AP-046

INTERIM GUIDE OF GOOD PRACTICE FOR INCINERATION AT FEDERAL FACILITIES

HEALTH, EDUCATION, AND WELFARE

Environmental Health Service

INTERIM GUIDE OF GOOD PRACTICE FOR INCINERATION AT FEDERAL FACILITIES

prepared by
Engineering Branch
Division of Abatement

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Consumer Protection and Environmental Health Service
National Air Pollution Control Administration
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INTERIM GUIDE OF GOOD PRACTICE FOR INCINERATION AT FEDERAL FACILITIES

1 INTRODUCTION

Section 111 (a) of the Clean Air Act as amended requires any Federal department or agency having jurisdiction over any building, installation, or other property to cooperate with the Department of Health, Education, and Welfare in preventing and controlling air pollution. In furtherance of this purpose, Presidential Executive Order 11282 requires establishments of the Executive Branch of the Government to provide leadership in the nationwide effort to improve the quality of our air by, among other measures, keeping the emissions of fly ash and other particulate matter to a minimum. Acting upon Executive Order 11282 the Secretary of Health, Education, and Welfare has prescribed standards for implementing these goals and has requested that guides to good practice be issued for specific operations to aid Federal departments, agencies, and establishments in the selection of equipment and methods for meeting the standards. This document is the first such Guide to be issued.

Standards issued as a result of this Executive Order appear as Part 76 in Subchapter F of Title 42, Code of Federal Regulations. As these Standards apply to incinerators, they are detailed in Sections 1.3 and 1.4 of this Guide.

Requests for guides of good practice, technical material, or consultation should be directed either to the Chief, Federal Facilities Branch, Division of Abatement, National Air Pollution Control Administration, Public Health Service, Consumer Protection and Environmental Health Service, Department of Health, Education, and Welfare, Ballston Center Tower No. 2, 801 North Randolph Street, Arlington, Virginia 22203, or to the appropriate Regional Air Pollution Control

Director of the Public Health Service at Department of Health, Education, and Welfare Regional Offices. (See Table 14-6 for addresses of Regional Directors.)

1.1 PURPOSE OF INTERIM GUIDE OF GOOD PRACTICE

This Interim Guide of Good Practice is to be used by Federal agencies to select incinerators for burning Types 0, 1, 2, and 4 wastes as defined in Section 3. The information in this Guide applies to incinerators having a burning capacity of 2000 pounds per hour or less of general refuse and up to 200 pounds per hour of pathological waste. Advice on burning other types of waste may be obtained from the Federal Facilities Branch (See Section 5).

The designs recommended herein are believed to be such as to produce incinerators that will operate in compliance with the Code of Federal Regulations. It is not the intent of this Guide to inhibit progress and ingenuity in the development of other incinerator designs or methods of waste disposal. For this reason, specific provisions have been made in Section 5 to allow incinerators of designs other than those given herein to be approved for use in Federal installations.

In addition, the entire Guide has been designated as an "Interim" Guide until studies presently being conducted show whether incinerators of other designs, suitably controlled, can comply with Federal emission standards. When additional designs have been proven capable of meeting Federal emission standards, they may be included in a subsequent Guide of Good Practice for Incineration at Federal Facilities.

1.2 APPLICABILITY OF FEDERAL REGULATIONS TO INCINERATORS

The provisions of this Guide apply to Federal Facilities in the 50 states, the District of Columbia, the Commonwealth of Puerto Rico, the Virgin Islands, Guam, and American Samoa. However, if state or local emission standards applicable to incinerators are more strict than those given herein, then the Chief, Federal Facilities Branch, should be consulted prior to installation of an incinerator of the designs described in this Guide.

1.2.1 Existing Incinerators

All existing incinerators must comply with the standards set forth in the Code of Federal Regulations under Title 42, Chapter 1, Subchapter F, Part 76, Section 76.8, as amended. (See Sections 1.3 and 1.4 of this Guide.) Compliance may be achieved by one or more of the following actions.

1.2.1.1 <u>Modification of Incinerator</u> Usually, modification will be practicable only if the changes are relatively minor, such as the addition of bricks to the flame port, the addition of a secondary burner, or the installation of a barometric damper. If extensive changes in the brickwork are required, the cost and results usually justify installation of a new incinerator.

1.2.1.2 Addition of Air Pollution Control Device The most commonly employed air pollution control device is the low-pressure-drop scrubber. Design specifications for such a control device that would be suitable for use with incinerator designs described herein are given in Section 8. When a scrubber is used to upgrade an existing incinerator, however, it would probably be desirable to use a more efficient scrubber than that described herein, inasmuch as the incinerators described in this Guide will emit less particulate matter than incinerators in need of upgrading.

1.2.1.3 Replacement of Incinerator See Sections 6 and 7 of this Guide for recommendations for new incinerators.

1.2.1.4 Alternative Method of Refuse Disposal In considering alternatives, assistance may be sought from the Bureau of Solid Waste Management, Division of Technical Operations, 12720 Twinbrook Parkway, Rockville, Maryland 20852.

1.2.2 New Incinerators

All new incinerators must comply with the standards set forth in the Code of Federal Regulations under Title 42, Chapter 1, Subchapter F, Part 76, Section 76.8, as amended. These standards are given in Sections 1.3 and 1.4 of this Guide.

1.3 STANDARDS FOR PARTICULATE EMISSIONS

Particulate emissions shall be measured by the test procedures described in "Specifications for Incinerator Testing at Federal Facilities" (PHS publication, October 1967) and any amendments or revisions thereof.

1.3.1 Incinerators of Over 200 Pounds per Hour Capacity

Incinerators having burning rates of more than 200 pounds per hour shall not emit more than 0.2 grain of particulate matter per standard cubic foot of dry flue gas corrected to 12 percent carbon dioxide (without the contribution of carbon dioxide from auxiliary fuel).

1.3.2 Incinerators of 200 Pounds per Hour Capacity and Less

Incinerators having burning rates of 200 pounds per hour or less shall not emit more than 0.3 grain of particulate matter per standard cubic foot of dry flue gas corrected to 12 percent carbon dioxide (without the contribution of carbon dioxide from auxiliary fuel).

1.4 STANDARDS FOR VISIBLE EMISSIONS

1.4.1 Incinerators Acquired On or After June 3, 1966

For incinerators acquired on or after June 3, 1966, the density of any emission to the atmosphere shall not exceed number 1 on the Ringelmann Scale or the Smoke Inspection Guide for a period or periods aggregating more than 3 minutes in any 1 hour, or be of such opacity as to obscure an observer's view to an equivalent degree.

The Ringelmann chart should be used in accordance with the Procedures in the Bureau of Mines Information Circular No. 8333. The Smoke Inspection Guide should be used in accordance with procedures in Title 42, Chapter 1, Subchapter F, Section 75.2 of the Code of Federal Regulations.

1.4.2 Incinerators Acquired Prior to June 3, 1966

For incinerators acquired prior to June 3, 1966, the density of any emission to the atmosphere shall not exceed number 2 on the Ringelmann Scale or the Smoke Inspection Guide for a period or periods aggregating more than 3 minutes in any 1 hour or be of such opacity as to obscure an observer's view to an equivalent degree.

1.5 CONSIDERATIONS FOR GOOD PLANNING OTHER THAN INCINERATOR DESIGN

In addition to the design of the incinerator itself, careful consideration must be given to the following items when installation of an incinerator is being planned:

1. Collection and method of charging the refuse.
2. Ample areas around the incinerator for charging, stoking, ash handling and general maintenance.
3. Adequate air supply to the incinerator room at the stoking and charging levels.
4. Effect of air conditioning and ventilating equipment on the air supply or the draft available from the draft-producing equipment.
5. Adequate draft (negative pressure) to handle all theoretical and excess air required to assure safe operation and complete combustion at reasonable temperatures.
6. Location of the top of the chimney or stack with respect to ventilation intakes, penthouses, or other obstructions.

2 DEFINITIONS OF INCINERATOR TERMS

Air Supply

All air supplied to the incinerator equipment for combustion, ventilation, and cooling. Standard air is air at standard temperature and pressure, namely, 70°F and 29.92 inches of mercury.

1. Air Jets Streams of high-velocity air issuing from nozzles in the incinerator enclosure to provide turbulence. The air jets, depending on their location, may be used to provide excess, primary, secondary, or overfire air.

2. Excess Air The air remaining after a fuel has been completely burned, or the air supplied in addition to the theoretical quantity.

3. Overfire Air Any air, controlled with respect to quantity and direction, supplied beyond the fuel bed, as through ports in the walls of the primary combustion chamber, for the purpose of completing combustion of combustible materials in the gases from the fuel bed or reducing operating temperatures within the incinerator.

4. Primary Air Any air, controlled with respect to quantity and direction, forced or induced, supplied through or adjacent to the fuel bed, to promote combustion of the combustible materials in the fuel bed.

5. Secondary Air Any air, controlled with respect to quantity and direction, supplied beyond the fuel bed, as through ports in the walls or bridge wall of the primary combustion chamber (overfire air), or the secondary combustion chamber, to complete combustion of combustible materials in the gases from the fuel bed or to reduce operating temperature within the incinerator.

6. Theoretical Air The stoichiometric amount of air required for complete combustion of a given quantity of a specific fuel.

7. Underfire Air - Any air, controlled with respect to quantity and direction, forced or induced, supplied beneath the grate, that passes through the

fuel bed.

Auxiliary-Fuel Firing Equipment

Equipment to supply additional heat, by the combustion of an auxiliary fuel, for the purpose of attaining temperatures sufficiently high (1) to dry and ignite the waste material; (2) to maintain ignition thereof; and (3) to effect complete combustion of combustible solids, vapors, and gases.

Baffle

Any refractory construction intended to change the direction of flow of the products of combustion.

Breeching or Flue Connection

The connection between the incinerator and auxiliary equipment, between the incinerator and stack or chimney, or between auxiliary equipment and stack or chimney.

Bridge Wall

A partition wall between chambers over which products of combustion pass.

British Thermal Unit

The quantity of heat required to raise 1 pound of water 1° Fahrenheit, abbreviated Btu and B. T. U.

Burner

A device for the introduction of a flame by delivering fuel and its combustion air, at desired velocities and turbulence, to establish and maintain proper ignition and combustion of the fuel.

1. Afterburner A burner installed in the secondary combustion chamber or in chambers separated from the incinerator proper. (Also referred to as a secondary burner.)
2. Primary Burner - A burner installed in the primary combustion chamber to dry out and ignite the material to be burned.
3. Secondary Burner - A burner installed in the secondary combustion chamber to maintain temperature and complete the combustion process. (Also referred to as an afterburner.)

Burning Area

The horizontal projected area of the grate, hearth, or combination thereof on which burning takes place.

Burning Rate

The amount of waste incinerated per unit of time, usually expressed in pounds per hour.

Bypass

An arrangement of breechings or flue connections and dampers to permit the alternate use of two or more pieces of equipment by directing or diverting the flow of the products of combustion.

Capacity

The amount of waste stipulated as the incineration rate for specific types of refuse, expressed in pounds per hour.

Charging Chute

A passage through which waste materials are conveyed from above to the primary combustion chamber.

Charging Door

A closure for the primary chamber loading entrance.

Checkerwork

A pattern of multiple openings in refractory structures through which the products of combustion pass to promote turbulent mixing of the gases.

Chimney, Stack, Flue

A passage for conducting products of combustion to the atmosphere.

Clinker

Hard sintered or fused material, formed in the fire by the agglomeration of residual ash, metals, glass, and ceramic material.

Combustion Chamber, Expansion Chamber, Settling Chamber

Any chamber designed to reduce the velocity of the products of combustion to promote the settling of fly ash from the gas stream and to allow space and time to complete combustion.

Curtain Wall

A partition wall between chambers, which serves to deflect gases in a downward direction. (Also referred to as a drop arch.)

Damper

A manually or automatically controlled device to regulate draft or the rate of flow of air or combustion gases.

1. Barometric Damper - A hinged or pivoted valve placed and adjusted by counterbalancing so as to admit air to the breeching, flue connection, or stack to maintain automatically the required draft in the incinerator.

2. Butterfly Damper - A throttling disk or valve that rotates on its hinged axis to control airflow in a duct, breeching, flue connection, or stack.

3. Guillotine Damper - An adjustable, counterbalanced blade installed in a breeching or flue connection and arranged to move vertically across the breeching or flue connection.

4. Sliding Damper - An adjustable blade installed in a duct, breeching, flue connection, or stack and arranged to move horizontally across the duct, breeching, flue connection or stack.

Down Pass

Chamber or passage between two chambers that carries the products of combustion in a downward direction.

Draft

The pressure difference between the incinerator or any component part and the atmosphere, that causes a continuous flow of air and products of combustion through the gas passage of the incinerator to the atmosphere.

1. Forced Draft The pressure difference created by the action of a fan, blower, or ejector to supply primary combustion air greater than atmospheric pressure.

2. Induced Draft - The pressure difference created by the action of a fan, blower, or ejector installed between the incinerator and the stack, or at the stack exit.

3. Natural Draft - The pressure difference created by stack or chimney because of its height and the temperature difference between the flue gases and the atmosphere.

Dust Loading

The amount of fly ash carried in the products of combustion, usually expressed in grains per standard cubic foot at 12 percent carbon dioxide, without the contribution of carbon dioxide from the burning of auxiliary fuel.

Effluent

The flue gas or products of combustion that reach the atmosphere from the burning process.

Expansion Chamber, Combustion Chamber, Settling Chamber

See definition under Combustion Chamber, Expansion Chamber, Settling Chamber.

Flame Port

A small port in the parting wall through which the flames and products of combustion from the burning refuse must pass.

Flue Gas

All gases leaving the incinerator by way of the flue, including gaseous products of combustion, water vapor, excess air, and nitrogen.

Fly Ash

Suspended ash particles, charred paper, dust, soot, and other partially incinerated matter carried in the products of combustion. (Also referred to as particulate matter or pollutant.)

Fly Ash Collector

Auxiliary equipment designed to remove fly ash in dry form from the products of combustion.

Gas Washer or Scrubber

Equipment for removing fly ash and other objectionable materials from the products of combustion by means of water sprays or wetted baffles.

Grate

Surface that supports waste material, but with suitable openings to permit passage of air through the burning waste. It is usually located in the primary combustion chamber and is designed to permit removal of ash and unburned residue. Grates may be horizontal or inclined, stationary or movable.

Hearth

A solid surface on which waste material with high moisture content, or waste material that may turn to liquid before burning, is placed for drying or burning.

1. Cold Hearth - A surface on which waste material is dried and/or burned by the action of hot combustion gases that pass only over the waste material.

2. Hot Hearth A heated surface on which waste material is dried and/or burned by the action of hot combustion gases that pass first over the waste materials and then under the hearth.

Heating Value

The heat released by combustion of a unit quantity of waste or fuel, measured in British Thermal Units (Btu). In this Guide heating value is on an as-fired basis for refuse and on the higher or gross heating value for fuel.

Heat Release Rate

The amount of heat liberated during the process of complete combustion and expressed in Btu per hour per cubic foot of the internal furnace volume in which such combustion takes place.

Ignition Chamber, Primary Chamber

The chamber of the incinerator in which refuse is burned.

Incineration

The process of igniting and burning solid, semisolid, liquid, or gaseous combustible waste to carbon dioxide and water vapor.

Incinerator

An engineered apparatus capable of withstanding heat and designed to efficiently reduce solid, semisolid, liquid, or gaseous waste by combustion at specified rates, to residues containing little or no combustible material. As used herein, a general-refuse incinerator is a multiple-chamber incinerator designed primarily for burning waste of Types 0, 1, and 2 at rates of from 50 to 2000 pounds per hour. A pathological incinerator is a multiple-chamber incinerator designed to burn 200 pounds per hour or less of Type 4 waste.

Mixing Chamber

A chamber usually placed between the primary combustion chamber and an expansion chamber wherein thorough mixing of the products of combustion is accomplished by turbulence created by increased velocities of gases, checkerwork, and/or changes in direction of the gas flow.

Multiple-Chamber Incinerator

A multiple-chamber incinerator is any article, machine, equipment, contrivance, structure, or part of a structure consisting of three or more refractory-lined combustion chambers in series, physically separated by refractory walls and interconnected by gas passage ports or ducts that is used to dispose of waste material by burning.

Particulates or Particulate Matter

Suspended ash particles, charred paper, dust, soot, and other partially incinerated matter carried in the products of combustion. (Also referred to as fly ash.) For the purposes of determining compliance with Section 76.8, Title 42 of the Code of Federal Regulations, particulate matter is defined as any material, except uncombined water, which is suspended in a gas stream as a liquid or solid at standard conditions.

Parting Wall

In retort incinerators, the parting wall separates the primary chamber from both a secondary chamber and an expansion chamber.

Primary Chamber, Ignition Chamber

See definition under Ignition Chamber, Primary Chamber.

Settling Chamber, Expansion Chamber, Combustion Chamber

See definition under Combustion Chamber, Expansion Chamber, Settling Chamber.

Side Chamber

A small chamber used for burning pathological waste that is built into the side of a general-refuse burner.

Spark Arrester

A screen-like device that prevents sparks, embers, and other ignited materials larger than a given size from being expelled to the atmosphere.

Standard Conditions

Standard conditions are a gas temperature of 70° Fahrenheit and a gas pressure of 14.7 pounds per square inch, absolute. Results of all analyses and tests should be calculated or reported at this gas temperature and pressure.

3 WASTE CLASSIFICATIONS

Type 0

A mixture of highly combustible waste such as paper, cardboard cartons, wood boxes, and floor sweepings from commercial and industrial activities. The mixture contains up to 10 percent by weight of plastic bags, coated paper, laminated paper, treated corrugated cardboard, oily rags, and plastic or rubber scraps.

This type of waste contains 10 percent moisture and 5 percent noncombustible solids, and has a heating value of 8, 500 Btu per pound as fired.

Type 1

A mixture of combustible waste such as paper, cardboard cartons, wood scrap, foliage, and floor sweepings from domestic, commercial, and industrial activities. The mixture contains up to 20 percent by weight of restaurant waste, but contains little or no treated paper, plastic, or rubber wastes.

This type of waste contains 25 percent moisture and 10 percent incombustible solids, and has a heating value of 6, 500 Btu per pound as fired.

Type 2

An approximately even mixture of rubbish and garbage by weight

This type of waste, common to apartment and residential occupancy, consists of up to 50 percent moisture and 7 percent incombustible solids, and has a heating value of 4, 300 Btu per pound as fired.

Type 3

Garbage such as animal and vegetable wastes from restaurants, hotels, hospitals, markets, and similar installations.

This type of waste contains up to 70 percent moisture and up to 5 percent incombustible solids, and has a heating value of 2, 500 Btu per pound as fired.

Type 4

Human and animal remains, such as organs, carcasses, and solid organic wastes from hospitals, laboratories, slaughterhouses, animal pounds, and similar sources, consisting of up to 85 percent moisture and 5 percent incombustible solids, and having a heating value as low as 1,000 Btu per pound as fired.

Type 5

Gaseous, liquid, or semiliquid by-product waste, such as tar, paint, solvent, sludge, and fumes from industrial operations. Btu values must be determined by the individual materials to be destroyed.

Type 6

Solid by-product waste, such as rubber, plastic, and wood waste from industrial operations. Btu values must be determined by the individual materials to be destroyed.

4 RECOMMENDED INCINERATOR AND GAS WASHER DESIGNS

The incinerator designs described herein are recommended for use in Federal facilities. The incinerator designs given in Sections 6 and 12 are recommended for incinerators that are to burn up to 2,000 pounds per hour of Types 0, 1, and 2 waste. The designs set forth in Sections 7 and 13 are recommended for incinerators that will burn up to 200 pounds per hour of Type 4 waste.

Incinerators of the design given in this Guide have been tested and found to meet the Code of Federal Regulations for incinerators with capacities of 200 pounds per hour or less. An incinerator of more than 200 pounds per hour capacity must be equipped with scrubbers of the types described in Section 8, or with scrubbers of equivalent efficiency, to meet the stricter limits of the Code of Federal Regulations applicable to the larger incinerator sizes (see Section 1.3 of this Guide), unless the unit by itself can be shown to meet the limits of the Code.

Incinerators and incinerator-washer combinations built as recommended herein will be considered to be in compliance with the Code of Federal Regulations. Testing will not be required for such units.

See Section 5 for information about obtaining approval for incinerators and gas washers of designs other than those recommended herein.

Multiple-chamber incinerators designed to burn general refuse or pathological waste that conform to Incinerator Institute of America (IIA) Standards will be accepted as alternate incinerators when such incinerators are tested according to Section 14 and meet the emission standards of Section 1. Any gas washers employed should meet the requirements of Section 8.

5 ALTERNATE INCINERATOR AND GAS WASHER DESIGNS

The Federal Facilities Branch, Division of Abatement, National Air Pollution Control Administration, Arlington, Va. 22203, or the appropriate Regional Air Pollution Control Director located in a Department of Health, Education, and Welfare Regional Office (see Table 14.6) may be consulted for information and assistance in regard to:

1. Modifying existing incinerators.
2. Installing incinerators of the following types:
   a. Incinerators for burning waste that is 100 percent garbage.
   b. Incinerators for burning more than 200 pounds per hour of human and animal remains.
   c. Incinerators for burning wood, plastic, and organic liquids.
   d. Incinerators for burning Types 0, 1, 2, and 4 waste (in amounts of over 200 pounds per hour), the designs of which are other than those specified in this Guide.
3. Testing incinerators.

Before incinerators not of the designs specified herein, including upgraded units, are accepted, they must meet the Federal emission limits as given in Sections 1.3 and 1.4. To show compliance, a testing organization may conduct tests provided the organization (hereafter called tester) has had experience in testing incinerators or can establish competency to conduct tests. Either the Federal Facilities Branch or the appropriate Regional Air Pollution Control Director may be consulted for assistance in choosing a tester. The Federal Facilities Branch should be notified 1 month in advance of any acceptance test to allow an observer to attend. Test procedures used shall be those described in "Specifications for Incinerator Testing at Federal Facilities" (PHS Publication, October, 1967) and any amendments or revisions thereof. Said document is available from the Federal Facilities Branch.

In addition to meeting all emission standards, incinerator systems must, in the judgment of the Federal Facilities Branch, be constructed of refractories, insulation, and other materials equivalent in resistivity and quality to the construction standards recommended in Section 9.

Once an incinerator system has been found to meet all applicable construction and emission standards, all other systems of an essentially identical design will be acceptable in Federal Facilities.

6 DESIGN RECOMMENDATIONS FOR GENERAL-REFUSE INCINERATORS

6.1 BASIS FOR DESIGN RECOMMENDATIONS

Tests on incinerators designed according to these recommended standards have shown that when properly operated, the incinerators can meet, without the use of scrubbers, the applicable Federal emission standards for incinerators with rated burning capacity of 200 pounds per hour or less. At capacities of more than 200 pounds per hour, incinerators should be equipped with scrubbers to ensure that applicable Federal emission limits are met.

6.2 TYPES OF GENERAL-REFUSE INCINERATORS

Multiple-chamber incinerators are of two general types. Figure 6-1 illustrates the retort type, named for the return flow of gases through the "U" arrangement of the component chambers; and Figure 6-2 shows the in-line type, so called because the three chambers follow one another in a line.

6.2.1 Multiple-Chamber Retort Incinerators

The following guidelines are recommended:

1. That general-refuse retort incinerators installed in Federal facilities have the configuration shown in Figure 6-3.
2. That retort incinerators with rated capacities of over 1,000 pounds per hour not be built.
3. That incinerators of over 200 pounds per hour rated capacity be equipped with gas washers as specified in Section 8 of this Guide, or equivalent gas washers as determined by the Federal Facilities Section.
4. That the actual dimensions of incinerators shown in Figures 6-1 and 6-3 be established by using the design considerations given in Section 12 of this Guide.

6.2.2 Multiple-Chamber In-Line Incinerators

The following guidelines are recommended:

1. That all in-line incinerators installed in Federal facilities for the purpose of burning wastes of Types 0, 1, or 2 have the configuration shown in Figure 6-4.

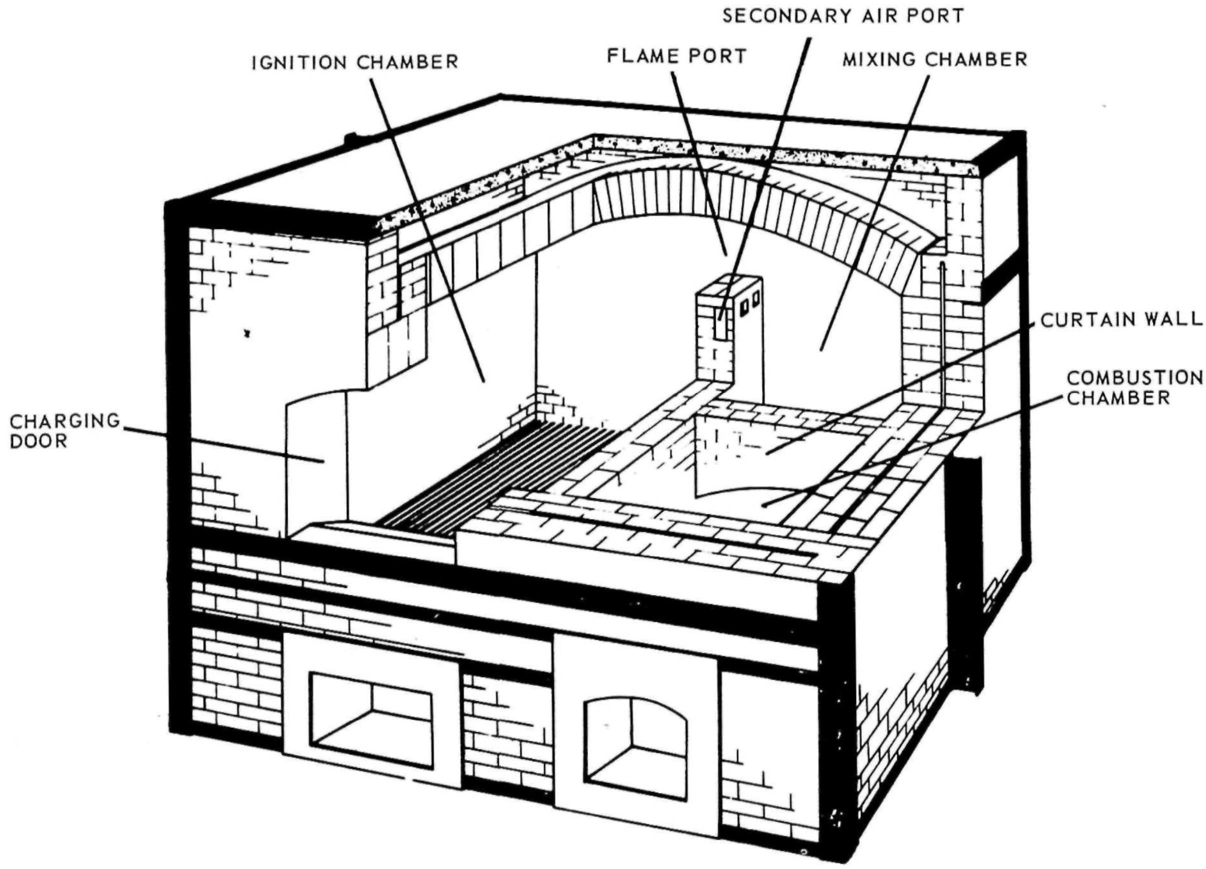


Figure 6-1. Cutaway drawing of multiple-chamber retort incinerator.

2. That in-line incinerators with a rated burning capacity of less than 750 pounds per hour not be built.

3. That all in-line incinerators be equipped with gas washers as specified in Section 8 of this Guide, or equivalent gas washers, as determined by the Federal Facilities Branch.

4. That the actual dimensions of incinerators shown in Figures 6-2 and 6-4 be established by using the design considerations in Section 12 of this Guide.

6.3 RECOMMENDATIONS FOR AUXILIARY GAS BURNERS

6.3.1 Incinerators Requiring Burners

Secondary burners alone need be installed on incinerators that are to be used solely to burn Type 0 waste. If the incinerator is to burn wastes of Types 1, 2, 3, or 4, both primary and secondary burners should be installed. The need for

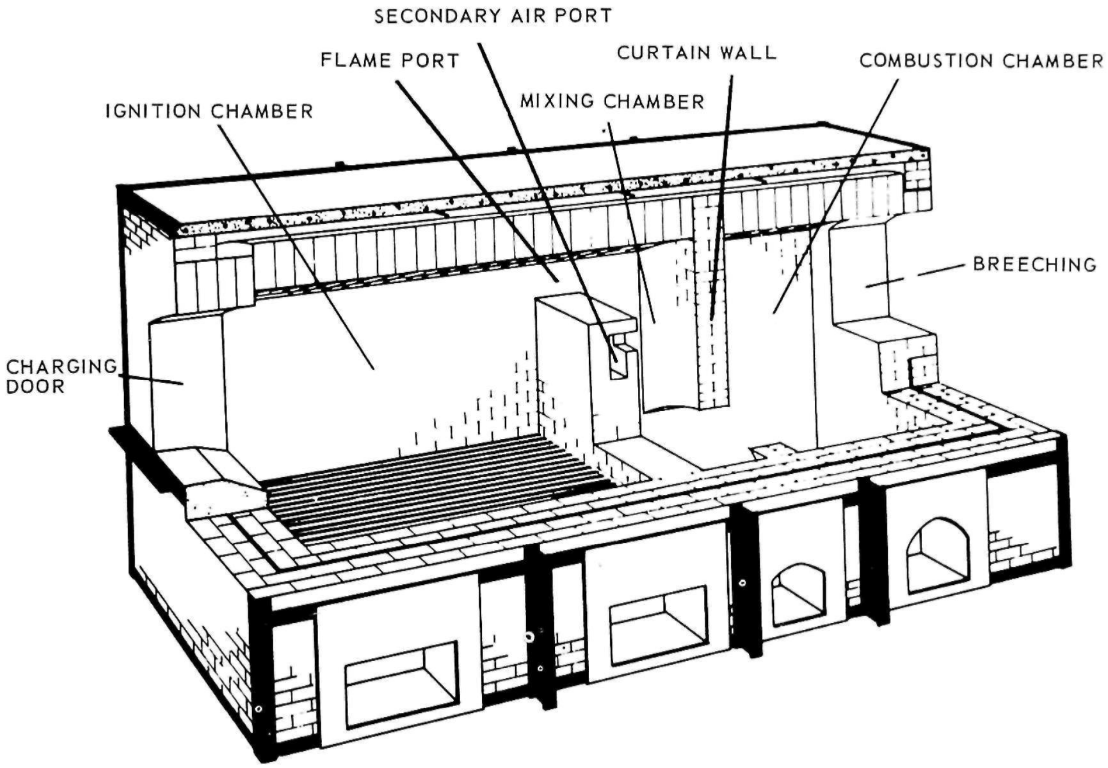


Figure 6-2. Cutaway drawing of multiple-chamber in-line incinerator.

burners in incinerating other types of waste is dictated by the nature of the waste itself.

6.3.2 Types of Natural Gas Burners Recommended

Incinerators having a capacity of less than 200 pounds per hour that use burners rated at less than 400,000 Btu per hour may be of either the atmospheric or power-burner type. In either case, a continuously or intermittently burning stable pilot adequate to ensure safe, reliable ignition should be installed. A flame safeguard should be used so that no gas can flow to the main burner unless satisfactory ignition is assured. The response time of this flame safeguard to de-energize the gas shutoff device on flame failure should not exceed 180 seconds.

Auxiliary burners on incinerators with ratings of 200 pounds per hour or more, i.e., those equipped with a fan and scrubber, should be of the power-burner type, because this type of burner usually retains its flame better when a fan is used to induce draft. For burners with ratings of more than 400,000 Btu per hour input, the burner equipment shall be of the power type that utilizes a forced-draft

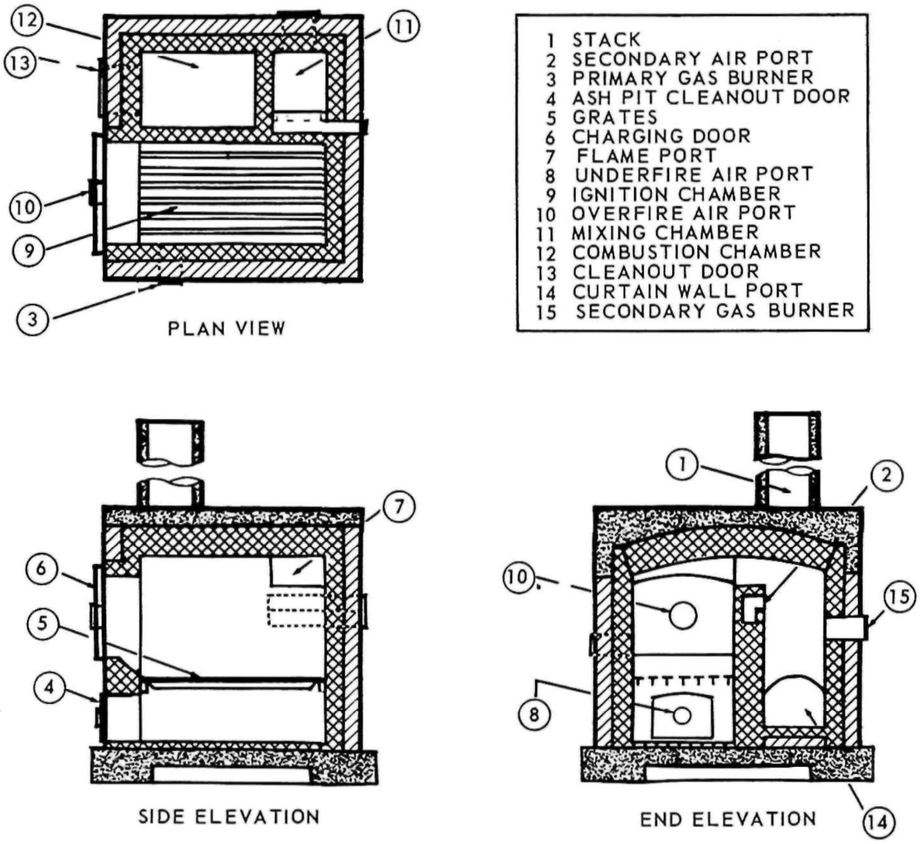
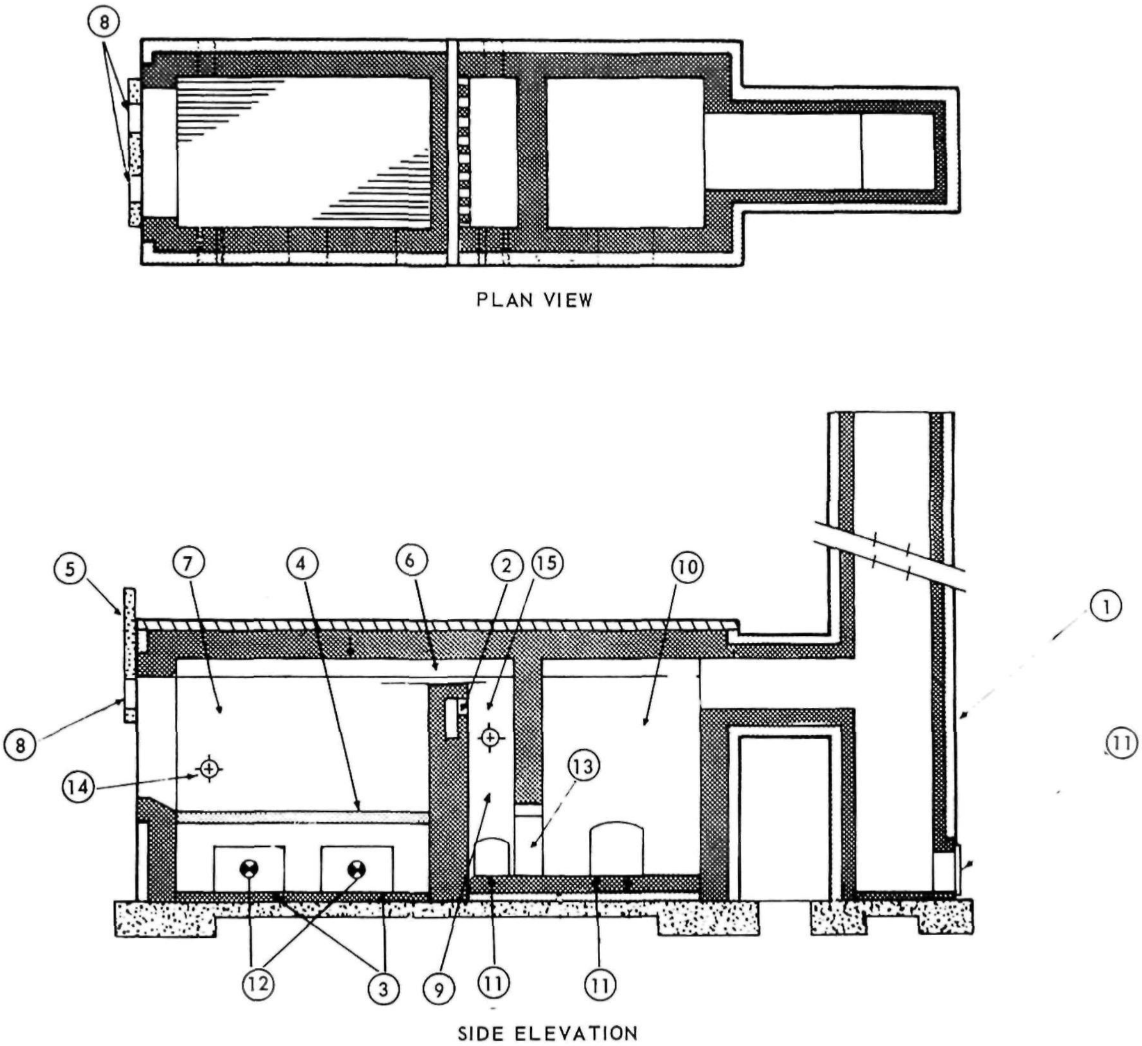


Figure 6-3. Recommended plan for multiple-chamber retort incinerators.

blower to supply air needed for combustion under controlled conditions. A continuously or intermittently burning pilot should be used to ensure safe and reliable ignition. Automatic spark ignition should be used on pilots for burners with input of more than 1,000,000 Btu per hour. A suitable flame safeguard should be used so that no gas can flow to the main burner unless satisfactory ignition is assured. On burners with inputs of from 400,000 to 1,000,000 Btu per hour, the response time of the flame safeguard to de-energize the gas shutoff device on flame failure should not exceed 180 seconds. In capacities of more than 1,000,000 Btu per hour, the response time of the aforementioned flame safeguard should not exceed 4 seconds.

The burner assembly should consist of the main burner, pilot burner, automatic valve, the necessary manual valves, and accessory equipment, plus interconnecting pipes and fittings with provision for rigid mounting. The burner should be constructed so that parts cannot be incorrectly located or incorrectly fitted together. Power burners sealed to the walls of incinerators with capacities of



1 STACK
2 SECONDARY AIR PORTS
3 ASH PIT CLEANOUT DOORS
4 GRATES
5 CHARGING DOOR
6 FLAME PORT
7 IGNITION CHAMBER
8 OVERFIRE AIR PORTS
9 MIXING CHAMBER
10 COMBUSTION CHAMBER
11 CLEANOUT DOORS
12 UNDERFIRE AIR PORTS
13 CURTAIN WALL PORT
14 PRIMARY GAS BURNERS
15 SECONDARY GAS BURNERS

Figure 6-4. Recommended plan for multiple-chamber in-line incinerators.

more than 100,000 Btu per hour must be supplied with a means of proving air supply before the main gas valve can be energized.

Electrical motors of more than 1/12 horsepower on power burner equipment should be designed for continuous duty and should be provided with thermal overload protection or current-sensitive devices.

When a complete automatic pilot shutoff system is utilized, the controls should be readily accessible and arranged so that the main burner gas can be manually shut off during lighting of the pilot. When a complete automatic pilot system is not utilized, a readily accessible, manually operated, quarter-turn, lever-handle, plug-type valve should be provided to shut off or turn on the gas supply to the main burner manifold. This valve should be upstream from all controls except the pilot control valve.

Clearly defined and complete instructions for lighting and shutting down the burner should be provided in durable, weatherproof material for posting in a position where they can be read easily.

6.3.3 Sizes of Burners Recommended

Where auxiliary burners are used, their capacity range should include the values shown in Table 6-1.

Table 6-1. GAS BURNER RECOMMENDATIONS FOR GENERAL-REFUSE INCINERATORS

Capacity of incinerator, lb/hr	Size of burners, 10^3 Btu/hr		
	Primary burners		Secondary burners
	Type 1 refuse	Type 2 refuse	All refuse
50	150	250	200
100	200	550	300
150	250	650	400
250	300	750	650
500	550	1100	1000
750	750	1500	1300
1000	900	1700	1700
1500	1100	2200	2100
2000	1600	3300	2700

6.3.4 Other Fuels

If natural gas is not available, equivalent amounts of liquid fuels may be used. Fuel oils of grades higher than Number 2, however, should not be used. The National Fire Protection Association Standard No. 31, Installation of Oil Burning Equipment (1965), should be adhered to where oil burners are used.

If liquified petroleum gas is used, burners should be equipped with a device that will automatically shut off the main gas supply in the event the means of ignition becomes inoperative. The arrangement should be such as to shut off the fuel supply to the pilot burner also.

7 DESIGN RECOMMENDATIONS FOR PATHOLOGICAL INCINERATORS

7.1 BASIS FOR DESIGN RECOMMENDATIONS

Tests have shown that when properly operated, incinerators of the design recommended herein can meet the applicable Federal emission standards in sizes of 200 pounds per hour or less rated burning capacity.

Because the tests do not at present extend beyond incinerators having a burning capacity in excess of 200 pounds per hour, the specifications given herein apply only to incinerators having a lesser burning rate. Assistance in the design of larger incinerators of this class may be obtained from the Federal Facilities Branch, Division of Abatement, National Air Pollution Control Administration.

7.2 MULTIPLE-CHAMBER PATHOLOGICAL INCINERATORS – GENERAL

The pathological incinerators specified in this Guide are of one configuration, that of a retort incinerator, as shown in Figure 7-1. To be heated before entering the expansion chamber, gases from the mixing chamber pass under the hearth. This flow pattern holds for sizes of 100 pounds per hour and greater. For smaller sizes, a hot hearth and underhearth ports are not required, and the gases pass, as in a conventional retort incinerator, directly from the mixing chamber into the expansion chamber. Additional basic design information on these incinerators may be found in Section 13.

Small amounts of Type 4 waste may be burned in a chamber built on the side of a general-refuse incinerator. An incinerator with such a side chamber is shown in Figure 7-2.

7.2.1 Pathological Retort Incinerators

The following guidelines are recommended:

1. That all pathological incinerators with rated burning capacities of less than 200 pounds per hour built in Federal facilities have the configuration shown in Figure 7-3.

2. That pathological incinerators of 200 pounds per hour burning capacity or less have no scrubbers.

3. That the design considerations given in Section 13 of this Guide be used to

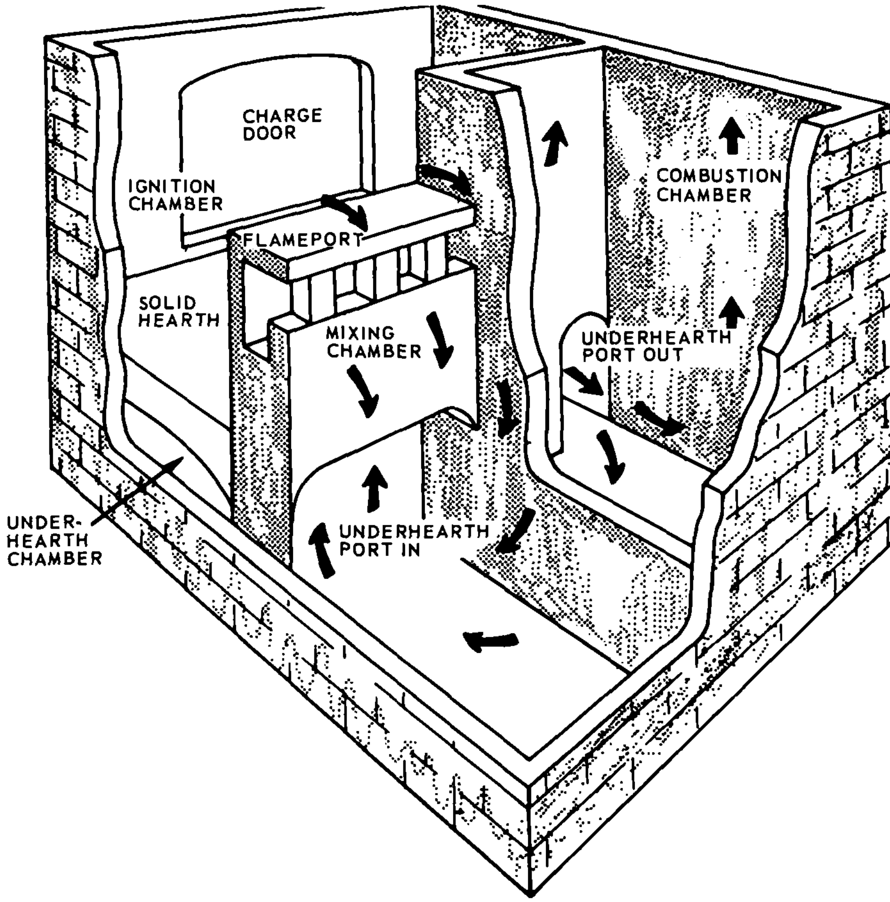


Figure 7-1. Multiple-chamber pathological incinerator.

establish dimensions for pathological incinerators in keeping with the configuration shown in Figure 7-3.

4. Assistance in the design of incinerators of larger capacity should be obtained from the Federal Facilities Branch, Division of Abatement.

7.2.2 Side Chamber for Pathological Refuse

1. Side chambers should be used only when small amounts of waste relative to the main capacity of the larger incinerator are to be burned. A drawing of a typical side chamber is shown in Figure 7-4.

2. Design information on side chambers may be found in Section 13.

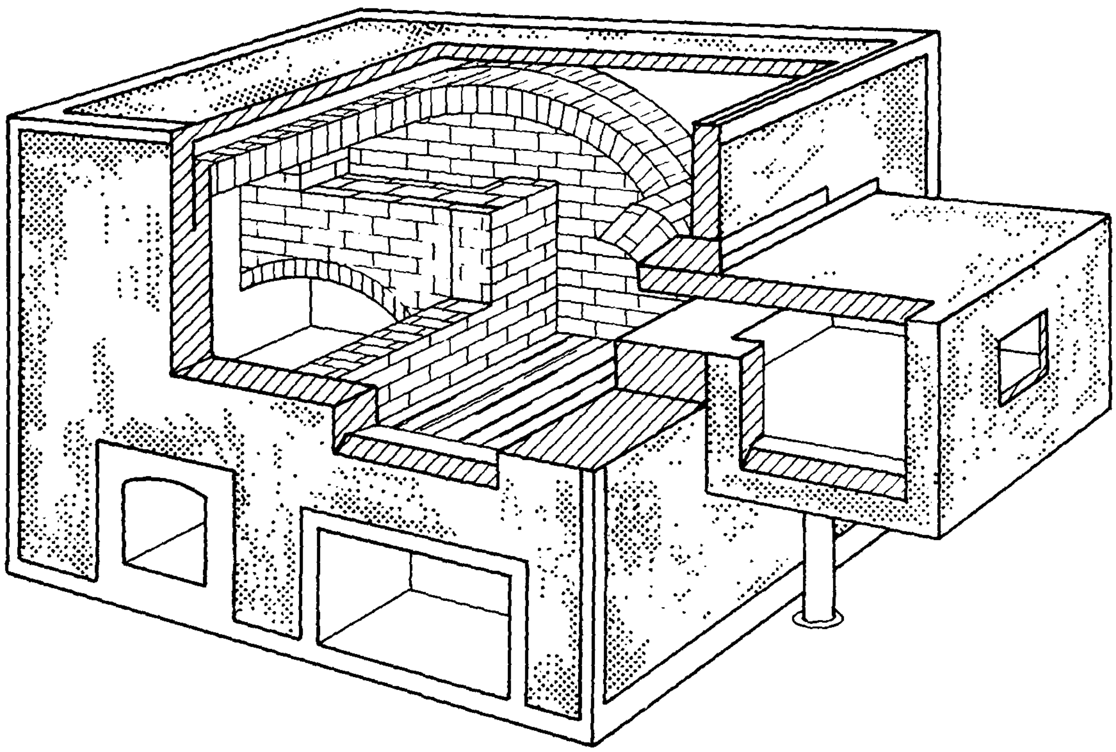


Figure 7-2. Multiple-chamber incinerator with pathological retort.

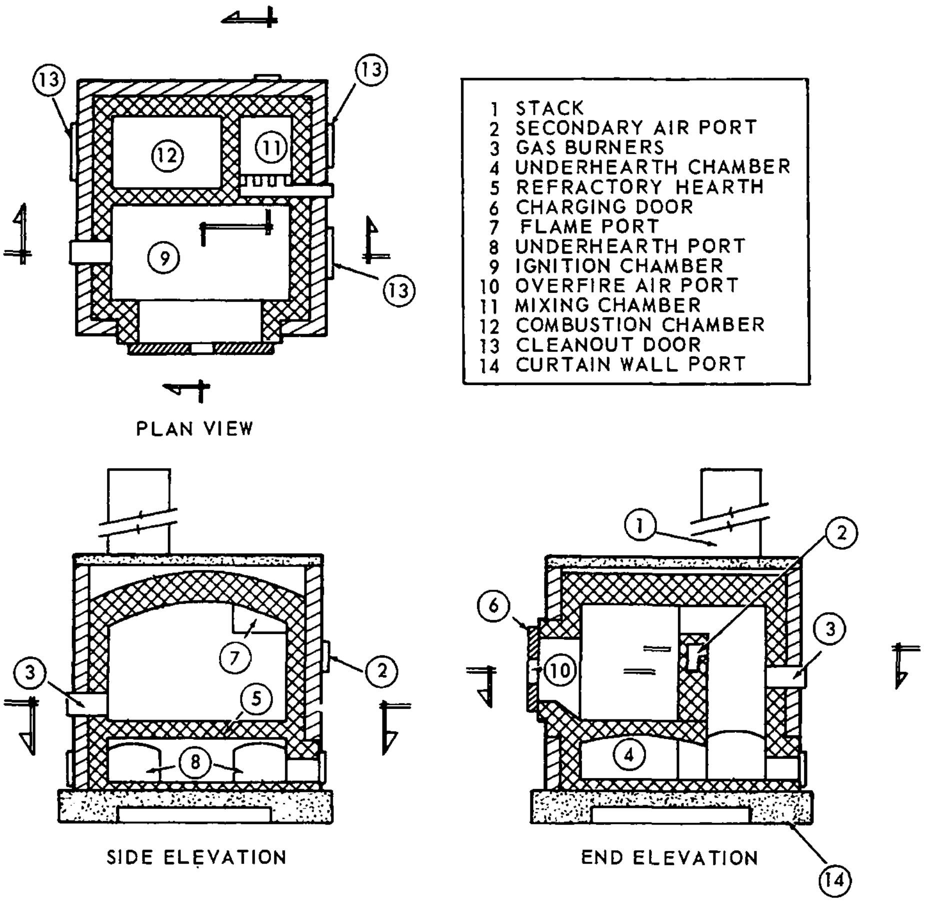


Figure 7-3. Recommended plan for pathological incinerators.

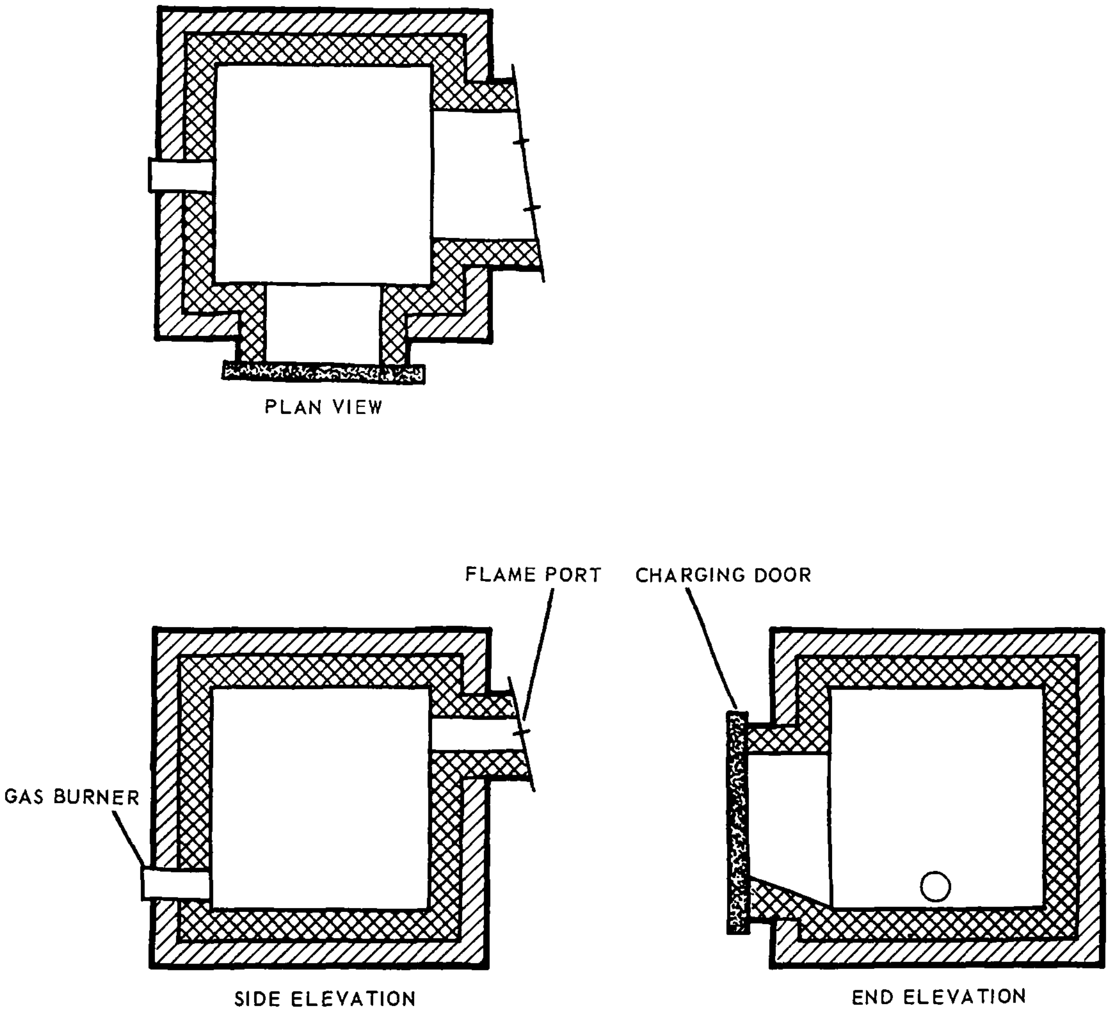


Figure 7-4. Side chamber for pathological refuse.

8 DESIGN RECOMMENDATIONS FOR INCINERATOR SCRUBBERS

A specific scrubber design is recommended herein, but other designs may be used if they are of an efficiency equal to that of the recommended design and are constructed of materials of equivalent resistivity to corrosion, heat, and other applicable stresses.

8.1 GENERAL

Effluents from general-refuse incinerators burning more than 200 pounds per hour should be cleaned in scrubbers to meet the particulate limit requirement. Since this will generally mean that scrubbers will be widely employed, the disadvantages associated with their use should be recognized.

When scrubbers are used, power lines may have to be installed to furnish energy to operate the induced-draft fan and water pump. Provisions must also be made to supply scrubbing water and a means of disposing of contaminated water from the scrubber. In some areas it will also be necessary to adjust the pH and process the contaminated water through a clarifier to remove fly ash and other collected solids before the water is sewered.

A scrubber may require considerable maintenance as a result of corrosion caused by the acidic water continuously flowing from it. Scrubber water is seldom recirculated because this increases its acidity and, therefore, the rate of corrosion. Even when scrubbers are lined with dense refractory material, corrosion of the steel casing may ultimately occur. In addition, there may be noticeable corrosion and erosion of the fan impeller and, to some lesser degree, of the fan housing. The continuous contact of the acidic water in the sump of the scrubber may gradually attack this surface.

8.2 SCRUBBER DESIGN PARAMETERS

Several basic factors are considered in designing scrubbers. To satisfactorily collect the fly ash, the water-gas mixture must be retained within the scrubber for 1 to 1-1/2 seconds at gas velocities not exceeding 15 feet per second. The residence time in the scrubber should also be sufficient to vaporize all the water droplets within the effluent gas stream. Complete vaporization is important since nuisance complaints may result from the carryover of water droplets deposited on the surrounding area. From an appearance standpoint, the scrubber should not be longer or higher than the incinerator. The scrubber width should be limited to allow the scrubber to be easily located either adjacent to or at the rear of any incinerator of the retort type. The usual location for scrubbers serving the in-line type incinerator is at the rear of the combustion chamber. Placing the scrubber adjacent to the final combustion chamber is also feasible.

Air dilution of the gases from the incinerator prior to entering the scrubber is unnecessary. Water is introduced into the effluent as it enters the scrubber and flows concurrently down its first pass. By immediately introducing the water into the gas stream, the water has a longer period to mix and evaporate, which accomplish the desired cooling. The average velocity of the gas-water mixture in the first pass ranges from 9 to 10 feet per second. The velocity of the gases in the upward pass is determined by calculating the remaining time requirement so that the gases are within the scrubber for a total time of approximately 1-1/4 seconds. The curtain wall port is sized to permit an air velocity range of 18 to 20 feet per second to prevent excessive pressure drop from occurring and to prevent water from the sump from being re-entrained in the effluent. The gases exit from the extreme top of the uppass so that its full length can be used for the evaporation of any remaining water in the gas stream. This location of the exit at the top also prevents water traveling up the back side of the scrubber from becoming re-entrained in the gas stream. Another feature that reduces re-entrainment of water droplets is a 4-inch channel at the bottom of the curtain wall. The channel collects the larger droplets and carries the water across the width of the scrubber, down its side walls, and into the sump below. Additional structural support for the refractory of the dividing wall is also provided by this channel.

Water in the base of the scrubber collects fly ash and other materials removed from the gas stream may be easily deposited and retained. The water depth is maintained at approximately 3 inches by extending the end of the overflow pipe 3 inches above the floor of the scrubber. Another drain pipe should be installed at floor level so that fly ash and other solids can be washed down the sloping floor of the scrubber.

Design parameters recommended are as follows:

1. The water rate to the scrubber should be 1 gallon per minute for every 100 pounds per hour of rated capacity of the incinerator. This gives a water-to-gas ratio of 1 gallon per minute for every 400 standard cubic feet of effluent stack gas.

2. Configuration of scrubbers for retort and in-line incinerators are given in Figures 8-1 and 8-2, respectively. A graph showing internal areas of the various ports in scrubbers versus incinerator size is given in Figure 8-3.

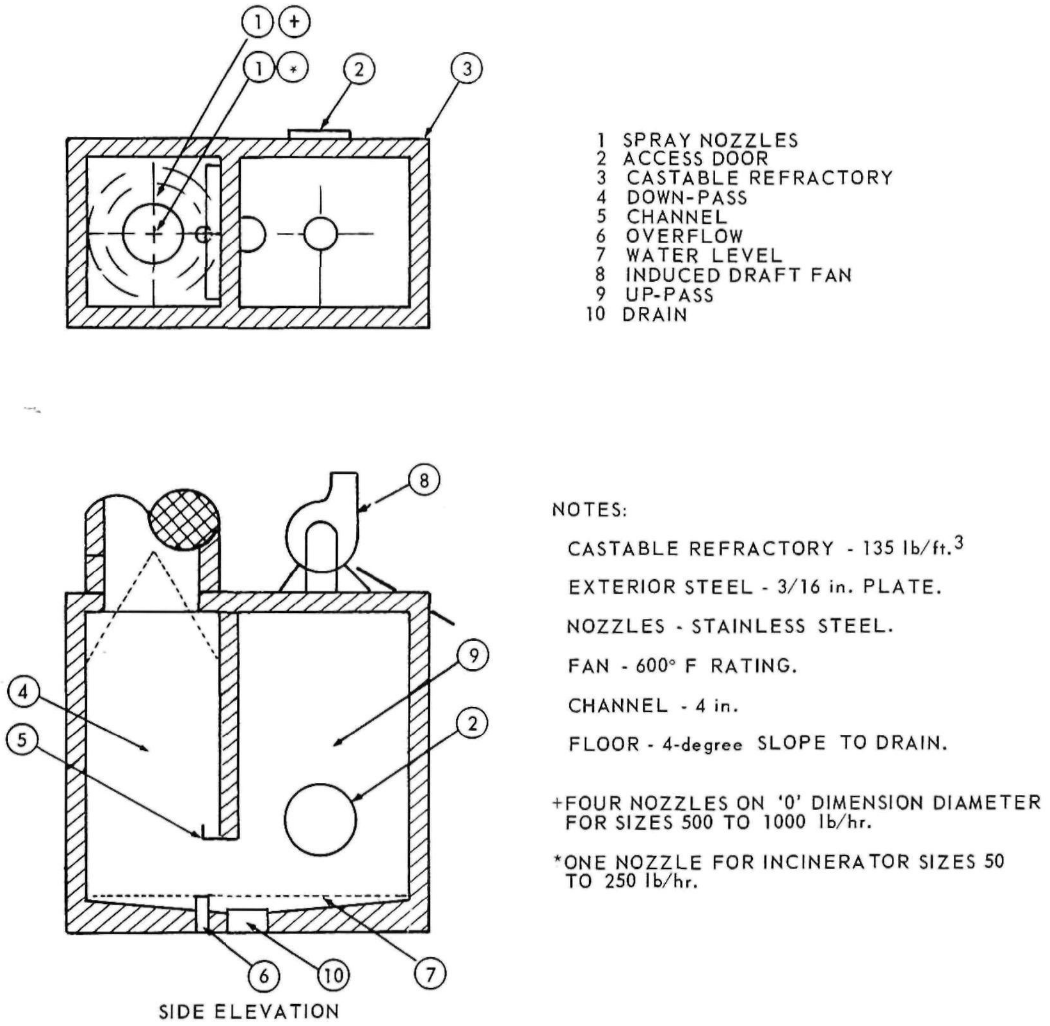
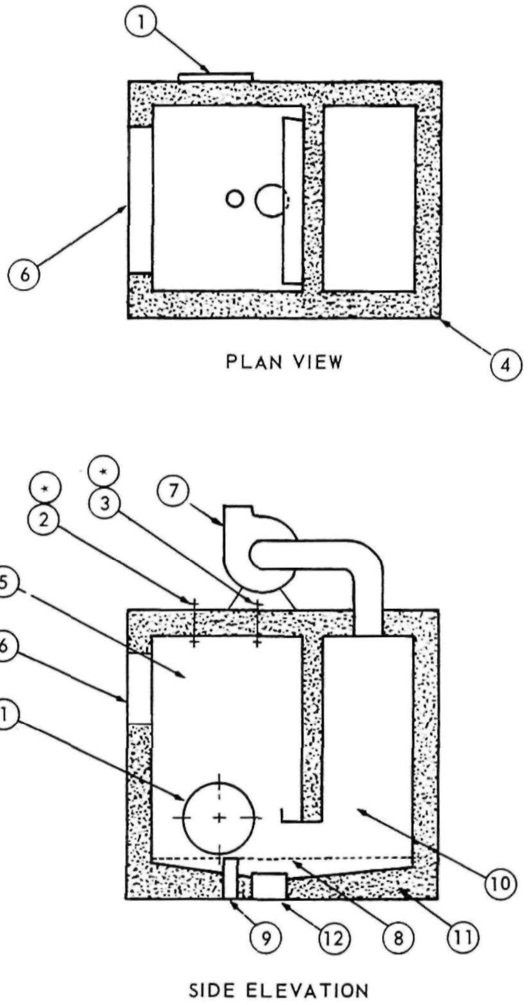


Figure 8-1. Design recommendations for retort incinerator scrubbers.



1 ACCESS DOOR
2 PRIMARY SPRAYS
3 SECONDARY SPRAYS
4 CASTABLE REFRACTORY
5 DOWN-PASS
6 EFFLUENT INLET
7 INDUCED DRAFT FAN
8 WATER LEVEL
9 OVERFLOW
10 UP-PASS
11 CHANNEL
12 DRAIN

NOTES:

CASTABLE REFRACTORY - 135 lb/ft.^{3}

EXTERIOR STEEL - 3/16 in. PLATE.

NOZZLES - STAINLESS STEEL.

FAN - 600° F RATING.

CHANNEL - 4 in.

FLOOR - 4-degree SLOPE TO DRAIN.

*ALL SPRAY NOZZLES TO BE EQUALLY SPACED WITHIN THE N DIMENSION

Figure 8-2. Design recommendations for in-line incinerator scrubbers.

8.3 SCRUBBER CONTROLS

While it is recommended that the scrubber controls described herein be installed, it should be realized that a special maintenance and testing program must be established to keep the control systems in good operating condition.

Many types of automatic controls are used to regulate the temperature of the gases leaving the scrubber. Satisfactory controls, which have proved to be both simple and economical, consist of a hand-operated control valve and two automatic solenoid valves. The hand-operated valve is installed in parallel with the solenoid valves between the water supply and the nozzles.

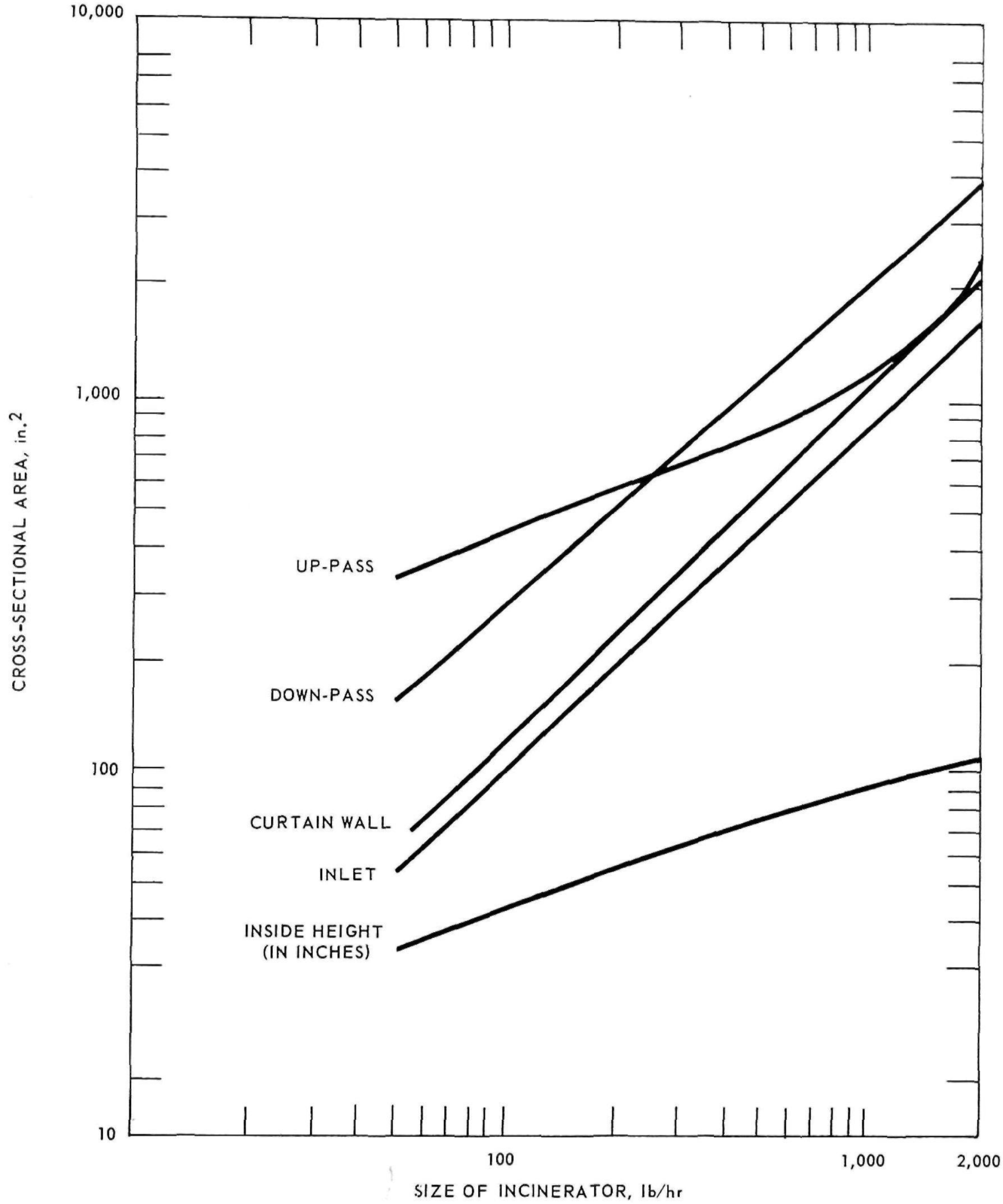


Figure 8-3. Internal sizing of scrubbers.

The solenoid valves are electrically connected so that one opens when the fan is placed in operation. The flow of water through this valve is adjusted to approximately 40 percent of the scrubber needs. The other valve is controlled by a thermocouple located at the fan inlet. When the temperature at the fan inlet reaches 220°F, the second solenoid valve opens and the remainder of the water is delivered to the nozzles. This arrangement is used to keep the temperature of the gases from exceeding 350°F. Should the automatic control system fail, the operator may open the hand valve and furnish sufficient water to the scrubber.

A back-up system also may be installed to prevent heat damage to the fan in case the automatic system just described fails. One such system frequently used consists of a thermocouple located at the fan inlets and additional solenoid-valve-controlled nozzles located in either the downpass or the uppass of the scrubber. The nozzles should be capable of supplying at least the same quantity of water as the combined volume of the primary and secondary sprays. Should the temperature at the fan inlet exceed 500°F, the back-up solenoid valve opens, and the full volume of water flows to the nozzles to cool the effluent to an acceptable level. As a final precaution, a warning alarm, actuated at 550°F, by a thermocouple at the fan inlet, may be installed to alert the operator to excessive temperature increases.

Back-up systems must be tested frequently so that they are operable when the need arises. Consequently, a safety system of this type would be of doubtful value unless a regular maintenance and testing program were established. .

8.4 SCRUBBER CONSTRUCTION

The steel exterior of the scrubber should be constructed of 3/16-inch-thick steel plate. Hangers should be mounted on the walls and top of the scrubber on 9-inch centers to hold the lining firmly to the walls. Linings of 135-pound-per-cubic-foot castable refractory should be 3 inches thick for incinerators with capacities of 750 pounds per hour or less. Units with capacities in excess of 750 pounds per hour should utilize 4-inch linings. The castable refractory floor should be sloped upward from the center of the scrubber at a 4-degree angle to facilitate the removal of collected fly ash and solids. The primary spray nozzles should be of the flat-spray type so that water droplets do not enter the connecting breeching and damage the refractory in the final combustion chamber of the incinerator. The secondary nozzles should be of the full cone type with a discharge angle of approximately 60 degrees. Nozzles mounted within the inlet duct should be provided with an access opening for cleaning or replacement. Nozzles mounted in the top of the unit should be installed out of the hot gas stream and should be removable from the exterior of the scrubber. Nozzles should be constructed of brass or stainless steel.

8.5 INDUCED-DRAFT FAN

8.5.1 General

The induced-draft fan should be constructed of mild steel and be capable of withstanding 600°F. The fan should be capable of at least two-speed operation or have a variable speed drive that is adjustable from maximum delivery volume to one-third of maximum delivery volume. Controls of this type permit the operator to reduce the volume handled by the fan when the incinerator is operating at less than the rated capacity. The resultant reduction in cooling in turn will increase the operating temperature within the incinerator and reduce the possibility of water carry-over from the scrubber. The controls for such a fan should be readily accessible to the operator so that he can reduce the fan speed and thus increase the overall efficiency of the incinerator. The fan housing should have a cleanout door and a water drain.

8.5.2 Design Parameters

8.5.2.1 Volume Requirements The fan should be sized to deliver 700 cubic feet per minute of gas at 350°F for every 100 pounds per hour refuse capacity of the incinerator.

8.5.2.2 Static Pressure Requirements The fan should provide 1/2-inch of water static pressure, at 350°F, for a 50-pound-per-hour incinerator. Its ability to develop static pressure should increase uniformly so that it will develop 1-1/2 inches of water, at 350°F, for a 2000-pound-per-hour incinerator. Fans operating at 350°F develop approximately two-thirds of the static pressure for which they are rated at ambient temperatures. Consequently, the induced-draft fan selected should be able to develop static pressures 50 percent higher than those desired at 350°F. For example, a fan selected for a 50-pound-per-hour incinerator should develop a static pressure of 3/4 inch of water at ambient temperatures, and a fan for a 2000-pound-per-hour incinerator should develop a static pressure of 2-1/4 inches water at ambient temperatures.

8.5.2.3 Horsepower Requirements The horsepower requirements of the fan should be based upon the full capacity of the fan at ambient temperature, not at 350°F.

8.5.2.4 By-Pass Arrangements For inside installations, a by-pass arrangement of breechings, or flue connections with dampers, to by-pass the scrubber and induced-draft fan is recommended.

8.6 MIST ELIMINATORS

Installation of mist eliminators is not usually necessary. There are, however, occasions when water droplets may be discharged from the exhaust fan. Should this be a serious problem, the inclusion of an eliminator section near the top of the uppass is desirable. In general, eliminators need be installed only when the performance of a unit has proved to be unsatisfactory.

8.7 ALTERNATE SCRUBBER DESIGNS

The following criteria should be used in the design of alternate scrubbers or gas washers.

1. The scrubber or gas washer should contain sprays, wetted baffles, or orifices arranged singly or in combination so as not to permit the discharge of particulate matter in violation of the Code of Federal Regulations.

2. Unlined gas washers or scrubbers should have welded or gasketed seams and be corrosion resistant. Lined gas washers or scrubber casings should be made of at least 12-gauge steel and be welded or gasketed. The density of refractory lining should be no less than 120 pounds per cubic foot. The refractory should never be less than 2 inches thick and must be adequately anchored to the casing.

3. Scrubbers requiring an induced-draft fan should have a motor capable of cold startup (70°F). When the impeller of an induced-draft fan is in the gas stream, the fan must be equipped with a cleanout door and drain.

4. Where spray nozzles are employed, an optimum spray pattern must be provided to cover all the area of the gases as they pass through the gas washer or scrubber. Nozzles and valves should be arranged for independent removal by means of unions or flanges. When water is recirculated, a pressure regulator and a strainer should be provided.

5. An access door for cleanout should be provided on all scrubbers.

6. Interlocks should be provided when induced-draft fans and sprays are used.

7. When the outside skin temperature of a gas washer or scrubber exceeds 260°F, protection should be provided.

8. For inside installations, a by-pass arrangement of breeching, or flue connections with dampers, to by-pass the scrubber and induced-draft fan is recommended.

9 RECOMMENDATIONS FOR CONSTRUCTION

This Guide sets forth minimum construction standards. When a designer feels additional strength or resistive qualities are required because of special applications, he should include them in his specifications. It is not, however, the intent of this Guide to preclude the use of specialty refractory materials for construction even though such special refractory does not have all the resistive qualities of the refractories outlined herein. Such refractory material may be used in certain areas where its special characteristics are of particular advantage, provided the materials have all the resistive qualities required for the area. For example, where weight of the structure is an important factor, insulating firebrick or insulating castable refractory may be used, but they cannot be used in any area where they will be subject to abrasion from tools, materials, or high-velocity gases.

9.1 MATERIALS OF CONSTRUCTION

Throughout this section reference is made to refractories in an abbreviated manner such as high heat duty and super duty. For exactitude, the American Society for Testing and Materials (ASTM) specifications for these materials follows.

9.1.1 High-Temperature Block Insulation

The high-temperature block insulation required by this Guide is in accordance with ASTM Designation C-392-63 Class 2 and has the following physical properties.

Density	14 to 20 lb/ft^3
Service temperature	up to 1800°F
Moisture absorption	nil
Fire resistance	incombustible
Linear shrinkage at 1800°F. (max.)	4.0 percent

Thermal conductivity in Btu per inch per square foot (maximum) per hour is as follows:

200°F mean temperature	0.36
600°F mean temperature	0.51
1000°F mean temperature	0.755

9.1.2 High-Heat-Duty Firebrick

The high-heat-duty firebrick required by this Guide is classified as spall resistant in accordance with ASTM Designation C-106-67. It has the following physical properties:

Pyrometric cone equivalent	31-1/2 minimum
Panel spalling loss (2910°F)	10 percent
Modulus of rupture	500 psi minimum

9.1.3 Super-Duty Firebrick

The super-duty firebrick required by this Guide is classified as spall resistant in accordance with ASTM Designation C-106-67. It has the following physical properties:

Pyrometic cone equivalent	33 minimum
Panel spalling loss (3000°F)	4 percent maximum
Reheat shrinkage (2910°F)	1 percent maximum
Modulus of rupture	600 psi minimum

9.1.4 Class C Hydraulic Castable Refractory

The hydraulic setting castable refractory required to meet the minimum standards of this Guide is in accordance with ASTM Designation C-213-66 Class C and has the following physical properties:

Service temperature	2600°F maximum
Permanent linear shrinkage	1.5 percent after heating to 2500°F for 5 hours
Modulus of rupture	300 psi after drying to 220°F

9.1.5 Class D Hydraulic Castable Refractory

The hydraulic setting castable refractory required to perform satisfactorily in areas of high-heat flux, such as in the arches of pathological incinerators, should meet the provisions of ASTM Designation C-213-66 Class D and have the following physical properties:

Service temperature	2800°F maximum
Permanent linear shrinkage	1.5 percent after heating to 2700°F for 5 hours
Modulus of rupture	300 psi after drying to 220°F

9.1.6 Use of Castable Refractories

All castable refractory walls should be installed to form a monolithic structure and should be anchored to the exterior shell of the incinerator. Suspended arches should be constructed so that their weight does not rest on the refractory walls. Alloy steel or refractory anchors should be used and spaced not more than 24 inches horizontally and vertically, and in accordance with the refractory manufacturer's recommendations.

All such castable material should be delivered to the job site in containers with the manufacturer's name and instructions stamped thereon. The manufacturer's written instructions should be followed for the preparation and application, and also for its curing.

9.1.7 Insulation Castable Refractories

Although other types of insulating castable refractories may be used as their resistive properties warrant, two classes, one for areas receiving direct-flame radiation, and the other for areas that do not normally receive direct-flame radiation, are recommended herein.

9.1.7.1 Class Q Insulating Castable   Where weight is a problem, as in an afterburner, and there is no abrasion from tools, materials, or gases, and the refractory is to receive direct-flame radiation, the minimum refractory employed must not be less resistive than that given in ASTM Designation C-401-60 for Class Q Insulating Castables. Certain physical properties of this class follow:

Permanent linear shrinkage	1.5 percent maximum when fired at 2300°F for 5 hours
Maximum bulk density	95 lb/ft^3 after drying to 220°F

9.1.7.2 Class O Insulating Castables   Where there is no abrasion from tools, materials, or gases and the refractory will not normally receive direct-flame radiation, as in a stack, the minimum refractory employed must not be less resistive than that given in ASTM Designation C-401-60 for Class O Insulating Castables. Certain physical properties of this class follow:

Permanent linear shrinkage	1.5 percent maximum when fired at 1900°F for 5 hours
Maximum bulk density	65 lb/ft^3 after drying to 220°F

9.1.8 Air-Setting Plastic Refractory

Two types of air-setting plastic refractory are specified by ASTM Designation C-176-67: high duty and super duty. The high-duty material represents the minimum type of air-setting plastic refractory recommended by this Guide. The super-duty material is recommended for use in areas of high-heat flux, such as the arches of pathological incinerators.

9.1.8.1 High-Duty Plastic Refractory The high-duty air-setting plastic refractory required by this Guide is in accordance with ASTM Designation C-176-67. It has the following physical properties:

Water content	15 percent maximum as received
Workability index	15 35 percent deformation
Pyrometric cone equivalent	31 minimum
Maximum reheat shrinkage	3 percent
Panel spalling loss	15 percent (2910°F)

9.1.8.2 Super-Duty Plastic Refractory The super-duty air-setting plastic refractory recommended by this Guide is in accordance with ASTM Designation C-176-67. It has the following properties:

Water content	15 percent maximum as received
Workability index	15 35 percent deformation
Pyrometric cone equivalent	32-1/2 minimum
Maximum reheat shrinkage	2.5 percent
Panel spalling loss	5 percent (3000°F)

9.1.9 Use of Air-Setting Plastic Refractories

All plastic refractory walls should be installed to form a monolithic structure and should be anchored to the exterior shell of the incinerator. Suspended arches should be constructed so that their weight does not rest on the refractory walls. Alloy steel or refractory anchors should be used and spaced not more than 24 inches horizontally and vertically, and should be of flexible design, and installed according to the refractory manufacturer's instructions.

The plastic refractory should be delivered to the job site in containers with the manufacturer's name and instructions stamped thereon. The manufacturer's written instructions should be followed in preparing and applying the plastic and also in its curing and baking.

9.1.10 Air-Setting Refractory Mortar

The air-setting refractory mortar required by this Guide should meet the requirements for the high duty classification under ASTM Designation C-178-47 (1958). The mortar should have the following physical properties:

Refractoriness test temperature	2730°F
Maximum water content	25 percent
Bonding strength of joints	200 psi
Particle size	95 percent <No. 40 ASTM sieve
	0.5 percent >No. 20 ASTM sieve

If super-duty refractories are used, it is recommended that mortars meet the super-duty class of ASTM Designation C-178-47 (1958).

9.1.11 ASTM Standards

Should questions arise about specifications for any refractory or insulation construction, they may be resolved by reference to the appropriate ASTM Designation referred to above. Where ASTM Designations are modified, the latest modification should be followed.

9.2 GENERAL REFUSE INCINERATORS

There are as many methods of erecting the walls of a multiple-chamber incinerator as there are materials from which to build them. The exterior of the incinerator may be either brick or steel plate construction. Refractory lining may be firebrick, castable refractory, or plastic firebrick. Protection of exterior walls from extreme temperature conditions may be provided by either peripheral air space, air cooling passages, or insulation. Stacks, in small to medium size incinerators (less than 750 pounds per hour refuse) may be mounted directly on the incinerator, may be free standing, or may be an integral part of the building structure of the incinerator.

Incinerators with capacities of 500 pounds per hour or less, will usually be prefabricated. Larger size units, and some specially designed smaller units, are erected on the site.

The most important element of multiple-chamber incinerator construction, other than the basic design, is the proper installation and use of refractories. The manufacturer must use suitable construction materials and be experienced in high-temperature furnace fabrication and refractory installation. Service conditions should dictate the type of lining for any furnace when a choice of available materials is made.

9.2.1 Refractories for Walls and Arches

The minimum refractory specification recommended for firebrick used in walls and arches of incinerators is the classification of high-heat duty. Firebrick should be laid in air-setting high temperature cement. Equivalent duty hydraulic-setting castable refractory and air-setting plastic refractory should be suitably anchored to the exterior wall.

Recommended minimum exterior wall thickness of incinerators is as follows:

1. Up to and including 500 lb/hr refuse capacity all refractories, whether firebrick, castable, or plastic, should be a minimum of 4-1/4 inches thick.
2. Over 500 lb/hr of refuse capacity, all refractories should be a minimum of 9 inches thick.

The minimum thickness of interior refractory walls (i.e., those walls inside the incinerator, the bridge wall, curtain wall, or parting wall) will generally follow the recommendations for the exterior walls. The bridge wall, with its internal secondary air distribution channels, will require greater thickness. The minimum width of refractory material between the air channel and the ignition or charging chamber, should never be less than 2-1/2 inches in the very small size units, 4-1/2 inches in units up to 250 pounds per hour, and 9 inches in units larger than 250 pounds per hour.

Sufficient expansion joints in the refractory construction are necessary to prevent bulging and destruction of the walls and arches. Each foot of wall made with firebrick clay refractory will expand when heated and contract when cooled from 1/16 to 3/32 inch. Provisions for vertical expansion should be sufficient between the arch and sidewalls to allow for the vertical movement. Horizontal expansion of the various vertical walls will have to be provided for. No hard and fast rules may be laid down for the provision of expansion joints. Their proper design requires complex calculation based on the experience of the contractor and engineering knowledge.

9.2.2 Insulation Requirements

Where the incinerator is constructed with a steel plate exterior wall, insulation must be used between the refractory wall and the steel plate. A high-temperature insulating block should be used. Minimum thickness for insulation is 2 inches. Units larger than 500 pounds per hour should have 2-1/2 inches. Loose-fill insulation is not satisfactory because of its packing into the lower portion of the unit over long periods of time. When the exterior wall is of regular clay brick construction, a minimum of 1 inch air space between the exterior brick and the refractory brick, with adequate venting of the insulating air space should be provided.

9.2.3 Exterior Casing

Minimum thickness of steel plates used for the exterior casing of multiple-chamber incinerators should be 12 gauge. The steel casing and the structural framework should be erected and set plumb before any brickwork is started. The exterior, or steel casing, should be reinforced with structural members, or if the exterior is brick, should be reinforced with structural steel to withstand interior thrusts from all arches and to support all doors, burners, and appurtenant assemblies. Exterior brick walls and casings must conform to minimum building code structural requirements, but in no instance, where clay or shale brick is used, should the exterior walls be less than 8 inches thick.

9.2.4 Floors

The thickness of refractory lining and insulation for the floors of multiple-chamber incinerators is dependent primarily on their physical location. For incinerators installed on their own concrete foundations outside of buildings, 2-1/2 inches of firebrick lining backed by 1-1/2 inches of high-temperature insulating material will be satisfactory. Heat transfer through this insulation will be high; but if the concrete pad cracks, only minor damage will occur. Portable incinerators mounted on 4-inch channels will have sufficient air space provided beneath the incinerator to eliminate possible damage to the pad. When incinerators are installed within buildings, provisions should be made to prevent physical damage to the building. Building damage can be eliminated by providing cooling passages beneath the incinerator, thus preventing excessive heat from reaching the structure. Additional insulation should be provided within the floor of the incinerator when cooling passages are not feasible. For incinerators up to 500 pounds per hour, 4-1/2 inches of firebrick and 2-1/2 inches of insulation should be provided on the floor of the mixing and final combustion chambers. For incinerators with capacities of 500 to 2000 pounds per hour, 4-1/2 inches of firebrick backed by 4 inches of insulation should be provided.

9.2.5 Foundations

Foundation requirements for all incinerators are determined by the weight of the incinerator and the soil conditions. The prefabricated, portable units have sufficient air space between them and the foundation to prevent any problem. The on-site constructed units must provide either air insulation or a layer of insulating material.

Prefabricated incinerators should have a minimum of three heavy supports beneath their floors to provide support for their three bearing walls and to permit them to be moved safely.

When incinerators are mounted on floors, the floors should be of fire-resistant construction with no combustible material against the underside of the floor, or on fire-resistant slabs or arches having no combustible material against the underside thereof. Such construction should extend not less than 3 feet beyond the appliance on all sides, and it should extend not less than 8 feet at the front or side where ashes are removed.

9.2.6 Charging Doors

Guillotine charging doors used in the recommended design should be lined with refractory material with a minimum service temperature of 2600°F. Units of less than 100 pounds per hour capacity should have door linings at least 2-inches thick. In the size range of 100 to 350 pounds per hour, lining thickness should be increased to 3 inches. From 350 pounds per hour to 1000 pounds per hour, the doors should be lined with 4 inches of refractory. On units of 1000 pounds per hour and larger, linings should be 6 inches thick.

9.2.7 Grates

Grates should be made of cast iron and weigh at least 40 pounds per square foot. They should have at least 40 percent open area. Because the length of the ignition chamber increases as the size of the incinerator increases, especially in incinerators larger than 750 pounds per hour, the rear section of the grate is difficult to keep completely covered. The use of a solid hearth at the rear of the ignition chamber in these units is therefore good practice. Hearths at this location prevent open areas from being formed in the refuse pile that is normally thin at the rear of a long ignition chamber. The solid hearth prevents excessive underfire air from entering immediately in front of the bridge wall. Such underfire air will quench the hot gases and cause excessive carryover of ash and unburned material into the mixing chamber. Sloping grates (grates that slant down from the front to the rear of the ignition chamber) facilitate proper charging. The sloping grate results in an increased distance between the arch and the grate at the rear of the chamber, reducing the amount of fly ash entrainment.

9.2.8 Air Inlets

All combustion air inlets should provide positive control. While round "spinner" controls with rotating shutters should be used for both underfire and overfire air openings in retort incinerators, they should only be used for underfire air openings in the in-line incinerator. Rectangular ports with butterfly or hinged dampers should be provided for all secondary air openings and overfire air openings of in-line incinerators. All air inlet structures should be of cast iron. Sliding rectangular dampers become inoperative and should not be used.

9.2.9 Flues

When flue gas temperature is not reduced, flue connections or breechings must be constructed with a Number 12 U.S. gauge steel exterior, lined with refractory, and provided with a guillotine or horizontal sliding damper. Flue connections and breechings having an internal cross-section of not more than 350 square inches should have high heat duty refractory lining 2-1/2 inches thick, and high heat duty refractory 4-1/2 inches thick for those having an internal cross-section of more than 350 square inches. Guillotine dampers provided for draft regulation should be properly counterbalanced, and horizontal dampers should be equipped with suitable rollers and tracks to insure easy operation. The dampers should be constructed of a steel frame with refractory lining or they may be constructed entirely of alloy steel to withstand the high temperature. All such dampers should be provided with a damper box constructed of Number 12 U.S. gauge steel to completely house the damper when in its open position. When a barometric damper is also provided, its free area should not be less than the percentage of the cross-sectional area of the flue connection, breeching, or stack in which it is located, as called for in Section 12. Gas velocity in any flue connection or breeching should not exceed 30 feet per second, calculated at 1400°F.

9.2.10 Chimneys (Stacks)

The construction of incinerator chimneys (stacks) may vary from location to location, and local building and fire protection codes must be consulted. All chimneys exposed or partially exposed to wind load should be designed to withstand the dynamic load imposed by 100-mile-per-hour wind in addition to the dead load.

Incinerator chimneys should extend not less than 4 feet above a sloping roof measured from the highest point of penetration of the chimney through the roof and at least 8 feet above a flat roof. In no case shall the chimney (stack) be less than 2 feet above any obstruction or portion of the building within a 20-foot radius. Local codes should be consulted for regulations requiring greater heights than those given herein.

Prefabricated refractory-lined chimneys, or stacks, with the refractory providing the structural strength, may be used. The thickness of the refractory lining and the class of refractory used should be in accordance with the Underwriters Laboratory approved listing. The exterior jacket should be a minimum of 28 gauge galvanized steel or stainless steel. Adequate support, without placing any of the load on the refractory walls of the incinerator, must be provided for any stack installed on top of an incinerator.

Prefabricated steel refractory-lined chimneys, or stacks, with the steel casing providing the structural strength, may be used. The steel casing should be designed in accordance with acceptable structural design practice and the thickness of the steel should not be less than shown in Table 9-1.

Table 9-1. MINIMUM THICKNESS FOR STEEL STACK WALLS

Stack diameter, inches	Thickness
Up to 28	12 gauge
29 to 48	3/16 inch
49 to 80	1/4 inch

The refractory lining should conform to ASTM Classification C-401-60 Class Q. The thickness of the refractory lining should not be less than shown in Table 9-2.

Table 9-2. MINIMUM REFRACTORY STACK LINING THICKNESS

Stack diameter, inches	Thickness, inches
Up to 28	2
29 to 48	3
49 to 80	4

The refractory lining should be secured to the steel shell by means of stainless steel anchors or steel shelf angles. The spacing of the anchors should not be more than 24 inches on centers with a minimum of 4 anchors per perimeter.

Firebrick-lined steel chimneys or stacks should be constructed of not less than 12 gauge steel and should be designed in accordance with acceptable structural steel practices. The steel shell should have a 4-1/2-inch firebrick lining for the full height.

Masonry chimneys or stacks may be used, but in no case should the firebrick lining be anchored to the exterior masonry shell. A clear air space must be provided between the exterior shell and the firebrick lining.

Brick masonry chimneys or stacks should be constructed with a minimum wall thickness of 8 inches of common brick with a 4-1/2-inch-thick firebrick lining for the full height.

Concrete chimneys or stacks should be constructed with a minimum shell thickness of 6 inches of concrete with a 4-1/2-inch-thick firebrick lining for the full height.

Stone chimneys or stacks should be constructed with a minimum wall thickness of 12 inches of stone masonry with a 4-1/2-inch-thick firebrick lining for the full height.

Radial brick chimneys or stacks should be constructed with a minimum wall thickness of 7-1/2 inches of radial brick with a 4-1/2-inch-thick firebrick lining for the full height.

Unlined steel chimneys or stacks may be used only when flue gas temperatures do not exceed 600°F, and the interior is protected against corrosion from the flue gas by a suitable temperature-, moisture-, and acid-resistant coating. However, unlined steel chimneys or stacks are not permitted on incinerators with emergency gas washer bypass flues, where the possibility of high-temperature gases in the chimney exits. Corrosion protection of the steel chimney is required because of the presence of moisture in the flue gases carrying an appreciable degree of acidity. Condensation of water vapor with acid characteristics will cause rapid deterioration of steel chimneys, especially on outside installations.

9.2.11 Clearances

Incinerators should be installed to provide a clearance to combustible material of not less than 36 inches at the sides and rear, and not less than 48 inches above, and not less than 8 feet at the front of the incinerator; except in the case where an incinerator is encased in brick, then the clearance may be 36 inches at the front and 18 inches at the sides and rear. A clearance of not less than 1 inch should be provided between incinerators and walls or ceilings of noncombustible construction. Walls of the incinerator should never be used as part of the structural walls of the building.

9.2.12 Incinerator Rooms or Compartments

1. When the combined hearth and grate area of the combustion chamber of an indoor incinerator is 7 square feet or less, the incinerator should be enclosed within a room that is separated from other parts of the building by walls, floor, and ceiling assemblies having a fire resistance rating of not less than 1 hour, with floor of earth or other noncombustible material, and used for no other purpose other than storage of waste materials and refuse to be burned or building heating equipment. Openings to these rooms should be protected by self-closing or automatic fire doors suitable for Class B situations (metal-clad doors) as defined in National Fire Protection Association Standard 80, Fire Doors and Windows, 1967.

2. Incinerators where the combined hearth and grate area of the combustion chamber exceeds 7 square feet, should be enclosed within a room that is separated from other parts of the building by walls, floor, and ceiling assemblies which are constructed of noncombustible material that has a fire resistance rating of not less than 2 hours and have a floor of earth or other noncombustible material, and used for no other purpose except storage of waste material and refuse to be burned or building heating equipment. Openings to such rooms should be protected by self-closing or automatic fire doors suitable for Class B situations (metal-clad doors) as defined in the National Fire Protection Association Standard No. 80, Fire Doors and Windows, 1967.

3. Automatic sprinklers and a short length of hand hose connected to a suitable water supply are recommended in the incinerator room.

9.2.13 Rubbish or Refuse Chutes

Rubbish or refuse chutes should rest on substantial noncombustible foundations. Thickness of enclosing walls of refuse chutes should be 8 inches of shale brickwork or clay, or 6 inches of reinforced concrete. Such chutes should extend at least 4 feet above the roof and be covered by a metal skylight, glazed with thin plain glass.

9.2.14 Chute Terminal Rooms or Bins

1. Rubbish or refuse chutes should terminate in, or discharge directly into, a room or bin that is separated from the incinerator room and from other parts of the building, by walls, floor, and ceiling assemblies that have a fire resistance rating equal to chute specifications. Openings to such rooms or bins should be protected by self-closing or automatic fire doors suitable for Class B situations (metal-clad doors), as defined in the National Fire Protection Association Standard No. 80, Fire Doors and Windows, 1967.

2. Properly installed automatic sprinklers provide a reliable and effective means for fire extinguishment and should be installed in all chute terminal rooms or bins, particularly where combustible waste is handled. A short length of hand hose connected to a suitable water supply should also be provided. Fires occurring at chute terminals are usually difficult to control because of the large amount of smoke evolved, causing access by the fire department to be difficult. Automatic extinguishment of such fires in the early stage is therefore of primary importance.

9.2.15 Ventilation of Incinerator Rooms

Rooms containing incinerators should be supplied with an adequate amount of air for combustion and ventilation. Air supply may be furnished by one of the following means:

1. A screened or louvered ventilator opening, or other suitable air intake. If communicating to other parts of the building the opening should be protected by a fire damper.

2. A duct leading from the incinerator room to the outside.

3. A duct leading to a boiler or furnace room as prescribed in Section 9.2.12 for incinerators of a given capacity, with sufficient air supply provided for both rooms.

Ducts extending from an incinerator room to other parts of a building should be constructed and protected in accordance with the National Fire Protection Association Standard No. 90A, Installation of Air Conditioning and Ventilating Systems of Other than Residence Type.

9.3 PATHOLOGICAL INCINERATORS

The general discussion for the construction, insulation, and refractory specifications of multiple-chamber incinerators given in Section 9.2, will cover most of the problems to be found in constructing pathological incinerators. The use of super-duty refractories, particularly in the arches of these units, is desirable. Refractory walls, roof, hearth, parting wall, curtain wall, and baffles should not be less than 4-1/2 inches thick for incinerators with a capacity up to 150 pounds per hour. Incinerators with a capacity of over 150 pounds per hour should have at least 9-inch thick refractory in walls, roof, hearth, parting wall, curtain wall, or baffles.

Hearth construction must have the physical strength to sustain maximum loads at elevated temperatures. Initial charges for pathological waste incinerators could have a total weight in excess of the hourly capacity of the unit; therefore, hearths should be designed for loadings of at least twice the hourly burning rate.

10 MISCELLANEOUS RECOMMENDATIONS

10.1 STACK VIEWER

When possible, it is advisable to arrange a system of mirrors to allow an incinerator operator, who would otherwise be unable to see the top of the stack because of his location, to view the stack outlet.

10.2 RECOMMENDATIONS FOR SAMPLING PORTS

Each new incinerator stack should have two sampling ports 3-1/2 inches in diameter. Each port should be positioned in the stack at right angles to each other. They should be located, when possible, eight to ten stack diameters downstream from any bend or disturbance of gas flow, and two stack diameters upstream of the exit of the stack. The ports should be provided with suitable removable, replaceable caps.

11 OPERATING PROCEDURES

11.1 GENERAL-REFUSE INCINERATORS WITHOUT SCRUBBERS

The emission control of the multiple-chamber incinerator is built in. Even so, the discharge of smoke or solid contaminants is in large measure a function of the action of the operator, and to some degree, the type of material charged. Smoke control is attained by the proper admission of air for combustion and by proper utilization of secondary burners, where the refuse has a low heating value or a high moisture content. Use of the secondary burners is required occasionally to maintain the combustion efficiency of the secondary chamber. Proper functioning of this chamber depends upon luminous flames and a temperature adequate for gaseous-phase combustion. Use of secondary burners is readily determined by observations of the flame travel from the ignition chamber, and flame coverage at both the flameport and the curtain wall port.

Before any incinerator is placed into operation, the grate and the ash pit beneath should be cleaned and the damper properly adjusted. Incinerators with full ash pits concentrate heat on the grates, causing them to soften, bend, and even fall from their mountings.

The secondary burner, or burners, should be ignited a few minutes before the incinerator is charged in order to heat the secondary chambers. The charging and clean-out doors should be closed, and the air ports open during this preheating period. Should the flames from the secondary burners be driven upward and through the flameport when ignited, instead of downward through the mixing chamber in incinerators with natural draft, the burners should be shut off. To overcome this problem, a small piece of paper may be inserted through the clean-out door in the combustion chamber, and ignited. The door is then closed and the secondary burners are re-ignited. The burning paper in the combustion chamber will direct the movement of air up the stack and result in proper operation of the burners.

The overfire and underfire air ports should usually be approximately half-open at lightoff. They should be opened gradually to an open position, as the incinerator reaches stable operation at its rated burning capacity. Air admission is usually not critical during normal incineration.

The most important single aspect of the operation of multiple-chamber incinerators is the charging of the refuse into the ignition chamber. Proper charging is necessary to reduce the issuance of fly ash, to maintain adequate flame coverage of the burning rubbish pile and the flameport, and to prevent the fuel bed from becoming too thin at the rear of the ignition chamber in the larger units.

The initial charge should fill the ignition chamber with refuse to a depth of one-half to three-quarters the distance between the pile below the flameport opening. The initial charge should be ignited at the top rear of the pile below the flameport opening, and the charging door closed. The primary burners in the ignition chamber are used when the refuse is very moist. If use of this burner is required, care should be exercised to prevent the blocking of the primary burner by the refuse pile.

When approximately one-half of the initial refuse charge has been burned, the remaining refuse may be carefully stoked. The burning refuse should then be pushed as far as possible to the rear of the grates. This operation should be performed carefully to prevent excessive emission of fly ash. Additional refuse may now be charged to the incinerator. The new refuse should be charged at the front section of the grates but not on top of the burning pile already in the incinerator. This method of charging will prevent smothering the fire and will maintain live flames over the entire rear half of the chamber, filling the flameport and extending well into the mixing chamber. Flames will propagate evenly over the surface of the newly charged material, minimizing the possibility of smoke emissions. This method of charging also minimizes the necessity of stoking or otherwise disturbing the burning pile, so that little, if any, fly ash is emitted. After the waste material has been charged into the incinerator, the unit enters the "burn-down" phase of its operation. When the last charge has been reduced to one-half, or less, of its original size, all air port openings to the incinerator are reduced to one-half open. The secondary burners are always left on, until the issuance of smoke from any material remaining on the grates has ceased. At this time, all burners are shut off.

When incinerators are burning only paper, caution is always exercised to insure that the burning pile at the rear of the grate does not become too thin. Should this happen, excessive underfire air admitted at this point quenches the hot gases entering the flameport, reduces combustion and produces smoke with as high as 100 percent opacity. Use of adequate secondary burners will prevent the incomplete combustion resulting from the thin bed at the rear of the ignition chamber.

Smoke emissions around the charging door or ash pit door, or both, usually result from overcharging. The following steps, in sequence, have been found to successfully eliminate smoke:

1. Check damper adjustment.
2. Shut off the primary burner, if operating.
3. Observe the burning pile, and move any material blocking the flame port.
4. Make sure that the clean-out doors, or doors in any of the secondary chambers of the incinerator, are closed. Any air port on these doors should also be closed.
5. Allow the fuel bed to burn down to normal operating depth, and do not overcharge the incinerator again.

White smoke appearing at the incinerator stack is usually caused by excess air entering the incinerator. The following steps, in sequence, have been found to eliminate white smoke:

1. Check damper adjustment.
2. Ignite the secondary chamber burner, or check to see that it is still burning.
3. Close the secondary air port, or ports.
4. Close the underfire air port.
5. Reduce the overfire air port opening.
6. If all the secondary burner capacity is not being used, gradually increase the operating rate of the burner until full capacity is reached.
7. If all of these operations fail to stop the issuance of white smoke, examine the material to be charged. Possibly the white smoke is the result of finely divided mineral material present in the charge and being carried out the stack. Paper sacks that contain pigments or other metallic oxides, and minerals such as calcium chloride, cause white smoke.

Black smoke is usually caused by insufficient amounts of air for combustion, or a burning rate greatly in excess of the capacity of the incinerator. The following steps, in sequence, have been found to eliminate this black smoke:

1. Check damper adjustment.
2. Shut off the primary burner, or burners, if in operation.
3. Open the secondary air port, or ports.
4. Open the overfire air port.
5. Either ignite the secondary chamber burner, or check to see that it is still burning.
6. If the black smoke still continues, gradually open the charging door until it is approximately one-quarter open.
7. Should these steps fail to eliminate the black smoke, examine the material remaining to be charged. Highly combustible materials (i.e., rubber, plastics, etc.) that are charged in too great a proportion to the other refuse, will result in a too rapid combustion rate for the incinerator to handle. These materials may be charged in very small quantities and in relatively small pieces along with general refuse. If such materials must be burned frequently, experimentation as to the quantity that may be charged along with other materials, may be necessary. Generally, highly combustible materials must be charged at less than 10 percent by weight of the total charge.

11.2 GENERAL-REFUSE INCINERATORS WITH SCRUBBERS

11.2.1 Incinerator Operation

Operation of the incinerator is the same as described under Section 11.1.

11.2.2 Scrubber Operation

The fan should be started before either the burner or refuse is ignited. If the interlock system described in Section 8.3 has not been supplied, water should be manually turned on to the scrubber. After the fan and water have been started, burners and refuse may be ignited. If the electrical interlock system described in Section 8.3 is installed, the water will flow to the nozzles when the fan is started.

If, during the operation of the system, the alarm sounds to indicate too high a fan temperature, the primary chamber burners should be shut off, charging stopped, and the door and air ports opened to cool the incinerator. The secondary burners may also be turned off to reduce the fan temperature to the point where the alarm will cease operating.

Maintenance should be conducted on a regular basis. The scrubber basin should be drained and cleaned daily. Nozzles, pumps, and the backup system should be checked weekly.

11.3 PATHOLOGICAL INCINERATORS WITHOUT SCRUBBERS

Preheating the secondary combustion zone is essential before charging and operating these units. The primary burner should not be ignited before charging has been completed or the charge door closed. The waste material should be so distributed on the hearth to assure maximum exposure to the flame of the primary burner. Normally, deposition completely covering the hearth would provide material in excess of the hourly capacity of the unit. To further overcharge the unit by placing one component of the charge on top of another is improper practice. Care should be exercised to insure that the primary burner port is not blocked by any element of the charge. If the initial charge is too large, smoke will escape from the incinerator doors. Experience should enable the operator to size the initial charge, as well as subsequent charges, to avoid this condition.

Additional refuse should be charged, and the burning material stoked, after a considerable reduction of the initial charge. The primary burner should be shut off before the charge door is opened for stoking or additional charging.

The adjustment of air ports is usually only of minor importance in the operation of these incinerators. Adjustments to the secondary air port are usually not necessary once it has been adjusted to provide proper operation under normal burning conditions. The only operating difficulty will occur when large deposits of fatty tissue or hair are exposed to the burner flame. The sudden volatilization of this material causes a rush of gases and vapors through the unit, and black smoke may issue from the stack. This surge of gas, if very large, could pressurize the ignition chamber and cause smoke to be forced out around the charging door. When this occurs the ignition chamber burner should be throttled down. Under exceptional conditions it may be necessary to shut the ignition chamber burner off for a few minutes. White smoke issuing from the stack usually indicates low incinerator temperatures, and is best overcome by increasing secondary or primary burner rates. Occasionally, adjustment of the secondary air port to decrease the admission of cold air is necessary.

There is essentially no "burndown" period in the operation of pathological waste incinerators. The degree of destruction desired for the waste material will dictate the length of time the primary burner is left in operation. Burning is normally ended when the material has been reduced to clean, white bone. When reduction of the bone to powdery ash is desired, the primary burners may be continued in operation. The secondary burner should not be shut off, however, until smoldering from the residual material on the hearth in the primary chamber has stopped.

The hearth should be frequently cleaned to prevent buildup of ash residue. The frequency with which the combustion or settling chamber is cleaned will depend on incinerator use. Deposits in this chamber should be removed to avoid re-entrainment in the exit gases with further use of the incinerator.

12 THEORETICAL BASIS FOR GENERAL-REFUSE INCINERATOR DESIGN RECOMMENDATIONS

12.1 PRINCIPLES OF COMBUSTION

The principles of solid fuel combustion that generally apply to incineration and basic precepts for combustion efficiency include the following:

1. Air and fuel must be in proper proportion.
2. Air and fuel, especially combustible gases, must be mixed adequately.
3. Temperatures must be sufficient for ignition of both the solid fuel and the gaseous components.
4. Furnace volumes must be large enough to provide the retention time needed for complete combustion.
5. Furnace proportions must assure that the ignition temperatures are maintained and fly ash entrainment is minimized.

The problem of fuel quality fluctuation is one of the factors that makes satisfactory incinerator design difficult. In addition to the wide ranges of fuel composition, moisture and volatility, there is diversity in ash content, bulk density, heats of combustion, burning rates, and component particle sizes. All of these affect, to some extent, the operating variables of flame propagation rate, flame length, combustion air requirements, and the need for auxiliary heat.

The ignition process consists primarily of fuel-bed surface combustion, attained by maximum utilization of overfire combustion air, limited use of underfire air, and a method of charging to attain concurrent travel through the ignition chamber of the air and refuse.

12.2 IGNITION CHAMBER PARAMETERS

The desired ignition mechanism of fuel bed surface combustion is attained by using a predominance of overfire combustion air and a method of charging that provides concurrent travel of air and refuse. Underfire air must be severely restricted to maintain a relatively low fuel-bed temperature and to limit the entrainment of solid particulate matter in the combustion gas stream from the chamber. Locating the charging door at the end of the ignition chamber farthest from the flame port permits the refuse to move through the ignition chamber from the *front to the rear*. This design and method of charging ensures that volatiles from the fresh charge will pass through the flames of the stabilized and heated portion of the burning fuel bed. Thus, the rate of ignition of unburned refuse is controlled, and the flash volatilization, flame quenching, and smoke creation normally encountered with top and side charging methods are avoided. Top or side charging is not considered acceptable because of the suspension of dust, disturbance of the fuel bed, and additional stoking required.

The ignition chamber of retort incinerators with rated capacities up to 500 pounds per hour should have a length-to-width ratio of from 2:1 to 2.5:1. Retorts over 500 pounds per hour capacity should have a length-to-width ratio of 1.75:1. For in-line incinerators, the length-to-width ratio starts at 1.75:1 for the 750-pound-per-hour capacity unit and diminishes linearly to approximately 1.2:1 for incinerators in the 2000-pound-per-hour capacity range.

The arch height and permissible grate loadings for incinerators are determined on the basis of their hourly burning capacity from Figures 12-1 and 12-2.

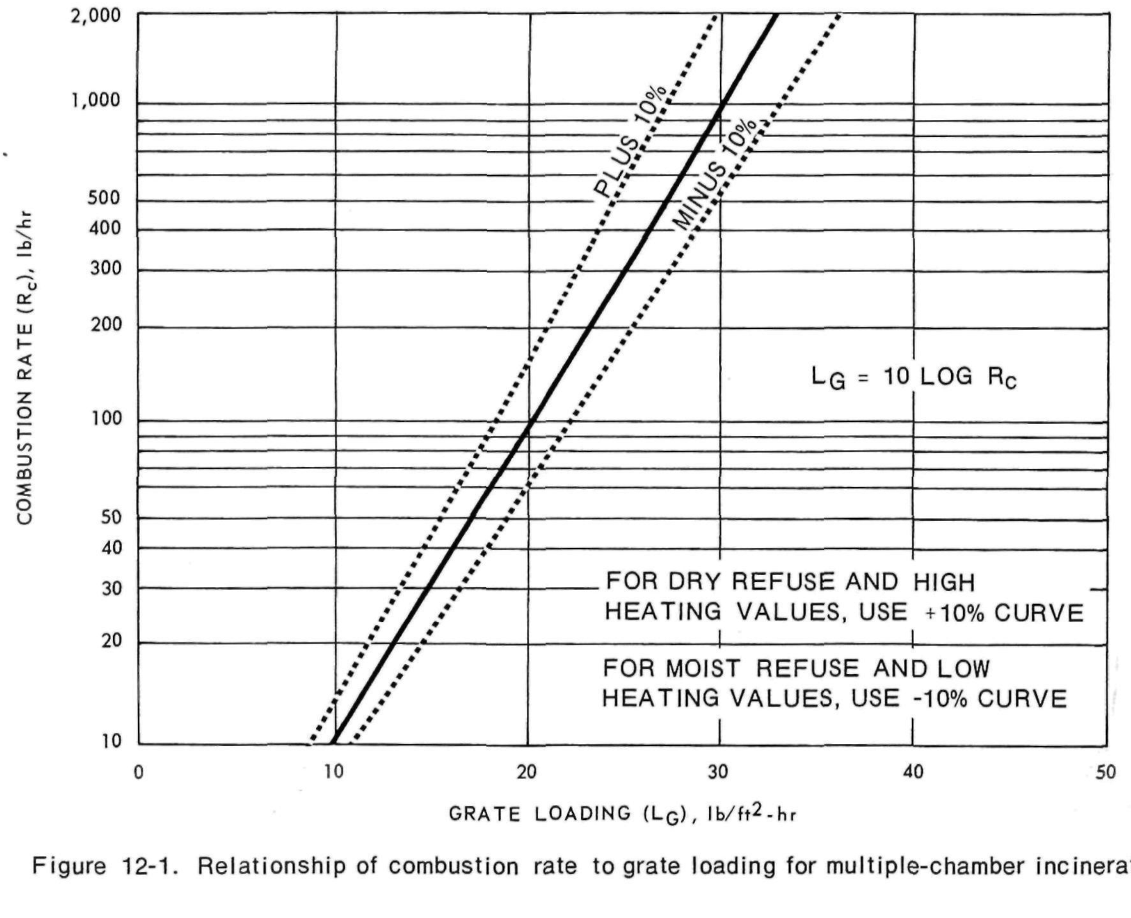


Figure 12-1. Relationship of combustion rate to grate loading for multiple-chamber incinerators.

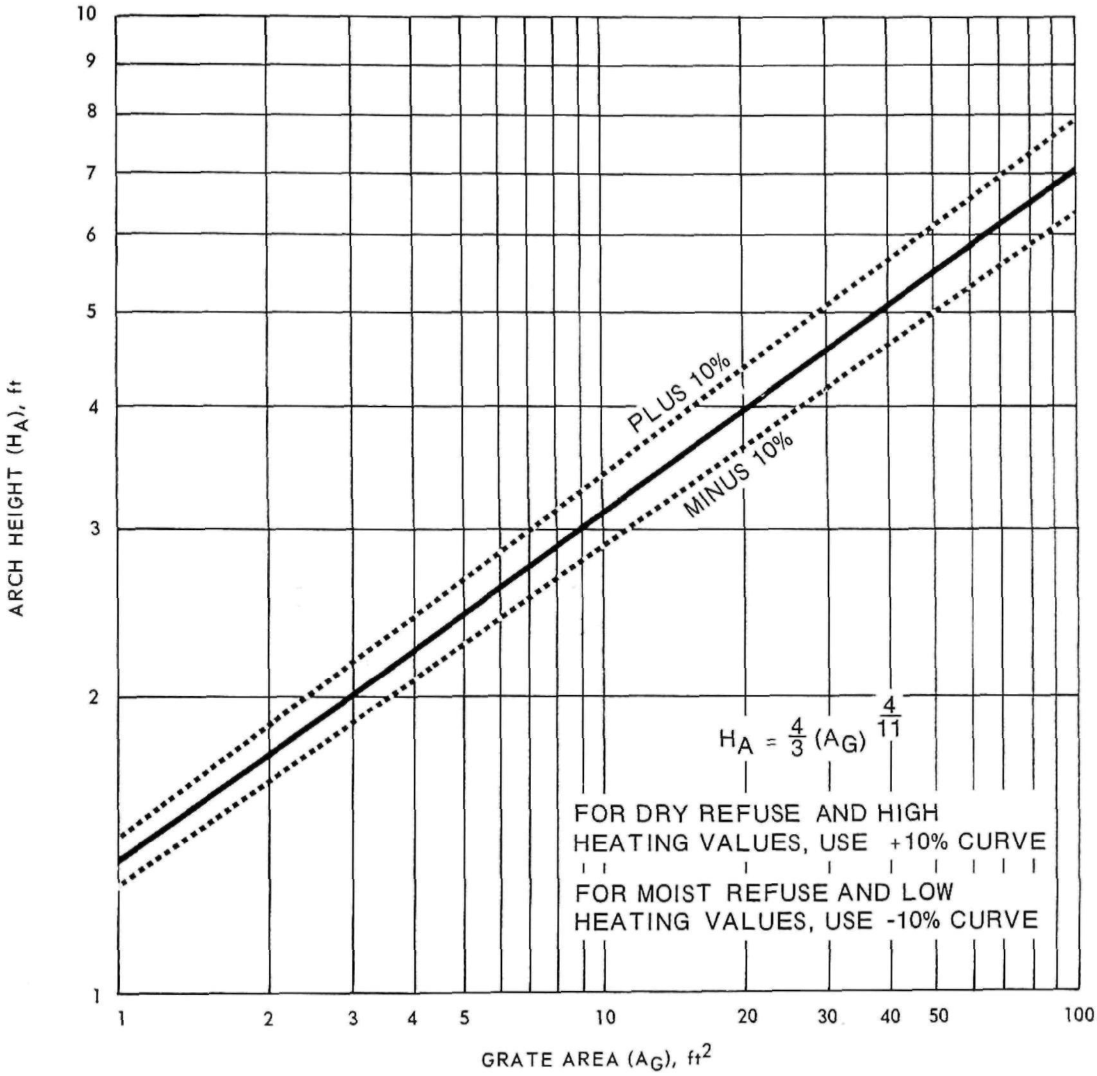


Figure 12-2. Relationship of arch height to grate area for multiple-chamber incinerators.

The curves in each figure have an upper gross heating value of 9000 Btu or more per pound and a lower gross heating value of 7500 Btu or less per pound for the refuse as charged. Interpolation between the upper and lower curves gives the correct arch height and grate area for refuse with a gross heat between these values. An allowable deviation of plus or minus 10 percent is permitted. Figures 12-1 and 12-2 may be used to determine appropriate values.

It is desirable to provide burners as specified in Section 6.3.1. The higher the moisture content of the refuse, the higher the auxiliary fuel requirements. The capacity of the primary burner is given in Table 12-1 in terms of the moisture content of the refuse. The determination of the size of the primary burner should

Table 12-1. GENERAL-REFUSE MULTIPLE-CHAMBER INCINERATOR DESIGN FACTORS

Item and symbol	Recommended value	Allowable deviation
Primary combustion zone		
Grate loading (L_G)	10 Log R_c, lb/hr-ft^2; where R_c equals the refuse combustion rate in lb/hr see (Figure 12-1)	± 10%
Grate area (A_G)	$R_c \div L_G$, ft^2	± 10%
Average arch height (H_A)	4/3 (A_G) 4/11; ft (see Figure 12-2)	--
Length-to-width ratio (approximate):		
Retort	Up to 500 lb/hr 2½:1 to 2:1. Over 500 lb/hr 1.75:1	--
In-line	Diminishing from about 1.7:1 for 750 lb/hr to about 1.2:1 for 2,000 lb/hr capacity. Over square acceptable in units of more than 11-ft ignition chamber length.	--
Secondary combustion zone 7		
Gas velocities		
Flame port @ 1000°F (V_{FP})	55 ft/sec	± 20%
Mixing chamber @ 1000°F (V_{MC})	25 ft/sec	± 20%
Curtain wall port @ 950°F (V_{CWP})	About 0.7 of mixing chamber velocity	--
Combustion chamber @ 900°F (V_{CC})	5 to 6 ft/sec; always less than 10 ft/sec	--
Mixing chamber down-pass length (L_{MC}) from top of ignition chamber arch to top of curtain wall port.	Average arch height, ft	± 20%
Length-to-width ratios of flow cross sections		
Retort, mixing chamber, and combustion chamber	1.3:1 to 1.5:1	--
In-line	Fixed by gas velocities because of constant incinerator width	--
Combustion air		
Air requirement batch charging operation	Basis: 300% excess air. 50% air requirement admitted through adjustable ports: 50% air requirement met by open charge door and leakage	
Combustion air distribution		
Overfire air ports	70% of total air required	--
Underfire air ports	10% of total air required	--
Mixing chamber air ports	20% of total air required	--
Port sizing, nominal inlet velocity pressure	0.1-in. water gage	--
Air inlet ports oversize factors		
Primary air inlet	1.2	
Underfire air inlet	1.5 for over 500 lb/hr to 2.5 for 50 lb/hr	
Secondary air inlet	2.0 for over 500 lb/hr to 5.0 for 50 lb/hr	
Furnace temperature		
Average design temperature for combustion products	1000°F	± 20°F
Auxiliary burners		
Normal duty requirements:		
Primary burner	3,000-10,000 Btu/lb moisture in refuse	
Secondary burner	4,000-12,000 Btu/lb moisture in refuse	
Draft requirements		
Theoretical stack draft (D_T)	0.15 for 50 lb/hr 0.30 for 1,000 lb/hr Uniformally increasing between sizes 0.35 for 2,000 lb/hr	--
Available primary air induction draft (D_A) (Assume equivalent to inlet velocity pressure)	0.1-in. water gage	
Natural draft stack velocity (V_S)	Less than 30 ft/sec @ 900°F	--

be based upon the refuse containing the highest amount of moisture to be burned in the incinerator.

Although heat release rates are not used in sizing any of the chambers in a multiple-chamber incinerator, their values are within the acceptable limits of furnace design. For comparative purposes, Figure 12-3 has been included for those who are more familiar with sizing combustion equipment by this method. In small multiple-chamber incinerators, the heat release rate approximates 30,000 Btu per cubic foot per hour, and in the largest of the in-line units the heat release rate is approximately 15,000 Btu per cubic foot per hour.

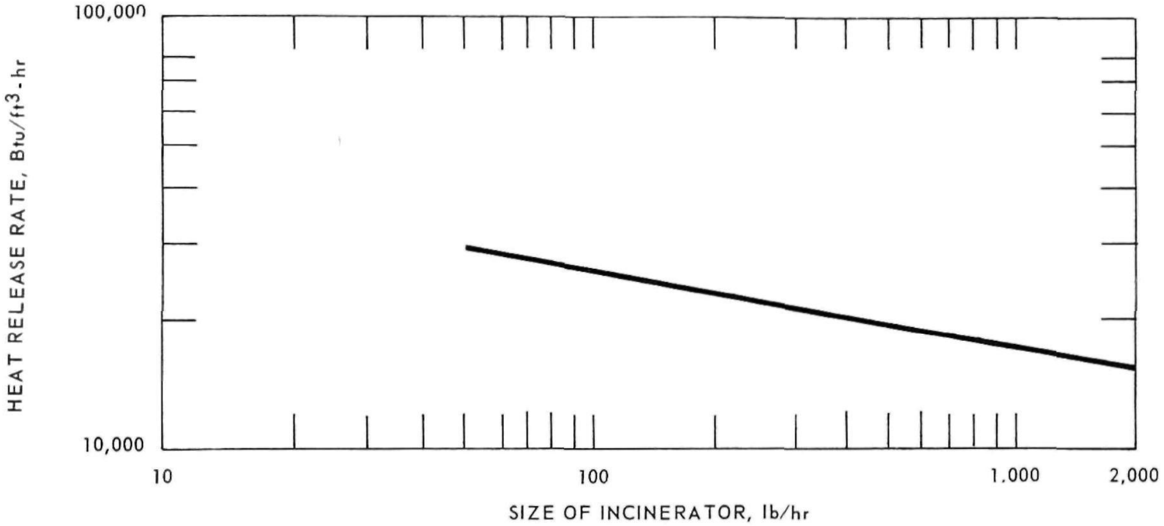


Figure 12-3. Heat release rates for general-refuse incinerators.

12.3 MIXING AND EXPANSION CHAMBERS

The mixing chamber is designed to promote mixing between the effluent from the ignition chamber, secondary air, and supplemental heat of the secondary burner. This mixing is accomplished by sizing the flame port for a gas velocity of from 45 to 65 feet per second at operating temperatures. The desired expansion is accomplished by reducing the gas velocity in the mixing chamber to the range of 20 to 35 feet per second. The cross-sectional area of the curtain wall port is approximately 50 percent larger than that of the mixing chamber in order to minimize draft losses. Restriction at the curtain wall port is not necessary since adequate mixing has already occurred in the mixing chamber and the majority of the gas phase combustion has been completed. An undersized curtain wall port will increase the draft loss and cause the effluent from the mixing chamber to sweep the floor of the expansion chamber, thus reducing its ability to effectively collect fly ash. On the other hand, an oversized curtain wall port will reduce the effective length of the mixing chamber and the gaseous phase combustion in the mixing chamber may not be completed.

During normal operation, sufficient primary combustion air is usually available to complete the gaseous phase burning in the mixing chamber, without use of secondary air. Occasionally the rapid volatilization of the refuse results in a deficiency of combustion air in the ignition chamber, then smoke and other incomplete products of combustion pass through the flame port into the mixing chamber. Under these circumstances, secondary air is essential for complete combustion and smokeless operation of the incinerator. Therefore, provisions for secondary air are always made in the design of incinerators.

Whether the secondary burner is used or not when burning Type 1 refuse is solely dependent upon the attention of the incinerator operator. Multiple-chamber incinerators are designed to eliminate the use of secondary burners in the burning of Type 1 refuse; however, reasonable care should be taken by the operator.

Secondary burners are required to prevent excessive smoke. The higher moisture content of Type 2 refuse causes a difficulty in burning because of its low gross heating value. This necessitates the continuous use of secondary burners.

12.4 COMPARISON OF RETORT AND IN-LINE INCINERATOR DESIGN FEATURES

12.4.1 Retort Type

The retort type of design is distinguished by the following features:

1. The arrangement of the chambers causes the combustion gases to flow through 90-degree turns in both horizontal and vertical directions.
2. The return flow of the gases permits the use of a common wall between the primary and both secondary chambers.
3. Mixing chambers, flame ports, and curtain wall ports have length-to-width ratios in the range of 1:1 to 2.4:1.
4. Bridge wall thickness under the flame port is a function of dimensional requirements in the mixing and combustion chambers. The resulting bridge wall construction is unwieldy in incinerators in the size range above 500 pounds per hour.

12.4.2 <u>In-Line Type</u>

Distinguishing features of the in-line design are:

1. Flow of the combustion gases is straight through the incinerator with 90-degree turns in only the vertical direction.

2. The in-line arrangement of the component chambers gives a rectangular plan to the incinerator. This style is readily adaptable to installations that require separated spacing of the chambers for operating, maintenance, or other reasons.

3. All ports and chambers extend across the full width of the incinerator and are as wide as the ignition chamber. Length-to-width ratios of the flame port, mixing chamber, and curtain-wall-port flow cross sections, range from 2:1 to 5:1.

12.4.3 <u>Comparison of Types</u>

A retort incinerator of optimum size range offers the advantages of compactness and structural economy due to its cubic shape and reduction in exterior wall length. The retort incinerator performs more efficiently than its in-line counterpart in the capacity range of 50 to about 750 pounds per hour. The in-line incinerator is well suited to high-capacity operation, but is not too satisfactory for service in small sizes. The secondary stage combustion of the smaller in-line incinerators is less efficient than retort types. The in-line incinerator functions best when the unit has a capacity of over 1000 pounds per hour.

The in-line and retort incinerators, in the capacity range between 750 and 1000 pounds per hour, are equally efficient. The choice of the in-line, or retort incinerator is dictated by personal preference, space limitations, and the nature of the refuse and charging conditions.

The factors which tend to cause a difference in the performance of the two incinerator types are: (1) proportioning of the flame port and mixing chamber in order to maintain adequate gas velocities within the dimensional limitations imposed by the particular type involved, (2) maintenance of proper flame distribution over the flame port and across the mixing chamber, and (3) flame travel through the mixing chamber into the combustion chamber.

The additional turbulence and mixing, promoted by the turns in the retort incinerators, allow the nearly square cross sections of the ports and chambers in small units to function adequately. In the retort sizes above 1000 pounds per hour, the reduced effective turbulence in the mixing chamber that is caused by the increased size of the flow cross section, results in inadequate flame penetration, effluent distribution, and secondary air mixing.

As the capacity increases, the in-line model exhibits structural and performance advantages. Certain weaknesses of the small in-line type are eliminated as the size of the unit increases. For instance, with an in-line incinerator of less than 750 pounds per hour capacity, the shortness of grate length in the ignition chamber tends to inhibit flame propagation across the width of the ignition chamber. This, coupled with thin flame distribution over the bridge wall, may result in smoke from a smoldering fuel bed passing straight through the incinerator and out of the stack without adequate mixing and secondary combustion. In-line models in sizes of 750 pounds per hour or larger have grates long enough to maintain burning across their width to provide flame distribution in the flame port and mixing chamber. Since smaller in-line incinerators have relatively short grates, a problem of construction is added. Usually, the bridge wall is not provided with any structural support or backing; and because secondary air passages are built into it, the wall is very susceptible to mechanical failure. Careless stoking and grate cleaning in short-chambered in-line incinerators can ruin the bridge wall in a short time.

Incinerators under 2000 pounds per hour may be standardized for construction purposes to a great degree. However, incinerators of larger capacity are not readily standardized because problems of construction, material usage, mechanized operation with stoking grates, induced draft systems, and other factors make each installation essentially one of custom design.

12.5 AIR SUPPLY

Combustion air enters a multiple-chamber incinerator at a number of locations. The quantity and location of combustion air is governed by the need to promote surface burning of the refuse in the ignition chamber. This is accomplished by providing the majority of the combustion air over the surface of the refuse. A small portion of air should be provided through the burning pile of refuse in order to maintain a satisfactory and uniform burning rate. Occassionally, during the combustion process, excessive quantities of refuse are consumed with insufficient amounts of overfire and underfire air. If additional air is not provided elsewhere in the incinerator, smoke will be discharged from the stack. To prevent this, additional air is provided in the mixing chamber near the top of the bridge wall. Air introduced into this chamber is called "secondary air." When secondary air is mixed with the smoky effluent and live flame of the secondary burner, smokeless operation usually results.

Tests have shown that efficiently designed multiple-chamber incinerators utilize from 100 to 300 percent excess combustion air. Approximately one-half of the total combustion air admitted into the incinerator through the air ports is provided for this purpose. The remaining air enters through expansion joints, cracks, and leaks in the exterior walls of the incinerator, and through the open charging door during the charging operation. Since approximately 50 percent of the total combustion air is supplied through air ports, the ports are sized to furnish a theoretical quantity of air, plus 100 percent excess air.

The overfire air port should be located at the end of the ignition chamber, farthest from the flame port. It should be sized to admit 70 percent of the combustion air. The underfire air port should be located beneath the grates and, if possible, at the same end of the incinerator as the overfire air port and charging door. The air port should permit admission of 10 percent of the combustion air.

The secondary air port is normally located where the bridge wall connects with the exterior wall. It is sized to permit the admission of 20 percent of the combustion air. An air passage is normally constructed through the exterior wall and into the bridge wall. Small ports, located on the mixing chamber side of the bridge wall just below the flameport, permit the entrance of secondary air.

12.6 DRAFT CONTROL

Many of today's high-rise buildings require that stacks be considerably higher than ideal so that the effluent from the incinerator will be discharged above the roof level. Sometimes the height of the stack must be higher than optimum so that the incinerator effluent will exit above nearby windows. There are several ways to reduce the draft to an acceptable level. One of the most common methods is the use of a guillotine damper. This method has several drawbacks, the most serious of which is the need for constant adjustment, particularly during the light-off period, to maintain the draft at a satisfactory level. At best, this is a very rough method for adjusting the draft and leaves much to be desired.

A more satisfactory device for controlling draft to a uniform level is a barometric damper. The barometric damper, after initial adjustment, automatically regulates the draft without an operator. When the stack draft is inadequate, the barometric damper closes. When the draft is too great, the damper gradually opens and permits the introduction of ambient air. Air introduced through the damper at the base of the stack cools the stack gases, and thereby reduces the theoretical draft produced by a given stack. In addition, the introduction of air increases the velocity through the stack, thus increasing frictional losses and, again, reduces the available draft. If a stack higher than ideal must be installed, Figure 12-4 may be used to size the barometric damper.

12.7 TYPICAL DESIGN CALCULATIONS

12.7.1 General

To use the factors itemized in Table 12-1, calculations must be made that will yield incinerator data in usable form. The calculations fall into three general categories: (1) combustion calculations based upon the refuse composition, assumed air requirements, and estimated heat loss; (2) flow calculations based upon the properties of the products of combustion and assumed gas temperatures; and (3) dimensional calculations based upon simple mensuration and empirical sizing equations.

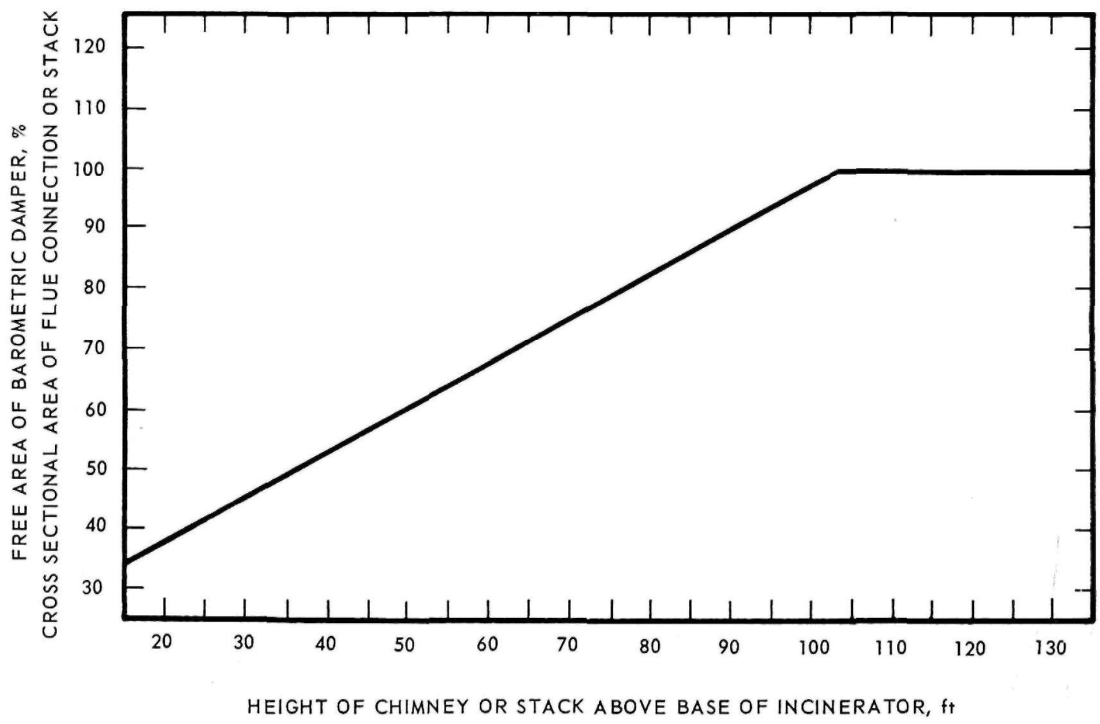


Figure 12-4. Minimum free area of barometric dampers

Simplifying assumptions that are made in connection with the incineration process should be reasonable estimates of conditions known to exist. Their value lies in the resultant ease of application of the calculated data in preparing incinerator designs and comparing them with the established parameters and with similar satisfactory units. The simplifying assumptions upon which calculations are based may be summarized as follows:

1. The burning rate and average refuse composition are taken as constant. An exception may be required when extremes in material quality and composition are encountered. The most difficult burning condition is assumed in such cases.

2. The average temperature of the combustion products is determined through normal heat balance calculations, except that losses due to radiation, refractory heat storage, and residue heat content are assumed to average 20 to 30 percent of the gross heating value of the refuse during the first hour of operation. Furnace data generally available indicate that the losses approximate 10 to 15 percent of the gross heat after 4 to 5 hours of continuous operation.

3. The overall average gas temperature should be about 1000°F when calculations are based on 300 percent excess combustion air and on the heat loss assumptions previously given. The calculated temperature does not indicate the probable maximum temperatures attained in the flame port or mixing chamber. Should the temperature be lower than the calculated value, the need for auxiliary primary burners is indicated. Burner size should be as indicated in Table 12-1. The temperatures used in checking gas velocities are approximations of the actual temperature gradient in the incinerator as the combustion products cool en route from the flame port to the stack outlet.

   Air ports are sized for admission of theoretical air, plus 100 percent excess. The remaining air enters the incinerator through the open charging door during batch operation and through such places as expansion joints and cracks around doors.

4. In-draft velocities in the combustion air ports (overfire, underfire, and secondary) are assumed to be equal, with a velocity pressure of 0.1 inch water column (equivalent to 1265 ft/min). The design of the draft

system should give an available firebox draft of about 0.1 inch water column. Oversizing of adjustable air ports insures maintenance of proper air induction.

The combustion calculations needed to determine weights, velocities, and average temperatures of the products of combustion may be derived from standard calculation procedures when the preceding assumptions are followed, using average gross heating values and theoretical air quantities. Inlet air areas in the proportions designated are readily sized once the volumes of air and inlet velocities are established. In practice, the minimum areas required should be oversized by the factor indicated in Table 12-1 in order to provide operational latitude.

Volume and temperature data of the products of combustion are the only requirements for determining the cross-sectional flow areas of the respective ports and chambers. Calculations for draft characteristics follow standard stack design procedures common to all combustion engineering. The stack velocity given for natural draft systems is in line with good practice and minimizes flow losses in the stack.

The remainder of the essential calculations needed to design an incinerator are based on substitution in the proper equations. Recommended grate loading, grate area, and average arch height may be calculated or estimated from Figures 12-1 and 12-2. Proper length-to-width ratios may be determined and compared with proposed values.

Supplementary computations are usually required in determining necessary auxiliary-gas-burner sizes and auxiliary fuel supply line piping. Where moisture content of the refuse is less than 10 percent by weight, auxiliary burners are not usually required. Moisture content from 10 to 20 percent normally indicates the necessity for installing mixed-chamber burners, and moisture percentages of over 20 percent usually mean that ignition chamber burners must be included.

The criteria presented for incinerator design are applicable to the planning of most combustible refuse burners. The allowable deviations given in Table 12-1 should be interpreted with discretion to avoid consistently high or low deviations from the optimum values. Application of these factors to design evaluation must be tempered by judgment and by an appreciation of the practical limitations of construction and economy.

12.7.2 Sample Calculations

The following example shows the mathematical calculations necessary to design an incinerator.

Problem: Design a multiple-chamber incinerator to burn 100 pounds per hour of paper containing 15 percent moisture.

Solution:

1. Composition of refuse:

Dry combustibles	(100 lb/hr) (0.85)	85 lb/hr
Moisture	(100 lb/hr) (0.15)	15 lb/hr

2. Gross heat of combustion:

From Table 14-4 in Appendix, the gross heating value of dry paper is 7590 Btu/lb

(85 lb/hr) (7590 Btu/lb)	645,200 Btu/hr

3. Heat losses:

From Table 14-4 in Appendix, 0.56 lb of water is formed from the combustion of 1 lb of dry paper.

Radiation, etc. (assume 20% loss)	
(645,200 Btu/hr) (0.20)	= 129,040 Btu/hr
Evaporation of contained moisture	
(15 lb/hr) (1060 Btu/lb)	= 15,900 Btu/hr
Evaporation of water from combustion	
(0.56 lb/lb) (85 lb/hr) (1060 Btu/lb)	50,400 Btu/hr
Total	195,340 Btu/hr

4. Net heat:

645,200 Btu/hr 195,340 Btu/hr	449,860 Btu/hr

5. Weight of products of combustion with 300% excess air:

From Table 14-4 in Appendix, 21.7 lb of products of combustion is formed from the combustion of 1 lb of paper with 300% excess air.

Paper (85 lb/hr) (21.7 lb/lb)	= 1844 lb/hr
Water 15 lb/hr	= 15 lb/hr
	1859 lb/hr

6. Average gas temperature:

The specific heat of the products of combustion is approximately 0.26 Btu/lb-°F

$$\Delta T = \frac{Q}{C_p M}$$

Where: ΔT = Temperature difference, °F

Q = Gross heat, Btu

C_p = Specific heat, Btu/lb-°F

M = Weight, lb

$$\Delta T = \frac{449,860 \text{ Btu/hr}}{(0.26 \text{ Btu/lb-°F})\ (1859 \text{ lb/hr})} \quad - \quad 930°F$$

$T = \Delta T + 60°F$

$T = 930°F + 60°F$ = 990°F

7. Combustion air requirements:

Basis: Assume 300% excess air; 200% excess air is admitted through the open charging door, and leakage around doors, ports, and expansion joints.

From Table 14-4 in Appendix, 68.05 ft^3 of air is theoretically necessary to burn 1 lb of dry paper.

Total air required at 100% excess air:

(85 lbs/hr) (68.05 ft^3/lb) (2) = 11,580 ft^3/hr

or 192.8 ft^3/min

or 3.2 ft^3/sec

8. Air port opening requirements at 0.1 in. water column:

1265 ft/min is equivalent to a velocity pressure of 0.1 in.

$$\text{Total} = \frac{(192.8 \text{ cfm})\ (144 \text{ in}^2/\text{ft}^2)}{1265 \text{ ft/min}} = 22.0 \text{ in}^2$$

Air Supply from Table 12-1

Overfire, 70%; Underfire, 10%; Secondary, 20%

Overfire air port (0.7) (22.0 in^2) = 15.4 in^2

Underfire air port (0.1)(22.0 in^2) = 2.2 in^2

Secondary air port (0.2) (22.0 in^2) = 4.4 in^2

9. Volume of products of combustion:

From Table 14-4 in Appendix, 283.33 ft^3 of products of combustion are formed from the combustion of 1 lb of paper with 300% excess air.

Basis: 60°F and 300% excess air

Paper	$(85\ lb/hr)(283.33\ ft^3/lb)$	=	$24,080\ ft^3/hr$
Water	$(15\ lb/hr)\dfrac{379\ ft^3/lb\text{-}mol}{18\ lb/mol}$	=	$316\ ft^3/hr$
			$24,396\ ft^3/hr$
	or		$6.8\ ft^3/sec$

10. Volume of products of combustion through flame port per second:

Total volume minus secondary air

$6.8\ ft^3/sec \quad (3.2\ ft^3/sec)(0.20) = 6.16\ ft^3/sec$

11. Flame port area:

From Table 12-1, velocity is 55 ft/sec

$$\frac{(6.16\ ft^3/sec)(1560°R)}{(55\ ft/sec)(520°R)} = \underline{0.34\ ft^2}$$

12. Mixing chamber area:

From Table 12-1, velocity is 25 ft/sec

$$\frac{(6.8\ ft^3/sec)(1460°R)}{(25\ ft/sec)(520°R)} \qquad \underline{0.76\ ft^2}$$

13. Curtain wall port area:

From Table 12-1, velocity is 20 ft/sec

$$\frac{(6.8\ ft^3/sec)(1410°R)}{(20\ ft/sec)(520°R)} = \underline{0.92\ ft^2}$$

14. Combustion chamber area:

From Table 12-1, velocity is 6-10 ft/sec, use 6 ft/sec

$$\frac{(6.8\ ft^3/sec)(1360°R)}{(6\ ft/sec)(520°R)} = \underline{2.96\ ft^2}$$

15. Stack area:

From Table 12-1, velocity is <30 ft/sec, use 25 ft/sec

$$\frac{(6.8\ ft^3/sec)(1360°R)}{(25\ ft/sec)(520°R)} = \underline{0.71\ ft^2}$$

16. Grate area:

From Figure 12-1, the grate loading for average refuse is $18\ lb/ft^2$ - hr.

$$\frac{(100\ lb/hr)}{18\ lb/ft^2\ \ hr} = \underline{5.56\ ft^2}$$

17. Arch height:

From Figure 12-2, the arch height - <u>27 in.</u>

18. Stack height:

(Interpolated) From Table 12-1, D_t 0.17 in. wc

$$D_t \quad 0.52\ PH \left(\frac{1}{T} - \frac{1}{T_1}\right)^{*}$$

Where: D_t Draft, in. wc

P = Barometric pressure, psi

H = Height of stack above grates, ft

T = Ambient temperature, °R

T_1 = Average stack temperature, °R

$$H - \frac{D_t}{(0.52)\,(P)\left(\frac{1}{T} \quad \frac{1}{T_1}\right)}$$

$$H = \frac{0.17^{**}}{(0.52)\,(14.7)\left(\frac{1}{520} \quad \frac{1}{1360}\right)}$$ <u>18.75 ft</u>

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*R. T. Kent, Mechanical Engineer's Handbook, pp. 6-104, 11th Edition, John Wiley and Sons, Inc., New York, 1936.

**Allowance is made for friction losses by assuming a value for theoretical draft on the high side of the range.

13 THEORETICAL BASIS FOR PATHOLOGICAL INCINERATOR DESIGN RECOMMENDATIONS

13.1 SPECIAL CHARACTER OF TYPE 4 WASTE

Pathological waste is defined as whole, or parts of animal carcasses, animal organs, or organic animal waste. Chemically, this waste is composed principally of carbon, hydrogen, and oxygen. Slight amounts of many minerals, along with a trace of nitrogen, are also present. Physically, this waste consists of cellular material and fluids. The cells of interest are those of hair, fatty tissue, and bone. The proportions of these different types of cells vary between different types of animals. Blood and various other fluids in the organs are almost completely water.

The average chemical composition of whole animals, except for the proportion of water present, is very similar in all types of animals. The proportion of water present to the total weight of the animal varies quite widely between different types of animals, and between various conditions of freshness or decomposition of the animal material. Average chemical properties and combustion data of pathological waste are given in Tables 13-1 and 13-2. The combustion data have been found to provide good results when used in design calculations for almost all pathological waste incinerators.

Table 13-1. COMPOSITION OF PATHOLOGICAL WASTE[a]

Constituent	As charged, % by weight	Ash-free combustible, % by weight
Carbon	14.7	50.8
Hydrogen	2.7	9.35
Oxygen	11.5	39.85
Water	62.1	-
Nitrogen	Trace	
Mineral (ash)	9.0	

[a]Dry combustible empirical formula - $C_5H_{10}O_3$

A principal factor to be considered in the design of pathological waste incinerators is the release of fluids as the material is destroyed. Fluids are frequently released, momentarily, in such quantities that they are not immediately

Table 13-2. COMBUSTION DATA FOR PATHOLOGICAL WASTE[a]
(Based on 1 lb dry ash-free combustible material)

Constituent		Quantity, lb	Volume, scf
Theoretical air		7.028	92.40
40% sat. @ 60°F		7.059	93.00
Flue gas with	CO_2	1.858	16.06
Theoretical air	N_2	5.402	73.24
40% saturated	H_2O formed	0.763	15.99
	H_2O air	0.031	0.63
Products of combustion total		8.054	105.92
Gross heat of combustion		8,820 Btu/lb	

[a]Los Angeles County Air Pollution Control District data.

evaporated. This release of fluids requires the use of a solid hearth, rather than grates, in the ignition chamber of pathological incinerators. Pathological waste does not form a fuel bed during incineration, and the passage of air through the burning material is not required.

The relatively high percentage of moisture in each individual cell of pathological waste creates a difficult evaporation problem. The moisture must be evaporated before the combustible animal tissue can be ignited, but moisture evaporates only from those cells on or near the surface of the material exposed to heat. Deeper lying tissue is almost completely insulated from the heat in the chamber and is heated slowly. Evaporation of moisture from deeper cells, therefore, cannot take place until the destruction of the cellular material above them exposes them to heat also.

While the heat of combustion of dry cellular material is considerable, this material is present in such a small proportion, relative to the amount of water present in tissue, that its heat of combustion is not sufficient to sustain combustion. Auxiliary fuel must, therefore, be used to accomplish the necessary dehydration of pathological wastes.

13.2 DESIGN CALCULATIONS — GENERAL

Incinerator design calculations for pathological waste incinerators fall into three general categories: (1) combustion calculations based upon the auxiliary fuel heat input, waste composition, and assumed air requirements and heat losses; (2) flow calculations based upon the products of combustion and assumed gas temperatures; and (3) dimensional calculations based upon simple mensuration and empirical sizing equations. The factors to be used in these calculations for pathological incinerator design are given in Tables 13-3 and 13-4.

Table 13-3. PATHOLOGICAL IGNITION CHAMBER DESIGN FACTORS
(Incinerator capacity = 25 to 200 lb/hr)

Item	Recommended value	Allowable deviation
Hearth loading	See Figure 13-1	± 10%
Hearth length-to-width ratio	2	± 20%
Arch height	See Figure 13-2	± 20%
Primary fuel	See Figure 13-3	± 10%
Gross heat release in ignition chamber	See Figure 13-4	± 20%
Specific heat of the products of combustion including combustion of waste and natural gas	0.29 Btu/lb-°F	-

Table 13-4. GAS VELOCITIES AND DRAFT FOR PATHOLOGICAL INCINERATORS WITH HOT GAS PASSAGE BELOW SOLID HEARTH

Item	Unit	Recommended values	Allowable deviation
Gas velocities			
Flame port at 1600 °F	fps	15	± 20%
Mixing chamber at 1600 °F	fps	15	± 20%
Port at bottom of mixing chamber at 1550 °F	fps	15	± 20%
Chamber below hearth at 1400°F	fps	8	± 50%
Port at bottom of combustion chamber at 1400 °F	fps	10	± 20%
Combustion chamber at 1200 °F	fps	5	± 50%
Stack at 1000 °F	fps	15	± 25%
Draft			
Combustion chamber	in. wc	0.20 to 0.25[a]	± 10%
Ignition chamber	in. wc	0.05-0.10	+ 0%

[a]Draft can be 0.20 in. wc for incinerators with a cold hearth.

The following simplifying assumptions may be made:

1. The evaporation and burning rate, auxiliary fuel burning rate, and average waste composition are taken as constant. Design parameters should be based on that waste containing the highest percentage of moisture that may be expected to be destroyed in the unit.

2. The average temperature of the combustion products is determined through the heat loss calculation, using radiation and storage losses as determined in Table 13-5.

Table 13-5. IGNITION CHAMBER HEAT LOSSES (Storage, convection, and radiation losses during initial 90 minutes of pathological incineration operation)

Incinerator capacity lb/hr	Heat loss, Btu/hr	Heat loss, %
25	125,000	36
50	180,000	33
100	278,000	30
200	390,000	25

3. The overall average gas temperature should be about 1500°F when calculations are based on air for the combustible waste at 100 percent excess of theoretical and air for the primary burner at 20 percent excess of theoretical. The minimum temperature of the gases leaving the ignition chamber should be 1600°F.

4. In-draft velocity in the air ports is assumed to be at 0.1 inch water column velocity pressure (1265 ft/min.).

5. The secondary air port is sized to provide 100% theoretical air for the combustible material in the waste charged.

6. A primary air port of 5 $in.^2$/100 lb of combustible waste is recommended.

The combustion calculations needed to determine weights and velocities of the products of combustion along with average temperatures may be derived from standard calculation procedures when the preceeding assumptions are followed. The sizing of inlet air areas required is minimum and should be oversized in practice to provide for operational latitude.

13.3 IGNITION CHAMBER PARAMETERS

Ignition chamber dimensions are determined by deriving hearth loading and area, average arch height, and chamber volume from Figures 13-1 and 13-2, and from the factors given in Table 13-3. The ignition chamber burner input capacity may be determined from the curve given in Figure 13-3. Maximum heat release rate, at the gross fuel heating value, in the whole incinerator will range from 20,000 to 15,000 Btu/hr-ft^3 for sizes from 30 to 200 lb/hr as shown in Figure 13-4.

Length-to-width ratios for the hearth are not critical; however, to provide for single-layer deposition of the material upon the hearth, a length-to-width ratio of 1:2 is the most practical.

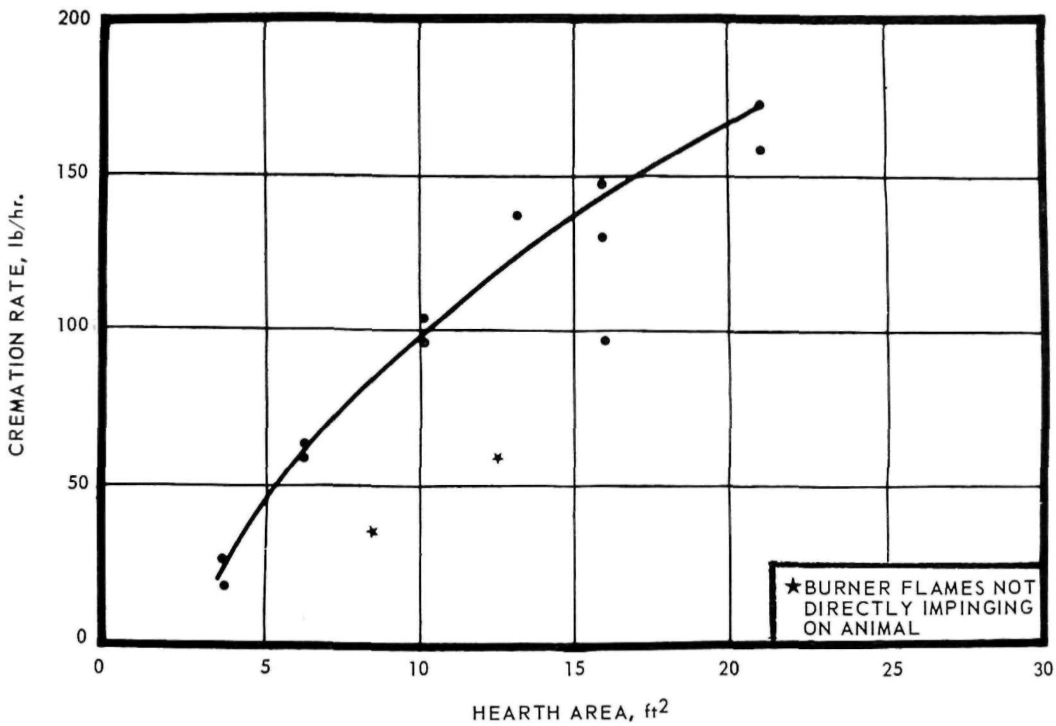

Figure 13-1. Pathological incinerator cremation rate.

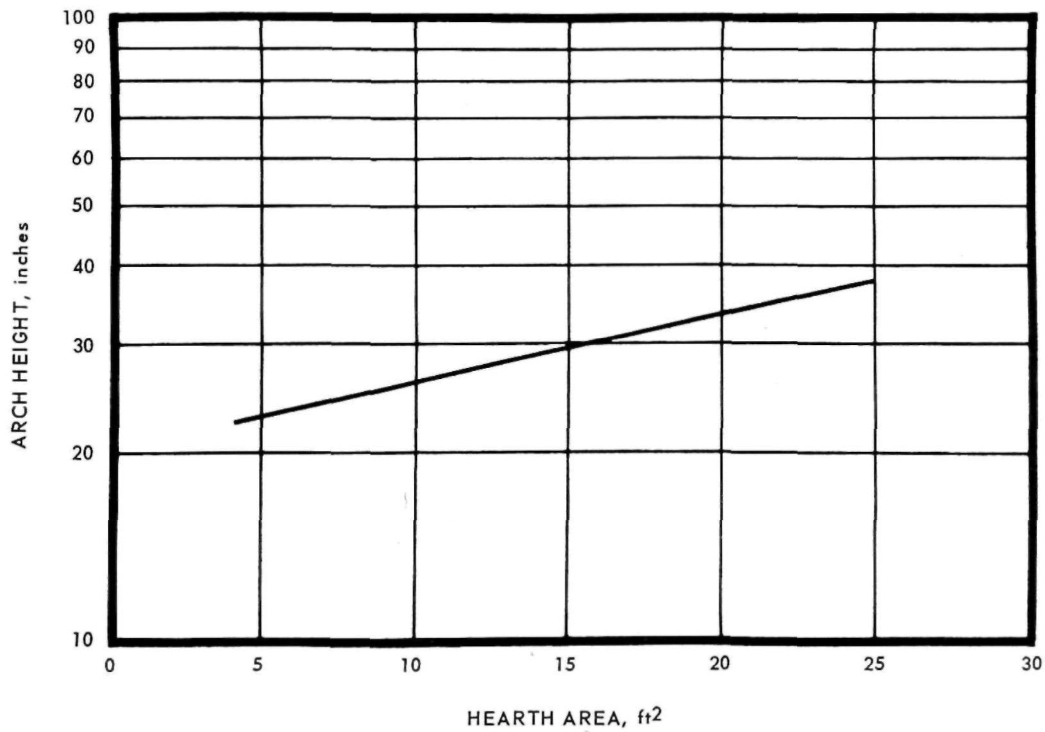

Figure 13-2. Pathological incinerator arch height.

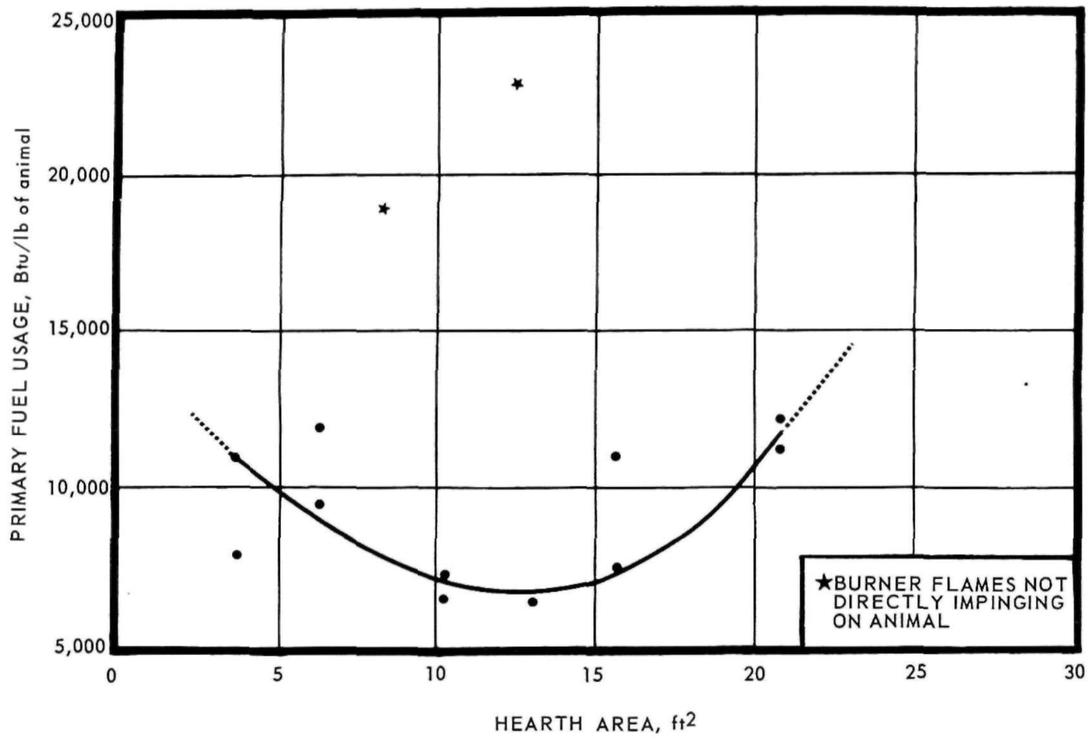

Figure 13-3. Pathological incinerator fuel usage.

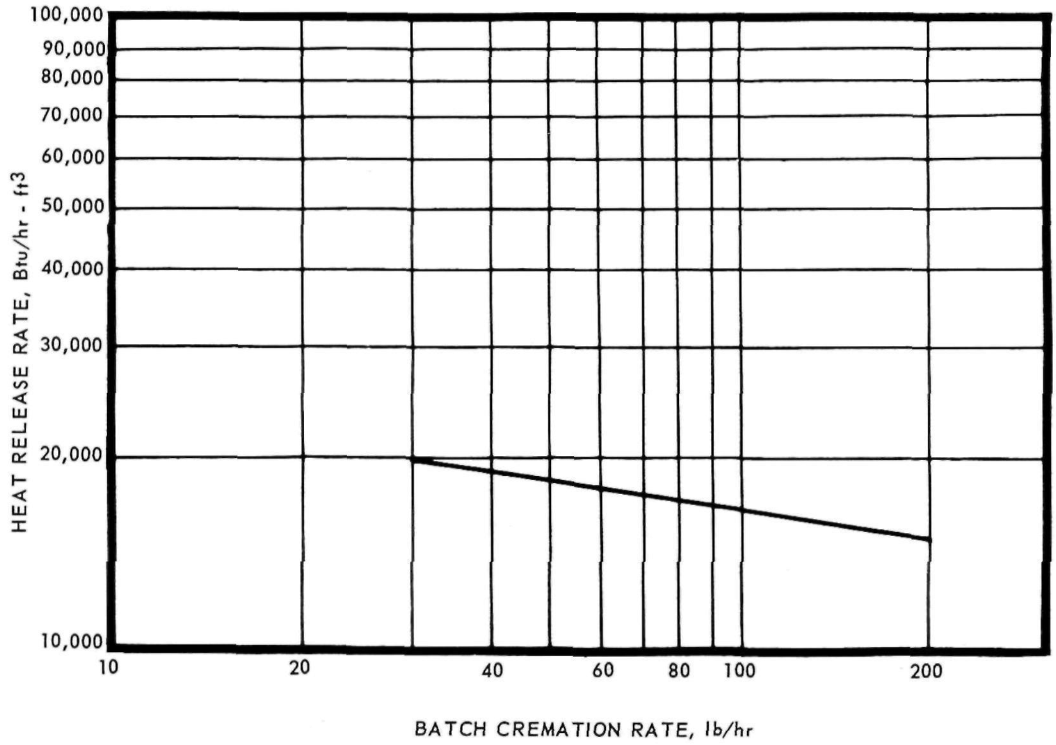

Figure 13-4. Heat release rates for pathological incinerators.

The location of the gas burner in the ignition chamber is the most critical aspect of the design of a pathological incinerator. The flames from the burner must impinge directly on the material being incinerated, or excessive fuel consumption will result. Figures 13-1 and 13-5 graphically illustrate this point.

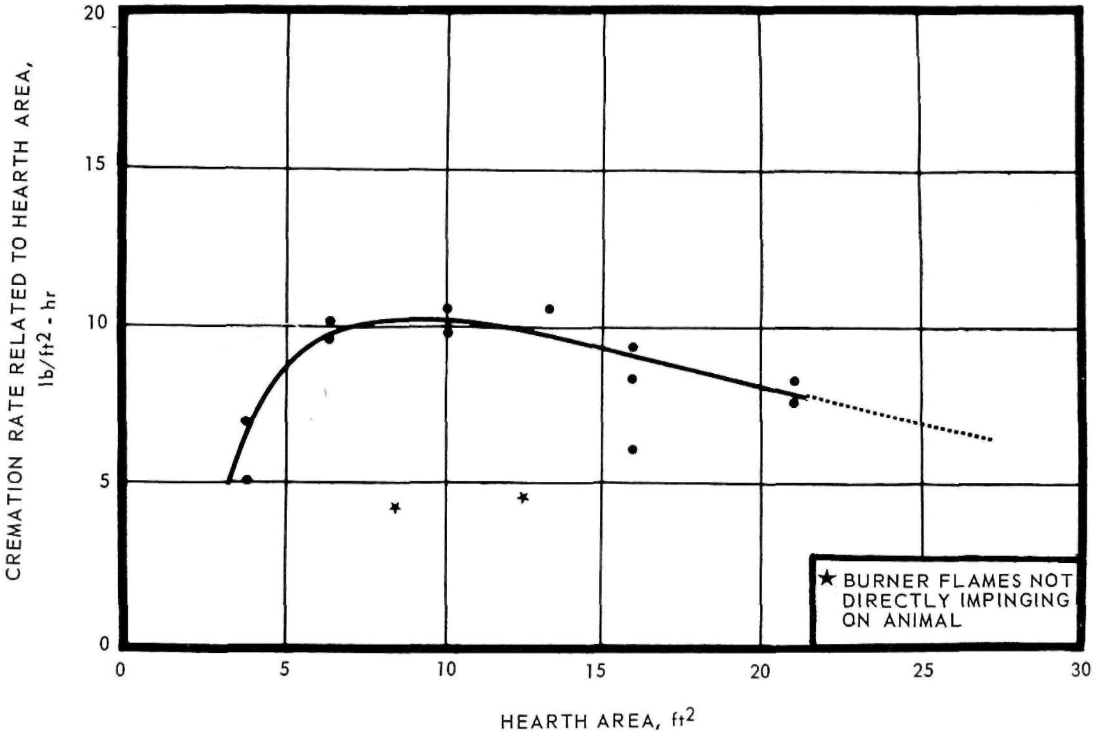

Figure 13-5. Pathological incinerator cremation rate related to hearth area.

Further substantiation has been obtained from operating data on an incinerator with high fuel consumption. Cremation rate can be increased 100 percent by merely allowing a 4-inch layer of ash and bone residue to remain on the hearth. The net effect was to raise the material being cremated into the direct path of the burner flames.

To provide maximum penetration of heat into the animal matter being cremated, a flame retention pressure burner, equipped with a blower, is required. Of course, full safety controls should be provided. The larger incinerators require multiple burners in order to distribute the heat over the resultant larger area.

Figure 13-3 shows that maximum utilization of fuel in a retort configuration is reached with a hearth area of about 12 square feet. As the hearth area is increased or decreased, the fuel requirement is increased or decreased. The obvious conclusion is that the retort design should not be used for units larger than 22 square feet of hearth area. An analysis of the configuration reveals the reason for this phenomenon and again confirms that burner location is of vital importance. In the retort configuration, only one wall is available for burners to be conveniently located, and inadequate flame distribution occurs in the larger hearth sizes.

13.4 SECONDARY COMBUSTION ZONE PARAMETERS

The velocity parameters stated in Table 13-4 are not too critical in these units. The relatively small amount of combustible material in the waste does not provide too severe a problem to achieve complete combustion. Particulate discharge from these incinerators has been found to be very light (see Table 15-3), and their principal design consideration is an effective rate of destruction of the waste. Design consideration, however, must be given to one particular problem in the burning of this waste material. Rapid volatilization results whenever fatty tissue or hair is exposed to flame or high-temperature gases. The sudden volatilization causes a flooding of gases and vapors that is beyond the combustion capacity of equipment designed for high velocities in the secondary combustion zone on the basis of an average rate of operation. These periods of sudden volatilization then result in considerable amounts of unburned gases and vapors issuing from the stack or charging doorway. Design of the secondary combustion zone for low-velocity gas movement at average volumes will provide for adequate combustion even during the periods of abnormally high operating rates.

An additional auxiliary burner, having the heating capacity shown in Table 6-1 for secondary burners, located in the secondary combustion zone, is necessary for these incinerators. The type and location of the auxiliary burners are not nearly so critical as they are for the burner in the ignition chamber. Atmospheric mixers equipped with full safety controls are adequate for incinerators rated at 100 pounds per hour or less, but in larger units the nozzle mix type is required in order to obtain optimum incineration.

The burner capacity need only be sufficient to maintain a 1600°F temperature in the gases. To do this, the burner should be located so that the gas flowing from the ignition chamber can first mix with secondary air before flowing through the flame of the secondary burner. The secondary burner should also be located so that the length of passage in the mixing chamber is sufficient to permit secondary combustion to occur. Its heating capacity should be that given in Table 6-1 for secondary burners.

13.5 STACK DESIGN

Calculations for stack design should be based on a gas temperature of 1000°F. Because design calculations are based on an average rate of operation, which is sometimes exceeded, stack design velocity should be at, or below, 15 feet per second. Stack height should be determined so as to provide a minimum available draft of 0.15 inches of water column. This is the minimum draft provision for pathological incinerators. When a hot gas passage is required beneath the hearth, the minimum available stack draft at the breeching should be increased by 10 percent. This additional draft will compensate for the additional gas flow resistance in the incinerator, caused by such a design.

13.6 PATHOLOGICAL SIDE CHAMBER

Figure 7-2 illustrates a retort for the burning of pathological waste added to a standard multiple-chamber incinerator. When such construction is used, the gases from the retort should pass into the rear of the ignition chamber of the standard incinerator. The design of the chamber is based on the same factors given for the design of the ignition chamber of a pathological incinerator. The general-refuse multiple-chamber design will be only negligibly influenced by the addition of this unit under most circumstances. This design concept may only be used at locations where the pathological waste material load occurs periodically, and in small amounts, usually not more than 10 percent of the rated capacity of the standard incinerator. In order not to restrict the flow of the products of combustion from the pathological chamber, the gas passage from the chamber should be designed for about 10 feet per second.

13.7 ILLUSTRATIVE PROBLEM

Problem: Design an incinerator to dispose of 100 lb/hr of dog bodies.

Design: Select a multiple-chamber retort-type incinerator with a hot-gas passage below a solid hearth.

Solution:

1. Design features of ignition chamber:

   From Figure 13-1 at 100 lb/hr

   Hearth area = 10 ft^2

From Table 12-1, hearth dimensions:

Length-to-width ratio 2

Let w - width of hearth in ft.

$$(w)(2w) = \text{hearth area}$$

$$2w^2 = 10 \text{ ft}^2$$

w =	2.24 ft
Length 2w =	4.48 ft
From Figure 13-2, arch height	26 in.
Total ignition chamber volume =	21.6 ft^3

2. Capacity of primary burner:

   From Figure 13-3, primary burner consumption is 7000 Btu/lb.

   (7000 Btu/lb x 100 lb/hr ÷ 1100 Btu/scf = 635 scf/hr)

3. Composition by weight of refuse:

Dry combustibles	(100 lb/hr)(0.29)	=	29 lb/hr
Contained moisture	(100 lb/hr) (0.62)	=	62 lb/hr
Ash	(100 lb/hr) (0.09)	=	9 lb/hr
Total			100 lb/hr

4. Gross heat input:

   From Table 13-2, the gross heating value of waste is 8,820 Btu/lb. A gross heating value of natural gas of 1100 Btu/scf may be assumed for purposes of calculation.

Waste (29 lb/hr) (8,820 Btu/lb)	=	256,000 Btu/hr
Natural gas (635 ft^3/hr) (1100 Btu/scf)	=	700,000 Btu/hr

5. Heat losses:

   a. From Table 13-5, gross heat losses by storage, conduction and radiation are 29.75 percent of gross heat input.

      (0.2975) (956,000 Btu/hr) = 285,000 Btu/hr

   b. Evaporation of contained moisture at 60°F.

      The heat of vaporization of water at 60°F is 1060 Btu/lb.

      (62 lb/hr) (1060 Btu/lb) = 65,700 Btu/hr

   c. Evaporation of water formed from combustion of waste at 60°F.

      From Table 13-2, combustion of 1 lb of waste yields 0.763 lb of water.

(0.763 lb/lb) (29 lb/hr) (1060 Btu/lb) = 23,450 Btu/hr

d. Evaporation of water formed from combustion of natural gas at 60°F. There is 0.099 lb of water formed from combustion of 1 scf of natural gas. (Composition of gas and hence its combustion products will vary with location.)

$$\left(\frac{0.099 \text{ lb water}}{1 \text{ scf}}\right)(635 \text{ scf/hr}) (1060 \text{ Btu/scf}) = 66,600 \text{ Btu/hr}$$

e. Sensible heat in ash

Assume ash is equivalent in composition to calcium carbonate. Average specific heat is 0.217 Btu/lb-°F.

$$H = W_A (C_p) (T_2 - T_1)$$

Where: H Sensible heat, Btu/hr

W_A Weight of ash, lb/hr

C_p = Average specific heat of ash, Btu/lb-°F

T_2 = Final temperature, °F

T_1 Initial temperature, °F

H (9 lb/hr) (0.217 Btu/lb-°F) (1600°F 60°) 3000 Btu/hr

f. Total heat losses

(a) + (b) + (c) + (d) + (e) = total heat losses

285,000 Btu/hr + 65,700 Btu/hr + 23,450 Btu/hr

+66,600 Btu/hr + 3000 Btu/hr = 443,750 Btu/hr

6. Net heat available to raise product of combustion:

Gross heat input - heat losses net heat available

956,000 Btu/hr 443,750 Btu/hr = 512,250.

7. Weight of products of combustion:

From Table 13-2, combustion of 1 lb waste with 100% excess air will yield 15.113 lb of combustion products. Combustion of 1 scf natural gas with 20% excess air will yield 0.999 lb of combustion products. (Composition of gas and hence its combustion products will vary with location.)

Waste (29 lb/hr) (15.133 lb/lb)		438 lb/hr
Contained moisture	=	62 lb/hr
Natural gas (635 cf/hr) (0.999 lb/scf)	=	632 lb/hr
Total weight of combustion products		1,132 lb/hr

8. Average gas temperature:

Assume the average specific heat of combustion products is 0.29 Btu/lb °F

$$Q = (W_c)\ (C_p)\ (T_2 \quad T_1)$$

Where: Q = Net heat available, Btu/hr

W_c = Weight of combustion products, lb/hr

C_p = Average specific heat of combustion products, Btu/lb-°F

T_2 = Average gas temperature, °F

T_1 = Initial temperature, °F

$$T_2 \quad T_1 + \frac{Q}{(W_c)\ (C_p)}$$

$$T_2 = 60 + \frac{512,250}{(1132)\ (0.29)} = 1620°F$$

This average temperature exceeds minimum design temperature of 1600°F; therefore, the primary burner has adequate capacity.

9. Secondary air port size:

Design secondary air port 100% oversize with an indraft velocity of 1255 ft/min at 0.1 in. wc velocity pressure.

From Table 13-2, 1 lb of waste requires 93 scf of air.

(29 lb/hr) (93.0 scf/lb) 2697 ft^3/hr

or 44.93 ft^3/min

or 0.749 ft^3/sec

$$\frac{(44.93\ ft^3/min)\ (144\ in.^2/ft^2)\ (2)}{155\ ft/min} \quad 10.3\ in.^2$$

10. Weight of maximum air through secondary port:

Assume that the density of air is 0.0763 lb/scf

(2) (2697 ft^3/hr) (0.0763 lb/scf) <u>411.5 lb/hr</u>

11. Heat required to raise maximum secondary air from 60° to 1600°F:

From Table 14-5, 396.8 Btu is required to raise 1 lb air from 60° to 1600°F.

(411.5 lb/hr) (396.8 Btu/lb) = <u>164,400 Btu/hr</u>

12. Natural gas required by secondary burner:

Design for combustion of natural gas with 20% excess air.

Taking the heating value of natural gas as 552 Btu/scf at 1600°F:

(164,400 Btu/hr) ÷ (552 Btu/scf) = 300 ft^3/hr

13. Volume of products of combustion:

a. Through flame port

From Table 13-2, combustion of 1 lb waste with 100% excess air will yield 198.92 scf of combustion products. Combustion of 1 scf natural gas with 20% excess air will yield 13.53 scf of combustion products. (Composition of gas and hence its combustion products will vary with location.)

Waste (29 lb/hr) (198.92 scf/lb)		=	5,769 scf/hr
Water (63 lb/hr) (379 scf/lb mole)		=	1,305 scf/hr
Natural gas (635 scf/hr) $\left(\frac{13.53 \text{ scf}}{\text{scf}}\right)$		=	8,550 scf/hr
Total volume of gases			15,624 scf/hr
	or		260 scf/min
	or		4.33 scf/sec

b. Through exit from mixing chamber

Design secondary burner for combustion at 20% excess air.

Products of combustion through flame port		15,624 scf/hr
Products of combustion from secondary burner (300 ft^3/hr) (13.53 scf/scf)		4,060 scf/hr
Maximum air through secondary air port (2) (2697 scf/hr)		5,394 scf/hr
		25,078 scf/hr
	or	418 scf/min
	or	6.97 scf/sec

14. Incinerator cross-sectional areas:

a. Flame port area

Design flame port for 15 ft/sec velocity at 1600°F.

$$\text{Area} = \frac{(4.33 \text{ scf/sec})\ (2060°\text{R})}{(15 \text{ ft/sec})\ (520°\text{R})} \qquad \underline{1.15 \text{ ft}^2}$$

b. Mixing chamber area

Design mixing chamber for 15 ft/sec velocity at 1600°F.

$$\text{Area} \quad \frac{(6.97 \text{ scf/sec})\ (2060°\text{F})}{(15 \text{ ft/sec})\ (520°\text{R})} = \underline{1.84 \text{ ft}^2}$$

c. Port area at bottom of mixing chamber

design port for 15 ft/sec velocity at 1550°F.

$$\text{Area} = \frac{(6.97\ \text{scf/sec})\ (2010°\text{R})}{(15\ \text{ft/sec})\ (520°\text{R})} \qquad \underline{1.80\ \text{ft}^2}$$

d. Chamber area beneath hearth

Design chamber for 8 ft/sec velocity at 1400°F.

$$\text{Area} = \frac{(6.97\ \text{scf/sec})\ (1860°\text{R})}{(8\ \text{ft/sec})\ (520°\text{R})} \qquad \underline{3.12\ \text{ft}^2}$$

e. Port at bottom of combustion chamber

Design port for 10 ft/sec velocity at 1400°F.

$$\text{Area} = \frac{(6.97\ \text{scf/sec})\ (1860°\text{R})}{(10\ \text{ft/sec})\ (520°\text{R})} = \underline{2.50\ \text{ft}^2}$$

f. Combustion chamber

Design combustion chamber of 5 ft/sec velocity at 1200°F.

$$\text{Area} = \frac{(6.97\ \text{scf/sec})\ (1660°\text{R})}{(5\ \text{ft/sec})\ (520°\text{R})} = \underline{4.45\ \text{ft}^2}$$

g. Stack

Design stack for 15 ft/sec velocity at 1000°F.

$$\text{Area} \quad \frac{(6.97\ \text{scf/sec})\ (1460°\text{F})}{(15\ \text{ft/sec})\ (520°\text{R})} = \underline{1.3\ \text{ft}^2}$$

15. Stack height:

Design stack for a draft of 0.20 in. wc in the combustion chamber.

Stack height

$$D_t = 0.52\ PH\left(\frac{1}{T} - \frac{1}{T_1}\right)$$

Where D_t = Draft, in. wc

T = Ambient air temperature, °R

T_1 Average stack gas temperature, °R.

P Atmospheric pressure, lb/in.^{2}

H = Stack height, ft

$$H = \left(\frac{(0.20)}{(0.52)\ (14.7)}\right)\left(\frac{1}{\frac{1}{520} - \frac{1}{1460}}\right) = \underline{21\ \text{ft}}*$$

*Allowance is made for frictional losses by assuming a high value for theoretical draft.

14 APPENDIX

14.1 COSTS OF INCINERATORS AND SCRUBBERS

Approximate costs of recommended multiple-chamber incinerators and scrubbers are given in Table 14-1.

A number of factors affect the construction cost of multiple-chamber incinerators throughout the United States. The factors that normally contribute to a variation usually include the keenness of local competition, differences in labor costs, specific type of construction used, and the appurtenances specified by the buyer. In general, material costs are essentially the same throughout the country and do not normally contribute to a variation in the original cost.

Appurtenances such as mechanical grates, continuous ash removal systems, and mechanical charging mechanisms may also add as much as 150 to 200 percent to the cost of an incinerator. The need for such items is usually based upon the size of the incinerator, as well as the operational manpower saved by their installation.

In general, the approximate cost of multiple-chamber incinerators presented in Table 14-1 should be within 15 percent of the basic cost of the incinerator anywhere in the United States.

14.2 ADDITIONAL INFORMATION

Information on emissions from general-refuse and pathological incinerators not equipped with gas washers is given in Tables 14-2 and 14-3, respectively.

Chemical properties and combustion data for paper, wood, and garbage are presented in Table 14-4. Table 14-5 gives enthalpies of gases from 60°F in Btu per pound of gas.

A list of addresses of regional air pollution control directors is given in Table 14-6.

Table 14-1. APPROXIMATE COSTS OF RECOMMENDED MULTIPLE-CHAMBER INCINERATORS AND SCRUBBERS IN 1968[a]

"Size" of incinerator, lb/hr	General-refuse incinerators	Scrubbers[b]	Pathological incinerators
50	$ 1,200	$ 2,200	$2,000
100	1,700	3,000	2,700
150	2,000	3,600	4,000
250	2,700	4,400	5,500[c]
500	5,000	6,200	
750	9,500	7,600	
1000	12,500	8,800	
1500	20,000	11,200	
2000	25,000	13,200	

[a]Incinerator costs are exclusive of foundations.
[b]Scrubber costs are exclusive of foundations but include reasonable utility connections.
[c]For a 200-pound-per-hour incinerator.

Table 14-2. EMISSIONS FROM GENERAL-REFUSE INCINERATORS WITHOUT GAS WASHERS

	Test number								
	1a	1b	2	3	4	5	6	7	8
Operational conditions	Normal no burners	Normal with burners	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Incinerator capacity, lb/hr	50	50	250	750	1000	850	1000	2500	6000
Weight of refuse burned, lb	30	26	203	713	770	650	820	3825	6500
Test conditions: Testing period, min	38	34	66	60	55	60	60	101	60
Burning rate; lb/hr burned	47	46	185	713	870	650	820	2300	
Capacity, % rated	95	92	74	95	88	76	82	92	100
Charging rate, lb/batch	2-4	2-4	10-15	20	75	50-100	40	400	650
min/batch	2-4	2-4	5	2	6-7	3-5	3	10	10
Composition of refuse charged:									
% paper	100	69	85	71	83	100	100	100	65
% garbage	0	31	15	17	17	0	0	0	0
% wood	0	0	0	12	0	0	0	0	35
Auxiliary fuel:									
Primary chamber burner, scfh	None	165	185	None	None	None	None	None	None
Mixing chamber burner, scfh	None	165	800	1125	2850	822	1390	Oil-2.5 gph	None
Combustion air:									
Primary air-overfire % total supply	85	45	40	79	50	80	54	60	70
Primary air-underfire % total supply	15	10	10	7	20	10	7	3	10
Secondary air-mixing chamber % total supply	0	45	50	14	30	10	39	37	20
Stack:									
Flow rate, scfm	174	193	480	1970	2190	6300	2700	13400	27500
Moisture at stack conditions, %	8.3	13.2	14.9	10.8	12.0	4.4	7.8	5.7	11.9
Orsat analysis - % CO_2	4.8	6.4	9.3	6.0	7.4	2.4	5.6	2.2	6.3
% O_2	13.8	6.3	4.1	12.6	9.9	18.0	13.9	18.3	9.4
% CO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% N_2	81.4	87.3	86.6	81.4	82.7	79.6	80.0	79.5	84.3
Stack temperature, °F	1160	1475	1600	910	1560	872	1080	N.A.	N.A.
Particulates:									
grains/scf of stack gas	0.0987	0.058	0.0852	0.075	0.083	0.047	0.060	0.0197	0.0920
grains/scf of stack gas @ 12% CO_2 (CO_2 from refuse only)	0.270	0.300	0.254	0.205	0.248	0.274	0.140	0.113	0.200
Smoke emissions:									
Maximum opacity of stack gases, %	10	0	80	45	10	20	0	15	0
Duration of smoke of maximum opacity, min	1	0	1.5	1.0	2.5	1	0	9	0

Table 14-3. EMISSIONS FROM PATHOLOGICAL INCINERATORS WITHOUT GAS WASHERS

	Test number							
	1	2	3	4	5	6	7	8
Type of waste	Human tissue	Human tissue	Animals	Animals	Animals	Animals	Animals	Animals
Batch destruction rate to dry bone and ash, lb/hr	19.2	64	62	35	99	137	149	160
Particulates								
gr/scf	0.014	0.017	0.032	0.015	0.0936	0.013	0.024	0.0202
gr/scf at 12% CO_2 (CO_2 from refuse only)	0.240	0.400	0.183	0.106	0.295	0.260	0.240	0.135
Organic acids,								
gr/scf	0.006	0.0003	0.010	N. A.	0.013	0.0033	0.0018	0.0002
lb/hr	0.010	0.003	0.034	N. A.	0.050	0.075	0.012	0.002
lb/ton	1.04	0.093	1.10	N. A.	1.01	1.10	0.161	0.025
Aldehydes,								
gr/scf	N. A.	0.008	0.013	0.004	0.006	0.0032	0.012	0.010
lb/hr	N. A.	0.076	0.041	0.014	0.020	0.072	0.082	0.12
lb/ton	N. A.	2.37	1.32	0.80	0.40	1.05	1.10	1.50
Nitrogen oxides,								
ppm	42.7	35	134	111	131	60	165	102
lb/hr	0.085	0.29	0.37	0.29	0.099	1.2	0.94	1.1
lb/ton	8.86	9.05	12.0	16.6	2.00	17.5	12.6	13.7
Stack emissions:								
Opacity, %	0	0	0	0	0	0	0	0
Time, min								
Auxiliary fuel:								
Primary, scfh	190	700	530	600	640	800	1020	1800
Mixing, scfh	185	230	170	300	260	600	480	500
Gas flow, scfm	260	1150	380	370	450	2640	780	1400
Gas temperature, °F	410	307	590	950	800	346	1020	910
Stack gases, %								
CO_2	3.4	2.1	5.6	6.3	7.6	1.6	4.9	5.0
O_2	12.5	16.5	9.8	7.7	4.8	17.7	10.8	10.8
CO	0.0009	0.0	0.004	0.0	0.02	0.0	0.0	0.0
N_2	74.0	74.8	71.5	71.9	67.2	75.5	71.2	73.1
H_2O	10.1	6.6	13.1	14.1	20.4	5.2	13.1	11.1
Cost of incinerator, $	2400	2500	4250	1300	2700	3200	3000	6000

Table 14-4. CHEMICAL PROPERTIES AND COMBUSTION DATA FOR PAPER, WOOD, AND GARBAGE

		Sulfite paper[a]		Average wood[b]		Douglas fir[c]		Garbage[d]	
Analysis, %									
Carbon		44.34		49.56		52.30		52.78	
Hydrogen		6.27		6.11		6.30		6.27	
Nitrogen				0.07		0.10			
Oxygen		48.39		43.83		40.50		39.95	
Ash		1.00		0.42		0.80		1.00	
Gross heating value (dry basis), Btu/lb		7590		8517		9050		8820	
Constituent (based on 1 lb)		Cubic feet	Pounds	Cubic feet	Pounds	Cubic feet	Pounds	Cubic feet	Pounds
Theoretical air		67.58	5.165	77.30	5.909	84.16	6.433	85.12	6.507
Theoretical air 40% sat. @ 60°F		68.05	5.188	77.84	5.935	84.75	6.461	85.72	6.536
Flue gas with theor. air	CO_2	13.993	1.625	15.641	1.816	16.51	1.917	16.668	1.935
	N_2	53.401	3.947	61.104	4.517	66.53	4.918	67.234	4.976
	H_2O formed	11.787	0.560	11.487	0.546	11.84	0.563	11.880	0.564
	H_2O (air)	0.471	0.023	0.539	0.026	0.587	0.028	0.593	0.029
Total		79.652	6.155	88.771	6.905	95.467	7.426	96.375	7.495
Flue gas with % excess air as indicated	0	79.65	6.16	88.77	6.91	95.47	7.43	96.38	7.50
	50.0	113.44	8.74	127.42	9.86	137.55	10.64	139.24	10.77
	100.0	147.23	11.32	166.07	12.81	179.63	13.86	182.00	14.04
	150.0	181.26	13.91	204.99	15.79	222.01	17.09	224.86	17.21
	200.0	215.28	16.51	243.91	18.75	264.38	20.12	267.72	20.58
	300.0	283.33	21.70	321.75	24.68	349.13	26.58	353.44	27.12

[a]Sulfite paper constituents:

Cellulose	$C_6H_{10}O_5$	84%
Hemicellulose	$C_5H_{10}O_5$	8
Lignin	$C_6H_{10}O_5$	6
Resin	$C_6H_{10}O_5$	2
Ash	$C_{20}H_{30}O_2$	1

[b]Kent, R. T., Mechanical Engineer's Handbook, 11th Edition, John Wiley and Sons, New York, 1936, pp. 6-104.

[c]Kent, R. T., Mechanical Engineer's Handbook, 12 Edition, John Wiley and Sons, New York, 1961, pp. 2-40.

[d]Estimated on dry basis.

Table 14-5. ENTHALPIES OF GASES FROM 60°F
(Btu/lb of gas)

Temp., °F	CO_2	N_2	H_2O	O_2	Air
100	5.8	6.4	17.8	8.8	9.6
150	17.6	20.6	40.3	19.8	21.6
200	29.3	34.8	62.7	30.9	33.6
250	40.3	47.7	85.5	42.1	45.7
300	51.3	59.8	108.2	53.4	57.8
350	63.1	73.3	131.3	64.8	70.0
400	74.9	84.9	154.3	76.2	82.1
450	87.0	97.5	177.7	87.8	94.4
500	99.1	110.1	201.0	99.5	106.7
550	111.8	122.9	224.8	111.3	119.2
600	124.5	135.6	248.7	123.2	131.6
700	150.2	161.4	297.1	147.2	156.7
800	176.8	187.4	346.4	171.7	182.2
900	204.1	213.8	396.7	196.5	211.4
1000	231.9	240.5	447.7	221.6	234.1
1100	260.2	267.5	499.7	247.0	260.5
1200	289.0	294.9	552.9	272.7	287.2
1300	318.0	326.1	606.8	298.5	314.2
1400	347.6	350.5	661.3	324.6	341.5
1500	377.6	378.7	717.6	350.8	369.0
1600	407.8	407.3	774.2	377.3	396.8
1700	438.2	435.9	831.4	408.7	424.6
1800	469.1	464.8	889.8	430.4	452.9
1900	500.1	493.7	948.7	457.3	481.2
2000	531.4	523.0	1003.1	484.5	509.5
2100	562.8	552.7	1069.2	511.4	538.1
2200	594.3	582.0	1130.3	538.6	567.1
2300	626.2	612.3	1192.6	566.1	596.1
2400	658.2	642.3	1256.8	593.5	625.0
2500	690.2	672.3	1318.1	621.0	654.3
3000	852.3	823.8	1640.2	760.1	802.3
3500	1017.4	978.0	1975.4	901.7	950.3

Source of data: Kobe, K. A. and Long, E. G., Petroleum Refiner, 28, No. 11, 127, (1949).

Note: The enthalpies tabulated for H_2O represent a gaseous system, and the enthalpies do not include the latent heat of vaporization. It is recommended that the latent heat of vaporization at 60°F (1059.9 Btu/lb) be used where necessary.

Table 14-6. ADDRESSES OF REGIONAL AIR POLLUTION CONTROL DIRECTORS[a]

Regions	States and Addresses
I	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont DHEW, J. F. Kennedy Federal Building, Boston, Massachusetts 02203
II	Delaware, New Jersey, New York, and Pennsylvania DHEW - PHS, Federal Office Building, 26 Federal Plaza (Foley Square), New York, N. Y. 10007
III	District of Columbia, Kentucky, Maryland, North Carolina, Virginia, West Virginia, Puerto Rico, and Virgin Islands DHEW, 220 Seventh Street, N.E., Charlottesville, Virginia 22901
IV	Alabama, Florida, Georgia, Mississippi, South Carolina and Tennessee DHEW, Room 404, 50 Seventh Street, N.E., Atlanta, Georgia 30323
V	Illinois, Indiana, Michigan, Ohio, and Wisconsin DHEW, Room 712, New Post Office Building, 433 W. Van Buren St., Chicago, Illinois 60607
VI	Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, and South Dakota DHEW, 601 E. 12th Street, Kansas City, Missouri 64106
VII	Arkansas, Louisiana, New Mexico, Oklahoma, and Texas DHEW, 1114 Commerce Street, Dallas, Texas 75202
VIII	Colorado, Idaho, Montana, Utah, and Wyoming DHEW, Room 8026, Federal Office Building, 19th and Stout Street, Denver, Colorado 80202
IX	Alaska, Arizona, California, Hawaii, Nevada, Oregon, Washington, Guam, and American Samoa DHEW, 50 Fulton Street, Federal Office Building, San Francisco, California 94102

[a]Correspondence should be addressed to the Regional Air Pollution Control Director, National Air Pollution Control Administration, at the appropriate address given above.

15 ACKNOWLEDGMENTS

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