlled		
Cyclone	0.08	E
Cyclone/venturi/impingement	4.51	E
Impingement	4.12	E
Electrostatic precipitator	1.96	E
Fabric filter	0.014	E
Venturi/impingement/afterburner	0.9	E
Venturi/impingement	0.9	A
Cyclone/venturi	0.35	E
Venturi	0.06	E
Cyclone/impingement	1.3	D
Venturi/WESP	0.003	E
Fluidized bed		
Uncontrolled	17.8	E
Controlled		
Venturi/impingement	1.7	E
Venturi/impingement/WESP	0.005	E
Perchloroethylene		
Multiple hearth		
Uncontrolled		
Controlled	0.4	E
Cyclone/venturi		
Venturi	0.3	E
Venturi/impingement/afterburner	0.2	E
Venturi/impingement	0.95	E
	3.5	E
Fluidized bed		
Controlled		
Venturi/impingement	0.12	E

TABLE 4-58. SUMMARY OF ORGANIC AND METAL EMISSION DATA
(Continued)

Pollutant/source	Average emission factor, g/Mg	Emission factor rating
Phenol		
Multiple hearth		
Uncontrolled	22.4	E
Controlled		
Venturi/impingement	1.8	E
Phosphorus		
Multiple hearth		
Uncontrolled	380	D
Controlled		
Cyclone	8.9	E
Electrostatic precipitator	6.9	E
Fabric Filter	0.2	E
Venturi/impingement	12.5	D
Venturi	0.96	E
Potassium		
Multiple hearth		
Uncontrolled	52.8	E
Controlled		
Cyclone	0.9	E
Venturi/impingement	7.3	E
Fluidized bed		
Controlled		
Venturi/impingement	0.6	E

TABLE 4-58. SUMMARY OF ORGANIC AND METAL EMISSION DATA
(Continued)

Pollutant/source	Average emission factor, g/Mg	Emission factor rating
Selenium		
Multiple hearth		
Uncontrolled	0.15	D
Controlled		
Cyclone	0.2	E
Fabric Filter	0.12	E
Electrostatic precipitator	0.8	E
Venturi/impingement	2.2	D
Cyclone/venturi	0.3	E
Venturi	0.06	E
Fluidized bed		
Controlled		
Venturi/impingement	0.2	E
Silicon		
Multiple hearth		
Uncontrolled	346	E
Controlled		
Cyclone	4.63	E
Venturi/impingement	44.4	E
Fluidized bed		
Controlled		
Venturi/impingement	3.2	E
Silver		
Multiple hearth		
Uncontrolled	0.65	E
Controlled		
Electrostatic precipitator	0.006	E
Venturi/impingement	0.09	E
Venturi	0.4	E
Fabric Filter	0.0001	E

TABLE 4-58. SUMMARY OF ORGANIC AND METAL EMISSION DATA
(Continued)

Pollutant/source	Average emission factor, g/Mg	Emission factor rating
Sodium		
Multiple hearth		
Uncontrolled	47	C
Controlled		
Cyclone	1.8	E
Electrostatic precipitator	0.55	E
Fabric Filter	0.01	E
Venturi/impingement	14.3	D
Sulfur		
Multiple hearth		
Uncontrolled		
Controlled	3630	D
Cyclone		
Electrostatic precipitator	19.5	E
Fabric Filter	7846	E
Venturi/impingement	60.4	E
	107.8	E
Fluidized bed		
Controlled		
Venturi/impingement	8.6	E
Tetrachloroethane		
Multiple hearth		
Controlled		
Venturi	11.8	E
Tin		
Multiple hearth		
Uncontrolled	13.3	C
Controlled		
Cyclone	5.9	E
Electrostatic precipitator	0.20	E
Fabric Filter	0.02	E
Venturi/impingement	7.9	D
Fluidized bed		
Controlled		
Venturi/impingement	0.35	E

TABLE 4-58. SUMMARY OF ORGANIC AND METAL EMISSION DATA
(Continued)

Pollutant/source	Average emission factor, g/Mg	Emission factor rating
Titanium		
Multiple hearth		
Uncontrolled	51.3	C
Controlled		
Cyclone	0.1	E
Electrostatic precipitator	0.9	E
Fabric Filter	0.006	E
Venturi/impingement	3.1	D
Fluidized bed		
Controlled		
Venturi/impingement	0.4	E
Toluene		
Multiple hearth		
Uncontrolled		
Controlled	7.8	D
Venturi		
Cyclone/venturi	15.5	E
Venturi/impingement/afterburner	3.3	E
Venturi/impingement	0.66	E
	6.5	D
Fluidized bed		
Controlled		
Cyclone/impingement		
	0.35	E
Trans-1,2-dichloroethene		
Multiple hearth		
Uncontrolled	0.09	E
Controlled		
Venturi/impingement/afterburner	0.04	D
Venturi/impingement	0.05	E
Venturi	5.2	E

TABLE 4-58. SUMMARY OF ORGANIC AND METAL EMISSION DATA (Continued)

Pollutant/source	Average emission factor, g/Mg	Emission factor rating
Trichloroethene		
Multiple hearth		
Uncontrolled	0.5	E
Controlled		
Venturi/impingement/afterburner	1.53	E
Venturi/impingement	1.07	E
Fluidized bed		
Controlled		
Venturi/impingement	0.03	E
Vanadium		
Multiple hearth		
Uncontrolled	3.3	C
Controlled		
Cyclone	0.3	E
Electrostatic precipitator	0.99	E
Fabric filter	0.002	E
Venturi/impingement	0.8	E
Vinyl chloride		
Multiple hearth		
Uncontrolled	6.6	E
Controlled		
Cyclone	177	E
Cyclone/venturi	1.0	E
Electrostatic precipitator	0.80	E
Venturi/impingement	3.7	D
Xylene, m,p		
Multiple hearth		
Controlled		
Venturi	2.02	E
Xylenes, total		
Multiple hearth		
Uncontrolled	0.95	E
Controlled		
Venturi	1.4	E

TABLE 4-58. SUMMARY OF ORGANIC AND METAL EMISSION DATA
(Continued)

Pollutant/source	Average emission factor, g/Mg	Emission factor rating
Zinc		
Multiple hearth		
Uncontrolled	65.9	C
Controlled		
Cyclone	11.1	E
Electrostatic precipitator	0.39	E
Fabric filter	0.04	E
Venturi/impingement/afterburner	33	E
Venturi/impingement	24.2	C
Venturi	4.4	E
Cyclone/venturi	38.5	E
Venturi/WESP	0.2	E
Fluidized bed		
Controlled		
Venturi/impingement	1.0	E

4.2.1 Total Particulate Matter Emissions Data

Both uncontrolled and controlled particulate matter emission factors were determined from the data contained in the reference documents described above. In the case of uncontrolled emissions, References 5o, p, r; 7; 21; 34n and s; 35e; 39; 91; 98; 104; 106; and 107 contained useful data. For all of these except Reference 39, the emission factors were determined from the test data by manual and computer calculations from emission factors expressed in units other than mass of pollutant per megagram of dry sewage sludge incinerated. For Reference 39, the appropriate uncontrolled emission factor was extracted directly from the test report. References 34n and s each contained a single-run value for uncontrolled particulate matter emissions. As discussed in Section 4.1.16, these emission results were used as order-of-magnitude values only.

For controlled processes, a procedure similar to that described above for determining uncontrolled emission factors was used. References 4, 5o through 5r, 7, 9 through 21, 22a through 22d, 24 through 30, 32, 33, 34n and 34s, 35a, 35c, 35d, 35e, 39, 49, 53, 54, 67 through 72, 75, 77 through 81, 84, 91, 98, 101, 104, 106, and 107 contained useful data. Except for References 4, 10, 11, 13, 15, 17 through 22a-22d, 23, 24, 25, 32, 33, 34n and 34s, 35c and 35d, 39, 42, 47, 48, 49, and 70, the controlled emission factors were calculated from data presented in other terms. A summary of all available particulate matter emission factors is shown in Table 4-1.

4.2.2 Particle Size Data

Both uncontrolled and controlled particulate matter emission factors were determined from the data contained in the reference documents described above. In the case of uncontrolled emissions, References 7, 21, 35a, 34n and s, and 35e contained useful data. For controlled emissions, References 4, 7, 21, 35a, and 35e contained useful data. A summary of all available PM10 emission factors is shown in Table 4-2.

4.2.3 Other Criteria Pollutant Emissions Data

4.2.3.1 Volatile Organic Compounds. Controlled VOC emission factors were determined for both methane and nonmethane VOC's. References 68, 79, and 84 were used to determine controlled nonmethane VOC emission factors. References 6, 26 through 29, and 69 were used to determine controlled methane VOC emission factors. Uncontrolled nonmethane VOC emission factors were determined from data contained in References 1, 2, 39, and 40. No data were available to develop emission factors for uncontrolled methane VOC's. In all cases, the emission factors were determined from the test data by calculations from emission factors expressed in terms other than mass of pollutant per megagram of dry sludge incinerated. A summary of VOC emission factors is shown in Table 4-3.

4.2.3.2 Lead. Controlled Pb emission factors were determined from the data contained in References 4, 5o through 5r, 28, 39, 84 through 88, 90 through 92,95,97 through 99, 101, 102, 104, 106, and 107. References 39, 85, 86, 88, 90, 91, 101, and 102 contained uncontrolled emissions data. None of the data reports indicated that Pb emission values were based on data from lead compounds. Therefore, elemental Pb was assumed in each case. Because the lead emission factor is the sum of both front- and back-half catches, the lead emission weight cannot be compared to the particulate matter emission weight.

In each case, calculations were performed to convert from the units used in the reports to conventional emission factor units. A summary of Pb emission factors is shown in Table 4-4.

4.2.3.3 Sulfur Dioxide, Oxides of Nitrogen and Carbon Monoxide. Data for determining uncontrolled emission factors for SO_2 were taken from References 1, 3, 5o, 5p, 5r, 35e, 39, 98, 104, 106, and 107. Controlled emissions data used to determine SO2 emission factors were taken from References 5o through 5r, 26 through 29, 35e, 45, 69, 71, and 72. Because water based scrubbers offer virtually no control of NO_x or CO emission factors for these pollutants were determined by using both uncontrolled and controlled test data. Uncontrolled emissions data for

NO_x were available from References 1, 3, 35e, 39, 106, and 107; and for controlled emissions data from References 26 through 28, 35e, 68, 69, 71, 72, 98, 99 and 106. Uncontrolled emissions data for CO were available from References 1, 3, 39, 84, and 106.; and for controlled emissions data from References 29, 68, 72, 99, 101, 104, 106, and 107. The emission factors were determined from the test data by calculations. Tables 4-5 through 4-7 present a summary of emission factors for those pollutants.

4.2.4 Noncriteria Pollutant Emissions Data

4.2.4.1 Acid Gases. Reference 5o, 5p, 5r, 98, and 99 contained data for uncontrolled acid gas (H_2SO_4) emissions. References 5o through 5r, 27,98, and 99 provided data for the determination of controlled emission factors for H_2SO_4. References 26 through 28, and 99 were used for emission factors for HCl. Calculations were required to convert into conventional emission factor units. A summary of acid gas emission factors is shown in Table 4-8.

4.2.4.2 Organic Compounds. References 1, 2, 3, 84, 88, 99, and 106 were used for the development of controlled emission factors for several dioxin and furan compounds. Tables 4-9 through 4-14 present summaries of dioxin and furan emission factors. References 85, 86, 87, 88, 89, 99, 101, 106, and 108 were used for the development of controlled and uncontrolled emission factors for other organic compound emissions, including acetaldehyde, acetone, acrolein, acrylonitrile, benzene, butadiene, carbon tetrachloride, ethylbenzene, formaldehyde, perchlorolethylene, styrene, toluene, vinyl chloride, and xylene. These emission factors are listed in Table 4-17 through 4-35.

4.2.4.3 Inorganic Compounds. References 4, 26, 28, 39, 86 through 92, 99, 101, 102, 106, and 107 provided emissions data for arsenic (As). References 86, 99, 104, and 106 provided emissions data for beryllium (Be). References 4, 5o-5r, 7, 26, 28, 39, 84, 85-88, 90, 91, and 97-102 presented cadmium (Cd) emissions data. References 4, 5o-5r, 26, 28, 39, 84, 85 through 87, 89 through 92, 95, 97 through 100, 102, 104, 106, and 107 presented data for chromium (Cr). Mercury (Hg) data were presented in References 28, 53, 95, 99 and 101. Nickel (Ni) data were presented in References 5o, 26, 28, 39, 84 through 92, 97 through 102, 104, 106, and 107. References 89, 90, 91, 95, 98 and 99 presented emissions data for aluminum (Al), barium (Ba), calcium (Ca), iron (Fe), magnesium (Mg), silver (As), sodium (Na), and titanium (Ti). References 90, 91, and 98 presented emissions data for antimony (Sb) and phosphorous (P). Emissions data for manganese (Mn) and zinc (Zn) were provided in References 89, 90, 91, 98, 99 and 101. Gold (Au) and sulfur (S) emissions data were presented in References 89 through 91. Potassium (K) and silicon (Si) data are presented in Reference 98. Cobalt (Co) and tin (Sn) data are presented in References 89, 90, and 98. Copper (Cu) emissions data were presented in References 88 through 92, 97 through 99, 101, and 102. References 90, 91, 98, 101, and 102 presented selenium (Se) data, and References 89 through 91 presented emissions data for vanadium. Summaries of emission factors for inorganic compounds are presented in Tables 4-36 through 4-55.

4.3 ENGINEERING METHODOLOGY

The emission data were averaged as the arithmetic mean of different sampling runs prior to inclusion in the data base. Test programs at most facilities consisted of three sampling runs conducted during distinct and controlled normal operating conditions.

Due to the variety of formats used to report units of measure at different sludge incineration facilities, the emission data required some preprocessing to standardize the units of measure prior to computer calculation of emission factors. Emission factors were then calculated in terms of kg/Mg of dry sludge and lb/ton of dry sludge for all pollutants. The list of conversion factors used is included as Table 4-18.

If the pollutant-specific data, D1, were reported in ng/dscm corrected to 12 percent CO_2 in the test report, the following calculation:

$$DI = D1 * (\text{percent concentration of } CO_2)/12$$

was performed to present the "uncorrected" value in the resulting table. When the data, D1, were reported in ng/dscf in the test report, the conversion

$$D1 = D1 * 35.31$$

was required to present D1 as ng/dscm. Acid gas and criteria pollutant data were presented in ppmdv corrected to 12 percent CO_2. In order to convert data, D1, from mg/dscm corrected to 12 percent CO_2 to ppmdv at 12 percent CO_2, the following relation was employed:

$$D1 = \frac{D1 * (1000 * 0.02404)}{(\text{molecular weight of pollutant})}$$

Calculation of emission factors was performed using conversion factors (CF's) to relate process conditions to emission concentration levels. The CF's were calculated manually for each facility that provided percent concentration of CO_2, process feed rate, and stack gas flow measurements. The emission factors in 10-10 lb/ton were calculated using the "corrected" concentration data in English units, E1 in 10-10 gr/dscf, and the following equation:

$$EF = CF * E1$$

where:

CF = (Percent concentration of CO_2)*(stack gas flow in dscfm)*($7.14x10^{-4}$)÷ process rate in ton/hr;

The emission factor in μg/Mg were then calculated using:

$$\text{EF in } \mu g/Mg = (\text{EF in } 10^{-10} \text{ lb/ton}) * 0.05$$

In order to calculate emission factors from data presented in ppmdv at 12 percent SO_2, a second conversion factor, CCF, was needed. CCF was defined as:

$$CCF = \frac{(\text{molecular weight of pollutant})\ (1.3 \times 10^{-8})\ (CF)}{(7.14 \times 10^{-4})}$$

An emission factor value may be calculated from:

$$EF \text{ in lb/ton feed} = (D1 \text{ in ppmdv @ 12 percent } CO_2)(CCF)$$

Because test periods were nonsimultaneous, CF values for some facilities were different for the various pollutants. Determinations of emission factors were made only when process feed rates were documented or derivable from plant records of sludge process rates.

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5.0 AP-42 SECTION 2.2

Section 2.2 of AP-42 is presented in the following pages as it would appear in the document.