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Combustible Waste Incinerator Engineering

Course Number: CH-02-317

PDH: 2

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396 Washington Street, Suite 159, Wellesley, MA 02481
Telephone – (508) 298-4787 www.PDH-Pro.com

Module 1: Incinerator Design

Learning Objectives

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

- **Identify** and define the primary structural components and functional chambers of a waste incinerator.
- **Select** the appropriate incinerator type based on refuse composition and heat release constraints.
- **Calculate** required incinerator capacity and preliminary design factors using standardized engineering metrics.

Executive Summary: Successful incinerator design requires a rigorous analysis of refuse composition—specifically the ratio of rubbish to wet garbage—to select between Type I and Type II units. Engineers must adhere to strict thermal limits (18,000 Btu/hr/ft^3) and gas velocity constraints to ensure complete combustion and structural longevity.

Design Fundamentals

Effective incinerator engineering begins with a precise understanding of the furnace's internal architecture. The following definitions establish the technical baseline for these structures:

- **Incinerator**: A specialized structure designed to reduce refuse to inert gases and solids through thermal processing.
- **Furnace**: The core assembly where combustion occurs, comprising the ignition, mixing, and combustion chambers, and the charging hood.
- **Grate**: The cast iron (**C.I.**) structure supporting the burning of dry materials.
- **Hearth**: An inclined floor for drying and burning wet material, constructed of firebrick or C.I. grate bars.
- **Effective Grate Area**: The total area of the grate plus the hearth area, adjusted for its effectiveness in terms of grate area.
- **Chambers**:
    - **Ignition Chamber**: The primary space between the grate/hearth and the furnace arch.
    - **Mixing Chamber**: Also known as the **downpass**; where gases mix before entering the final combustion stage.
    - **Combustion Chamber**: The final chamber ensuring complete gaseous combustion.

- **Structural Barriers**:
  - **Bridgewall**: Separates the ignition and mixing chambers.
  - **Target Wall**: Positioned between the mixing and combustion chambers.
- **Flow Control**:
  - **Flue**: The horizontal connection between the combustion chamber and the stack.
  - **Damper**: A vertical movable refractory slab used for precise **draft control**.

Classification of Incinerator Types

Engineers must classify the incinerator based on the moisture content and energy density of the waste stream:

- **Type I (Garbage and Rubbish)**: A general-purpose unit suitable for most installations. It is designed for 100% rubbish or a mixture of **65% rubbish and 35% garbage** by weight.
- **Type II (Wet Garbage)**: Designed to burn **65% wet garbage** and 35% rubbish without auxiliary fuel.

⚠️ **Safety Constraint**: Type II incinerators are not designed to withstand the high heat release produced by high percentages of rubbish. Do not specify Type II unless conditions are strictly unsuited for Type I.

Establishing Design Capacities

System requirements are dictated by the expected waste generation of the specific post.

- **Per Capita Benchmarks**: For average troop cantonments, assume 1.5 lbs rubbish, 0.50 lbs non-edible garbage, and 2.0 lbs edible garbage per day.
- **The 25% Excess Rule**: You must provide **25% excess capacity** over average hourly needs to account for irregular delivery schedules.
- **Operating Margin**: Do not use capacity factors for troop expansion; instead, increase operating time up to **16 hours per day** if needed, leaving 8 hours for cooling and maintenance.

🧮 **Calculation Note**: If a site requires burning 4 tons in 8 hours, the incinerator capacity must be 1,250 pounds per hour ([(4 tons * 2000 lbs) / 8 hours] * 1.25).

Engineering Design Requirements

The incinerator must be engineered for the **severest expected conditions**, typically defined as burning 100% dry material for Type I units.

- **Thermal Load**: Heat release per cubic foot of furnace volume must not exceed **18,000 Btu per hour**.
- **Surface Ratios**: The hearth area should be approximately equal to the grate area for both types.
- **Velocity Limits**:
    - Combustion Chamber: **15 fps** maximum.
    - Mixing Chamber/Flue/Stack: **35 fps** maximum.
- **Retention and Temperature**:
    - Combustion-chamber volume: Minimum **30 cubic feet** per pound of gas produced per second.
    - Temperature: Target complete combustion without exceeding **1,600°F**.
    - Combustion Time: Minimum **1.5 seconds** total gas residence time.

Stack Height Formula:

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

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)

💡 **Design Tip**: Control high combustion temperatures by adjusting the damper and introducing **excess air**.

Draft Requirement Calculations: Total draft must account for the following losses (expressed in inches of water):

Velocity Head Equation:

$$\text{Velocity head} = \frac{0.119BV^2}{14.7T_s}$$

Where:

- **Velocity head** = Velocity head (inches of water)
- **B** = Barometric pressure (psi)
- **V** = Velocity of gas (fps)
- **Ts** = Average stack-gas temperature in degrees F. (absolute)

Friction Loss Equation:

$$\text{Friction loss through stack and flue} = \frac{1.1 \times 10^{-6} T_s W^2 LP}{A^3}$$

Where:

- **Friction loss through stack and flue** = Friction loss (inches of water)
- **Ts** = Average stack-gas temperature in degrees F. (absolute)
- **W** = Gas weight flow rate (lb/sec)
- **L** = Length of flue and stack (feet)
- **P** = Perimeter of flue and stack cross-section (feet)
- **A** = Cross-sectional area of flue and stack (feet2)

Preliminary Design Parameters

Initial designs should be checked against the factors in Table 2-1 to ensure compliance before final analysis.

Table 2-1. Preliminary Design Factors | Parameter

	Type of Incinerator	
	I	II
Effective grate area per pound of refuse per hour (square feet)	0.022	0.04
Ratio of hearth area to grate area	1	1
Effectiveness of hearth area in terms of grate area (percent):		
Firebrick hearths	60	60
C. I. grate bars	80	80
Horizontal cross-sectional area of mixing chamber in terms of effective grate area (percent)	25	20
Horizontal cross-sectional area of combustion chamber in terms of effective grate area (percent)	60	30
Cross-sectional area of flue in terms of effective grate area (percent)	25	10
Cross-sectional area of stack in terms of effective grate area (percent)	22	10
Ratio of height of arch above grate to width of furnace not to exceed	1	1

Design Analysis Requirements

A comprehensive design analysis must accompany all construction requests. This analysis is required to explicitly state:

1. The specific type of material to be incinerated.

2. The empirical basis used to establish capacity requirements.