ENGINEER MANUAL

EM 1110-3-176
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ENGINEERING AND DESIGN

Incinerators

Mobilization Construction

DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, D.C. 20314

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1. Purpose. This manual provides guidance for the design of incinerators for combustible waste materials at U.S. Army mobilization facilities.

2. Applicability. This manual is applicable to all field operating activities having mobilization construction responsibilities.

3. Discussion. Criteria and standards presented herein apply to construction considered crucial to a mobilization effort. These requirements may be altered when necessary to satisfy special conditions on the basis of good engineering practice consistent with the nature of the construction. Design and construction of mobilization facilities must be completed within 180 days from the date notice to proceed is given with the projected life expectancy of five years. Hence, rapid construction of a facility should be reflected in its design. Time-consuming methods and procedures, normally preferred over quicker methods for better quality, should be de-emphasized. Lesser grade materials should be substituted for higher grade materials when the lesser grade materials would provide satisfactory service and when use of higher grade materials would extend construction time. Work items not immediately necessary for the adequate functioning of the facility should be deferred until such time as they can be completed without delaying the mobilization effort.

FOR THE COMMANDER:

PAUL F. KAVANAUGH
Colonel, Corps of Engineers
Chief of Staff

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CHAPTER 1

GENERAL

1-1. Purpose and scope. This manual contains instructions and information for the design of incinerators for combustible waste materials, including garbage. The design of rubbish incinerators will be based on the use of natural draft. Auxiliary burners will be necessary in some cases.

1-2. Selection of sites. Sites for incinerators will be selected for convenience with respect to the housing area to be served and for accessibility from the existing road net. The length of average one-way haul, in general, will not be more than 3 miles. Where additional roads are necessary, they will be over the most direct practical route to the site. In all cases, travel on and across primary roads will be held to a minimum. Site location will be at least 1,000 feet from inhabited buildings and out of the prevailing wind direction toward building areas. Drainage conditions will be adequate for runoff and to accommodate drains from the incinerator plant to sanitary sewers.

CHAPTER 2

INCINERATOR DESIGN

2-1. Definitions. Definitions of terms in their application to this manual are as follows:

a. Incinerator. A special type of structure for the reduction of refuse to inert gases and solids by burning.

b. Furnace. That part of the incinerator in which combustion takes place, including the ignition chamber, mixing chamber, combustion chamber, and charging hood if provided.

c. Arch. The arched ceiling of the furnace over the ignition, mixing, and combustion chambers.

d. Grate. The cast iron (C.I.) grate on which the dry material is burned.

e. Hearth. An inclined floor on which the wet material is dried and burned. It may be constructed of firebrick or of cast iron grate bars.

f. Effective grate area. The grate area plus the effective area of the hearth in terms of grate area.

g. Ignition chamber. The space between the grate and the arch and between the hearth and the arch.

h. Mixing chamber. The chamber adjacent to the ignition chamber where the gases mix before passing to the combustion chamber. This is often called the down pass.

i. Bridge wall. The wall at the end of the grate or hearth between the ignition chamber and the mixing chamber.

j. Combustion chamber. The final chamber of the furnace where combustion of the gases is completed.

k. Target wall. The wall between the mixing chamber and the combustion chamber.

l. Flue. The horizontal connection between the combustion chamber and the stack.

m. Damper. The vertical movable refractory slab in the flue for draft control.

n. Damper box. The box over the damper for housing it in its open position.

o. Charging hood. A structure directly over the ignition chamber provided with a door, through which the furnace is charged with refuse.

p. Charging throat. An extension from an opening in the arch to the charging floor, through which the furnace is charged with refuse.

2-2. Types of incinerators. Two types of incinerators are considered in this section: type I - garbage and rubbish incinerators and type II - wet garbage incinerators. Standard designs have been prepared for types I and II, drawings for which are listed in appendix B. Type I of these standard designs is a general purpose incinerator and is the most suitable for the present-day needs at a majority of installations. It will burn refuse consisting of all rubbish or, by proper control of the damper, a mixture of 65 percent rubbish and 35 percent garbage by weight. Type II will burn a mixture of 65 percent wet garbage by weight and 35 percent rubbish without the use of auxiliary fuel. However, this type is not designed to withstand the high heat release that would result from burning refuse containing a high percentage of rubbish and will not be constructed except when the conditions are definitely unsuited to the use of type I.

2-3. Incinerator capacities. Requirements will be based on the expected waste from the particular post. At an average troop cantonment, the per capita waste will approximate 1.5 pounds of rubbish, 0.50 pound of non-edible garbage, (citrus peels, coffee grounds, etc.) and 2.0 pounds of edible garbage per day. Quantity determinations, however, will be based on an actual survey whenever practicable. Capacity will be provided for 25 percent excess over the average hourly needs in order to make allowance for irregularity in the delivery of refuse to the incinerator. For example, if 4 tons are to be burned in 8 hours, the incinerator will have a capacity of 1,250 pounds per hour. Capacity factor for troop expansion will not be used, as the incinerator can be operated 16 hours per day if necessary, 8 hours remaining for cooling and cleaning. Little or no economy will result in designing special incinerators of sizes intermediate between the sizes indicated on the standard designs listed in appendix B.

2-4. Basic design requirements. The incinerator will be designed for the severest conditions that may reasonably be expected. For instance, a type I incinerator may be required to burn refuse consisting of all dry material and no garbage. The design, therefore, insofar as it involves heat release, gas quantities, velocities, etc., will be based on burning only dry materials. A drying hearth will be provided for the occasions when wet materials are to be burned. The design will conform to the following basic requirements:

a. Total furnace volume. The total furnace volume will be such that the heat release per cubic foot of furnace volume will not exceed 18,000 Btu per hour.

b. Hearth area. The hearth area will be approximately equal to the grate area for types I and II incinerators.

c. Effective grate area. For type I incinerators - 0.022 square foot for each pound of refuse per hour; and for type II - 0.04 square foot for each pound of refuse per hour. In determining effective grate area, the hearth may be considered to be 60 percent effective if made of firebrick and 80 percent if made of grate bars.

d. Gas velocity. A maximum of 15 fps through the combustion chamber and a maximum of 35 fps through the mixing chamber, flue, and stack.

e. Combustion-chamber volume. At least 30 cubic feet per pound of gas produced per second, including excess air required for cooling purposes.

f. Combustion-chamber temperature. Sufficient for complete combustion but not to exceed 1,600 degree F. (2,059 degrees F. absolute). This can be controlled by use of the damper and by the introduction of excess air.

g. Combustion time. A minimum of 1.5 seconds, total time required for the gases to pass through the furnace.

h. Stack height. Sufficient to provide the necessary draft and determined by the formula:

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

i. Draft. Sufficient to discharge the gases of combustion and required excess air. The total draft requirements will be determined in accordance with the following allowances for losses expressed in inches of water:

Velocity head: $\frac{0.119\,BV^2}{14.7T_s}$

Friction loss through the stack and flue: $\frac{(1.1 \times 10^{-6})T_sW^2LP}{A^3}$

Loss through each 90 degree turn in the gas passage: computed as a stack or conduit, the length of which is 12 times the square root of the area of the opening. Loss through grate: varies according to type of grate, quantity, and type of refuse burned, quantity of air and attention given to stoking. Under average conditions this loss may be considered to be 0.25 in type I incinerator and 0.15 in type II when the furnace is operating at rated capacity.

Abbreviations of terms used in the preceding formulas are:

- T_a - Atmospheric temperature in degrees F. (absolute).
- T_s - Average stack-gas temperature in degrees F. (absolute).
- H - Stack height above the grate (feet).
- A - Average inside cross-sectional stack area (square feet).
- B - Barometric pressure (psi).
- D - Static stack draft (inches of water).
- V - Gas velocity (fps).
- W - Weight of gas including excess air (pounds per second).
- L - Stack height above flue plus length of flue (feet).
- P - Inside stack perimeter (feet).

2-5. Preliminary design. A preliminary design will be made first and then checked and adjusted to assure compliance with the basic design requirements. For this purpose, table 2-1 may be utilized. The design of an incinerator is illustrated in appendix A.

Table 2-1. Preliminary Design Factors

	Type of incinerator	
	I	II
Effective grate area per pound of refuse per hour (square feet)	0.022	0.04
Ratio of hearth area to grate area	1	1
Effectiveness of hearth area in terms of grate area (percent):		
Firebrick hearths	60	60
C. I. grate bars	80	80
Horizontal cross-sectional area of mixing chamber in terms of effective grate area (percent)	25	20
Horizontal cross-sectional area of combustion chamber in terms of effective grate area (percent)	60	30
Cross-sectional area of flue in terms of effective grate area (percent)	25	10

Table 2-1. Preliminary Design Factors (Cont'd)

	Type of incinerator I	Type of incinerator II
Cross-sectional area of stack in terms of effective grate area (percent)	22	10
Ratio of height of arch above grate to width of furnace not to exceed	1	1

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2-6. Design analysis. A design analysis will accompany all requests for authority to construct incinerators and all incinerator plans and specifications, other than standard plans and specifications. The analysis will indicate the type of material to be incinerated and the basis upon which the capacity requirements were established.

CHAPTER 3

MATERIALS AND EQUIPMENT CONSIDERATIONS

3-1. General considerations. The structural design and the specifications relating to materials and to construction will provide for sturdy construction of all parts of the incinerator. In this respect, the effects of expansion and contraction due to high-temperature change will be considered. The type of construction will, in general, be as indicated on the standard drawings and in the guide specification listed in appendix B.

3-2. Furnace. The furnace will be constructed with an inner and outer shell. The walls of the inner shell and the arch will be approximately 9 inches thick and constructed of high-duty fire-clay brick or constructed of refractory plastic material having equivalent qualities. Firebrick will be laid in high-temperature, air-setting, bonding cement. The arch will be covered with a 2-1/2-inch layer of insulating material. The side walls of the outer shell will be 8-inch common brick walls securely braced to prevent settling and cracking. The bracing will consist of upright corner angles and intermediate upright channel buck stays, tied with rods and horizontal steel angles. The tie rods will be entirely outside the inner shell and will not be in contact with the refractory material at any point. The top, forming a part of the outer shell, will be reinforced concrete. If the top is not needed as a floor or as a roof for protection against the weather, it may be omitted and the arch covered with a 4-inch layer of common brick on top of the insulating brick. There will be no physical connections between the inner shell and the outer shell except the skewbacks of the arches, where the outer shell will be properly braced to take the arch thrust, and except around openings. The inner and outer shells will be separated by suitable insulating material or air space. The bridge wall and target wall will be 13-1/2-inches thick in incinerators of 1,000 pounds per hour capacity or larger and 9 inches thick in smaller sizes.

3-3. Stack. The stack will be constructed with an inner shell of fireclay brick for the entire height and an outer shell of common brick. The outer shell will be separated by a 2-inch air space from the inner shell and will have no physical contact with it at any point. The stack may be square or circular; however, the cross-sectional area will be the same for either shape.

3-4. Damper. The damper will be a movable vertical slab constructed of refractory material, steel shapes, and tie rods. It will be located in the flue and will fit freely in guide grooves. Suitable means, such as a chain hoist or cables, pulleys, and counterweights, will be provided for raising and lowering the damper. A damper box will be provided for housing the damper in its open position.

3-5. Furnace doors. The size, type, and location of the furnace doors will be determined with a view toward convenience of incinerator operation. The following comments relate to the doors of incinerators of 1,000 pounds per hour capacity or larger: Types I and II incinerators require means of charging the drying hearth with wet material. This can be accomplished through a charging throat extending from the furnace arch to the operating floor above. A removable lid will be provided for the charging throat. The charging of the grate with dry material is best accomplished through a guillotine type of door. In a type I incincerator this door will be in the side of a hood that extends above the operating floor and is directly above the grate. Both types I and II will be provided with a guillotine firing door in the side wall immediately above the grate. The guillotine doors and the lid on the charging throat will be constructed of refractory material. Cast iron furnace doors approximately 18 by 24 inches will be installed in the side wall of the furnace just above and opposite the drying hearth and at the firing-floor level opposite the mixing chamber, the combustion chamber, and the ash pit. The charging hood, the charging throat, and all openings will be adequately lined with refractory material.

3-6. Grate. The grate will be cast iron. The total area of the opening will be such that the loss of draft through the grate and refuse will not exceed the allowances indicated in paragraph 2-4.

3-7. Incinerator layout. Facilities will be carefully planned for the ready discharge of the refuse from delivery trucks directly on the charging floor or on a platform where it will be readily accessible for charging into the furnace. Space will be provided on the charging floor for storing refuse when the rate of delivery exceeds the furnace capacity for burning. Floor drains with removable, cast iron, slotted drain covers will be provided on both the charging floor and the firing floor.

3-8. Instrumentation. For purposes of controlling the temperature within safe limits for the refractory material, the combustion chamber will be provided with an indicating-recording pyrometer. A draft gage of the inclined tube type that will indicate the draft in the combustion chamber in inches of water is desirable.

3-9. Heat recovery equipment. Garbage cans, when emptied at the incinerator, will be soaked in hot water, then sprayed with hot water inside and outside. Water may be heated for this purpose by means of a hot-water pipe located in the combustion chamber and connected to a hot-water storage tank of required capacity.

APPENDIX A

SAMPLE DESIGN PROBLEM

A-1. Problem. Design a natural-draft incinerator for burning an average of 2,000 pounds of mixed refuse per hour consisting of 35 percent nonedible garbage containing 50 percent water, and 65 percent rubbish containing 10 percent water and 15 percent solid inerts; atmospheric temperature, 60 degrees F. (519 degrees F. absolute); combustion chamber temperature, 1,600 degrees F. (2,059 degrees F. absolute); average stack temperature, 1,500 degrees F. (1,959 degrees F. absolute). The chemical analysis of 1 pound of the refuse on a moisture free and solid inerts free basis is assumed to be as follows: Carbon, 0.47 pound; hydrogen, 0.07 pound; nitrogen, 0.04 pound; oxygen, 0.42 pound.

A-2. Preliminary design. A type I incinerator should be used to provide the required service. Using the preliminary design factors in table 2-1 and the capacity requirements set out in paragraph 2-3, the preliminary design is as follows:

Design capacity	2,000 x 1.25	2,500 pounds per hour
Effective grate area	2,500 x 0.022	55.0 square feet
C. I. grate area (assumed)		36 square feet
Hearth area (firebrick)	$\frac{(55.0 - 36)}{0.6}$	31.7 square feet
Inside width of furnace (assumed)		6 feet
Height of furnace arch above C.I. grate		6 feet
Horizontal cross-sectional area of mixing chamber	55.0 x 0.25	13.75 square feet
Horizontal cross-sectional area of combustion chamber	55.0 x 0.6	33.0 square feet
Stack cross-sectional area	55.0 x 0.22	12.10 square feet
Flue cross-sectional area	55.0 x 0.25	13.75 square feet

To provide the above areas, the dimensions will be:

Length of C.I. grate	6 feet 0 inches
Length of hearth	5 feet 6 inches
Length of mixing chamber	2 feet 3 inches
Length of combustion chamber	5 feet 8 inches
Width of flue	3 feet 6 inches
Height of flue to crown of arch	4 feet 0 inches
Size of stack	3 feet 6 inches square

The above dimensions are the dimensions shown in figure A-1.

A-3. Check of design. To assure conformance with the basic requirements of paragraph 2-3, a check involving heat release, heat balance, quantities of gases, velocities, draft, etc., should now be made of the preliminary design. The areas, volume, and dimensions shown on Standard Plan No. 414:43-369 and figure A-1 are used in this check. The specific heats, heats of vaporization, and molecular weights of the various substances are taken from standard handbooks. The heat absorbed by various gases as the temperature rises over a specified range can be ascertained by use of figure A-2. The following illustrates the method of checking the design. The oxygen requirements for complete combustion of 1 pound of moisture-free and solid inerts-free material of the stated chemical analysis are:

For burning carbon to CO_2	0.47 x 32 / 12	1.25 pounds
For burning hydrogen to H_2O	0.07 x 16 / 2	.56 pound
		1.81 pounds
Less oxygen in refuse		.42 pounds
Oxygen to be supplied by air		1.39 pounds

The air required to furnish the above amount of oxygen is 1.39 divided by 0.23 or 6.04 pounds (oxygen in air is 23 percent by weight). The nitrogen in this quantity of air amounts to 6.04 x 0.76 or 4.59 pounds. Therefore, the products of combustion of 1 pound of moisture-free solid inerts-free refuse will be:

H_2O	0.07 x 18 / 2	0.63 pound
CO_2	0.47 x 44 / 12	1.72 pounds
N_2	0.04 + 4.59	4.63 pounds
Total weight of gases		6.98 pounds

For conditions of burning all rubbish without wet garbage, the severest conditions under which the furnace will be required to operate insofar as heat release is involved, the products of combustion of 1 pound refuse, taking into consideration the content of 10 percent water and 15 percent solid inerts (0.75 pound on a moisture-free, solid inerts-free basis), will be:

H_2O	0.10 / 0.63 x 0.75	0.57 pound
CO_2	1.72 x 0.75	1.29 pounds
N_2	4.63 x 0.75	3.47 pounds
Total weight of gases as product of combustion		5.33 pounds

The heat of combustion of 1 pound of moisture-free and solid inerts-free refuse (using Dulong's formula for the determination of

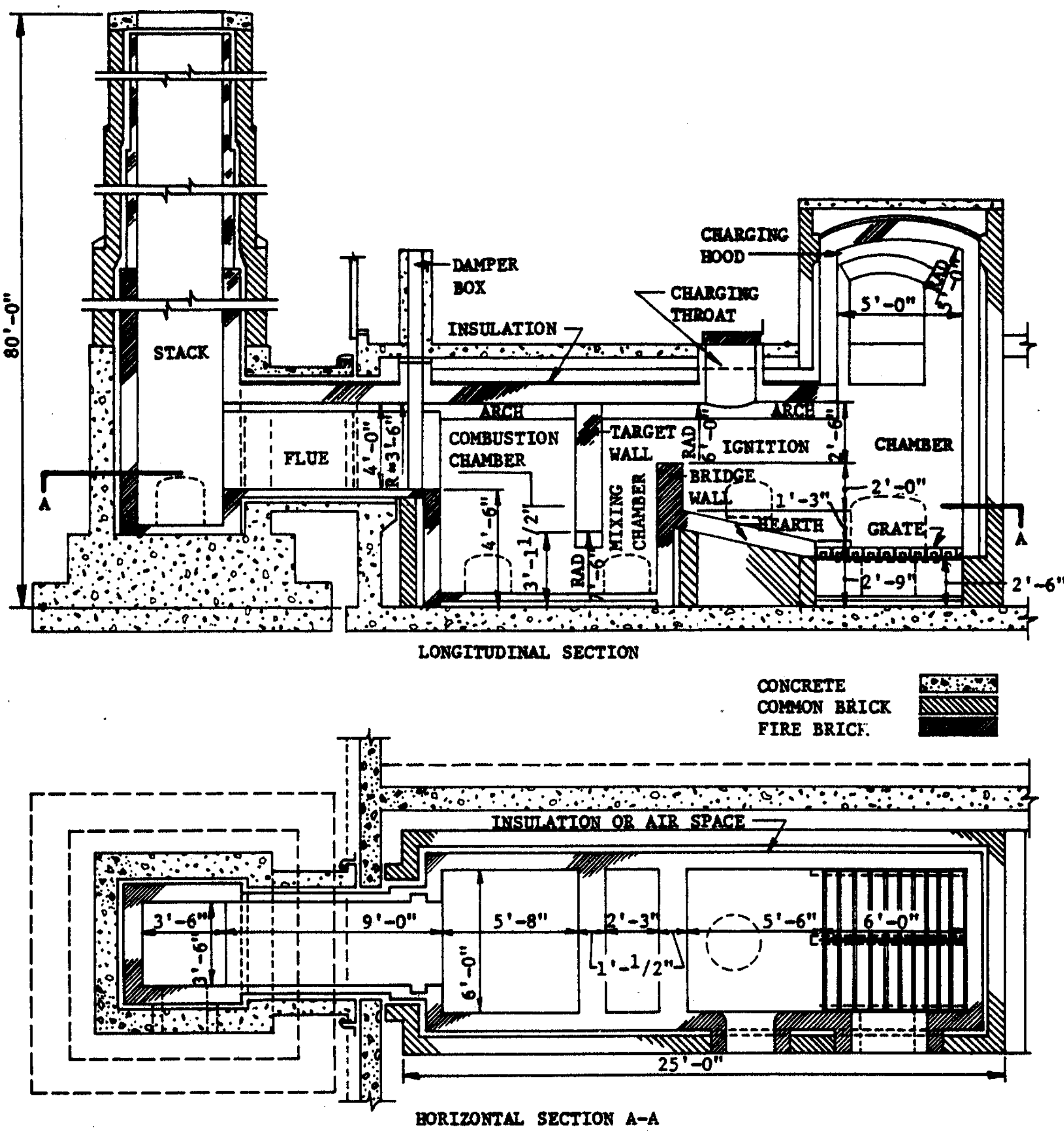

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FIGURE A-1. INCINERATOR FURNACE AND STACK

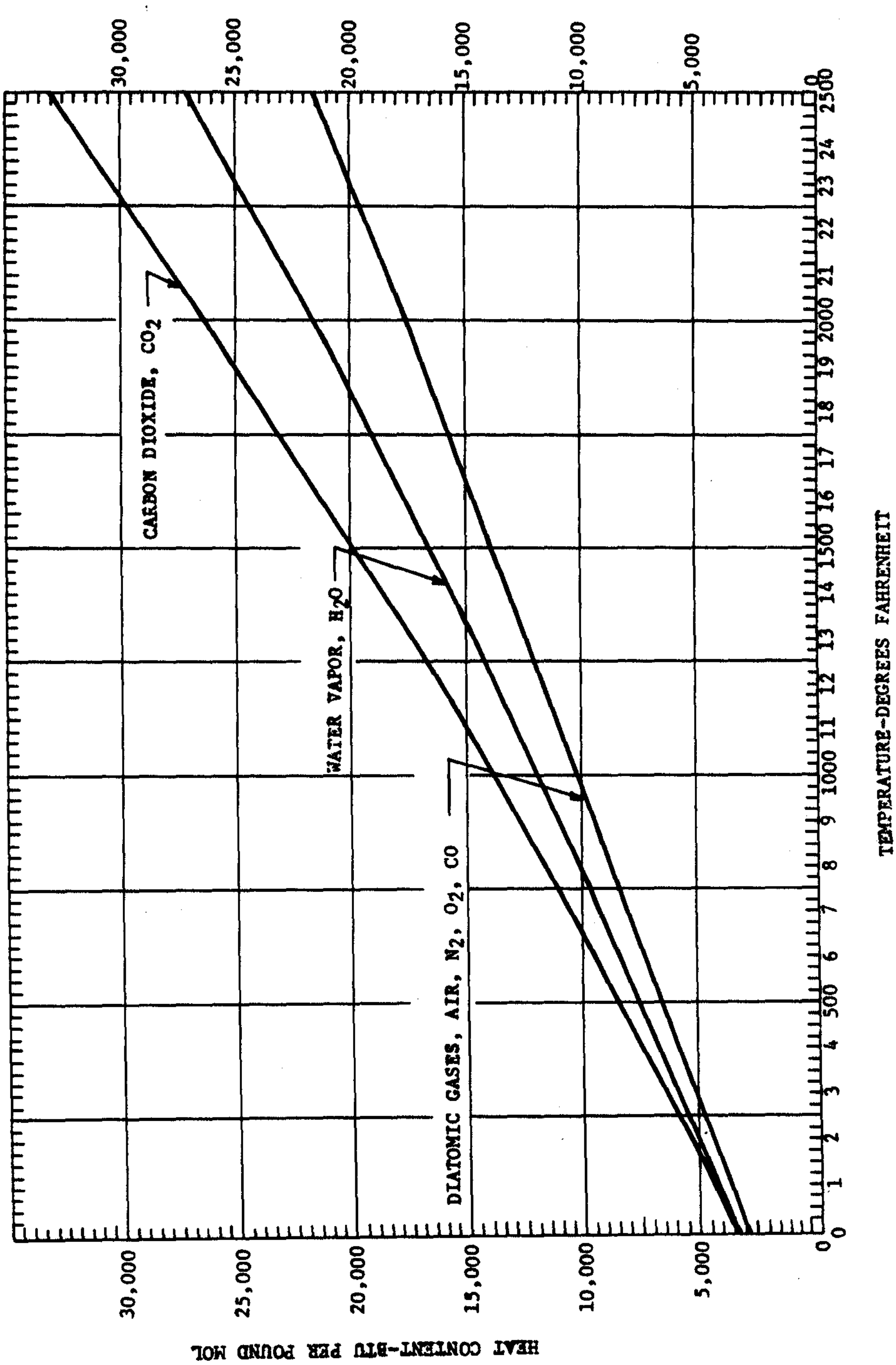

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FIGURE A-2. CHART OF HEAT CONTENT OF GASES (CONSTANT PRESSURE) calorific values) will be 14,500 x 0.47 + 62,000 [0.07 - (0.42/8)] equal to 7,900 Btu. The heat of combustion of 1 pound of the refuse, taking moisture and inert solids into consideration, will be 7,900 x 0.75 or 5,925 Btu. A portion of this heat combustion will be lost through radiation and solid inerts, a portion will be absorbed in heating and evaporating water, and a portion (the larger portion) will be absorbed in heating the gases. In figure A-2, which may be used in the determination of the heat absorbed by various gases, the difference between Btu per mol (defined as m pounds where m denotes molecular weight) at two temperatures in question is the heat absorbed by the gas as its temperature rises from the lower to the higher value. Btu per mol divided by the molecular weight (not atomic weight) gives Btu per pound. It should be noted that, for instance, the chart is graduated in degrees F. zero on the scale being 32 below the freezing temperature of water and not absolute zero which is used in most heat formulas. The heat lost or absorbed will be as indicated in the following heat balance:

Evaporating water from 60 degrees F.	--- 0.57 x 1122	--- 640 Btu
Heating water vapor from 212 degrees F. to 1,600 degrees F. (weight multiplied by the difference in heat content per mol at the two temperatures divided by molecular weight)	--- 0.57 x 12,300 / 18	--- 390 Btu
Heating CO_2 from 60 degrees F. to 1,600 degrees F.	--- 1.29 x 17,100 / 44	--- 502 Btu
Heating N_2 from 60 degrees F. to 1,600 degrees F.	--- 3.47 x 11,200 / 28	--- 1,388 Btu
Radiation through furnace walls, assuming a loss of 1,000 Btu per square feet per hour and a total radiating surface of 350 square feet	--- 350 x 1,000 / 2,500	--- 140 Btu
Heating 300 gallons of water per hour from 60 degrees F. to 180 degrees F. for can wash	--- 300 x 8.33 x 120 / 2,500	--- 120 Btu
Loss through solid inerts (assuming a specific heat of 0.20 and a temperature of 600 degrees F.)	--- 0.15 x 0.20 x (600-60)	--- 16 Btu
Subtotal		3,196 Btu
Balance to be absorbed by excess air (5,925 - 3,196)		2,729 Btu
Total heat of combustion (as above)		5,925 Btu

The excess air that will be required to absorb 2,729 Btu so that the combustion chamber temperature will not exceed 1,600 degrees F. (see fig A-2 for heat absorbed between 60 degrees F. and 1,600 degrees F.) will be 2,729 x 28.9 / 11,200, which is equal to 7.04 pounds. Therefore, the total weight of gases per pound of refuse burned (the products of combustion plus the excess air used for controlling maximum temperature of the combustion chamber) will be 5.33 + 7.04 which is equal to 12.37 pounds. As this gas has a molecular weight which is practically the same as air, it will be considered air from this point on. The volume of 1 pound of air at 60 degrees F. (519 degrees F. absolute) and 14.7 psi barometric pressure is approximately 13.1 cubic feet. Using the foregoing computations, formulas, quantities, temperatures, etc., the following determinations are made:

Total weight of gas produced per second	12.37 x 2,500 / 3,600	8.59 pounds
Total volume of gas passing through the combustion chamber	8.59 x 13.1 x 2,059 degrees /519 degrees	446 cfs
Velocity through combustion chamber	446 / (5.67 feet x 6 feet)	13.1 fps
Velocity through flue	446 / (3.5 feet x 4 feet)	31.8 fps
Velocity through mixing chamber	446 / (2.25 feet x 6 feet)	33.0 fps
Average volume of gas passing through the stack	8.59 x 13.1 x 1,959 degrees / 519 degrees	425 cfs
Velocity through stack	425 / (3.5 feet x 3.5 feet)	34.7 fps
Heat release per hour per cubic foot of furnace volume	5,925 x 2,500 / 930	15,925 Btu
Combustion time (total furnace volume excluding charging hood divided by volume of gas produced per second)	720 / 446	1.61 seconds
Combustion chamber volume per pound of gas produced per second	5 feet 8 inches x 6 feet x 7 feet 11 inches / 8.59	31.4 cubic feet
Draft loss in stack and flue (L = 51.5 feet + 9 feet = 60.5 feet)	$1.1 \times 10^{-6} \times 1,959 \times 8.59 \times 60.5 \times 14 / 12.25^3$	0.073 inch
Velocity head	$0.119 \times 34.7^2 \times 14.7 / (14.7 \times 1,959)$	0.073 inch

Loss through five turns through openings which have an average area of 14 square feet and an average perimeter of 16 feet taken as a stack whose height is 5 x 12 $\sqrt{14}$ or 224 feet --------- $1.1 \times 10^{-6} \times 2{,}059 \times 8.59^2 \times 224 \times 16 / 14^3$ -------------- 0.218 inch

Loss through grate (assumed) ------------------------- 0.250 inch

Total draft requirements --------- 0.073 + 0.073 + 0.218 + 0.250 ---------------------- 0.614 inch

Required stack height --------- $\dfrac{0.614}{0.52 \times 14.7\ (1/519 - 1/1{,}959)}$ 56.7 feet

which is 1 foot less than the height above grate shown in figure A-1.

From the above analysis the design complies with paragraph 2-4.

APPENDIX B

STANDARD PLANS AND SPECIFICATIONS

The following standard plans and specifications are available for the construction of incinerators when authorized:

Type I. Rubbish and Garbage Incinerators:

Incinerator, 2,500 pounds per hour capacity:
414:43-368 (formerly 672-310).
414:43-369 (formerly 672-311).
414:43-370 (formerly 672-312).
414:43-371 (formerly 672-313).
414:43-372 (formerly 672-414).
Incinerators, 1,250 pounds per hour capacity:
414:43-375.
414:43-376.
414:43-377.
414:43-378.
414:43-379.

Type II. Wet-Garbage Incinerators:
3 tons in 8 hours capacity - natural draft:
414:43-227.
414:43-227.1 (700-4437).
414:43-227.2.

5 tons in 8 hours capacity - natural draft:
414:43-320.
414:43-321.
414:43-322.
414:43-323.
414:43-324.
414:43-325.
414:43-326.
414:43-327.
414:43-328 (700-4443).
414:43-329.

Specifications for the incinerators listd above are covered in Mobilization Guide Specification (MOGS) 11171.2, INCINERATORS, GENERAL PURPOSE, FIELD ERECTED.