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Regulatory framework for the thermal treatment of various waste streams

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Abstract

Since 1990, regulations and standards have changed considerably. This article is an update of the regulatory requirements for the thermal treatment of various waste streams. The waste categories covered, along with the laws they are governed under, include:

- Hazardous waste under Subtitle C of the Resource Conservation and Recovery Act (RCRA) and under the Clean Air Act (CAA);
- Municipal solid waste under Subtitle D of the RCRA;
- Medical waste under Subtitle J of the RCRA;
- Superfund waste under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA);
- Toxic waste under the Toxic Substances Control Act (TSCA);
- Sludge waste under the Clean Water Act (CWA).

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1. Introduction

Past inadequate disposal of waste has caused various types of environmental damages such as: (1) pollution of groundwater; (2) contamination of surface water; (3) pollution

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of air; (4) fires and explosions; and (5) poisoning of humans and animals via either direct contact or via the food chain.

To deal with the problems of these environmental damages, both the Federal government and the States have enacted various laws for the management of solid waste from the point of generation to the point of disposal. In implementing these environmental laws, both the Environmental Protection Agency (EPA) and industry have often found that incineration is the best available technology for disposing of various waste streams when compared to other treatment technologies, according to Dempsey et al. [1]. As a result, incineration and other forms of thermal treatment have, over the years, been adopted as proven technologies to dispose of the following types of waste:

1. Hazardous waste, municipal solid waste, and medical waste regulated under the Resource Conservation and Recovery Act (RCRA);
2. Toxic substances under the Toxic Substances Control Act (TSCA)
3. Sludge waste under the Clean Water Act (CWA); and
4. Superfund waste under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA).

2. Regulatory framework relating to waste incineration and waste thermal treatment

The regulatory framework discussed below indicates that different types of waste are regulated by different sets of regulations and operators, which are often required to comply with different sets of standards. It is the responsibility of a design engineer to design a treatment system that can meet all applicable regulatory standards. It is also the responsibility of an operating engineer to operate a treatment system that will comply with the regulatory requirements on a consistent basis.

2.1. Hazardous waste

Hazardous waste is listed under Subtitle C of the Resource Conservation and Recovery Act (RCRA). The key elements of the new RCRA/CAA hazardous waste incineration regulations are specified in the Federal Register on September 30, 1999 [2]. The owners or operators of incineration facilities must comply with the specified standards by September 30, 2002 in order to receive a RCRA permit to operate. A summary of the standards and some of their important characteristics is as follows:

1. *DRE*: An incinerator must achieve a Destruction and Removal Efficiency (DRE) of 99.99% for each Principal Organic Hazardous Constituent (POHC) designated for each waste feed. For dioxin-listed wastes (such as F020-F023, etc.), the DRE limit is 99.9999%.
2. *DRE definition*: The DRE for an incinerator/air pollution control system is defined by the following formula:

$$\mathrm{DRE}\,(\%) = (W_{\mathrm{in}} - W_{\mathrm{out}})/W_{\mathrm{in}} \times 100,$$

where DRE = Destruction and Removal Efficiency, %; W_{in} = mass feed rate of POHC fed to the incinerator; W_{out} = mass emission rate of POHC to the atmosphere (as measured in the stack prior to discharge).

3. *Trial burn*: A trial burn (or data equivalent to a trial burn) is required to demonstrate the ability of a hazardous waste incinerator to comply with the above performance standards and to enable operating conditions to be set in the permit to ensure continued compliance.

In addition to the above requirements, under the joint authority of the Clean Air Act (CAA) and the RCRA, the EPA has promulgated the Maximum Achievable Control Technologies (MACT) standards shown in Table 1 for hazardous waste combustion facilities [2].

The permitting of a hazardous waste incineration facility has historically been a very complicated and time-consuming process. The two major environmental laws that dictate the regulatory requirements are the RCRA and the CAA. Originally, it took a minimum of 18 months to obtain a RCRA permit [3]. In addition to the RCRA/CAA permit, other permits from State and county authorities are still needed [4].

2.2. Municipal waste

Municipal waste is listed under Subtitle D of the RCRA. Subtitle D establishes a voluntary program through which participating States receive Federal financial and technical support to develop and implement nonhazardous (municipal) solid waste management plans. These plans are, among other things, intended to promote recycling of solid wastes, and require the closing or upgrading of all environmentally unsound landfills. EPA's role in the Subtitle D program is to assist States in developing and implementing their plans. EPA has also issued minimum technical standards that all solid waste disposal facilities must meet when disposing of solid wastes.

The key elements of municipal waste combustor standards are specified in Subpart E_b of 40 CFR 60 (the July 1, 1997 edition). For those combustors, which were built after September 20, 1994 and which are greater in capacity than 39 tons/day (250 tons/day for the NO_x standards, however), the operation of the combustors must comply with the following key elements of these emission standards:

1. *Particulate matter (PM)*: Not in excess of 24 mg/dry standard cubic meter (dscm), corrected to 7% oxygen;
2. *Opacity*: Not in excess of 10% opacity (6-min average);
3. *Cadmium*: Not in excess of 0.020 mg/dscm, corrected to 7% oxygen;
4. *Lead*: Not in excess of 0.20 mg/dscm, corrected to 7% oxygen;
5. *Mercury*: Not in excess of 0.080 mg/dscm or 15% of the potential mercury emission concentration (85% reduction by weight), corrected to 7% oxygen, whichever is less stringent;
6. *Sulfur dioxide*: Not in excess of 30 ppm by volume or 20% of the potential sulfur dioxide emission concentration (80% reduction by weight or volume), corrected to 7% oxygen (dry basis), whichever is less stringent;

Table 1
MACT (maximum achievable control technologies) standards for hazardous waste incinerators, cement kilns, and lightweight aggregate kilns[a]

Hazardous air pollutant (units) ↓	Incinerators		Cement kilns		Lightweight aggregate kilns	
Type of plant →	Existing	New	Existing	New	Existing	New
Dioxin/furans [ng TEQ[b]/dscm]	0.2[c]	0.2	0.2[c]	0.2[c]	0.2[c]	0.2[c]
Mercury [μg/dscm]	130	45	120	56	47	43
Total chlorine ($HCl + Cl_2$) [ppmv]	77	21	130	86	230	41
Semi-volatile metals (SVM; lead, cadium) [μg/dscm]	240	24	240	180	250	43
Low volatility metals (LVM; arsenic, beryllium, chromium) [μg/dscm]	97	97	56	54	110	110
Particulate matter (PM) [gr/dscf]	0.015 (equal to 34 mg/dscm)	0.015	~0.030[d] (equal to 69 mg/dscm)	~0.030[d]	0.025 (equal to 57 mg/dscm)	0.025
Carbon monoxide (CO)[e] [ppmv]	100	100	[f]Main Stack — not applicable, Bypass — 100	[f]Main Stack — not applicable, Bypass — 100	100	100
Hydrocarbons (HC)[e] [ppmv]	10	10	[f]Main Stack — NoStd; Bypass — 10	[f]Main Stack — 50,10 Bypass — 10	20	20

[a]All emission levels are corrected to 7% oxygen.
[b]Toxicity equivalence, the international method of relating the toxicity of various dioxin/furan congeners to the toxicity of 2,3,7,8-TCDD (tetrachlorinated dibenzo-*p*-dioxin).
[c]Or 0.4 ng TEQ/dscm if the temperature at the inlet to the initial PM control device is $\leq 400°F$.
[d]The actual PM standard for cement kilns is 0.15 kg/Mg dry feed and 20% opacity.
[e]Hourly rolling average. Hydrocarbons reported as propane.
[f]Cement kilns with bypass stacks must comply with either the CO or the HC standard in the bypass duct, but not both.

7. *Hydrogen chloride*: Not in excess of 25 ppm by volume or 5% of the potential hydrogen chloride emission concentration (95% reduction by weight or volume), corrected to 7% oxygen (dry basis), whichever is less stringent;
8. *Dioxin / furan*:
   - Not in excess of 30 ng/dscm (total mass), corrected to 7% oxygen, for the first 3 years following the date of initial startup,
   - Not in excess of 13 ng/dscm (total mass), corrected to 7% oxygen, after the first 3 years following the date of initial startup;
9. *Nitrogen oxide*:
   - Not in excess of 180 ppm by volume, corrected to 7% oxygen (dry basis) for the first year of operation,
   - Not in excess of 150 ppm by volume, corrected to 7% oxygen (dry basis), after the first year of operation. The averaging time is specified under 40 CFR 60.58b (h).

2.3. Medical waste

Medical waste is listed under Subtitle J of RCRA. The key regulatory elements of medical waste incineration standards are specified in Subpart E_c of 40 CFR 60 (so far, available from this internet address: http://www.epa.gov/ttn/uatw/factsns.html). The highlights of these regulations are described below.

The hospital/medical/infectious waste incinerator (HMIWI) source category is divided into three subcategories based on waste burning capacity:

- Small (less than or equal to 200 lb/h);
- Medium (between 200 and 500 lb/h); and
- Large (greater than 500 lb/h).

Highlights of the new HMIWI standards are as follows:

- 10% opacity limit for all new HMIWI;
- 5% visible emissions limit for fugitive fly ash or bottom ash emissions;
- Pollutant emission limits for new small HMIWIs appear in Table 2 and for new medium-sized and large HMIWIs, which appear in Table 3 (corrected to 7% oxygen).

2.4. Superfund waste

Superfund is the common name for the Comprehensive Environmental Response Compensation, and Liability Act (CERCLA) of 1980. The clean-up standards require that Superfund remedies must be protective of human health and the environment, be cost-effective, and utilize permanent solutions; they also require that alternative treatment technologies and resource recovery be used to the maximum extent practicable.

The on-site remedies must also meet applicable or relevant and appropriate regulations (ARARs) of other Federal laws such as RCRA, TSCA, and CAA. And, where

Table 2
Pollutant emission limits for new small HMIWIs
Abbreviations: APCD = Air Pollution Control Device; Cd = cadmium; dioxin/furan = chlorinated dibenzo-*p*-dioxins and dibenzofurans; CO = carbon monoxide; DI/FF = dry injection/fabric filter; HCl = hydrogen chloride; Hg = mercury; HMIWI = hospital/medical/infectious waste incinerator; mg/dscm = milligrams per dry standard cubic meter; ng/dscm = nanograms per dry standard cubic meter; NO_x = nitrogen oxides; Pb = lead; PM = particulate matter; ppmdv = parts per million by dry volume; SO_2 = sulfur dioxide; SD/FF = spray dryer/fabric filter; TEQ = toxic equivalency of 2,3,7,8-tetrachlorinated dibenzo-*p*-dioxin.

Pollutant	Emission limit	Basis
PM[a]	69 mg/dscm	Moderate efficiency wet scrubber[b]
CO[a]	40 ppmdv	Good combustion
Dioxin/furan[c]	2.3 ng/dscm TEQ or 125 ng/dscm total dioxin/furan	Wet scrubber[b]
HCl[a]	15 ppmdv or 99% reduction	Wet scrubber[b]
SO_2	55 ppmdv	No control
NO_x	250 ppmdv	No control
Pb	1.2 mg/dscm or 70% reduction	Wet scrubber[b]
Cd	0.16 mg/dscm or 65% reduction	Wet scrubber[b]
Hg	0.55 mg/dscm or 85% reduction	Wet scrubber[b]

[a] Emissions of PM, CO, and HCl must be determined by an annual stack test. However, if an HMIWI passes all three annual compliance tests in a 3-year period, then the HMIWI may forgo testing for the next 2 years. If any subsequent test indicates noncompliance, then annual testing would again be needed until three annual tests in a row indicate compliance.

[b] Includes good combustion.

[c] Dioxins/furans are measured as total tetra — through octa — chlorinated dibenzo-*p*-dioxins and dibenzofurans, and then TEQ is determined using the international toxicity equivalency factors as specified in the standard.

State standards are more stringent than Federal standards, State standards must be met. For wastes remaining on-site, the remedial actions are reviewed every 5 years. Legally speaking, treating Superfund waste on-site does not require a permit. However, in most cases, consent orders are negotiated which generally require that the RCRA incineration performance standards be achieved. The consent order route can save up to a year of permitting time for a clean-up project.

The off-site disposal provisions restrict disposal of Superfund wastes to those facilities in compliance with RCRA and TSCA and applicable State requirements. Specifically, the unit receiving Superfund wastes must not be releasing any hazardous wastes, and releases from other units at the facility must be controlled by a corrective action program. Several Superfund sites have experienced difficulties locating a commercial facility eligible to accept their waste.

2.5. Toxic substances

Toxic substances are regulated under the TSCA of 1976. The TSCA incineration regulations are specified in 40 CFR 761.70. Highlights of the regulations are as follows:

- Liquid PCBs — maintenance of the introduced liquids for a 2-s dwell time at 1200°C (+100°C) and 3% excess oxygen in the stack gas; or

Table 3
Pollutant emission limits for new medium and large HMIWIs
Abbreviations: APCD = Air Pollution Control Device; Cd = cadmium; dioxin/furan = chlorinated dibenzo-*p*-dioxins and dibenzofurans; CO = carbon monoxide; DI/FF = dry injection/fabric filter; HCl = hydrogen chloride; Hg = mercury; HMIWI = hospital/medical/infectious waste incinerator; mg/dscm = milligrams per dry standard cubic meter; ng/dscm = nanograms per dry standard cubic meter; NO_x = nitrogen oxides; Pb = lead; PM = particulate matter; ppmdv = parts per million by dry volume; SO_2 = sulfur dioxide; SD/FF = spray dryer/fabric filter; TEQ = toxic equivalency of 2,3,7,8-tetrachlorinated dibenzo-*p*-dioxin.

Pollutant	Emission limit	Basis
PM[a]	34 mg/dscm	High efficiency wet scrubber[b] or DI/FF[b] or SD/FF[b]
CO[a]	40 ppmdv	Good combustion
Dioxin/furan[c]	0.6 ng/dscm TEQ or 25 ng/dscm total dioxin/furan[c]	DI/FF with carbon[b] or SD/FF with carbon[b]
HCl[a]	15 ppmdv or 99% reduction	Wet scrubber[b] or SD/FF[b]
SO_2	55 ppmdv	No control
NO_x	250 ppmdv	No control
Pb	0.07 mg/dscm or 98% reduction	DI/FF[b] or SD/FF[b]
Cd	0.04 mg/dscm or 90% reduction	DI/FF[b] or SD/FF[b]
Hg	0.55 mg/dscm or 85% reduction	Wet scrubber[b] or DI/FF with carbon[b] or SD/FF with carbon[b]

[a] Emissions of PM, CO, and HCl must be determined by an annual stack test. However, if an HMIWI passes all three annual compliance tests in a 3-year period, then the HMIWI may forgo testing for the next 2 years. If any subsequent test indicates noncompliance, then annual testing would again be needed until three annual tests in a row indicate compliance.

[b] Includes good combustion.

[c] Dioxins/furans are measured as total tetra — through octa — chlorinated dibenzo-*p*-dioxins and dibenzofurans, and then TEQ is determined using the international toxicity equivalency factors as specified in the standard.

- Maintenance of the introduced liquids for 1.5-s dwell time at 1600°C (+100°C) and 2% excess oxygen in the stack gas. Combustion efficiency shall be at least 99.9% computed as follows:

$$\text{Combustion efficiency} = [CO_2/(CO_2 + C_{CO})] \times 100,$$

  where CO_2 = concentration of carbon dioxide; and C_{CO} = concentration of carbon monoxide;
- Nonliquid PCBs — the mass of emissions from the incinerator shall be no greater than 0.001g PCB/kg of the PCB introduced into the incinerator. (This is equivalent to 99.9999% DRE.)
- Similar to the RCRA requirements, a trial burn is generally required to demonstrate that the incinerator meets the above standards.

2.6. Sludge waste

Sludge waste including municipal sludge and industrial sludge is regulated under the CWA. Incineration of sludge is regulated under Section 405 (d) of CWA and is codified in 40 CFR 503.43 and 504.44 (see, for example, the July 1, 1998 edition of the CFR). Highlights of the sludge incineration regulations are as follows:

(a) Firing of sewage sludge in a sewage sludge incinerator shall not violate the requirements in the National Emission Standard for Beryllium in subpart C of 40 CFR 61.

(b) Firing of sewage sludge in a sewage sludge incinerator shall not violate the requirements in the National Emission Standard for Mercury in subpart E of 40 CFR 61.

(c) Pollutant limit — lead.

(1) The daily concentration of lead in sewage sludge fed to a sewage sludge incinerator shall not exceed the concentration calculated using Eq. (1):

$$C = (0.1 \times \text{NAAQS} \times 86{,}400)/(\text{DF} \times (1 - \text{CE}) \times \text{SF}), \tag{1}$$

where C = Daily concentration of lead in sewage sludge in milligrams per kilogram of total solids (dry weight basis); NAAQS = National Ambient Air Quality Standard for lead in micrograms per cubic meter; DF = Dispersion factor in micrograms per cubic meter per gram per second; CE = Sewage sludge incinerator control efficiency for lead in hundredths; SF = Sewage sludge feed rate in metric tons per day (dry weight basis).

(2) (i) When the sewage sludge stack height is 65 m or less, the actual sewage sludge incinerator stack height shall be used in an air dispersion model specified by the permitting authority to determine the dispersion factor (DF) in Eq. (1).

(ii) When the sewage sludge incinerator stack height exceeds 65 m, the creditable stack height shall be determined in accordance with 40 CFR 51.100(ii) and the creditable stack height shall be used in an air dispersion model specified by the permitting authority to determine the DF in Eq. (1).

(3) The control efficiency (CE) in Eq. (1) shall be determined from a performance test of the sewage sludge incinerator, as specified by the permitting authority.

(d) Pollutant limit — arsenic, cadmium, chromium, and nickel.

(1) The daily concentration for arsenic, cadmium, chromium, and nickel in sewage sludge fed to a sewage sludge incinerator each shall not exceed the concentration calculated using Eq. (2):

$$C = (\text{RSC} \times 86{,}400)/(\text{DF} \times (1 - \text{CE}) \times \text{SF}), \tag{2}$$

where C = Daily concentration of arsenic, cadmium, chromium, or nickel in sewage sludge in milligrams per kilogram of total solids (dry weight basis); CE = Sewage sludge incinerator control efficiency for arsenic, cadmium, chromium, or nickel in hundredths; DF = Dispersion factor in micrograms per cubic meter per gram per second; RSC = Risk specific concentration in micrograms per cubic meter; SF = Sewage sludge feed rate in metric tons per day (dry weight basis).

(2) The risk specific concentrations for arsenic, cadmium, and nickel used in Eq. (2) are (all in micrograms per cubic meter):

- Arsenic: 0.023;
- Cadmium: 0.057;
- Nickel: 2.0.

(3) The risk specific concentrations for chromium to be used in Eq. (2) are as follows or shall be calculated using Eq. (3), as specified by the permitting authority (all in micrograms per cubic meter):

- Fluidized bed with wet scrubber: 0.65;
- Fluidized bed with wet scrubber and wet electrostatic precipitator: 0.23;
- Other types with wet scrubber: 0.064;
- Other types with wet scrubber and wet electrostatic precipitator: 0.016.

$$\text{RSC} = (0.0085)/r, \tag{3}$$

where RSC = risk specific concentration for chromium in micrograms per cubic meter to be used in Eq. (2); r = decimal fraction of the hexavalent chromium concentration in the total chromium concentration measured in the exit gas from the sewage sludge incinerator stack in hundredths.

(4) (i) When the sewage sludge incinerator stack height is equal to or less than 65 m, the actual sewage sludge incinerator stack height shall be used in an air dispersion model, as specified by the permitting authority, to determine the DF in Eq. (2).

(ii) When the sewage sludge incinerator stack height is greater than 65 m, the creditable stack height shall be determined in accordance with 40 CFR 51.100(ii) and the creditable stack height shall be used in an air dispersion model, as specified by the permitting authority, to determine the DF in Eq. (2).

(5) The CE in Eq. (2) shall be determined from a performance test of the sewage sludge incinerator, as specified by the permitting authority.

(e) Pollutant limit — total hydrocarbons.

(1) The total hydrocarbons concentration in the exit gas from a sewage sludge incinerator shall be corrected to 0% moisture by multiplying the measured total hydrocarbons concentration by the correction factor calculated using Eq. (4):

$$\underset{\text{(percent moisture)}}{\text{Correction factor}} = 1/(1 - X), \tag{4}$$

where X = decimal fraction of the percent moisture in the sewage sludge incinerator exit gas in hundredths.

(2) The total hydrocarbons concentration in the exit gas from a sewage sludge incinerator shall be corrected to 7% oxygen by multiplying the measured total hydrocarbons concentration by the correction factor calculated using Eq. (5):

$$\underset{\text{(oxygen)}}{\text{Correction factor}} = 14/(21 - Y), \tag{5}$$

where Y = percent oxygen concentration in the sewage sludge incinerator stack exit gas (dry volume basis).

(3) The monthly average concentration for total hydrocarbons in the exit gas from a sewage sludge incinerator stack, corrected to 0% moisture using the correction factor from Eq. (4) and to 7% oxygen using the correction factor from Eq. (5), shall not exceed 100 ppm on a volumetric basis when measured continuously using the instrument required by 40 CFR 503.45(a).

3. Conclusion

Because environmental laws and regulations are the driving forces behind environmental protection, it is important to understand the thrust of these regulations. This article has provided an update of the regulatory requirements (set by the U.S. EPA in response to the dictates of extant Federal environmental laws) for the thermal treatment of various waste streams.

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