Engineering and Design of Incinerators for Combustible Waste

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PDH: 2

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Module 2: Incinerator Design

Learning Objectives

By the end of this section, you will be able to:

- **Identify** key incinerator components and their functional roles in the combustion process.
- **Calculate** required incinerator capacity based on waste types, per capita estimates, and hourly excess factors.
- **Evaluate** design parameters including gas velocity, furnace volume, and draft requirements to ensure code compliance.

Executive Summary: Successful incinerator design requires a systematic approach that balances refuse characteristics with precise thermodynamic and hydraulic constraints. For general installations, a Type I incinerator is standard, capable of handling up to 100% rubbish or a 65/35 rubbish-to-garbage mix. Engineers must design for the most severe conditions (all dry material) while providing infrastructure for wet materials, ensuring heat release does not exceed 18,000 Btu/hr per cubic foot of furnace volume.

Design Fundamentals

The following technical definitions establish the operational framework for the incinerator structure:

- **Incinerator**: A structure designed to reduce refuse to inert gases and solids through controlled burning.
- **Furnace**: The core assembly containing the ignition, mixing, and combustion chambers.
- **Effective Grate Area**: The total burning surface calculated as the sum of the physical grate area and the weighted effective area of the drying hearth.
- **Hearth**: An inclined floor (firebrick or cast iron) used specifically for drying and burning wet material.
- **Mixing Chamber (Down Pass)**: The area adjacent to ignition where gases blend before entering the final combustion stage.
- **Damper**: A vertical refractory slab located in the flue to regulate draft control.

Classification and Application

Engineers must select between two standard incinerator types based on the expected waste stream:

- **Type I (General Purpose)**: Optimized for rubbish and garbage. It handles 100% rubbish or a mixture of 65% rubbish and 35% garbage by weight. This is the preferred design for most installations.
- **Type II (Wet Garbage)**: Designed for 65% wet garbage and 35% rubbish by weight without auxiliary fuel.
    - ⚠️ **Safety Constraint**: Type II units are not designed for high heat release; do not use them for refuse containing high percentages of rubbish unless Type I is explicitly unsuited for the site.

Capacity Determinations

Establish requirements based on actual surveys or standard per capita waste approximations for troop cantonments:

- **Rubbish**: 1.5 pounds per day.
- **Non-edible Garbage**: 0.50 pounds per day.
- **Edible Garbage**: 2.0 pounds per day.

💡 **Design Tip**: To account for irregular delivery schedules, provide capacity for **25 percent excess** over average hourly needs.

🧮 **Calculation Note**: Do not use capacity factors for troop expansion. Instead, plan for extended operation up to **16 hours per day** if demand increases, leaving 8 hours for maintenance.

Basic Design Requirements

The design must conform to strict volumetric and thermal limits to ensure complete combustion and structural longevity.

Volumetric and Thermal Constraints

- **Heat Release**: Maximum **18,000 Btu per hour** per cubic foot of total furnace volume.
- **Combustion Temperature**: Minimum required for complete combustion, not to exceed **1,600 degrees F**.
- **Combustion Time**: Minimum **1.5 seconds** total gas residence time in the furnace.

Gas Velocity and Flow

- **Combustion Chamber**: Maximum **15 fps**.
- **Mixing Chamber, Flue, and Stack**: Maximum **35 fps**.
- **Chamber Volume**: Minimum **30 cubic feet per pound of gas** produced per second (including excess air).

Stack and Draft Calculations

Determine stack height (H) to provide sufficient draft for discharging combustion gases and excess air.

Equation 2-1 (Stack Height):

$$H = \frac{D}{0.52 \cdot B \cdot \left(\frac{1}{T_a} - \frac{1}{T_s}\right)}$$

Where:

- **H** = Stack height above the grate (feet)
- **D** = Static stack draft (inches of water)
- **B** = Barometric pressure (psi)
- **Ta** = Atmospheric temperature in degrees F. absolute
- **Ts** = Average stack-gas temperature in degrees F. absolute

Draft Loss Allowances (Inches of Water)

- **Velocity Head**: $\frac{0.119 \cdot B \cdot V^2}{14.7 \cdot T_s}$
- **Friction Loss (Stack/Flue)**: $\frac{(1.1\times10^{-6}) \cdot T_s \cdot W^2 \cdot L \cdot P}{A^3}$
- **90 Degree Turn**: Length equivalent to 12 times the square root of the opening area.
- **Grate Loss**: 0.25 for Type I; 0.15 for Type II at rated capacity.

Preliminary Design Factors

Utilize Table 2-1 for initial sizing before performing final design analysis.

Table 2-1. Preliminary Design Factors

Design Factor	Type I	Type II
Effective grate area per pound of refuse per hour (sq ft)	0.022	0.04
Ratio of hearth area to grate area	1	1
Effectiveness of hearth area (percent):		
- Firebrick hearths	60	60
- C. I. grate bars	80	80
Mixing chamber area (% of effective grate area)	25	20
Combustion chamber area (% of effective grate area)	60	30
Flue area (% of effective grate area)	25	10
Stack area (% of effective grate area)	22	10
Ratio: Arch height above grate to furnace width (max)	1	1

Design Analysis Requirements

Every request for construction authority must include a formal design analysis. This analysis must document:

1. The specific type of material to be incinerated.
2. The calculation basis for capacity requirements.

Checkpoint Quiz

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1. **Which incinerator component is specifically defined as the horizontal connection between the combustion chamber and the stack?**
   a) Mixing Chamber
   b) Flue
   c) Bridge Wall
   d) Damper Box

Answer: (b). The flue serves as the horizontal ducting connecting the final combustion stage to the exhaust stack.

2. **If an installation must burn 5 tons of refuse in an 8-hour shift, what is the required capacity (including the 25% excess factor)?**
   a) 1,250 lbs/hr
   b) 1,500 lbs/hr
   c) 1,562.5 lbs/hr
   d) 1,875 lbs/hr

Answer: (c). Base capacity is 10,000 lbs / 8 hrs = 1,250 lbs/hr. Applying the 25% excess factor (1,250 * 1.25) results in 1,562.5 lbs/hr.

3. **What is the maximum allowable gas velocity through the combustion chamber for a Type I incinerator?**
   a) 15 fps
   b) 25 fps
   c) 30 fps
   d) 35 fps

Answer: (a). Technical requirements limit combustion chamber velocity to 15 fps to ensure proper residence time, while mixing chambers and flues can accommodate up to 35 fps.

Module 3: Materials and Equipment Considerations

Learning Objectives

By the end of this section, you will be able to:

- **Select** appropriate refractory and structural materials for furnace and stack construction based on thermal expansion requirements.
- **Identify** mandatory instrumentation and safety features for temperature and draft monitoring.
- **Evaluate** furnace door types and layout configurations to optimize charging efficiency and operational safety.

Executive Summary: Durable incinerator construction relies on a dual-shell design that isolates high-temperature refractory components from structural outer masonry. Engineering specifications must prioritize high-duty fire-clay bricks for inner linings and incorporate thermal expansion allowances to prevent structural failure. Operational efficiency is further supported by specific door configurations (guillotine vs. cast iron) and integrated heat recovery systems for sanitation.

Design Fundamentals

The structural design and material specifications must ensure sturdy construction for all incinerator components. Engineers must specifically account for the effects of expansion and contraction resulting from high-temperature cycles. Standard construction should generally align with standard drawings and guide specifications.

Furnace Construction

The furnace utilizes a dual-shell system to manage extreme heat while maintaining structural integrity.

Inner Shell and Arch

- **Thickness**: Approximately 9 inches.
- **Materials**: High-duty fire-clay brick or refractory plastic of equivalent quality.
- **Assembly**: Firebrick must be laid in high-temperature, air-setting, bonding cement.
- **Insulation**: The arch requires a 2-1/2-inch layer of insulating material.

Outer Shell and Bracing

- **Walls**: 8-inch common brick.
- **Bracing**: Structural integrity is maintained via upright corner angles and intermediate upright channel buck stays, secured with tie rods and horizontal steel angles.
- **Top Construction**: Reinforced concrete is standard; however, if not utilized as a roof or floor, a 4-inch layer of common brick over insulating brick may be substituted.

⚠️ **Safety Constraint**: Tie rods must remain entirely outside the inner shell and shall not come into contact with refractory material at any point.