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EQUIPMENT FOR INCINERATION OF MUNICIPAL WASTE

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EQUIPMENT FOR INCINERATION OF MUNICIPAL WASTE

by

F.D. Friedrich*

ABSTRACT

Incineration offers one method of coping with the rapidly increasing quantities of solid municipal waste, but incinerators must be carefully designed and operated to avoid air pollution. Some of the North American codes governing incinerator construction are outlined, and a range of available equipment is described, from small incinerators suitable for apartment buildings or commercial establishments, to large European systems which produce steam for district heating or power generation.

It is pointed out that small incinerators are, essentially, volume reduction devices using substantial quantities of high-quality fuel to support the incineration process, whereas large heat-recovery incinerators use the waste as fuel to produce energy.

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Direction des mines

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L'ÉQUIPMENT D'INCINÉRATION DE LA POLLUTION MUNICIPAL

par

F. D. Friedrich*

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RÉSUMÉ

L'incinération offre une méthode pour disposer rapidement des ordures ménagères, mais il faut que les incinérateurs soient soigneusement construits et operés pour éviter la pollution atmosphérique. Des normes Nord-Américains sont déjà établis concernant l'incinération et un assortiment d'équipment disponible est décrit pour les maisons de rapport et les grands systèmes Européens qui produisent de la vapeur pour chauffage de ces edifices et la production d'électricité.

Les petits incinérateurs sont essentiellement des appareils pour diminuer le volume et qui ont besoin de beaucoup de combustibles de haute-qualité pour l'incinération des ordures ménagères tandis que les grands incinérateurs produisent leur propre énergie avec les ordures ménagères.

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INTRODUCTION

Waste is a penalty of affluence and, as our industrial society forges ahead, as our urban population increases, and as our standard of living rises, we are increasingly burdened by our own discards. North America, particularly Canada, is relatively fortunate in that most small and medium-sized cities can still find open country nearby, preferably downwind of the built-up areas, where waste can be dumped and forgotten, at least during the term of office of the current administration. On the other hand, large cities may have to haul waste to dumps many miles beyond their boundaries. Even if the environmental damage from uncontrolled dumping is ignored, hauling several thousand tons of waste per day over long distances becomes an expensive undertaking. This has led to some alternative solutions of considerable ingenuity, though of dubious merit. One, practiced by several maritime cities, is the use of barges to dump waste into the ocean, just outside territorial waters. Another, planned by Chicago and Indianopolis, involves the use of unit trains to haul 2,000 tons of waste per day to a dump near Pontiac, Illinois.

A more satisfactory solution, which reduces waste to a fraction of its original volume, and converts it from a malodorous, unsightly, germ-breeding source of pollution to a sterile, odor-free material suitable for landfill, is incineration. If proper precautions are taken, incineration can be accomplished without significant air pollution. Furthermore, under certain circumstances, it can provide useful by-products in the form of heat and scrap metal. This paper describes various types of incinerators which are now available for disposing of municipal waste and outlines the design requirements necessary to avoid air pollution. The discussion is limited to municipal waste because the handling of industrial waste could pose special problems that would each have to be discussed separately.

CLASSIFICATION OF SOLID WASTE

It has been said that the difference between science and art is largely a matter of orderly classification. Thus Mendeléyev's periodic table helped to convert the art of alchemy to the science of chemistry, and Carolus Linnaeus' system of classification was a cornerstone of the science of biology. In order to deal scientifically with the problems of solid-waste disposal, it was first necessary to classify the various forms of waste, therefore we are grateful to the gentlemen of the Incinerator Institute of America for, among other things, having defined the differences between rubbish, refuse, and garbage. Their complete classification system, now generally accepted in North America, is given in Table 1.

The Ontario classification, which differs only in that it gives a range for moisture content and calorific value, is given in Table 2 (1).

In addition to the six types of waste listed in these classification systems, the industry now commonly refers to another type which has not yet achieved official status. It is typically described as follows:

Type 0. Trash	Consists of highly combustible waste, mostly paper, wood and cardboard cartons. May contain up to 10% plastic, with some treated paper and rubber scraps. Moisture content may be up to 10%; ash content is about 5%. Calorific value is about 8500 Btu/lb.

TABLE 1

Classification of Wastes to be Incinerated,

Standards of the Incinerator Institute of America

Type	Description	Principal Components	Approximate Composition % by Wt.	Moisture Content % by Wt.	Incombustible Solids, % by Wt.	Calorific Value of Refuse as Fired, Btu/lb
*1	Rubbish	Combustible waste, paper, cartons, rags, wood scraps, floor sweepings; domestic commercial, industrial sources	Rubbish 100% (Garbage up to 20%)	25%	10%	6500
*2	Refuse	Rubbish and garbage; residential sources	Rubbish 50% Garbage 50%	50%	7%	4300
*3	Garbage	Animal & vegetable wastes, restaurants, hotels, markets; institutional, commercial, and club sources.	Garbage 100% (Rubbish up to 35%)	70%	5%	2500
4	Animal solids and organic wastes	Carcasses, organs, solid organic wastes; hospital, laboratory, abattoirs, animal pound, and similar sources	100% Animal and Human Tissue	85%	5%	1000
5	Gaseous, liquid or semi-liquid wastes	Industrial process wastes	Variable	Dependent on pre-dominant components	Variable according to wastes survey	Variable according to wastes survey
6	Semi-solid and solid wastes	Combustibles requiring hearth, retort, or grate burning equipment	Variable	Dependent on pre-dominant components	Variable according to wastes survey	Variable according to wastes survey

* The above figures on moisture content, ash, and B.T.U. as fired have been determined by analysis of many samples. They are recommended for use in computing heat release, burning rate, velocity and other details of incinerator designs. Any design based on these calculations can accommodate minor variations.

TABLE 2

Classification of Wastes According to the Air Management Branch[1/]

Waste matter may be divided into the following types:

Type 1 - Rubbish

Mainly cellulosic waste, up to 10 percent non-combustible, up to 25 percent moisture and a minimum gross heat value of 6,500 Btu per lb. It does not include halogenated hydrocarbons, rubber, leather or wood.

Type 2 - Refuse

A mixture of rubbish and garbage, with a moisture content of about 35 to 50 percent and with a gross heat value of 4000 - 6000 BTU per lb.

Type 3 - Garbage

Mixed animal and vegetable waste from restaurants, cafeterias, etc., a moisture content of 30 to 70 percent and a gross heat value of 1000 - 3000 BTU per lb.

Type 4 - Pathological

Carcasses, human and animal; organs and solid organic waste from hospitals, laboratories, abattoirs and animal compounds; disposable operating theatre garments and swabs; maternity, sanitary and incontinent pads, disposable diapers and other similar materials in which pathogenic bacteria might be present.

Type 5 - Industrial

Gaseous, liquid or semi-liquid compounds, materials such as tars, paints, solvents, etc. Heat value dependent on materials handled.

Type 6 - Industrial

Solid wastes such as rubber, plastic, wood, halogenated hydrocarbons, leather and similar materials. Heat value dependent on material handled.

[1/] From p. 3 of "Criteria for Incinerator Design and Operation", Ref. 1.

Table 3 gives a typical breakdown of municipal refuse in terms of components and ultimate analysis(2). It can be seen that plastics comprise less than one percent. However, the table was prepared in 1966. Since that time the plastics content has risen to about 1.5%, and it is expected to continue to rise. The average calorific value is also rising.

The increasing percentage of plastics in municipal waste is a matter of concern to air pollution authorities because some plastics are difficult to incinerate, and polyvinyl chloride, on thermal breakdown, forms hydrogen chloride vapour (HCl), which is a serious air pollutant.

INCINERATOR DESIGNS APPROVED BY CANADIAN CODES

The history of incineration describes the practice, in medieval towns, of pulling a wagon, protected against fire by a coating of clay, through the streets so that residents could throw burnable wastes onto the moving bonfire. Widespread use of incineration stems essentially from the beginning of this century and, since then, incinerators have appeared in a bewildering array of designs. Many of these, being comparable in sophistication to the clay-lined wagon, should never have been built but they are still to be found and continue to pollute the air as efficiently as on the day they were commissioned. However, there is little purpose in reviewing all the incinerator configurations that have appeared; this discussion will be limited to reviewing the types of incinerators being built now. A convenient starting point is to look at the types of incinerators that meet with the approval of Canadian code-writing organizations.

This paper will examine two such codes. One has been put forward by the Air Management Branch of the Ontario Department of Energy and Resources Management(1), the other was put into draft form by the Committee on Air Pollution of the Canadian Standards Association(3). These codes are essentially based on American codes and, in the opinion of the author, they fairly reflect the present state of incineration technology in North America in that they

TABLE 3

Composition and Analysis of an Average Municipal Refuse[1]

Component	Percent of All Refuse by Weight	Moisture (percent by weight)	Analysis (percent dry weight) Volatile Matter	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Noncombustibles[2]	Calorific Value (Btu/lb)
Rubbish, 64%										
Paper	42.0	10.2	84.6	43.4	5.8	44.3	0.3	0.20	6.0	7572
Wood	2.4	20.0	84.9	50.5	6.0	42.4	0.2	0.05	1.0	8613
Grass	4.0	65.0	—	43.3	6.0	41.7	2.2	0.05	6.8	7693
Brush	1.5	40.0	—	42.5	5.9	41.2	2.0	0.05	8.3	7900
Greens	1.5	62.0	70.3	40.3	5.6	39.0	2.0	0.05	13.0	7077
Leaves	5.0	50.0	—	40.5	6.0	45.1	0.2	0.05	8.2	7096
Leather	0.3	10.0	76.2	60.0	8.0	11.5	10.0	0.40	10.1	8850
Rubber	0.6	1.2	85.0	77.7	10.4	—	—	2.0	10.0	11330
Plastics	0.7	2.0	—	60.0	7.2	22.6	—	—	10.2	14368
Oils, paints	0.8	0.0	—	66.9	9.7	5.2	2.0	—	16.3	13400
Linoleum	0.1	2.1	65.8	48.1	5.3	18.7	0.1	0.40	27.4	8310
Rags	0.6	10.0	93.6	55.0	6.6	31.2	4.6	0.13	2.5	7652
Street sweepings	3.0	20.0	67.4	34.7	4.8	35.2	0.1	0.20	25.0	6000
Dirt	1.0	3.2	21.2	20.6	2.6	4.0	0.5	0.01	72.3	3790
Unclassified	0.5	4.0	—	16.6	2.5	18.4	0.05	0.05	62.5	3000
Food Wastes, 12%										
Garbage	10.0	72.0	53.3	45.0	6.4	28.8	3.3	0.52	16.0	8484
Fats	2.0	0.0	—	76.7	12.1	11.2	0	0	0	16700
Noncombustibles, 24%										
Metals	8.0	3.0	0.5	0.8	0.04	0.2	—	—	99.0	124
Glass and ceramics	6.0	2.0	0.4	0.6	0.03	0.1	—	—	99.3	65
Ashes	10.0	10.0	3.0	28.0	0.5	0.8	—	0.5	70.2	4172
Composite Refuse, as Received										
All refuse	100	20.7	—	28.0	3.5	22.4	0.33	0.16	24.9	6203

1/ Taken from Table 1-3, page 7, of "Principles and Practices of Incineration". Ref. 2

2/ Ash, metal, glass and ceramics.

prohibit domestic incinerators and other small incinerators of inadequate design; however neither they nor the American codes anticipate the large, steam-generating municipal incinerators that are now commonplace in western Europe.

CSA Draft Code

This code has yet to be published. As an interim measure, it has been proposed to adopt as approved designs the following:

A. Multiple-Chamber Incinerator Design Standard for Los Angeles County;
B. Criteria of the Department of Air Pollution Control, City of New York;
C. Regulations Governing Incinerators by the Department of Building, City of New York.

These deal with specific designs, and will be reviewed in some detail. In areas where the CSA Code is adopted, after it is completed, other incinerator designs will have to be tested and approved by a designated authority before they can be marketed, in much the same manner as domestic furnaces must be tested in the CSA laboratories before they are approved for sale.

A. Summary of the Multiple-Chamber Incinerator Design Standard for Los Angeles County

Rule 50 of the Los Angeles Air Pollution Control District Rules and Regulations prohibits the "emission of any air contaminant for a period or periods aggregating more than 3 minutes in any 1 hour which is:

(a) as dark or darker than No. 2 Ringelmann,
(b) of such opacity as to obscure an observer's view to a degree equal or greater than smoke as described in (a) above." (4)

Since the Ringelmann Chart is based on degree of blackness, clause (b) serves to control emissions which are not black; for example, the white dust from the chimney of a cement plant.

Also, Rule 53 of the same Rules and Regulations states that: "A single source shall not emit any one or more of the following contaminants, in any state or combination, exceeding in concentration at point of discharge:

(a) sulphur compounds calculated as SO_2: 0.2% by vol.

(b) combustion contaminants: 0.3 grain per cubic foot of gas, calculated to 12% CO_2 at standard conditions". In measuring combustion contaminants from incinerators, the CO_2 from any liquid or gaseous fuels shall be excluded from the calculation to 12% CO_2. (4).

Specifying the CO_2 concentration of the flue gas in which the contaminants are calculated to be dispersed is a convenient means of relating the total amount of contaminants emitted to the amount of refuse burned. Otherwise, the flue gas could be massively diluted with air to reduce the concentration of contaminants, while the total amount of contaminants remained unchanged.

To achieve these emission levels, Los Angeles County has prepared a design standard which permits only refractory-lined multiple-chamber incinerators of the retort type and the in-line type, and furthermore lays down detailed procedures for their design (5). Other types of incinerators may be erected only if adequate performance has been proven beforehand. This approach was developed on the basis of considerable test work with a variety of incinerator configurations, and the theory behind the design standard, as well as the design criteria and procedure, complete with examples, are given in the design standard and in "Air Pollution Engineering Manual" (6).

Both the retort type and the in-line type of multiple-chamber incinerator comprise three connected chambers as shown in Figures 1 and 2. The first chamber is an ignition chamber, equipped with a grate onto which the refuse is charged and on which primary combustion takes place.

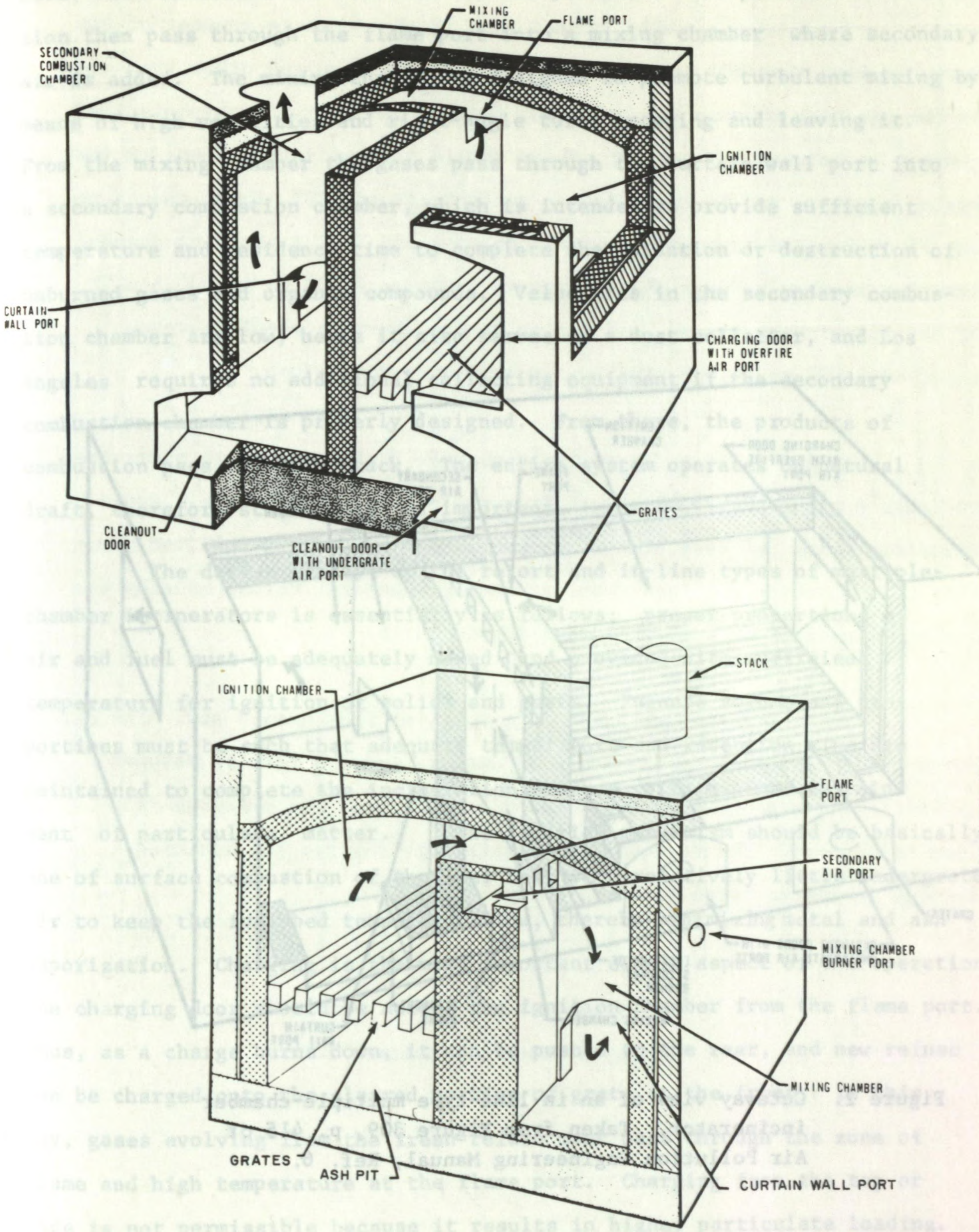


Figure 1. Cutaway views of a retort-type multiple-chamber incinerator. Taken from Figure 308, p. 414 of Air Pollution Engineering Manual, Ref. 6.

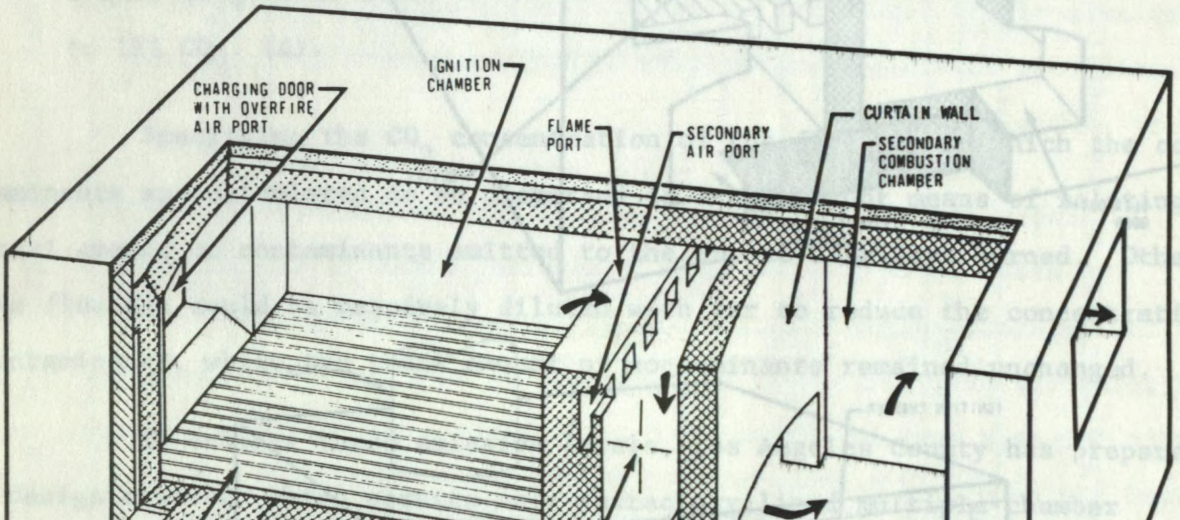


Figure 2. Cutaway view of an in-line-type multiple-chamber incinerator. Taken from Figure 309, p. 415 of Air Pollution Engineering Manual, Ref. 6.

Here, both underfire and overfire air are provided. The products of combustion then pass through the flame port into a mixing chamber where secondary air is added. The mixing chamber is designed to promote turbulent mixing by means of high velocities and right-angle turns entering and leaving it. From the mixing chamber the gases pass through the curtain wall port into a secondary combustion chamber, which is intended to provide sufficient temperature and residence time to complete the oxidation or destruction of unburned gases and organic compounds. Velocities in the secondary combustion chamber are low, hence it also serves as a dust collector, and Los Angeles requires no additional collecting equipment if the secondary combustion chamber is properly designed. From there, the products of combustion pass into the stack. The entire system operates on natural draft, therefore stack design is important.

The design concept of the retort and in-line types of multiple-chamber incinerators is essentially as follows: proper proportions of air and fuel must be adequately mixed and provided with sufficient temperature for ignition of solids and gases. Furnace volume and proportions must be such that adequate temperature and retention time are maintained to complete the incineration process, with minimum entrainment of particulate matter. The ignition mechanism should be basically one of surface combustion of the fuel bed, with relatively little undergrate air to keep the fuel-bed temperature low, thereby minimizing metal and ash vaporization. Charging is the most important single aspect of the operation. The charging door should be across the ignition chamber from the flame port. Thus, as a charge burns down, it can be pushed to the rear, and new refuse can be charged onto the cleared portion of grate at the front. In this way, gases evolving from the fresh refuse must pass through the zone of flame and high temperature at the flame port. Charging from the top or side is not permissible because it results in higher particulate loading. Fresh refuse must not be placed on top of burning refuse, and burning refuse must be disturbed as little as possible during recharging, to minimize entrainment.

The design standard states that if the moisture content of the waste is less than 10%, no auxiliary burners are required other than one in the ignition chamber to ignite the charge. However, if the moisture content is between 10% and 20%, there should be auxiliary burners in the mixing chamber, and if the moisture content exceeds 20%, there should be auxiliary burners both in the mixing chamber and in the ignition chamber. Ignition chamber burners should have an input of 3,000 to 10,000 Btu/lb of moisture in the refuse and mixing chamber burners should have an input of 4,000 to 12,000 Btu/lb of moisture in the refuse.

Design factors for multiple-chamber incinerators are summarized in Table 4. These were developed from tests with waste having a gross calorific value of less than 7,500 Btu/lb but have been modified somewhat to accomodate the fact that, at present, general refuse usually has a calorific value between 7,500 and 9,000 Btu/lb.

The design criteria assume a total of 300% excess air. The air ports are designed to admit half this amount, and the rest is assumed to infiltrate through cracks and leaks and through the charging door when it is open. The recommended distribution for the air admitted through the ports is as follows:

overfire air ports:	70%,
underfire air ports:	10%,
mixing chamber air ports:	20%.

TABLE 4

Multiple-Chamber Incinerator Design Factors[1/]

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	± 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	--
Length-to-width ratio (approx);		
Retort	Up to 500 lb/hr, 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 for 2,000 lb/hr capacity. Over-square acceptable in units of more than 11 ft ignition chamber length[2/]	--
Secondary combustion zone:		
Gas velocities:		
Flame port at 1,000°F, V_{FP}	55 ft/sec	± 20%
Mixing chamber at 1,000°F, V_{MC}	25 ft/sec	± 20%
Curtain wall port at 950°F, V_{CWP}	About 0.7 of mixing chamber velocity	--
Combustion chamber at 900°F, V_{CC}	5 to 6 ft/sec; always less than 10 ft/sec	--
Mixing chamber downpass 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	Range - 1.3:1 to 1.5:1	--
In-line	Fixed by gas velocities due to constant incinerator width	--

[1/] From Table 116, p. 418, Air Pollution Engineering Manual, Ref. 6.

[2/] Over-square means that the width of the primary combustion chamber may be greater than the length from the charging door to the flame port.

TABLE 4

Multiple-Chamber Incinerator Design Factors[1/] - (Cont'd)

Item and symbol	Recommended value	Allowable deviation
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	± 10%
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 inch 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 temperature, combustion products	1,000°F	± 20°F
Auxiliary burners:		
Normal duty requirements:		
Primary burner	3,000 to 10,000 - Btu per lb of moisture in the refuse	
Secondary burner	4,000 to 12,000 - Btu per lb of moisture in the refuse	
Draft requirements:		
Theoretical stack draft, D_T	0.15 to 0.35 inch water gage	--
Available primary air induction draft, D_A, (Assume equivalent to inlet velocity pressure.)	0.1 inch water gage	
Natural draft stack velocity, V_S	Less than 30 ft/sec at 900°F	--

1/ From Table 116, p. 418, Air Pollution Engineering Manual, Ref. 6.

The two different configurations, retort type and in-line type, were evolved to meet the design criteria with respect to (a) the proportioning of the flame port and mixing chamber, (b) maintenance of flame distribution over the flame port and through the mixing chamber, and (c) flame travel through the mixing chamber into the secondary combustion chamber. In the capacity range of 50 to 750 lb of waste per hour, the retort type is compact and economic because of its cubic shape, and offers efficient performance. In larger sizes, the increased size of the mixing chamber cross-section leads to reduced turbulence, inadequate flame distribution, and poor secondary air mixing.

On the other hand, the small-capacity in-line type has a short grate which tends to inhibit flame propagation across the ignition chamber and produces thin flame distribution over the bridge wall. As a result, smoke from smouldering grate sections can pass through the incinerator without adequate mixing and secondary combustion.

Of the two types, the retort type offers advantages in the capacity range of 50 to 750 lb of refuse per hour, between 750 and 1,000 lb/hr there is little difference between them, and above 1,000 lb/hr the in-line type is preferable. A more complete description of these two types, sufficient in fact to design one, can be obtained from the Los Angeles County Design Standard (5) or from the Air Pollution Engineering Manual (6).

B. Summary of the Incinerator Design Criteria of the Department of Air Pollution Control, the City of New York (7).

These criteria are intended for incinerators in multiple dwellings occupied by more than 12 families. They do not generally permit incinerators in smaller dwellings.

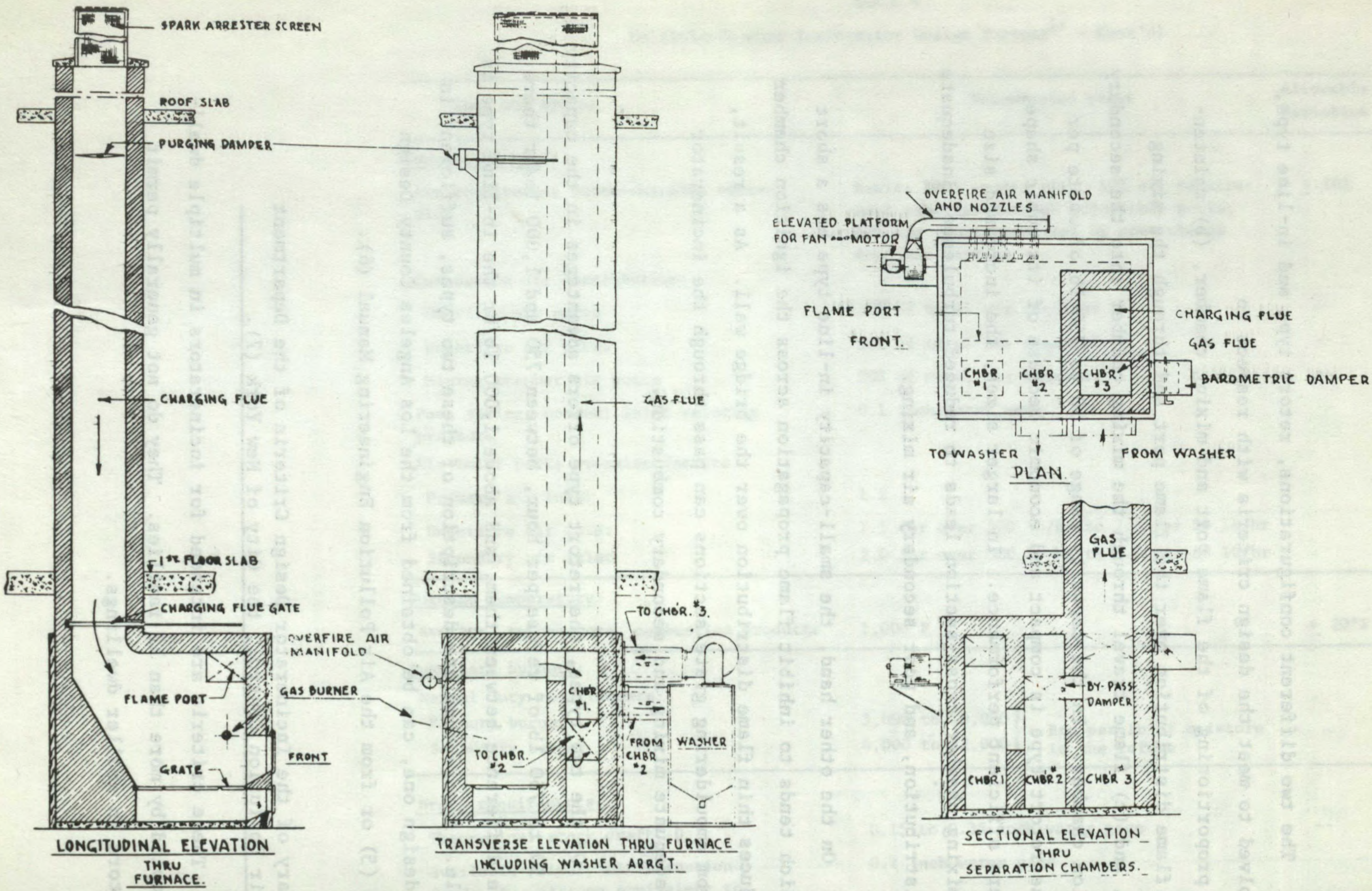


Figure 3. Sectional views of a double-flue incinerator. Taken from Figure 4B-2, pp. 92 and 93, of Principles and Practices of Incineration, Ref. 2.

Though the criteria are very detailed with respect to incinerator construction, they say little about permissible emissions. It is stated that dust loading in the stack shall not exceed 0.65 lb per 1,000 lb of gas corrected for dilution with excess air, and that unburned or putrescible residue shall comprise no more than 5% of the total residue removed from the furnace and ash pit.

The criteria call for steel-cased refractory-lined furnaces with combustion control equipment such as washers, scrubbers, electrostatic precipitators or cyclones, and double flues extending through the roof. The double-flue arrangement provides for one flue to be equipped with doors on each floor, for convenient charging of waste by the tenants, thus avoiding the mess involved in first collecting the waste and then charging the incinerator from the operating floor.

The arrangement of a double-flue incinerator is shown in Figure 3. Waste placed in the charging flue falls directly onto the incinerator grate or onto a charging gate which is periodically opened to permit the waste to enter the furnace. The combustion products pass through a flame port into a settlement chamber, then to a second settlement chamber, then to a gas cleaning system, then to a third settlement chamber, and finally out the gas flue. Underfire- and overfire-air are supplied by a blower, and an induced draft system is usually required.

These criteria, like those of Los Angeles, provide sufficient guidance to design an incinerator and detailed instructions on its operation. However, the concept, assumptions, and result are rather different from those of the Los Angeles criteria. The New York criteria are based on the following assumptions (7):

1. The population of a residential building is equal to the number of rooms.
2. The incinerator will operate a minimum of 4 burning cycles per day, or 25% of the total refuse per burning cycle.
3. The amount of refuse deposited is 1.44 lb/room/day.
4. The refuse weighs 4.1 lb/cu ft.
5. The gross calorific value as fired is 6,000 Btu/lb.
6. 200% excess air is used, and moisture in the refuse is 20%.

Buildings up to and including 1,000 rooms per incinerator are required to have incinerators sized according to Table 5, each equipped with the following:

(a) manually-cleaned grates or automatic stoking grates;
(b) a power-operated charging flue grate,
(c) an auxiliary blower-type burner with a furnace pressurestat, temperature control, and indicator for the range 1400 to 1600°F,
(d) an overfire air fan and nozzle system designed for 25% of the total air,
(e) fly-ash removal equipment, including an induced draft fan and a water recirculating pump, and
(f) a cycling clock to coordinate items b, c, d and e.

Buildings having 1,001 to 3,000 rooms per incinerator are required to have incinerators sized according to Table 6, and equipped as just described except that automatic stoking grates are mandatory.

TABLE 5

Design Criteria for Flue-Fed Incinerators - 100 to 1000 Rooms - Manual Grates[1/]

				COLUMN I	II	III	IV	V	VI	VII
1.	No. of rooms or population per incinerator			100	200	300	400	600	800	1000
2.	Refuse per day at 1.44 lbs per room		lbs	144	288	432	576	865	1152	1440
3.	Volume of refuse per day at 4.1 lbs/cu ft		cu ft	35.1	70	105	141	211	282	351
4.	Heat input per day at 6000 Btu/lb		Btu	864,000	1,728,000	2,590,000	3,460,000	5,180,000	6,912,000	8,640,000
5.	Refuse per burn at 25% - 4 burns per day		lbs	36	72	108	144	216	288	360
6.	Volume of refuse per burn at 4.1 lbs/cu ft		cu ft	8.8	17.6	26.3	35.2	52.7	70.2	87.8
7.	Heat input per burn at 6000 Btu/lb		Btu	216,000	432,000	648,000	865,000	1,300,000	1,730,000	2,160,000
8.	Projected area heat release - Fig. 1007-65		Btu/sq ft/hr	10,800	20,000	29,000	35,000	48,400	57,667	65,000
9.	Projected area - grate and hearth	Min.	sq ft	20	22	23	24	26.9	30	33
10.	Furnace length and width inside	Min.	ft	6'4" x 3'2"	6'7" x 3'3 1/2"	6'9 1/2" x 3'4 3/4"	7'0" x 3'6"	7'4" x 3'8"	7'7" x 3'9 1/2"	8'2" x 4'1"
11.	Grate area at 50% of burning area	Min.	sq ft	10	11	11.5	12	13.5	15	16.5
12.	Arch height above grate	Min.	ft	4'0"	4'3"	4'6"	4'9"	5'0"	5'4"	5'9"
13.	Basement height under beams or slab	Min.	ft	9'8"	9'11"	10'2"	10'5"	10'8"	11'0"	11'5"
14.	Furnace heat release rate - Fig. 1007-65		Btu/cu ft/hr	2,800	4,800	6,270	7,600	9,680	10,500	11,400
15.	Furnace volume - Fig. 1006-64		cu ft	80	90	103.5	114	134.5	160	190
16.	Gas weight leaving furnace at 200% excess air		lbs/hr	440	880	1,323	1,760	2,650	3,520	4,415
17.	Gas volume leaving furnace at 1600 F - Fig. 1005-65		CFM	379	758	1,138	1,515	2,280	3,030	3,900
18.	Gas volume in flue (after baro. damper) at 500 F		CFM	685	1,370	2,055	2,740	4,120	5,480	7,050
19.	Combustion air weight		lbs/hr	405	810	1,215	1,620	2,440	3,240	4,050
20.	Combustion air volume at 80 F - Fig. 1005-65		CFM	90	180	276	367	554	735	920
21.	Underfire air - 50% of total - at 80 F		CFM	45	90	138	183	277	367	460
22.	Adjustable air port area	Min.	sq in	50	100	153	200	310	420	510
23.	Overfire air fan at 25% of total at 1" S.P.		CFM	22.5	45	69	92	139	184	230
24.	Overfire air duct and manifold area at 2000 FPM		sq in	1.62	3.24	4.97	6.62	10.0	13.25	16.5
25.	Equivalent schedule 40 pipe size		in	2	2	3	3	4	4	6
26.	No. of 1" pipe nozzles for O.F. air		No.	4	4	5	5	6	7	9
27.	Flame port area at 1000 FPM		sq ft	1.0 min.	1.0 min.	1.5	1.5	2.3	3.0	3.9
28.	Separation chamber port area at 2000 FPM		sq ft	1.0 min.	1.0 min.	1.0	1.0	1.2	1.5	1.95
29.	Gas flue - baro. damper and fresh air inlet	Min.	sq ft	1.0 min.	1.37	1.86	2.36	3.29	4.05	4.86
30.	Auxiliary burner capacity at 1200 Btu/lb refuse	Min.	Btu	43,200	86,400	129,700	173,000	259,000	345,000	432,000

1/ From Table 1, Approved Incinerator Design, The Criteria of the Department of Air Pollution Control, City of New York, Ref. 7.

TABLE 6

Design Criteria for Flue-fed Incinerators - 1001 to 3000 Rooms - Stoking Grates[1/]

				COLUMN VIII	IX	X	XI	XII	XIII
1.	No. of rooms or population per incinerator			1200	1400	1600	1800	2000	3000
2.	Refuse per day at 1.44 lbs per room		lbs	1730	2015	2305	2590	2880	4320
3.	Volume of refuse per day at 4.1 lbs/cu ft		cu ft	422	492	562	633	703	1052
4.	Heat input per day at 6000 Btu/lb		Btu	10,360,000	12,100,000	13,830,000	15,500,000	17,300,000	26,000,000
5.	Refuse per burn at 25% - 4 burns per day		lbs	432	504	576	647	720	1080
6.	Volume of refuse per burn at 4.1 lbs/cu ft		cu ft	105.3	123	140.5	152.7	175.5	263.5
7.	Heat input per burn at 6000 Btu/lb		Btu	2,600,000	3,020,000	3,450,000	3,880,000	4,325,000	6,500,000
8.	Projected area heat release - Fig. 1007-65		Btu/sq ft/hr	74,800	61,000	87,000	93,000	99,300	123,500
9.	Projected area - grate and hearth	Min	sq ft	34.8	37.5	39.5	42	43.6	52.5
10.	Furnace length and width inside	Min	ft	8'4" x 4'2"	8'8" x 4'4"	8'10" x 4'5"	9'2" x 4'7"	9'5" x 4'8"	10'5" x 5'3"
11.	Grate area at 50% of burning area	Min	sq ft	17.4	18.75	19.75	21	21.8	26.2
12.	Arch height above grate	Min	ft	6'0"	6'4"	6'7"	6'8"	7'0"	8'0"
13.	Basement height under beams or slab	Min	ft	11'8"	12'0"	12'3"	12'4"	12'8"	13'8"
14.	Furnace heat release rate - Fig. 1007-65		Btu/cu ft/hr	12,000	12,900	13,400	13,900	14,200	15,450
15.	Furnace volume - Fig. 1006-64		cu ft	217	226	257	280	305	420
16.	Gas weight leaving furnace at 200% excess air		lbs/hr	5,300	6,160	7,050	7,920	8,830	13,250
17.	Gas volume leaving furnace at 1600 F - Fig. 1005-65		CFM	4,550	5,300	6,050	6,800	7,800	11,440
18.	Gas volume after baro. damper at 500 F		CFM	8,225	9,570	10,920	12,300	14,100	20,650
19.	Combustion air weight		lbs/hr	4,880	5,670	6,475	7,280	8,120	12,200
20.	Combustion air volume at 80 F - Fig. 1005-65		CFM	1,105	1,285	1,470	1,650	1,840	2,760
21.	Underfire air - 50% of total - at 80 F		CFM	552	642	735	825	920	1380
22.	Underfire air duct area at 2000 FPM	Min	sq in	39.7	46.2	52.9	59.4	66.3	99.3
23.	Overfire air by fan at 25% of total		CFM	276	321	368	413	460	690
24.	Overfire air duct and manifold at 2000 FPM		sq in	19.9	23.1	26.5	29.7	33.1	49.6
25.	Equivalent schedule 40 pipe size		in	6	6	6	6	8	8
26.	No. of 1 1/2" pipe nozzles at 65 CFM		No.	5	5	6	7	8	11
27.	Forced draft fan capacity at 2" S.P.		CFM	828	963	1,103	1,238	1,380	2,070
28.	Flame port area at 1000 FPM		sq ft	4.5	5.3	6.0	6.8	7.8	11.4
29.	Separation chamber port area at 2000 FPM		sq ft	2.25	2.65	3.02	3.4	3.9	5.72
30.	Gas flue - baro. damper and fresh air inlet	Min	sq ft	5.14	5.76	6.125	6.55	7.05	8.27
31.	Auxiliary burner capacity	Min	Btu	520,000	605,000	692,000	776,000	865,000	1,300,000

[1/] From Table 2, Approved Incinerator Design, The Criteria of the Department of Air Pollution Control, City of New York, Ref. 7.

The function of the cycling clock is to coordinate the other auxiliaries into the following operating cycle, with the duration of each step being adjustable. At least four cycles a day are specified.

1. Between burns;
   The charging flue gate is to remain closed, except that it may open briefly at 15 to 30-min intervals to discharge accumulated refuse.

2. Burning cycle:
   (a) open the charging flue gate,
   (b) start the induced draft fan and the fly-ash removal system,
   (c) start the auxiliary burner to ignite the refuse,
   (d) start the overfire air fan,
   (e) start the stoking grate movement, if any,
   (f) burn for a pre-set interval.

3. At the end of the burning cycle:
   (a) stop the auxiliary burner,
   (b) stop the overfire fan,
   (c) stop the fly-ash removal system and the induced draft fan,
   (d) close the charging flue gate,
   (e) stop the stoking grate, if any.

The residue and siftings may then be removed.

The criteria specify cast-iron grates weighing at least 40 lb/sq ft for manually stoked grates, and 70 lb/sq ft for automatically stoked grates.

The purpose of the auxiliary burner system is to ignite the refuse and maintain a temperature of 1600°F in the furnace. The system is to consist of one or more blower-type burners equipped with spark-ignited gas pilots, and flame failure protection. The preferred location is across the furnace from the flame port, high enough to avoid fouling with refuse, and angled downward. Burner capacities for different sizes of incinerators are listed in Tables 5 and 6, and are based on an input of 1,200 Btu/lb of refuse.

Inside dimensions of the charging flue are specified to be at least 22.5 in. square or 24 in. dia. for 1 to 6 storey buildings and at least 27 in. square or 30 in. dia. for buildings higher than 6 storeys. Gas flue cross-sections are specified in Tables 5 and 6. The support, construction, lining, and location of the flues are specified in detail. The top elevation of the flues is to be at least as high as any structure within a 100-ft radius, at least 10 ft above the roof of the building, and at least 4 ft above any penthouse or water tower on top of the building. Spark arrestors are also specified in detail.

The charging flue must be equipped with a purging damper, located near the top of the flue and operable from the incinerator room. It is normally closed, but is opened periodically according to an approved purge cycle, in order to sterilize the charging flue with hot gas from the auxiliary burner.

The criteria required at least two gravity separation chambers upstream of the fly-ash removal system. A by-pass damper may be installed between the second and third gravity separation chamber but it may only be used when it is necessary to take the fly-ash removal system out of service for repairs.

The double-flue incinerator is assumed to operate with a total of 200% excess air, which is to be divided as follows:

(a) 25% overfire air supplied by a blower through a manifold and nozzles according to a specified arrangement,

(b) 25% drawn down through the charging flue by the induced draft fan,

(c 50% underfire air, also to be supplied from the overfire air fan.

Adjustable dampers with locks are to be provided on the overfire and underfire air systems.

The foregoing is only an outline of the criteria of the Department of Air Pollution Control of the City of New York. The complete criteria are lengthy and detailed but they essentially provide an equipment specification on which tenders could be called.

C. Comments on the Incinerator Section of the Proposed New York City Building Code (8).

Although the Building Department is not responsible for enforcing the emission standards of New York's Air Pollution Code, construction standards were set with the Code in mind in order to prohibit any construction that would adversely affect emissions. Therefore, the requirements of the Incinerator Section of the Proposed New York City Building Code are essentially the Criteria of the Department of Air Pollution Control. However, some differences and elaborations are worthy of mention.

A commentary accompanying the proposed building code states that incinerators contribute upwards of 1/3 of the air pollution in New York City.

Single-flue, flue-fed incinerators are prohibited. Double-flue incinerators may have either a steel casing or a brick exterior finish.

Incinerators must achieve a reduction of 70% in weight and 90% in volume from raw charging conditions. The residue shall contain not more than 5% combustible by weight, shall be non-putrescible, and substantially odor-free.

The auxiliary burner shall maintain not less than 1500°F at the flame port and its input during burning shall be not less than 1,800 Btu/hr for each pound of refuse.

Summary of Criteria for Incinerator Design and Operation by Air Management Branch, Ontario Department of Energy and Resources Management (1).

The philosophy behind this code is summed up by the following quotation from its introduction: "It is not intended to stifle new ideas or to restrict design in any way. The basic principles behind these parameters are those inherent in any good incinerator design. This publication deals in detail with factors associated with the conventional 3-pass type of incinerator. They require that the conditions of temperature, retention time, and good mixing needed for complete combustion are met. Associated with these are other details of design which are aimed at the goal of reducing the possibility of poor operation due to the human factor. Any design which fulfils these requirements will be acceptable."

The criteria are similar to those of Los Angeles County and embrace incinerators for waste types 1 through 4, with the last receiving special attention. New flue-fed incinerators are prohibited. In some respects the Ontario criteria are more stringent than those of Los Angeles County and some of the significant differences are outlined in the following.

The auxiliary combustion equipment should comprise nozzle-mix power burners fitted and adjusted to produce, if possible, a flame to blanket the entire mixing chamber passageway and to create turbulence so as to thoroughly mix the combustibles with the combustion air. Auxiliary burners should be designed and located to ensure that the flame does not impinge on cold surfaces before combustion is complete.

TABLE 7

Minimum Reaction Temperatures and Retention Times for Complete Incineration of Typical Waste Products[1/]

Description of Waste	Minimum Reaction Temperature F	Retention Time (Sec.)
Type 1 (Rubbish)	1600	0.3
Type 2 (Refuse)	1600	0.5
Type 3 (Garbage)	1600	0.5
Most organic vapours	1600	0.5
Light smoke	1600	0.5
Odour control applications	1600	0.5
Heavy smoke (submicron coke-like particles)	1750	0.75
Type 4 (Pathological)	1800	0.5
Wood waste	1800	3.0
Halogenated hydrocarbons (e.g. D.D.T.)	2200	1.0
Organic cyanides	2200	1.0

[1/] From Table 1, "General Guidelines for Incineration Equipment", Air Management Branch, Department of Energy and Resources Management. Oct. 1970.

Design parameters for grate area have been modified. The Los Angeles criterion is used for Type 2 waste, a smaller grate area is acceptable for Type 1 waste, and a larger grate area is required for Type 3 waste. Total incinerator volume should be based on a total heat release value (waste plus auxiliary fuel) of about 25,000 Btu/cu ft/hr.

An important innovation of the Ontario criteria lies in the fact that both minimum retention times for each type of waste and a minimum gas temperature of 1600°F are specified. This information is summarized in Table 7. The total combustion air required is specified only as that which is calculated by heat balance to be sufficient to maintain a temperature of 1600°F in the mixing and combustion chambers. The recommended minimum input of the auxiliary burners is given in Table 8.

It is also stated that air cleaning equipment may be required, depending on the type of waste incinerated and on local land usage. The criteria are followed by some excellent examples of how to apply them in designing incinerators.

OTHER DESIGNS OF MEDIUM-SIZED INCINERATORS

The foregoing pages have described incinerator designs approved by Canadian codes. This by no means exhausts the repertoire of incinerator designs. The codes were written around certain designs known to offer satisfactory performance and leave other designs with the onus of demonstrating their worth before they can be approved. The Ontario code appears to be the most flexible. While its criteria are primarily aimed at multiple-chamber incineration, the code states that any design which meets the specified conditions of temperature, retention time, and mixing will be acceptable. Quite a number of good designs are now in existence, too

TABLE 8

Classification of Wastes and Recommended B.T.U. Requirements for Incinerators[1/]

Type	Description	Principal Components	Approximate Composition % by Weight	Moisture Content %	Incombustible Solids %	Combustible Solids %	Gross B.T.U Value/lb of Refuse (as fired)	Minimum Burner Input B.T.U./hr/lb Waste
1	Rubbish	Combustible waste, paper, cartons, rags, floor sweepings	Rubbish 100	25	10	65	6500	1,000 in Mixing Chamber
2	Refuse	Rubbish and garbage	Rubbish 50 Garbage 50	50	7	43	4300	4,000 1/3 in ignition Chamber 2/3 in Mixing Chamber
3	Garbage	Meat and vegetable wastes	Garbage 100 (Rubbish up to 35	70	5	25	2500	6,000 1/2 in ignition Chamber 1/2 in Mixing Chamber

NOTE: The above figures on moisture content, ash, and B.T.U. as fired have been determined by analysis of many samples. They are recommended for use in computing heat release, burning rate, velocity, and other details of incinerator designs. Any design based on these calculations can accommodate minor variations.

[1/] From page 11 of "Criteria for Incinerator Design and Operation", Air Management Branch, Ref. 1.

many to review in detail here, but it will be useful to look at a few which illustrate concepts different from the multiple-chamber designs already discussed.

The "Dual-Air" Incinerator

This is a proprietary design built by Plibrico (Canada) Ltd. It is a batch-type, single-chamber incinerator which offers the advantages of simplicity and automatic operation, and requires only part-time attendance.

The "Dual-Air" incinerator is shown schematically in Figure 4. It consists of a refractory-lined chamber having no grate but having one or more ignition burners in the walls and combustion air tuyeres in the floor. A refractory-lined stack is connected to the roof of the chamber and has a reactor section at its base. This comprises a ring of secondary air nozzles with an after-burner located above them. A single blower supplies air to the tuyeres and to the secondary air nozzles.

The charging door is of a walk-in size, and designed to provide a tight seal when closed. The combustion chamber may be almost completely filled with waste, then the door is closed, and the automatic burn cycle is started. The after-burner is ignited, the blower is started, and after a purge cycle, the ignition burners are started. Combustion air to the chamber is restricted in order to provide a quiescent distillation process rather than active turbulent combustion. The distilled combustibles are mixed with air in the reactor section and burn with sufficient temperature being provided by the after-burner and with sufficient residence time being provided by the refractory-lined stack. The ignition burners and after-burner are sized to meet the requirements of the Ontario

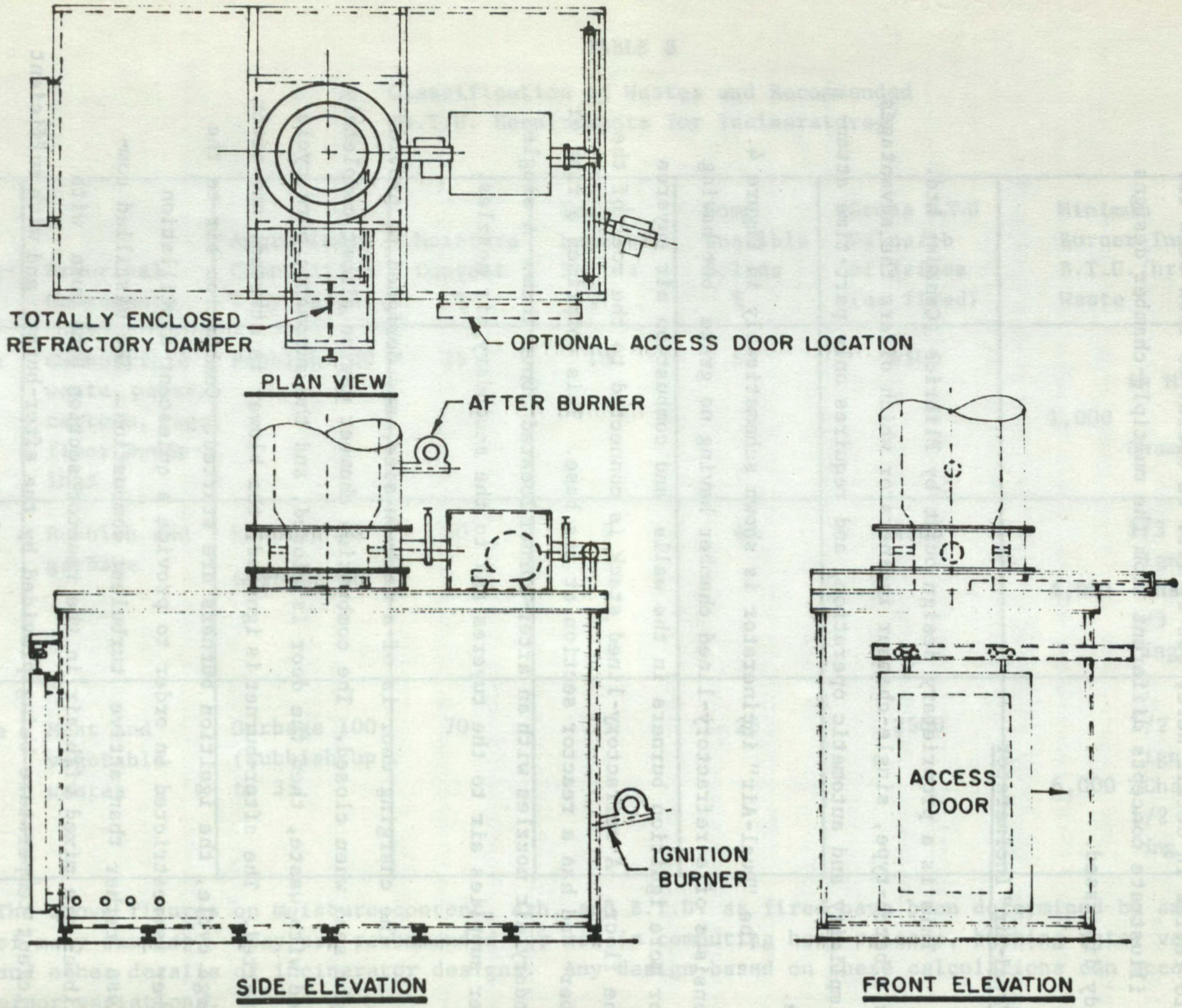


Figure 4. Schematic view of the "Dual-Air" incinerator. Courtesy Plibrico (Canada) Ltd.

code and, because the bed of waste burns slowly from the top down, entrainment is minimal. Tests have shown stack loading of particulate matter without a dust collector to be less than 0.2 grain per standard cubic foot of gas, corrected to 12% CO_2

The length of the burning period is adjusted to suit the type of waste. After an indicator light shows that the furnace has cooled down, the door can be opened, the residue can be removed, and the furnace may be recharged for another burning cycle.

The Combustion Cone Incinerator

This design was evolved in Germany in an attempt to provide a nearly-automatic, low-cost installation, suitable for medium-sized industrial works, or for communities of 10,000 to 80,000 inhabitants (9, 10). In the sizes presently available, refuse throughput ranges from 750 to 7,000 lb/hr.

The design is shown schematically in Figure 5. A conical or basket-shaped grate made of alloy cast iron bars is placed in a refractory-lined chamber. The axis of the grate makes an angle of 30° with the horizontal and the grate rotates slowly about its axis. Located directly above the open end of the grate are a charging chute and an after-burning chamber, and a support burner is located in the chamber wall opposite the grate.

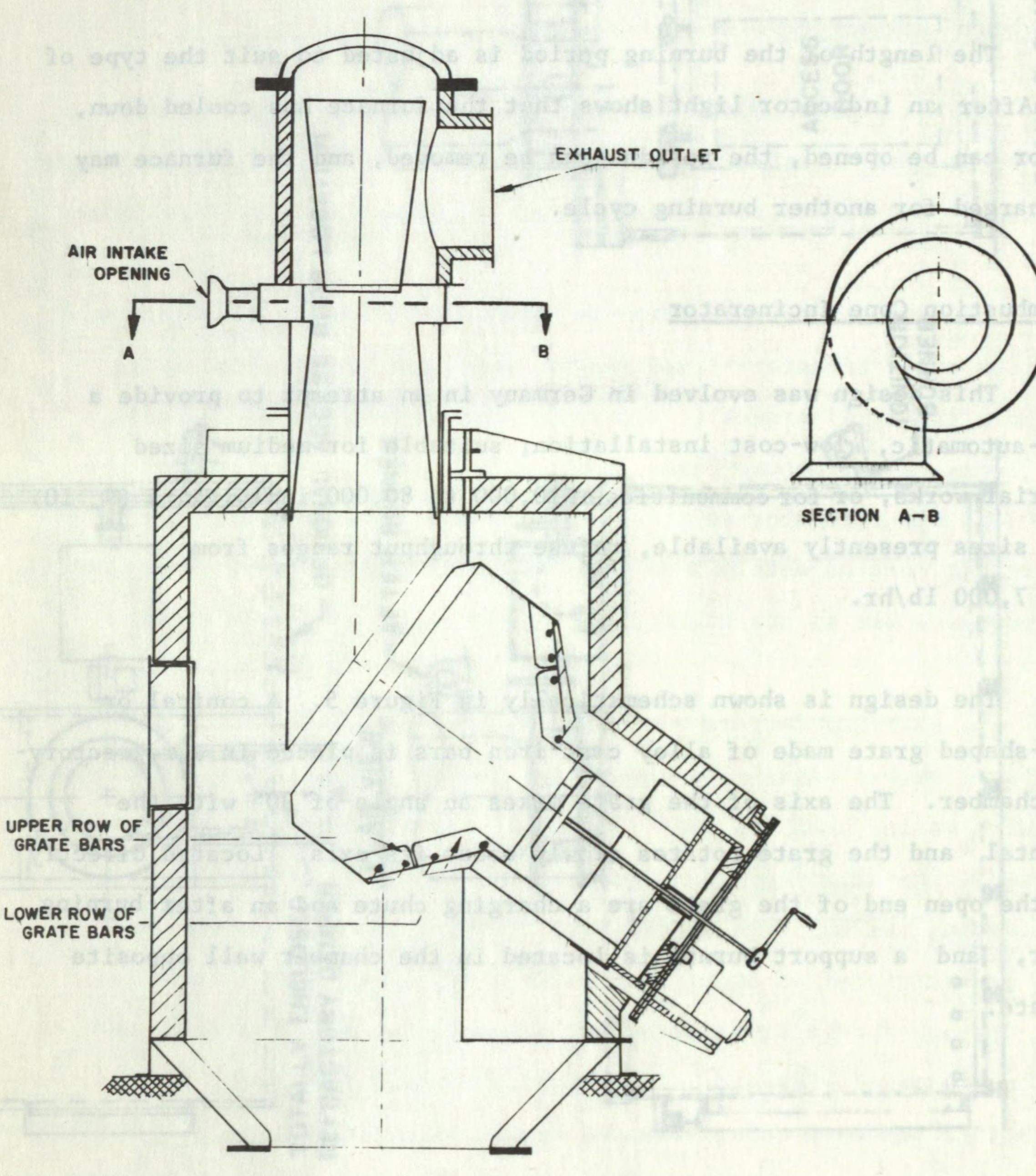
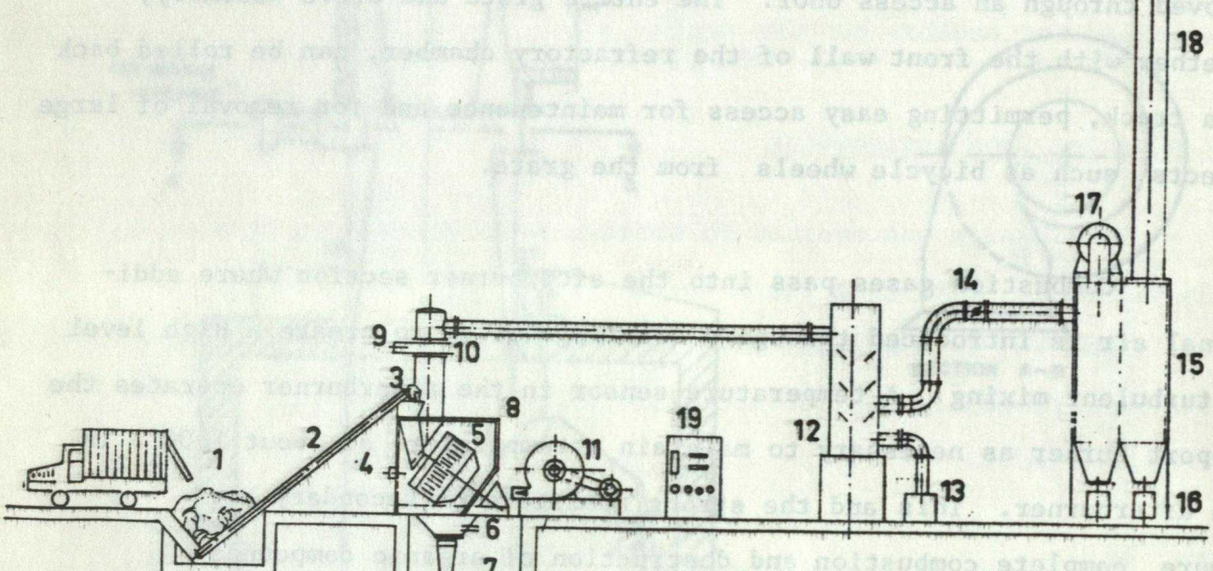


Figure 5. Schematic view of the combustion cone incinerator. Taken from Figure 5 of "The Development of the Combustion Cone for the Incineration of Refuse". Ref. 9.

Refuse, periodically charged through the chute, falls onto the grate and is ignited either by the support burner or by already burning refuse. A header and nozzle system under the grate blows combustion air up through the grate bars. The rotation of the grate continuously tumbles the refuse and enables ash particles to fall through the grate bars into a quench tank below. The shape and attitude of the cone cause clinkers, cans, and other non-combustible objects, too large to fall through the grate bars, to collect at the small end of the cone, where they can be removed through an access door. The entire grate and drive assembly, together with the front wall of the refractory chamber, can be rolled back on a track, permitting easy access for maintenance and for removal of large objects such as bicycle wheels from the grate.

Combustion gases pass into the afterburner section where additional air is introduced through a swirling device to create a high level of turbulent mixing. A temperature sensor in the afterburner operates the support burner as necessary to maintain a temperature of about 1600°F in the afterburner. This and the strong admixture of secondary air ensure complete combustion and destruction of organic compounds.

Normally the gases are cooled by a spray tower or heat exchanger and cleaned in a cyclone fly-ash removal system, before being exhausted to the stack. A typical plant layout is shown schematically in Figure 6.



1. Storage bunker	11. Combustion air fan
2. Plate conveyor	12. Spray tower
3. Charging chute	13. Cooling water drain
4. Oil burner	14. Butterfly valve
5. Combustion cone	15. Fly ash separator
6. Ash hopper	16. Fly ash container
7. Ash container	17. Induced draft fan
8. Furnace	18. Stack
9. Afterburner	19. Control panel
10. Air inlet	

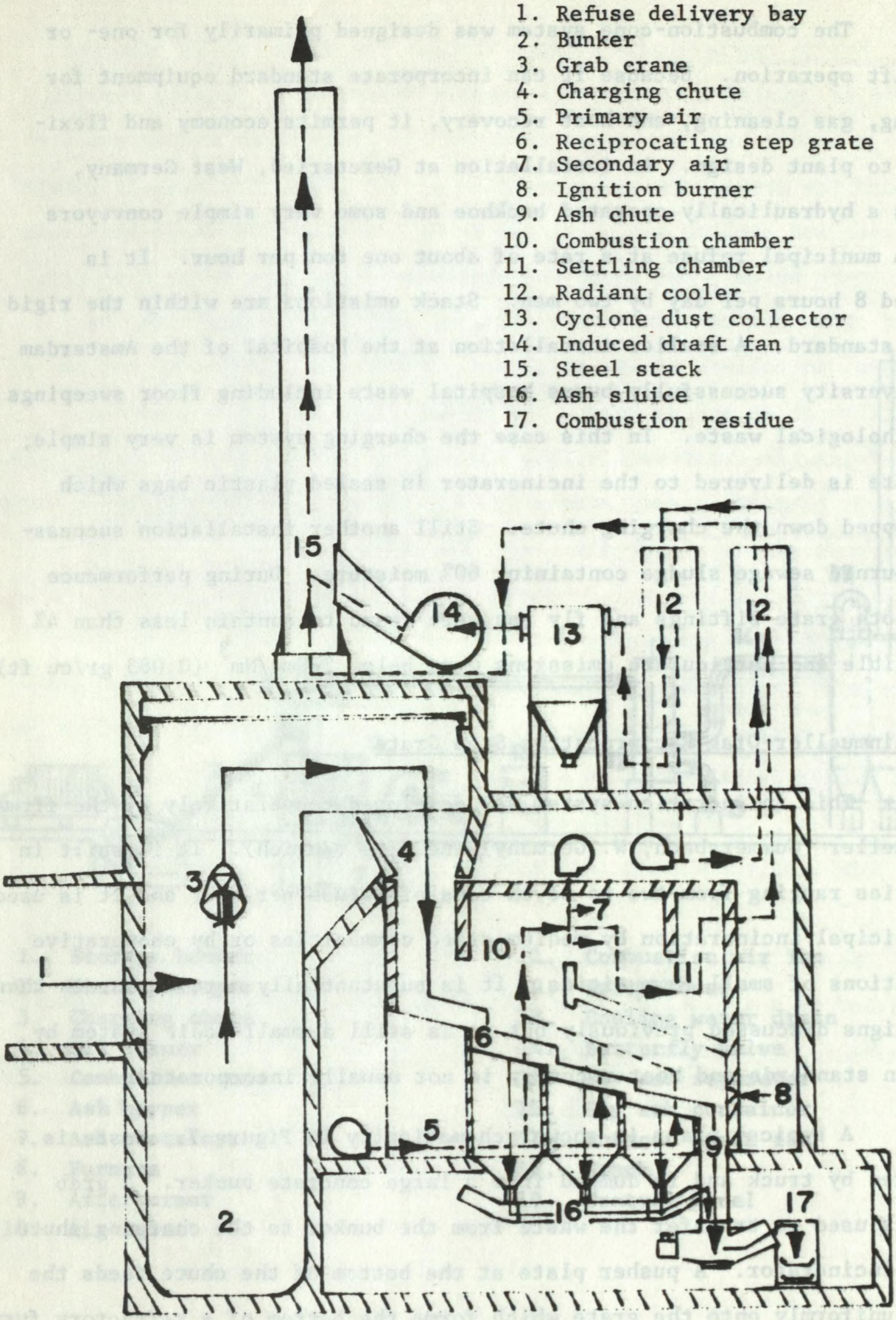
Figure 6. A typical plant layout using a combustion cone incinerator. Taken from Figure 2 of "Modern Incineration for Communities through Private Contractors", Ref. 10.

The combustion-cone system was designed primarily for one- or two-shift operation. Because it can incorporate standard equipment for charging, gas cleaning, and heat recovery, it permits economy and flexibility to plant design. An installation at Geretsried, West Germany, employs a hydraulically operated backhoe and some very simple conveyors to burn municipal refuse at a rate of about one ton per hour. It is operated 8 hours per day by two men. Stack emissions are within the rigid German standard. A smaller installation at the hospital of the Amsterdam New University successfully burns hospital waste including floor sweepings and pathological waste. In this case the charging system is very simple; all waste is delivered to the incinerator in sealed plastic bags which are dropped down the charging chute. Still another installation successfully burned sewage sludge containing 60% moisture. During performance tests both grate siftings and fly ash were found to contain less than 4% combustible and particulate emissions were below 200mg/Nm^3 (0.083 gr/cu ft).

The Steinmueller-Ofag Reciprocating Step Grate

This incineration system was developed cooperatively by the firms Steinmueller (Gummersbach, W. Germany) and Ofag (Zurich). It is built in capacities ranging from two to seven tons of refuse per hour and it is used for municipal incineration by medium-sized communities or by cooperative associations of small communities. It is substantially more elaborate than the designs discussed previously but it is still a small-scale system by European standards and heat recovery is not usually incorporated.

A typical plant is shown schematically in Figure 7. Waste is delivered by truck and is dumped into a large concrete bunker. A grab crane is used to transfer the waste from the bunker to the charging chute of the incinerator. A pusher plate at the bottom of the chute feeds the refuse uniformly onto the grate which forms the bottom of a refractory furnace.



1. Refuse delivery bay
2. Bunker
3. Grab crane
4. Charging chute
5. Primary air
6. Reciprocating step grate
7. Secondary air
8. Ignition burner
9. Ash chute
10. Combustion chamber
11. Settling chamber
12. Radiant cooler
13. Cyclone dust collector
14. Induced draft fan
15. Steel stack
16. Ash sluice
17. Combustion residue

Figure 7. Schematic view of a typical plant using a Steinmueller-Ofag reciprocating step grate. Courtesy OFAG, Zurich.

The grate consists of three inclined sections arranged in series, with vertical drops of 1.5 to 3 ft between sections. Blowers provide both underfire and overfire air and an ignition burner in the rear wall serves to ignite the refuse when the incinerator is put into service. Normally if the heat generated by the burning refuse is sufficient to achieve complete odour-free incineration, the ignition burner is turned off automatically when the furnace reaches the desired operating temperature. However, if the refuse has a very low calorific value, or is very wet, the ignition burner may be used as a support burner.

The residue from the grate falls into a quench tank. A drag conveyor moves it out of the quench tank onto a conveyor belt, thence to a storage bunker, whence it is hauled away by truck.

The flue gas passes through the furnace, which is baffled to provide a settlement chamber for fly ash, into a pair of radiant coolers arranged in series. The flue gas is then exhausted through a cyclone collector to the stack. The radiant coolers are simple heat exchangers cooled by air from a blower. Their purpose is to reduce the gas temperature enough to permit the use of mild steel in the construction of the cyclones and the induced draft fan. The indirect heat exchange avoids increasing the size of these components, as would be necessary if cooling were achieved by dilution with air. The hot air from the coolers is also vented to the stack and helps to maintain a high plume rise. Alternatively, the coolers and cyclones may be replaced by spray towers and electrostatic precipitators or one of several other possible combinations.

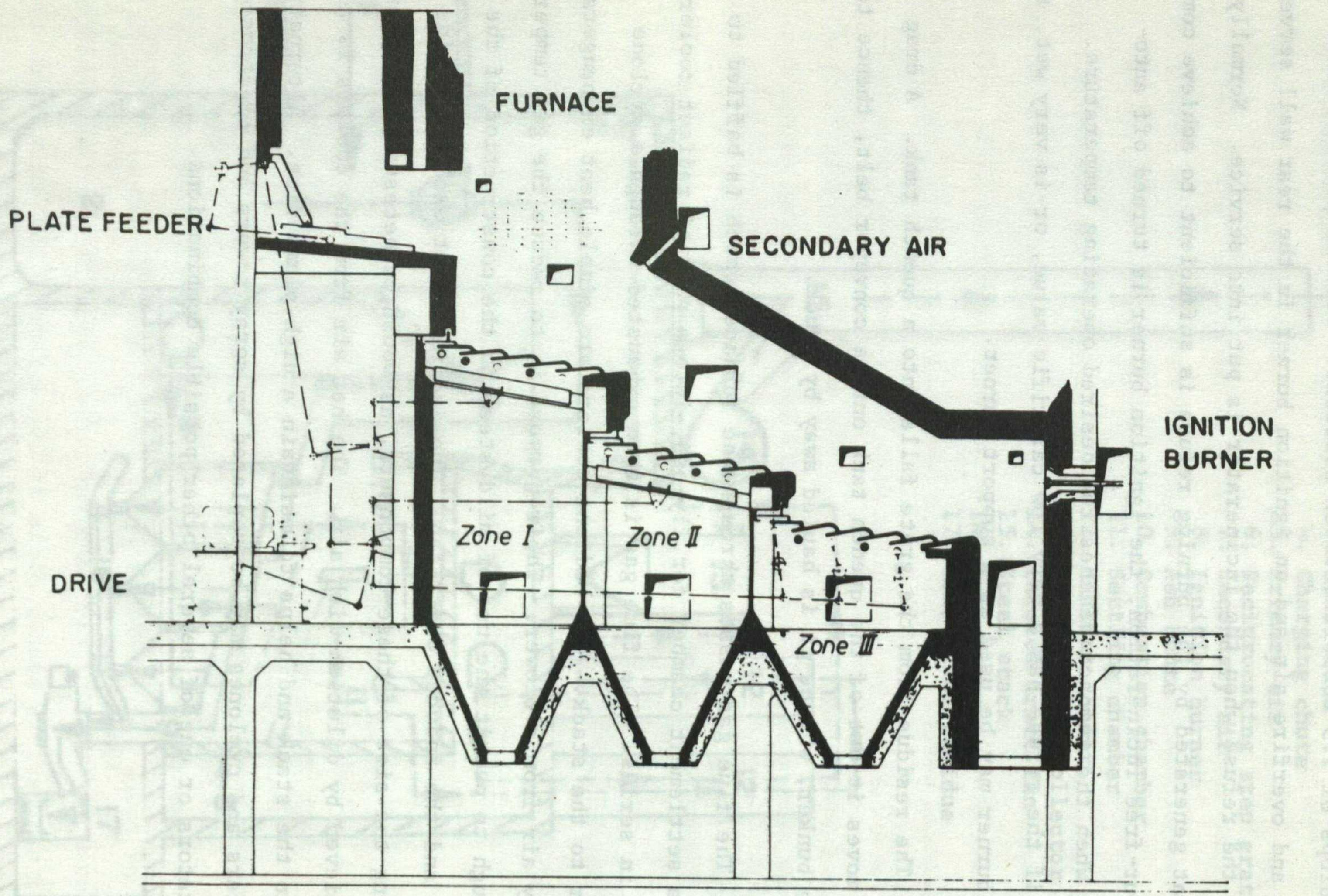


Figure 8. Schematic sectional view of the Steinmueller-Ofag reciprocating step grate. Courtesy L. & C. Steinmueller, GMBH, Gummersbach, W. Germany.

The grate, as a key component of the incineration system, deserves more detailed consideration. As shown in Figure 8, each section is composed of several overlapping rows of grate bars which are cast from a high-temperature alloy. Alternate rows are reciprocated by a stoker drive mechanism through a stroke ranging from 0 to 8 in., with the stroke in each grate section being separately adjustable. The speed of reciprocation is also adjustable. A separate windbox under each grate section permits the operator to control under-fire air distribution. The plate feeder at the bottom of the charging chute is also adjustable with respect to stroke and speed. In practice, it is usually adjusted to place about a 3-ft layer of refuse on the first grate section. This layer is subjected to rapid heating by radiation from the rear arch and the counter-current flame travel. This serves to dry and ignite the refuse but relatively little under-fire air is supplied. As the reciprocating action of the grate pushes the refuse forward, it falls off the lower edge onto the second grate. The fall serves to loosen up the refuse charge, and mixes the burning refuse with that which is not yet ignited. At this stage, ample under-fire air is supplied, and the major part of the refuse is burned or volatilized. The gaseous products must pass through a row of over-fire jets to reach the furnace; thus, turbulence and air for complete combustion are provided. The third grate section is essentially a burn-out zone. under-fire air is kept to a minimum, but sufficient temperature and residence time are available to ensure that the residue eventually dumped into the quench tank is low in combustible and essentially free of putrescible. These units normally operate with 50 to 80% excess air.

By virtue of carefully thought-out plant layout and a high degree of automation, plants such as this can be operated with a minimum of personnel (11). The author visited an installation in Switzerland which burned 3 tons of municipal refuse per hour on a one-shift basis and was operated by three men. One of these was the chief who weighed the

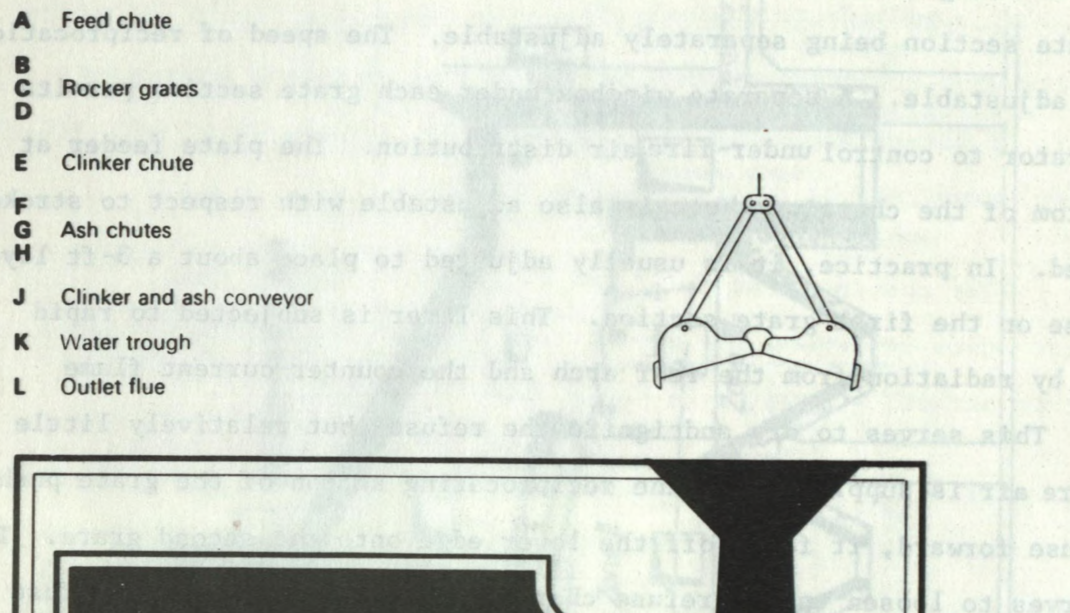


Figure 9. Sectional view of a Heenan-Nichols Rocking Grate Incinerator. Courtesy Heenan & Froude Limited, Worcester, England.

garbage loads and kept the plant records. The second was the incinerator operator who charged the refuse into the incinerator and loaded the residue onto the trucks. The third was a caretaker-maintenance man whose chief duties seemed to be polishing the control room floor and the brass fittings.

The Heenan-Nichols Rocking Grate Incinerator

This system is of a relatively recent British design, and units with refuse capacities up to 10 tons/hr have been built. Figure 9 shows the furnace and grate in section. Refuse is transferred from a storage bunker to the incinerator hopper by a grab crane and falls directly onto the first of three inclined grate stages. The hopper is kept full to prevent the escape of furnace gases; therefore, the initial fire-bed tends to be about 4 ft thick. Each grate stage is about 11 ft long, and is made up of rows of segment-shaped cast-iron bars with air spaces between them. Through a hydraulically operated drive mechanism each row can be tilted forward through an angle of about 80° as shown in Figure 10. By means of an automatic timer control, alternate rows in all three stages rock together. This action serves to move the burning refuse down the grate. Each grate stage has a separate windbox and combustion air is supplied as necessary. Essentially, drying and ignition occur on the first stage, vigorous combustion takes place on the second stage, and burn-out is completed on the third stage. Over-fire nozzles are provided in the front arch of the furnace, but are used only to reduce furnace temperature if necessary.

The furnace is of refractory construction with silicon carbide bricks in the sidewalls along the grate, where abrasion is likely to occur, and high-alumina firebrick elsewhere. An air curtain behind the brick serves to cool the refractory. Operating conditions are adjusted to maintain the furnace temperature between 1400 and 1600°F.

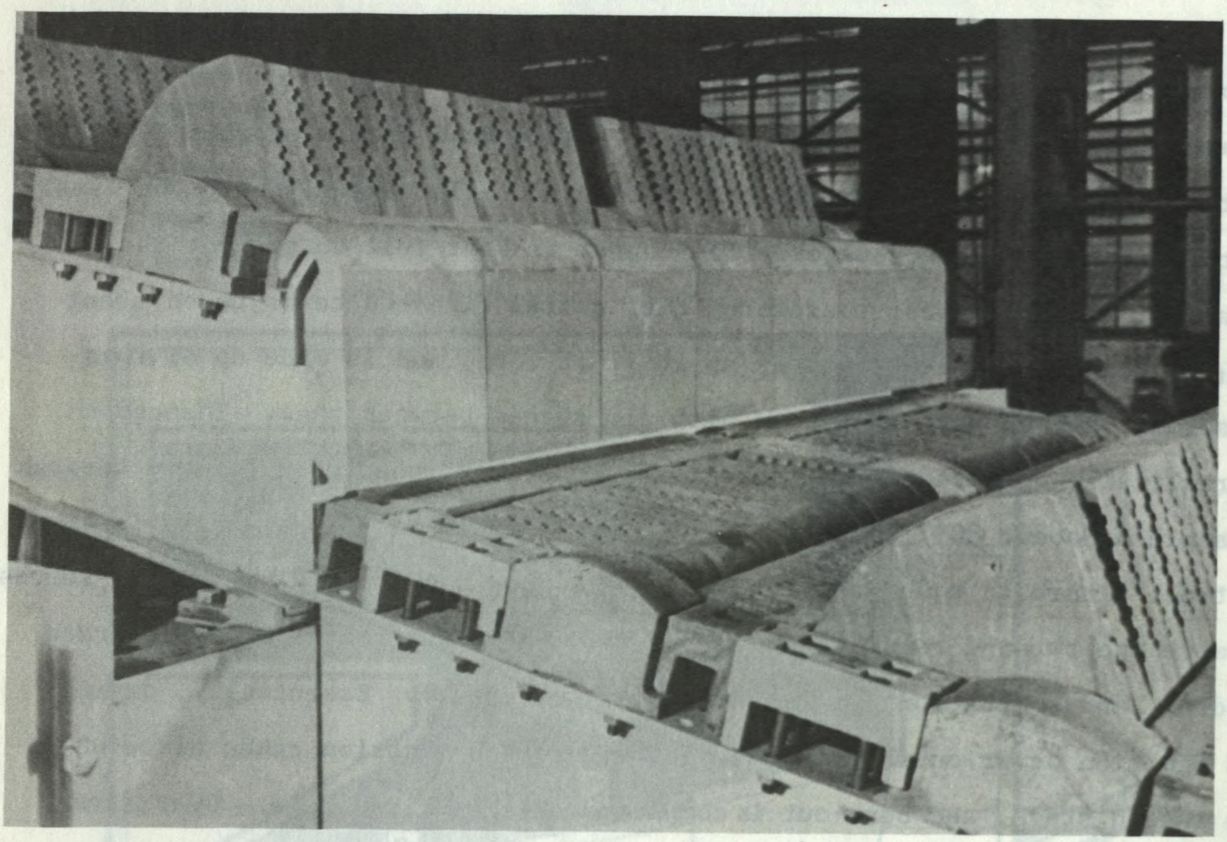


Figure 10. A view of the Heenan-Nichols rocking grate showing some grate sections in the raised position. Courtesy Heenan & Froude Limited, Worcester, England.

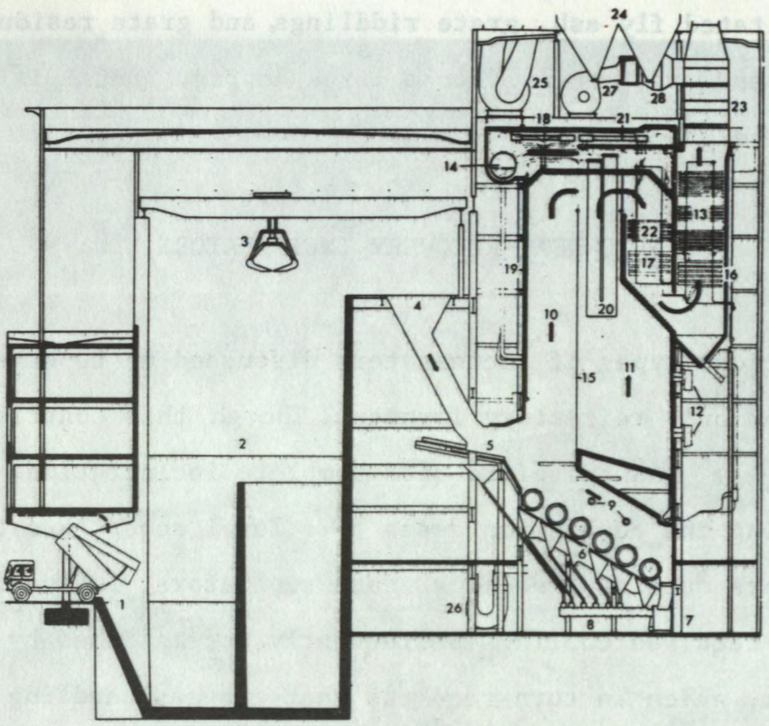
Flue gas treatment may vary from plant to plant. At Basingstoke, England, the installation was built in conjunction with a sewage treatment plant and, therefore, it can use cheap clarified water in a spray tower to reduce the gas temperature to 600°F. The gas then passes through an electrostatic precipitator to a 160-ft chimney.

Precipitated fly ash, grate riddlings, and grate residue are quenched in a water tank and conveyed to a large hopper. Metal is separated magnetically, baled, and sold.

LARGE HEAT-RECOVERY INCINERATORS

The various types of incinerators discussed up to this point have one feature in common - refractory furnaces. Though this contributes to high furnace temperatures and therefore aids complete incineration, it creates problems of cooling the combustion gases to a level acceptable to gas-handling components such as breeching, dust separators, induced draft fans, and stacks. The required cooling is frequently accomplished by massive dilution with air, which in turn requires that the gas-handling components be sized to accomodate the additional volume. Cooling may also be accomplished by spray towers or radiant-heat exchangers, each of which present problems of their own.

A more advanced class of incinerator is now gaining popularity, particularly in western Europe. This is the large municipal installation, with unit capacities ranging from 5 to 50 tons of refuse per hour. There are several designs of incinerator in this class but common features are:



1 Refuse dumping point
2 Reception pit
3 Refuse crane
4 Refuse feed hopper
5 Refuse push feeder
6 "Düsseldorf System" Roller Grate
7 Wet type ash extractor
8 Worm conveyor for grate riddlings
9 Oil light-off and stabilizing burners for roller grate
10 Refuse pass
11 Oil pass
12 2 x 3 main oil burners
13 Economizer
14 Boiler drum
15 Gastight membrane tube wall
16 Primary superheater, 1st stage
17 Primary superheater, 2nd stage
18 No. 1 spray attemperator
19 Radiant type superheater on front wall of refuse pass
20 Platen superheater
21 No. 2 spray attemperator
22 Final superheater
23 C.I. gilled-plate airheater
24 Electrostatic precipitator
25 I.D. fan
26 Flue-gas recirculation fan
27 F.D. fan
28 Steam coil airheater

Steaming capacity 125 tons/hr
Design pressure 77 kg./sq.cm.gauge
Superheated steam 525 deg.C
when burning heavy fuel oil alone and when burning heavy fuel oil in combination with 20 tons/hr of refuse throughput.

Figure 11. A sectional view of the Stuttgart-Muenster Incineration plant, a typical arrangement of the Duesseldorf-System roller grate. Courtesy Vereinigte Kesselwerke, A.G. Duesseldorf, W. Germany.

heat recovery by means of a boiler, some form of mechanical grate which provides agitation of the refuse, moderate levels of excess air, little or no auxiliary firing, fly-ash collection by electrostatic precipitators, and recovery of ferrous metal from the residue. Essentially, these incinerators are boilers burning a low-grade fuel. The steam generated may be used for power generation, as in Amsterdam; for heating feedwater in a large thermal generating station, as in Munich; for district heating, as in Hagen; or, as in some cases, it may be wasted via air-cooled condensers. Even though no use can be made of the steam, these incinerators are often built in conjunction with boilers because this tends to be cheaper than all-refractory construction, particularly in large sizes.

The most popular designs of heat-recovery incinerators are briefly described in the following.

The Duesseldorf-System Roller Grate

Roller-grate incinerators have been built in capacities ranging from 5 to 25 tons of refuse per hour, and a typical arrangement is shown in Figure 11. In this instance, rated throughput is 25 tons/hr with refuse having a net calorific value of 2,100 Btu/lb. The refuse is burned without support fuel firing but heavy oil is fired into a separate furnace to maintain a boiler steaming capacity of 275,000 lb/hr for power generation. It should be emphasized that the oil-firing system has nothing to do with the incineration system; the plant is essentially a thermal generating station which burns refuse to reduce its consumption of fuel oil.

Refuse is dumped from trucks into a bunker which has sufficient storage space to allow continuous operation of the incinerator, even though refuse is delivered on a 40-hr week basis. A travelling crane transfers the refuse to the incinerator charging chute which has a pusher feeding

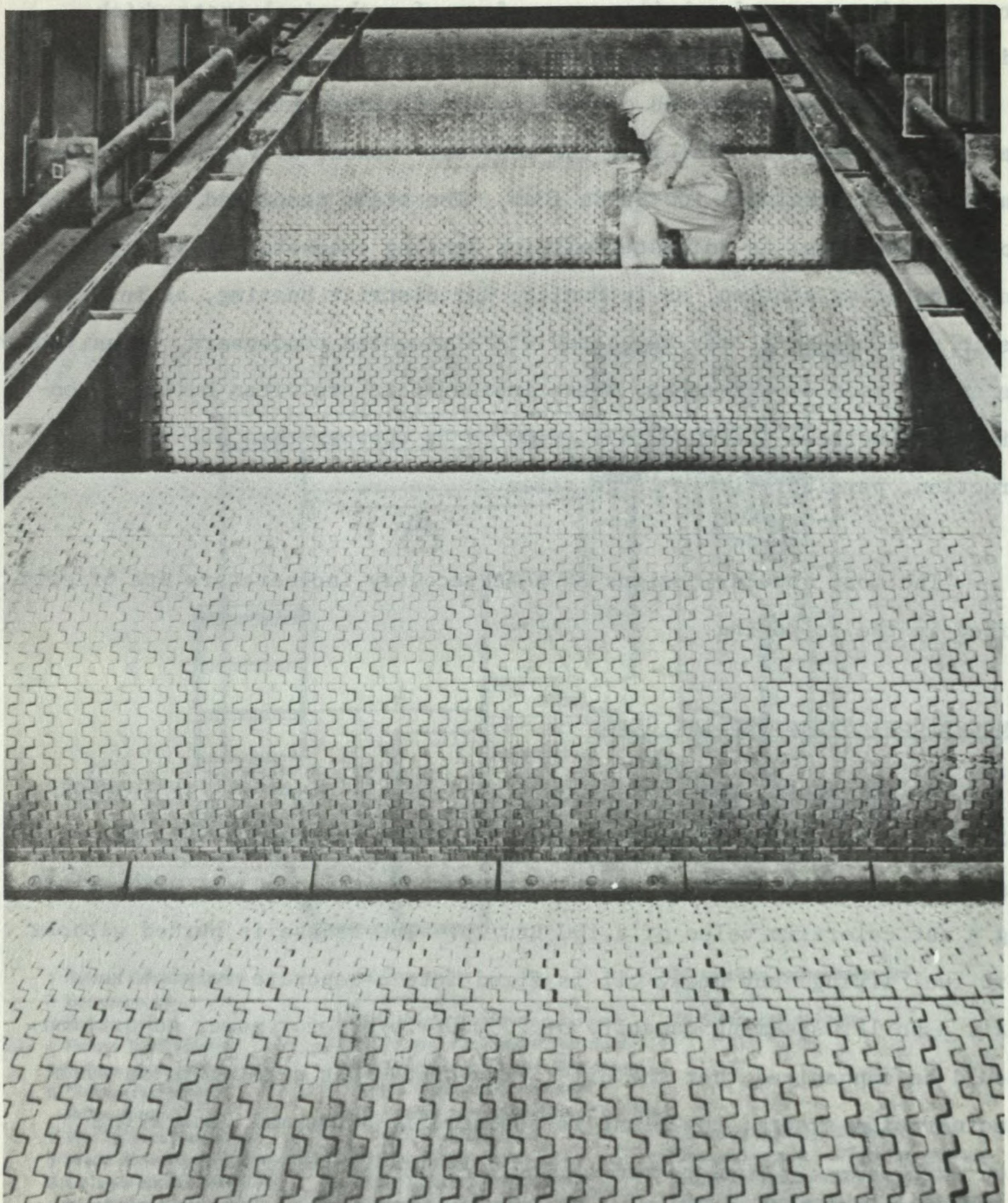


Figure 12. A view of the Duesseldorf-System roller grate during assembly. Courtesy Vereinigte Kesselwerke, A.G. Duesseldorf, W. Germany.

mechanism at the bottom. During operation, the chute must be kept full of refuse to seal the furnace from the bunker. A gate is provided to close the chute when the incinerator is taken out of service. The feeder charges the refuse onto the grate, which consists of six rollers, approximately 5 ft in diameter, and up to 10 ft wide, depending on the capacity of the unit. The rollers are made up of cast-iron segments mounted on a cylindrical framework as shown in Figure 12. Each has its own windbox and its own reversible variable speed drive. In general, drying and ignition occurs on the first roller, active combustion occurs on the next three rollers, and burn-out is achieved on the last two rollers. The tumbling action provided by the rollers continually exposes fresh refuse surfaces, and leads to good mixing and thorough combustion. By adjusting the rotational speed of and the air flow through each roller, the distribution of fuel and rate of combustion can be controlled. The residue falls into a quench tank and is removed mechanically. Magnetic separators are usually installed to recover ferrous metal.

A refractory-covered rear arch helps to maintain furnace temperature, and over-fire air jets located near the top of the arch provide secondary air and turbulence. A tall radiant furnace provides ample residence time, and gas velocities are kept low to minimize fly-ash entrainment. The flue gas then passes through convection banks, superheaters, economizers, air heaters, and finally, at a temperature of about 350°F, through a dust collector and an induced draft fan to the stack.

Experience with this system has resulted in the evolution of a furnace wall construction wherein watercooled tubes are brought down along the grate. The tubes are studded and covered with silicon carbide refractory up to the maximum flame height in the furnace. The refractory helps to protect the tubes against corrosion, while the tubes cool the refractory so that molten ash is less likely to stick to it than if the refractory were at a higher temperature.

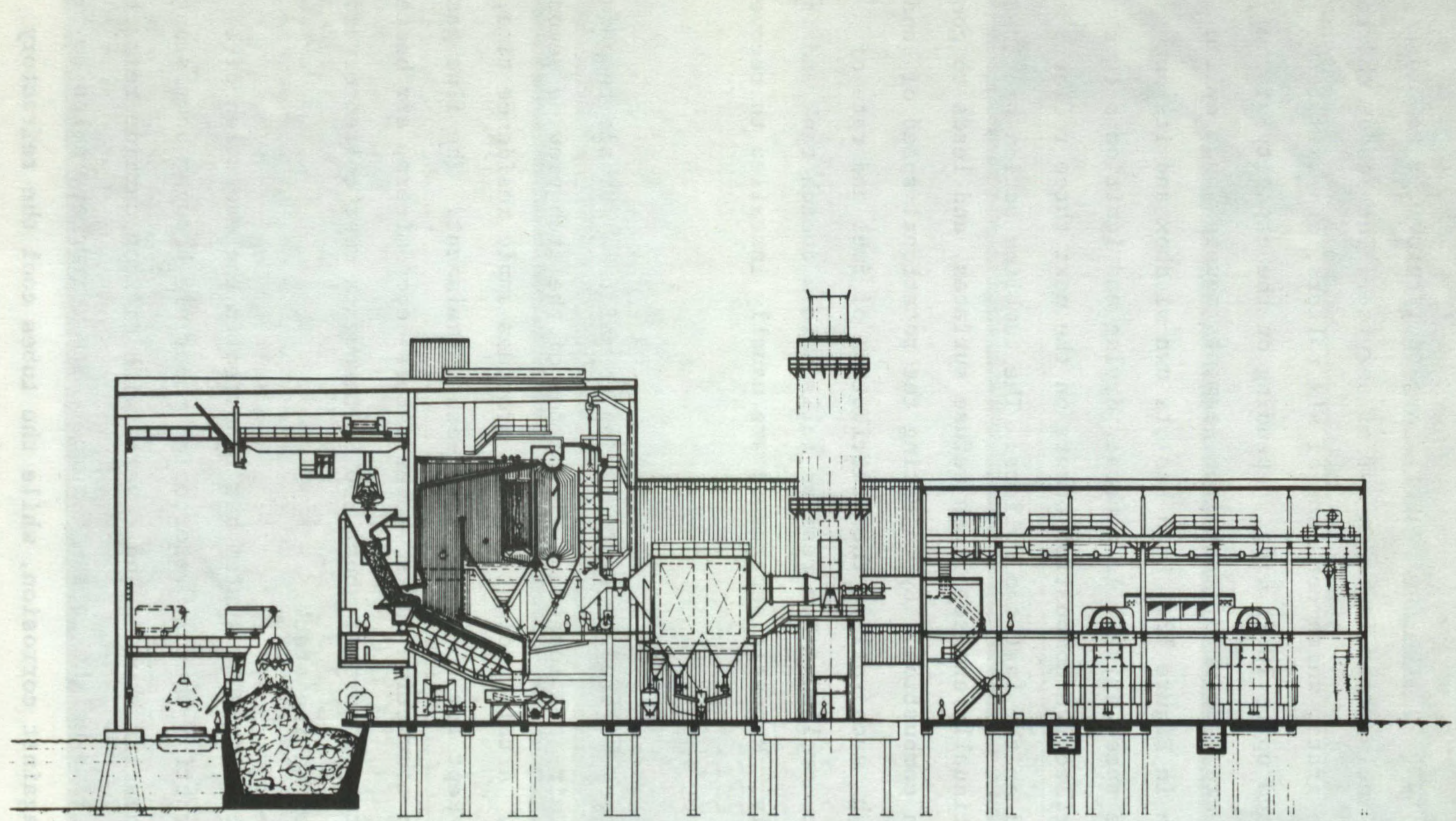


Figure 13. A sectional view of the Amsterdam incinerator plant with Martin grates. Courtesy Josef Martin Feuerungsbau, GMBH, Munich.

German standards require that incinerator residue not exceed 5 wt % combustible and 0.3 wt % putrescible and that dust loading in the stack not exceed 150 mg/Nm^3 (0.0656 gr/cu ft). The roller-grate incineration system generally meets the first two requirements without difficulty and is almost invariably equipped with high-efficiency electrostatic precipitators to meet the third requirement.

Another example of a roller-grate incinerator is the Greater London Council's Edmonton Plant, which was described at the Brighton Conference (12).

The Martin Reverse-Acting Reciprocating Grate Incinerator System

The Amsterdam incinerator plant, shown schematically in Figure 13, is in most respects a typical example of an incinerator with a Martin grate. This plant consists of four units, each rated at 20 tons of refuse per hour and capable of generating 95,000 lb of steam per hour. The net calorific value of the refuse ranges from 3,150 to 4,050 Btu/lb. The steam is used to generate electricity, which is fed into the Dutch grid system. The plant may be called on at any time to provide up to 33 MW. This can normally be achieved by burning refuse, but should refuse not be available as may happen on weekends, auxiliary light-oil burners can be used. The plant normally operates 24 hr/day for 5 days a week.

The plant is located on a canal, and refuse may arrive either by barge or by truck. Cranes unload the barges into a bunker, and move refuse from the bunker into the incinerator charging chutes. Bulky refuse, such as crates and discarded furniture, is first shredded in a hammermill. A hydraulically driven feed ram moves the refuse from the bottom of the chute onto the grate.

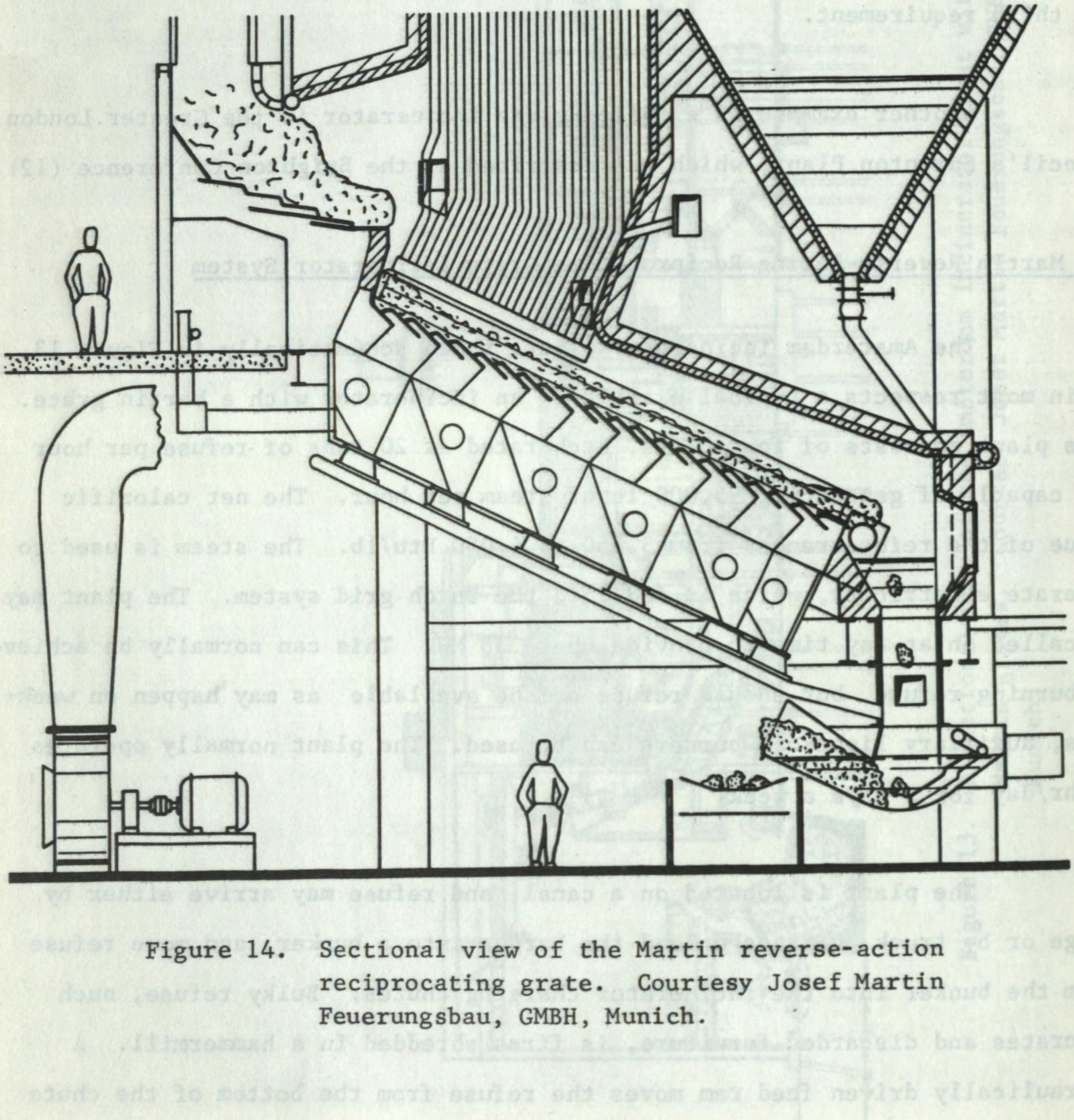


Figure 14. Sectional view of the Martin reverse-action reciprocating grate. Courtesy Josef Martin Feuerungsbau, GMBH, Munich.

The grate arrangement is shown in more detail in Figure 14. It can be seen that the charging hopper is so arranged that the refuse is exposed to furnace temperature and is likely to be ignited before it drops to the grate. The grate itself consists of 17 rows of alloy bars which are arranged in three longitudinal sections, each about 7 ft wide. Every second row of bars reciprocates approximately half of its length, and it can be seen from the way the bars overlap that this tends to push the bottom layer of refuse toward the feeder end of the grate. Thus, ignited refuse is continually mixed with unignited refuse, residence time is prolonged, and good burn-out is achieved. With this type of stoking action, the ash tends to clinker and the clinkers work their way along the top of the fire-bed to the grate discharge. There, a slowly rotating roll conveys the residue into a chute leading to a quench tank. The speed of the roll controls the fuel bed thickness.

The grate is designed for high air resistance, having only 2% air opening. This minimizes fly-ash entrainment. The under-fire air system incorporates elaborate controls; each of the three grate sections has six windboxes and the air flow to each of the 18 windboxes is automatically controlled according to the firing rate. The operator can bias the proportioning of air up to 20% either way. These units normally operate with 50% excess air, 20% to 25% of the total air being injected through front and rear over-fire nozzles. The fire-bed tends to be thin (2 ft or less in thickness) and almost the entire grate surface is involved in active combustion. Since fire-bed thickness is determined by optimum combustion rates, grate length is determined by residence time requirements and is essentially constant for incinerators of different capacity. The desired capacity is achieved by varying grate width, and units burning up to 50 tons of refuse per hour have been built.

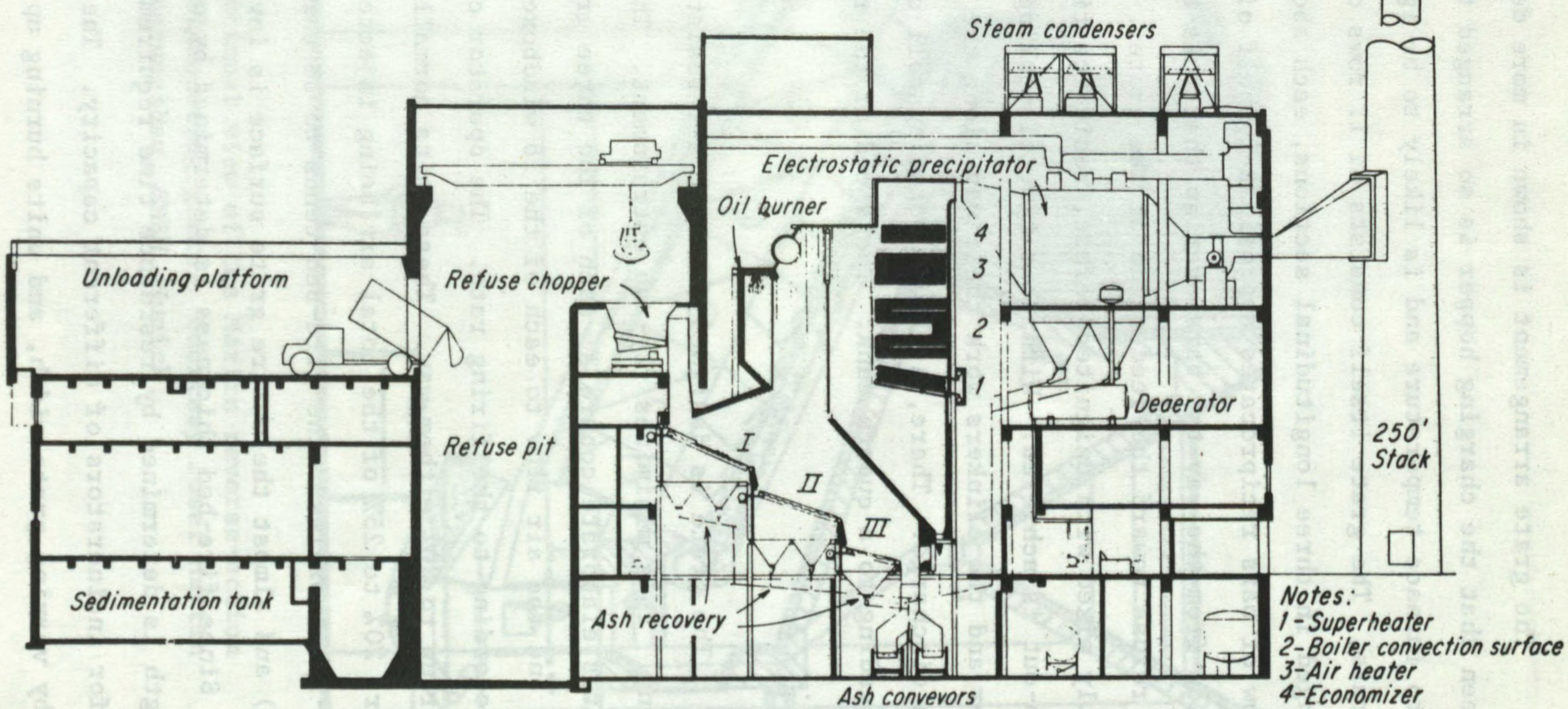


Figure 15. Sectional view of an incinerator unit in the Montreal plant.
Taken from "Montreal Incinerator is Twofold Innovator", Ref. 16.

The furnace incorporates a refractory rear arch, but is otherwise cooled to the grate line. However, the tubes at the level of the refuse bed are protected against abrasion by Bailey blocks and, above this, they are studded and clad with silicon carbide refractory to the elevation of the maximum flame travel. This is to protect the tubes against corrosion but it is argued that the layer of refractory must be thin to avoid slag formations. The Amsterdam plant was designed to meet the emission standards of West Germany; therefore, it is equipped with high-efficiency electrostatic precipitators. The fly ash collected is sold for road-building purposes. The grate residue is cleared from the quench tank by a pusher mechanism and transported by conveyor belt to a crusher. Following the crusher are a magnetic separator and a screening plant. The separated metal is baled and sold as scrap, while the remaining residue, screened into two sizes, is sold as road fill.

In the case of the Amsterdam incinerator plant it is estimated that the proceeds from the sale of electricity, scrap iron and ash reduce the cost of incinerating refuse from about $7.50 a ton to $4.00 a ton.

Other examples of Martin incinerators have been well documented in the technical literature (13, 14).

The Von Roll Reciprocating Step Grate Incinerator

Von Roll incinerators are built with refuse throughput ranging from 1 ton/hr to 15 tons/hr, but the large units as purchased by the City of Montreal are more common (15). Each of the four Montreal incinerators is rated at 13 tons of refuse per hour and is shown in section in Figure 15 (16).

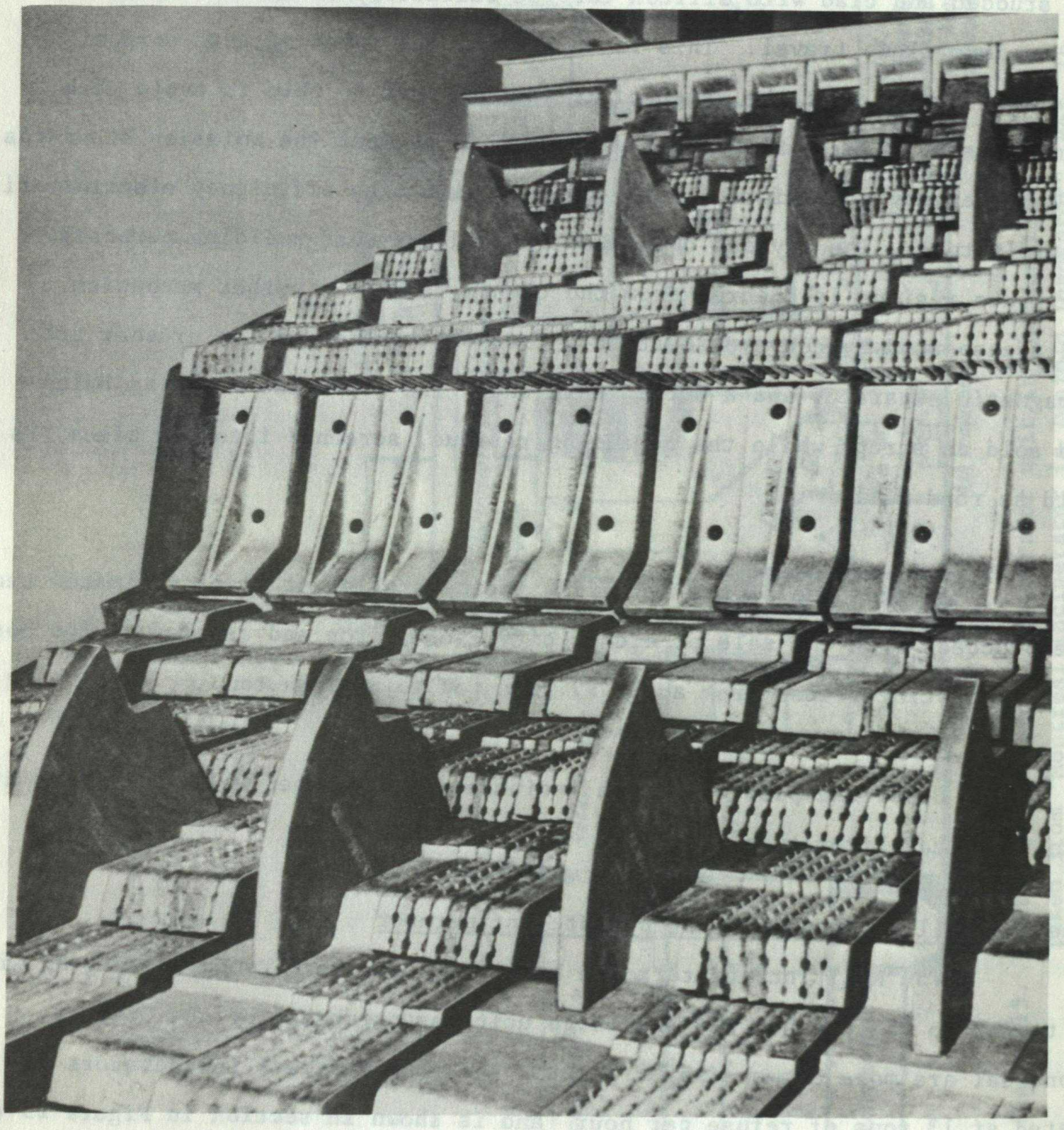


Figure 16. A view of a Von Roll incinerator grate with the grate blades in the raised position. Courtesy Von Roll, A.G., Zurich.

As with the large plants described previously, there is a truck unloading platform, a bunker, and a travelling crane to charge the incinerators. Each incinerator comprises a grate, a furnace, a boiler, an electrostatic precipitator, a quench tank, and ash conveyors. A large shear is provided to reduce bulky refuse, and the incinerators are charged by vibrating chutes.

The grates are cast in a high-chromium alloy and are of an inclined reciprocating design, with alternate columns rather than rows, reciprocating through a stroke of about 6 in. Large incinerators have three grate sections, smaller ones have two sections. The sections are separated by vertical distances of 3 to 5 ft to provide a tumbling action which loosens the refuse and exposes fresh surface. Commonly, the first section, which serves as a drying and ignition zone, is about 8 ft long and the next two are about 15 ft long. However, if wet refuse is anticipated, the designer may switch the first and third zones. Most of the combustion takes place on the second grate, while burn-out is completed on the third grate. The second and third grates are equipped with hydraulically driven blades which are periodically actuated by a timer. These serve to further loosen the fuel bed and promote complete combustion. Figure 16 shows them in the raised position.

The windbox has zone controls, and over-fire air nozzles are located in the side walls. The incinerator operates with 50% and 110% excess air, the quantity being adjusted to maintain furnace temperatures between 1470 and 1750°F. The total air is generally distributed as follows: up to 30% through the overfire nozzles, 10% to 15% through the first grate section, 10% to 15% through the third section, and the remainder through the second section.

The furnace has front and rear refractory arches and the boiler tubes do not extend down to the grate. Instead, the furnace side walls are built up of silicon carbide bricks to above the refuse level, and high-temperature refractory is used from there to the lower end of the furnace tube sections. Furthermore, the tubes are studded and covered with silicon carbide refractory to well above the maximum flame level. Again, this is a precaution against corrosion.

The Montreal incinerators are each capable of generating steam at the rate of 100,000 lb/hr when burning refuse alone. Unfortunately, at present there is little market for the steam produced and most of the heat is wasted via air-cooled condensers.

The Suspension-fired "SWARU" System

The heat recovery incinerators described up to this point, while differing in detail, are similar in concept. Waste is burned in the form in which it is delivered. Mixing may be carried out in the bunker and items too bulky to pass through the feed chute are crushed but, otherwise, the incinerator is expected to deal with unprepared waste, be it scraps of paper or discarded hot-water tanks.

A significant departure from established methods is represented by the East Hamilton Solid Waste Reduction Unit, or "SWARU", now under construction (17, 18). The chief feature of this system is that all waste is shredded by large hammermills when it arrives at the plant. This results in several advantages, the first being that the shredded waste can then be handled by conveyors, which are considered to be cheaper and more reliable than travelling cranes. Furthermore, shredding is an excellent way of mixing the refuse, and increases the bulk density, hence the storage volume requirements are reduced. The design of the shredders permits dense material to be separated ballistically. Therefore, scrap metal and some glass can be removed ahead of the incinerator.

The rest of the system is patterned after installations for burning bark or bagasse. Shredded waste is conveyed to storage tanks, is drawn off from the bottom of the tanks, and is pneumatically injected into the furnace. With this arrangement, perhaps half the waste burns in suspension; this reduces the combustion load on the grate which is a conventional single-stage travelling grate with no zoning of the windbox. Substantial over-fire air is provided. It is anticipated that the grate will operate with a 10-in. fire-bed and that the ash reaching the ash-pit will have cooled sufficiently to make quenching unnecessary. Electrostatic precipitators are provided to clean the flue gas.

The boiler is of conventional design, with a membrane-wall furnace having bare tubes down to grate level. Plant auxiliaries are equipped with turbine drives to utilize as much as possible of the steam produced. The remainder may be sold.

The present phase of construction provides for two units burning a total of 600 tons of refuse per 24-hr day, and producing 200,000 lb of steam per hour. Completion is scheduled in 1971.

If this system proves satisfactory, it will be an important Canadian contribution to incinerator technology because estimated capital cost is about 30% less than equivalent plants of European design.

THE POTENTIAL FUEL MARKET IN INCINERATION

An accurate assessment of the potential fuel market offered by incineration in any given area would require an extensive survey and careful thought. However, there are various guidelines which can be used to obtain a rough estimate and the results are rather startling. For example, the New York code suggests that residential waste is produced at the rate of 1.44 lb/person/day (6), although other authorities suggest as much as 5 lb/person/day. However, on the basis of the lower figure, if the population of Metropolitan Toronto is assumed to be 2.5 million, the daily production is about 3.5 million lb/day of Type 2 waste. Let us assume that all this waste is burned in multiple-chamber incinerators equipped with gas-fired support burners. Let us further assume - as inferred from Section 6 (a) of the Ontario Criteria - that the residence time in the incinerator is 1 hour. For Type 2 waste, the Ontario criteria require support firing at the rate of 4,000 Btu/hr/lb of waste (1). On the basis of these assumptions, incinerating only the residential waste in Metropolitan Toronto could require 14.4 million cu ft of natural gas per day. This is roughly equivalent to 15% of the fuel requirement of the R.L. Hearn generating station.

Industrial, commercial and institutional waste would have to be considered as additional to the foregoing. Using the guidelines in Section 6 of the Ontario criteria, one can quickly make the following estimates.

An office building having 100,000 sq ft of floor space would produce about 1,000 lb of Type 1 waste per day, which would require about 1,000 cu ft of natural gas for incineration.

A department store having 100,000 sq ft of floor space would produce about 4,000 lb of Type 2 and Type 3 waste per day, which would require 16,000 to 20,000 cu ft of natural gas for incineration.

A supermarket having 20,000 sq ft of floor space would produce about 1,800 lb of Type 3 waste per day, which would require 10,800 cu ft of natural gas for incineration.

A hotel having 500 rooms would produce about 2,500 lb of Type 3 waste per day and would require 15,000 cu ft of natural gas for incineration.

A hospital having 500 beds would produce about 4,000 lb of Type 2 and Type 3 waste per day plus perhaps 2,500 lb of pathological waste per day. (Some authorities consider the estimate of 5 lb of pathological waste per bed per day to be rather high.) The total waste could require up to 44,000 cu ft of natural gas for incineration.

The foregoing examples demonstrate that incineration is a substantial potential market for natural gas, even though most of our waste is not incinerated, not all incinerators require support firing and, of those that do, some may use other fuels.

CONCLUSIONS

The foregoing has attempted to outline the scope of incineration equipment presently available for municipal waste. It ranges from small refractory incinerators capable of burning a few dozen pounds per hour to enormous heat-recovery incinerators burning as many tons per hour. If properly designed and operated, any size of incinerator is capable of operating at acceptable levels of pollutant emission. The choice of system for a particular situation depends, at least to some extent, on the economics of that situation.

The author would now like to take the liberty of expounding his personal views on how we should approach our waste disposal problems. It must be stressed that these views are personal and that the viewpoint is that of a conservationist not an economist.

Except for large cities, landfill, sanitary or otherwise, generally provides the most economical method of waste disposal, if the system is not debited for damage to the environment through water pollution, air pollution, soil pollution and health hazard. The author feels that conventional landfill should be controlled much more strictly, and permitted only in situations where environmental damage can be avoided.

An attractive variation on the landfill technique is to first comminute or shred the waste. This method has been used extensively in Europe, it is practised to some extent in Montreal, and is being experimented with by the Greater London Council. Several advantages are reported. Shredding reduces the volume of waste by about 50%. Daily covering with soil is not necessary. Waste decomposes more rapidly when shredded, settling is reduced, and stable soil conditions are achieved in a few years. Shredded refuse has little or no odour, blowing of paper is minimal, and rats and other pests are not attracted to it. Finally, trucks and heavy equipment can travel on shredded waste even in wet weather. Machines suitable for shredding a wide range of wastes are now available, and it is felt that this technique should be incorporated into conventional landfill disposal systems wherever possible.

Incineration, as already pointed out, can be accomplished on almost any scale with minimal pollution. However, small incinerators require support firing and have little or no heat recovery. Large incinerators generally do not require support firing, and furthermore, can produce substantial quantities of useful thermal energy. The author has two basic objections to small incinerators. First, small incinerators have short chimneys, which means that their combustion products are emitted at relatively low levels; large incinerators can be equipped with tall chimneys that provide good dispersion. Second, small incinerators frequently require that good fuel be used to burn poor fuel. Canada, being an industrial nation in a northerly climate, faces an insatiable demand for thermal energy. Our fuel resources, though enormous, are not inexhaustible. Every effort should be made to use waste as a supplementary fuel, and this means large incinerators having heat recovery systems, with sufficient planning to ensure that there is a demand for the heat in the vicinity of the plant.

Typical municipal waste may contain about 40% paper, 7% metals, and 5% glass. At present, our most modern incinerators are content to recover only the ferrous metal. Recycling of paper and glass is virtually unknown. This is rather short-sighted. There is a slowly-growing concensus of opinion that waste is a resource to be thoroughly utilized, rather than an unpleasant problem to be disposed of as cheaply as possible. As conscientious caretakers of our environment, we should reuse our waste (recycle, to use popular terminology) to the fullest possible extent. Unfortunately, reusing tends to be expensive, because it involves sorting the waste, which requires a lot of manpower. As typical children of a technological age, we are inclined to look for automated machinery to solve our waste disposal problems while, at the same time, we are faced with chronic unemployment.

It is recognized that some of the foregoing proposals are economically infeasible, if "economic" means getting a large return on investment in a short time under the existing price structure, or if it means temporarily solving a problem at minimum expense. However, economics change. Frequently one generation destroys resources which are considered to be "low-grade" or "uneconomic" at the time, leaving succeeding generations with no alternative but to utilize even lower-grade resources.

Solid waste may be viewed in three ways: as a problem to be buried, as a low-grade fuel to be burned, or as an important resource to be utilized. At present the first view is predominant but, ultimately, the last view will emerge. The rate at which we change our thinking will be a measure of our social responsibility.

ACKNOWLEDGEMENTS

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