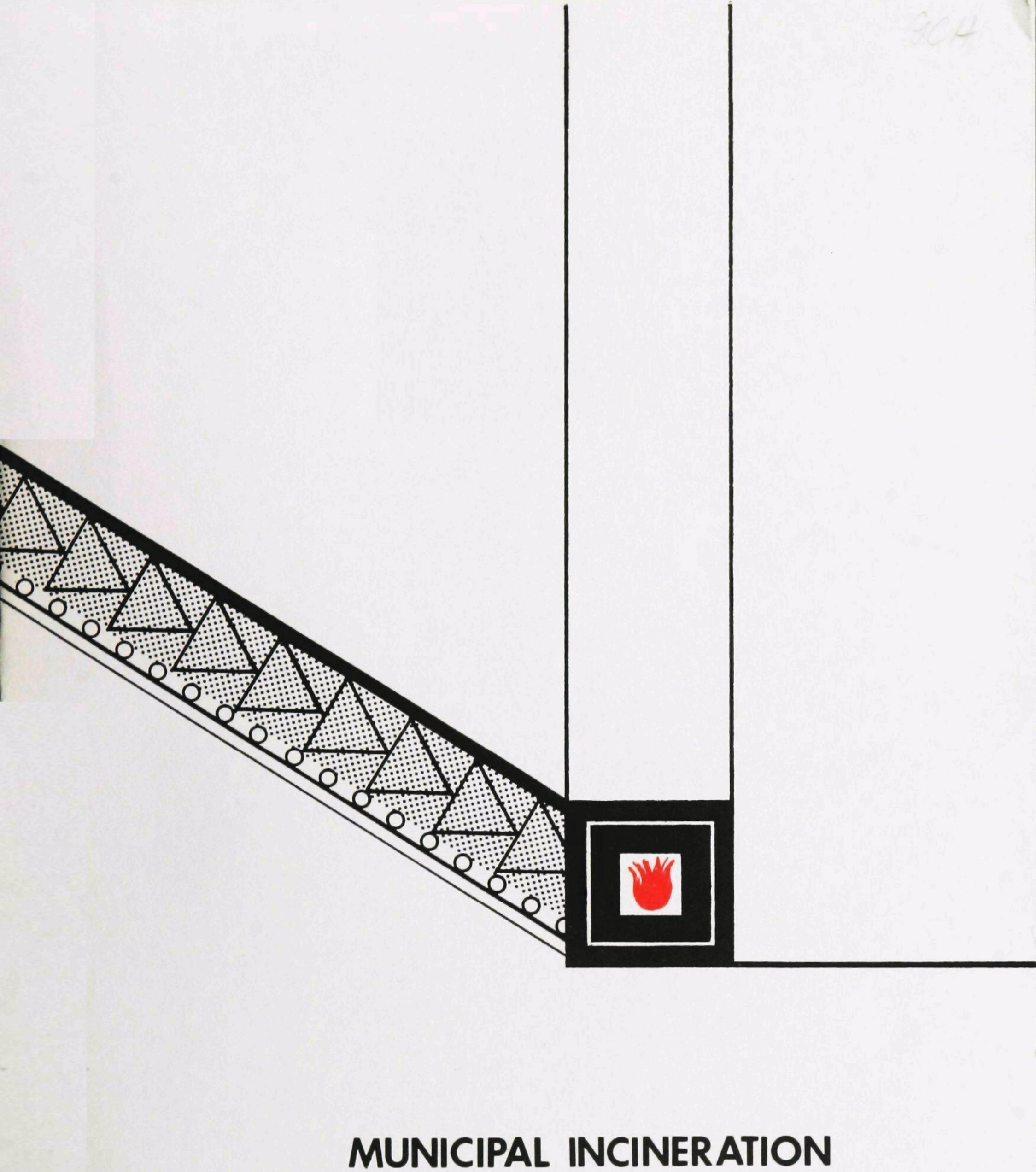

MUNICIPAL INCINERATION

A REVIEW OF LITERATURE

U. S. ENVIRONMENTAL PROTECTION AGENCY

MUNICIPAL INCINERATION:

A Review of Literature

by

James R. Stear
Office of Technical Information and Publications

ENVIRONMENTAL PROTECTION AGENCY
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The author, Mr. James R. Stear, is an employee of the National Oceanographic and Atmospheric Administration, U.S. Department of Commerce. He compiled this report while on assignment with the Office of Air Programs, Environmental Protection Agency.

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FOREWORD

This review is limited to municipal refuse incineration as it is practiced in the United States and several foreign countries. The review discusses incineration of municipal refuse in incinerators that are owned and/or operated either by governmental or non-governmental groups. Such incinerators are large when compared to most non-municipal such as domestic, industrial, and special purpose incinerators. The quantity of refuse generated and its present and future composition, as it relates to the incineration disposal method, is reviewed. A study of incinerators in operation and under construction shows that in the past the United States concentrated mainly on volume reduction. At the same time, European countries were not only concerned with volume reduction, but also the use of refuse as a fuel for steam and power generation. Air pollution control devices for removal of particulate matter are the concern of every country. Electrostatic precipitators, used extensively in Europe, seem to offer one of the better solutions for highly efficient emission control on municipal incinerators in this country.

Alternative refuse disposal methods are mentioned briefly, along with advantages and disadvantages of each method compared to incineration. Such a comparison should be of assistance in the evaluation of the method of incineration for a given locality.

Undoubtedly practices, methods, ideas, and equipment applicable to municipal refuse incineration have been left undiscussed. It is hoped that the cited references and the general bibliography of some 400 entries will lead readers to their special literature needs.

The literature selected for this review is limited generally to that published after 1961. However, some earlier literature, which determined to be an integral part of such a review, is included. Of the several hundred technical publications dealing with municipal incineration that were reviewed, 88 were selected as references for the present study. Additional pertinent references, which were not cited in the text because of constraints of time and space, are included in the appendix. The glossary of incinerator terms at the end of the text includes most of the terms commonly used in discussions of incinerators.

Inclusion of illustrations provided through the courtesy of various manufacturing companies is neither intended to be nor should be construed as an endorsement by the Environmental Protection Agency of the product or company represented.

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1. MUNICIPAL REFUSE

1.1 QUANTITY

The amount of refuse to be disposed of is a basic consideration in the design and operation of a city's refuse disposal facilities. The amount of municipally collected refuse is the total amount produced less the amount disposed of by on-site methods and nonmunicipal methods.

Until recently there has been a lack of information on refuse generation for large areas within the United States. Most of the information has dealt with selected metropolitan areas that are not necessarily representative of other cities or other areas on a nationwide scale. Recently, the first national survey of solid wastes was made by representatives of the Solid Wastes Program of the Public Health Service, state agencies, and consultants.[1] The survey was based on a large sample consisting of 92.5 million people (46 percent of the population of the United States) from 33 states.

1.1.1 Weight

Results of the national survey show that approximately 5.32 pounds of solid wastes per person is collected each day. Table 1[1] summarizes the amount of solid wastes collected in urban and rural areas by category of origin. Because the urban population is much larger than the rural population, the national averages more nearly approximate the urban average than the rural average.

Table 1. AVERAGE SOLID WASTE COLLECTED[1]
(lb/person-day)

Solid wastes	Urban	Rural	National
Household	1.26	0.72	1.14
Commercial	0.46	0.11	0.38
Combined	2.63	2.60	2.63
Industrial	0.65	0.37	0.59
Demolition, construction	0.23	0.02	0.18
Street and alley	0.11	0.03	0.09
Miscellaneous	0.38	0.08	0.31
Totals	5.72	3.93	5.32

Some communities do not collect household and commercial wastes separately, in which case a combined (household and commercial) average is reported.

Table 2. REFUSE PRODUCED, COLLECTED, AND DISPOSED OF IN NEW YORK CITY IN 1959 AND 1960
(tons/yr)

Handled by	Type produced	Amount	Type collected	Amount	Type disposed of	Amount
Department of Sanitation	Garbage and rubbish	2,287,000	Garbage, rubbish, unseparated ashes, and domestic incinerator residue	2,628,000	Garbage, rubbish, unseparated ashes, and domestic incinerator residue	2,628,000
	Garbage and rubbish burned in domestic incinerators. (Only 163,000 tons residue collected)	739,000	Separated domestic incinerator residue	47,000	Separated domestic incinerator residue	47,000
	Ashes (about 10% collected *separately for sale;* balance collected with garbage and rubbish)	250,000	Separated ashes (sold)	25,000	Grit and screenings from Department of Public Works sewage treatment works	40,000
	Grit and screenings from Department of Public Works sewage treatment works	40,000	Grit and screenings from Department of Public Works sewage treatment works	40,000		
Private industry	Burnable construction wastes (90% self-disposed of by onsite burning)	1,140,000	Burnable construction wastes (about 10% of total produced in city)	114,000	Burnable construction wastes	114,000
	Fats, bones, animals, and so forth (collected and disposed of by manufacturers of fertilizers, and so forth)	227,000	Fats, bones, animals, and so forth (collected for manufacturing of glues, oil, fertilizer)	227,000		
Private carriers	Garbage and rubbish	1,250,000	Garbage, rubbish, unseparated ashes	1,500,000	Garbage, rubbish, unseparated ashes	1,500,000
	Ashes (about 50% collected separately for sale; balance collected with garbage and rubbish)	500,000	Separated ashes (sold)	250,000		
	Swill (collected separately for disposal at piggeries)	37,000	Swill	37,000		
Federal and State agencies		168,000		168,000		168,000
Totals						
tons		6,638,000		5,036,000		4,497,000
lb/capita-day		4.54		1.44		3.08

The amount of refuse produced, collected, and disposed of for New York City is given in Table 2.[2] Even though the New York study is relatively old, and New York is not necessarily typical of other cities, the need for studies applicable to local conditions is emphasized. The figures in Table 2 show clearly how the refuse is produced and processed. Of the 4.54 pounds per capita produced per day, 3.44 pounds are collected and 3.08 pounds are disposed of. Refuse that is disposed of in domestic incinerators is obviously not municipally collected or disposed of. Some wastes such as ashes, swill, fats, and bones are collected but are then sold and/or used in various commercial operations.

More refuse is produced per capita in the United States than in Western Europe. Table 3 gives the output of refuse per capita, based on data from large, representative cities both in the United States and Europe.[3]

Table 3. REFUSE OUTPUT IN UNITED STATES AND WESTERN EUROPE[3]
(lb/person)

Yearly output		Daily output
United States		
Range	1,100 - 1,700	3.0 - 4.7
Average	1,450	4.0 (Some authors quote an average *considerably higher)*
Western Europe		
Range	400 - 900	1.1 - 2.5
Average		2.1

1.1.2 Volume

The quantity of refuse produced is also expressed as volume. An approximate figure often used is 108 cubic feet of uncompacted refuse per capita per year,[4] which is equivalent to 30 cubic feet of compacted refuse.

1.1.3 Geographical Areas and Collection Procedures

Table 3 does not delineate how the refuse output varies with geographical area or with local collection procedures. Generally, more refuse is produced annually in warmer climates where there is more yard rubbish. Cities that charge for refuse collection on the basis of quantity are notorious for low production figures.[2]

1.1.4 Seasonal Influences

Seasonal variations in refuse production can be of great importance in the design and operation of municipal incinerators. Peak loads may be the result of spring clean-up campaigns, autumn leaf collection, or the tourist season in a resort town. A plot of seasonal variations of the refuse incinerated in two American cities, shown in Figure 1, shows two different regimes.[2] Hartford, Connecticut, has an annual clean-up campaign that accounts for the peak in

April and May. In the autumn, great quantities of leaves are collected and incinerated. The minimum during July and August is perhaps a reflection of summer vacations. The pattern for Cincinnati, where there isn't an organized spring clean-up campaign, indicates that a more gradual increase in refuse occurs with the onset of spring and summer activities.

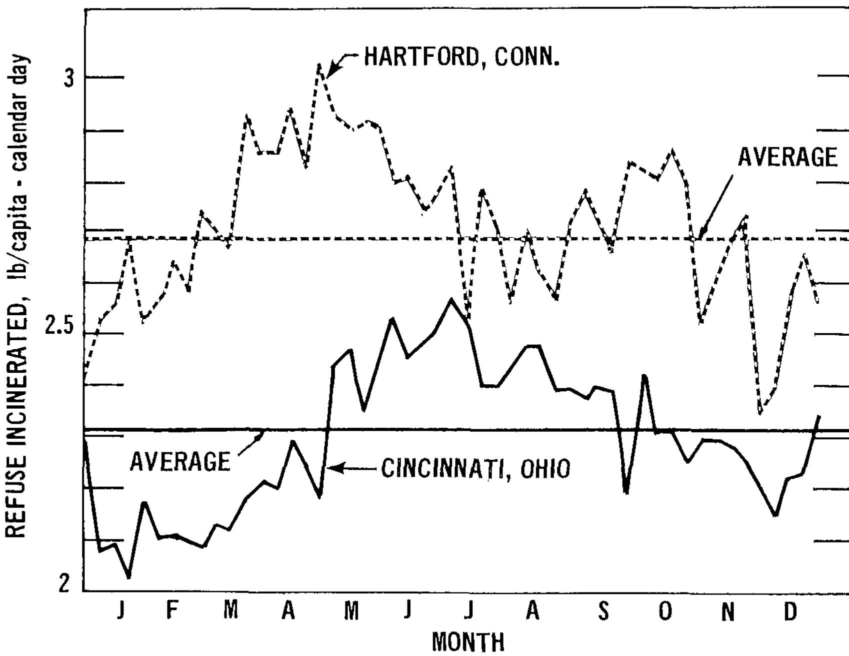


Figure 1. Seasonal differences in amounts of refuse incinerated in Hartford, Connecticut, and Cincinnati, Ohio, 1957.[2]

1.1.5 Projections

A projection of refuse generation and collections entail many considerations such as changes in packing technology, changes in collection procedures, changes in disposal costs, changes in per capita expenditure for consumption of goods, and perhaps most important, the projection of population. One of the most recent projections on a nationwide scale,[1] which assumes that per capita waste production increases at a rate similar to the per capita expenditure for consumption of durable and nondurable goods, shows that the amount of material to be collected through municipal and private agencies will rise to 8 pounds per capita per day by the year 1980 based on a 1968 per capita production of 5.32 pounds. A projection for Kenosha, Wisconsin, (population estimated at 75,000) shows that refuse production will increase from 2.76 pounds per capita in 1965 to 4 pounds by 1976.[5] The per capita projection coupled with the population projection would provide a projection of daily refuse disposal requirements.

1.2 COMPOSITION

The composition of refuse to be incinerated is a major consideration in the design of modern municipal incinerators. The composition of the refuse determines such important quantities as the calorific value, the amount of air required for combustion, the amount of heat released, the characteristics of the exhaust gases produced, and the amount of residue.

1.2.1 Chemical Composition

Refuse can be considered as a combination of moisture, dry combustible material, and noncombustible material. The moisture content of refuse can be either free (visible) or bound (nonvisible). Moisture content fluctuates with the weather, particularly with rain and humidity. A proximate analysis of 20 of the most common combustible components of municipal refuse (see Table 4) shows that vegetable and citrus wastes are highest in moisture content and paper is quite low in moisture content.[6] All samples showed a high loss of combustible carbon. The fixed carbon is that portion of the refuse that has to be burned out on the incinerator grate.

Table 4. PROXIMATE ANALYSIS OF COMBUSTIBLE COMPONENTS OF MUNICIPAL REFUSE AS DISCARDED BY HOUSEHOLDERS[6]
(percent by weight)

Refuse component	Moisture	Volatile matter	Fixed carbon	Ash	Btu/lb As discarded	Btu/lb Dry basis
Newspaper	5.97	81.12	11.48	1.43	7,974	8,480
Brown paper	5.83	83.92	9.24	1.01	7,256	7.706
Trade magazine	4.11	66.39	7.03	22.47	5,254	5,480
Corrugated paper boxes	5.20	77.47	12.27	5.06	7,043	7,429
Plastic coated paper	4.71	84.20	8.45	2.64	7,341	7,703
Waxed milk cartons	3.45	90.92	4.46	1.17	11,327	11,732
Paper food cartons	6.11	75.59	11.80	6.50	7,258	7,730
Junk mail	4.56	73.32	9.03	13.09	6,088	6,378
Vegatable food wastes	78.29	17.10	3.55	1.06	1,795	8,270
Citrus rinds and seeds	78.70	16.55	4.01	0.74	1,707	8,015
Meat scraps, cooked	38.74	56.34	1.81	3.11	7,623	12,443
Fried fats	0.00	97.64	2.36	0.00	16,466	16,466
Leather shoe	7.46	57.12	14.26	21.16	7,243	7,826
Heel and sole composition	1.15	67.03	2.08	29.74	10,899	11,026
Vacuum cleaner catch	5.47	55.68	8.51	30.34	6,386	6,756
Evergreen shrub cuttings	69.00	25.18	5.01	0.81	2,708	8,735
Balsam spruce	74.35	20.70	4.13	0.82	2,447	9,541
Flower garden plants	53.94	35.64	8.08	2.34	3,697	8,027
Lawn grass	75.24	18.64	4.50	1.62	2,058	8,312
Ripe tree leaves	9.97	66.92	19.29	3.82	7,984	8,869

The ultimate analysis for the same samples on a dry basis is given in Table 5.

Table 5. ULTIMATE ANALYSIS OF COMBUSTIBLE COMPONENTS OF MUNICIPAL REFUSE, DRY BASIS[6]
(percent by weight)

Refuse component	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
Newspaper	49.14	6.10	43.03	0.05	0.16	1.52
Brown paper	44.90	6.08	47.84	0.00	0.11	1.07
Trade magazine	32.91	4.95	38.55	0.07	0.09	23.43
Corrugated paper boxes	43.73	5.70	44.93	0.09	0.21	5.34
Plastic coated paper	45.30	6.17	45.50	0.18	0.08	2.77
Waxed milk cartons	59.18	9.25	30.13	0.12	0.10	1.22
Paper food cartons	44.74	6.10	41.92	0.15	0.16	6.93
Junk mail	37.87	5.41	42.74	0.17	0.09	13.72
Vegetable food wastes	49.06	6.62	37.55	1.68	0.20	4.89
Citrus rinds and seeds	47.96	5.68	41.67	1.11	0.12	3.46
Meat scraps, cooked	59.59	9.47	24.65	1.02	0.19	5.08
Fried fats	73.14	11.54	14.82	0.43	0.07	0.00
Leather shoe	42.01	5.32	22.83	5.98	1.00	22.86
Heel and sole composition	53.22	7.09	7.76	0.50	1.34	30.09
Vacuum cleaner catch	35.69	4.73	20.08	6.26	1.15	32.09
Evergreen trimmings	48.51	6.54	40.44	1.71	0.19	2.61
Balsam spruce	53.30	6.66	35.17	1.49	0.20	3.18
Flower garden plants	46.65	6.61	40.18	1.21	0.26	5.09
Lawn grass, green	46.18	5.96	36.43	4.46	0.42	6.55
Ripe tree leaves	52.15	6.11	30.34	6.99	0.16	4.25

Carbon is plentiful and is the principal fuel element. Sufficient hydrogen is present in most cases to burn all of the oxygen to water. Nitrogen is present in rather insignificant quantities except in leather, vacuum cleaner catch, lawn grass, and ripe tree leaves. Sulfur is present in most refuse in rather small quantities, particularly when compared to the sulfur content of coal and fuel oils.

1.2.2 Physical Composition

Up to this point we have been concerned solely with the chemical analyses of separate refuse components. These analyses can be used to simulate the total chemical composition for municipalities where accurate estimates of the components can be made. In those areas where component measurements are not feasible or practical, analyses from other municipalities can be useful in making a first estimate. One such analysis was made for Oceanside, Long Island, New York.[7] Refuse composition and moisture content for three tests are shown in Table 6. Large variations are apparent in both the components and moisture content. Results from these tests and others show that refuse composition and moisture content (as previously stated) both vary from day to day, season to season, on holidays, and with geographical area. The consuming patterns and uniformity of the standard of living throughout the United States are the main factors in creating uniformity in refuse.

A brief review of Table 6 shows that paper products are the main refuse components, generally comprising from 30 to 55 percent, of the total refuse at the Oceanside Refuse Disposal Plant. Grass and dirt obviously showed the greatest variance, ranging from 33 percent in June to essentially zero percent in February. Moisture content varies over a wide range of values depending upon the category of the refuse. The high moisture content of the paper products was explained by Kaiser,[7] as a result of absorption from other refuse components and weather elements.

Table 6. REFUSE COMPOSITION AND MOISTURE CONTENT OF EACH COMPONENT[7]

Component	Test 1 June 1, 1966		Test 2 June 23, 1966		Test 3 February 21, 1967	
	Weight, percent	Moisture, percent	Weight, percent	Moisture, percent	Weight, percent	Moisture, percent
Cardboard	1.59	23.78	6.75	13.22	5.78	16.10
Newspaper	8.88	37.77	11.27	19.20	21.35	18.00
Miscellaneous paper	22.25	36.98	21.78	24.68	26.20	21.90
Plastic film	1.76	18.80	1.77	20.47	1.20	2.85
Other plastics	0.69	20.50	1.67	29.60	2.34	4.38
Garbage	9.58	65.25	10.21	73.45	16.70	59.80
Grass and dirt	33.33	62.20	19.00	44.80	0.26	21.08
Textiles	3.00	31.40	3,33	22.40	2.24	26.05
Wood	1.22	24.98	6.58	8.70	1.46	13.20
Minerals	9.74	6.00	9.49	1.99	11.87	1.64
Metal	7.96	10.83	8.15	2.76	10.60	4.46
Totals	100.00		100.00		100.00	

1.3 HEATING VALUE

The calorific value is considered one of the most important factors of refuse composition for the incineration process. The overall calorific value of refuse is affected by the amount of moisture and the percentages of combustible and noncombustible elements in the refuse.

The heat value of refuse varies widely from country to country. Japanese refuse contains large amounts of moisture and, therefore, has a much lower calorific value than refuse in Europe and the United States.[8] The high moisture content in Japanese refuse is due mainly to the presence of more garbage and less paper. The current estimate of the average higher heating value (HHV) of the United States municipal refuse is 5,000 Btu per pound.[9] Average calorific values may be difficult to determine because values of from 2,000 to 10,000 Btu per pound can exist.

The heating value of refuse is normally determined by determining the components and their quantities in a representative sample of the refuse. By applying known heating values to the components, a reasonable calorific value of the refuse can be computed. Such an analysis, based on refuse composition from a number of incinerators during the 1950 to 1962 period, gives a calorific value of 4,917 Btu per pound as fired.[10] Table 7 gives the composite analysis from which the calorific value was determined.

Table 7. COMPOSITE ANALYSIS OF AVERAGE MUNICIPAL REFUSE, AS-RECEIVED BASIS[10]

	Percent	Theoretical combustion air, lb/lb refuse
Moisture	20.73	
Carbon	28.00	x 11.53 = 3.2284
Hydrogen	3.50 (0.71)[a]	x 34.34 = 0.2438
Oxygen	22.35	
Nitrogen	0.33	
Sulfur	0.16	x 4.29 = 0.0069
Noncombustible[b]	24.93	
Total	100.00	3.4791

Calorific value, Btu/lb: 4,917 as fired; 6,203 dry basis; 9,048 dry-ash-free basis

[a] The net hydrogen available for combustion (0.71 percent) equals the total hydrogen (3.50 percent) less 1/8 of the oxygen (22.35 percent/[8]).

[b] Noncombustibles: Ash, glass, ceramics, metals.

In his study of refuse at the Oceanside, N. Y., incinerator, Kaiser[7] computed the average calorific values (HHV) of the various components of refuse by using a bomb calorimeter. The results are presented in Table 8.

Table 8. HIGHER HEATING VALUES (Btu/lb)[7]

Component	As-received basis	Dry basis	Moisture- and ash-free basis
Cardboard	6,389	7,841	8,131
Newspaper	5,927	8,266	8,518
Miscellaneous paper	5,390	7,793	8,439
Plastic film	11,128	13,846	14,849
Other plastics	6,778	9,049	11,332
Garbage	2,226	7,246	9,287
Grass and dirt	2,970	6,284	9,002
Textiles	5,876	8,036	8,299
Wood	6,850	8,236	8,482
Minerals[a]	79	84	9,438
Metallic[a]	683	742	8,439

[a] Btu in labels, coatings, and remains of contents.

Because the heat produced by the oxidation of metals is highly variable among incinerators, it was not included.

1.4 BULK DENSITY

Density is perhaps most important to sanitary landfill operations, and will, therefore, not be discussed in detail. (One application of density important to municipal incineration is in determining average grapple loads, a figure that may be used in crane design and the estimation of furnace loading.) Density of refuse as collected has been decreasing in recent years because of the change in refuse composition.[2] However, this trend may be somewhat affected by some collection vehicles that have been designed to carry larger loads by the use of a compacting device. Density of refuse in an incinerator pit is obviously greater in the lower half than in the upper half because of compaction by the refuse itself. Studies at the Oceanside Refuse Disposal Plant, Hempstead, N. Y., show that 350 pounds per cubic yard may be a useful figure for pit design.[11] Table 9 gives the average pit densities of refuse for the Oceanside Refuse Disposal Plant. The lower density and moisture content in March reflect drier weather conditions, absence of dense, high-moisture-content yard wastes, and the drying effect of refuse during the domestic heating season.

Table 9. PIT DENSITIES OF REFUSE AT OCEANSIDE REFUSE DISPOSAL PLANT, N. Y.[11]

	Average density in pit, lb/yd^3		
	Moisture content, percent	Before settling	After settling
March 18, 19	26	349	375
June 13, 14	42	480	523

1.5 SAMPLING METHODS

There are apparently no standard procedures used in the sampling of refuse. Most methods have been developed to help a city determine what type of disposal method to use, and after selection of the method, to determine how the particular disposal system should be designed and operated. If a city has decided to build an incinerator, some characteristics of interest will be the amount, calorific value, density, physical composition, and chemical composition of the refuse. Representative samples are difficult to find because of the heterogeneity of the chemical and physical composition of the refuse. Heterogeneity is introduced also by day-to-day changes in composition, weather, and seasonal changes. Preparation of refuse as received at the incinerator may help provide more representative samples. The Swiss Federal Institute of Technology plans to obtain more representative samples of refuse by the use of a portable hammer mill that will grind, homogenize, and mix unsorted refuse.[12]

2. MUNICIPAL INCINERATOR TYPES

Numerous methods of classification of municipal incinerators are available. One classification system is based on refuse disposal capacity. Another classification system is based on use of by-products. The discussion of incinerators herein will be according to the method used to feed refuse to the furnace. A separate discussion of waste-heat-recovery incinerators will be included.

2.1 CONTINUOUS-FEED INCINERATORS

The continuous-feed incinerator is used almost exclusively for municipal incineration. Such an incinerator moves the refuse automatically from a hopper through the furnace on a grate (stoker). Refuse burns on the stoker as it passes through the furnace. Refuse is ignited while on the feeder grate, then tumbles off the feeder grate onto the burner grate where rapid combustion takes place. Some incinerators have more than one burner grate, each of which is successively lower so that tumbling of the refuse from grate to grate further exposes unburned portions of the refuse to the combustion process, thereby assuring more complete combustion. A cross section of a continuous-feed incinerator is shown in Figure 2.

2.1.1 Traveling-Grate Incinerator

The traveling-grate continuous-feed incinerator consists of a continuously moving feeder grate and one or more burner grates. The feeder grate is located directly under a charging hopper from which refuse falls onto the grate. The refuse can be partially dried while it is on the feeder grate.

2.1.2 Reciprocating-Grate Incinerator

The reciprocating-grate incinerator moves refuse through the furnace from the hopper while the grate is actually stationary, except for alternating reciprocating movements of component stoker bars. The action of the stoker bars turns the refuse over and then tumbles it forward to the next successive stoker bar. Burning rate is adjusted by controlling the speed of the stoker bars.

2.1.3 Rotary-Kiln Incinerator

Refuse is dried and charged into the rotary-kiln incinerator in the same manner as for the traveling-grate incinerator. The difference in the two incinerators is in the burner grate. The refuse is dumped from the feeder grate into a rotary kiln that provides constant tumbling of the burning refuse. The kiln is continuously charged and provides continuous residue removal.

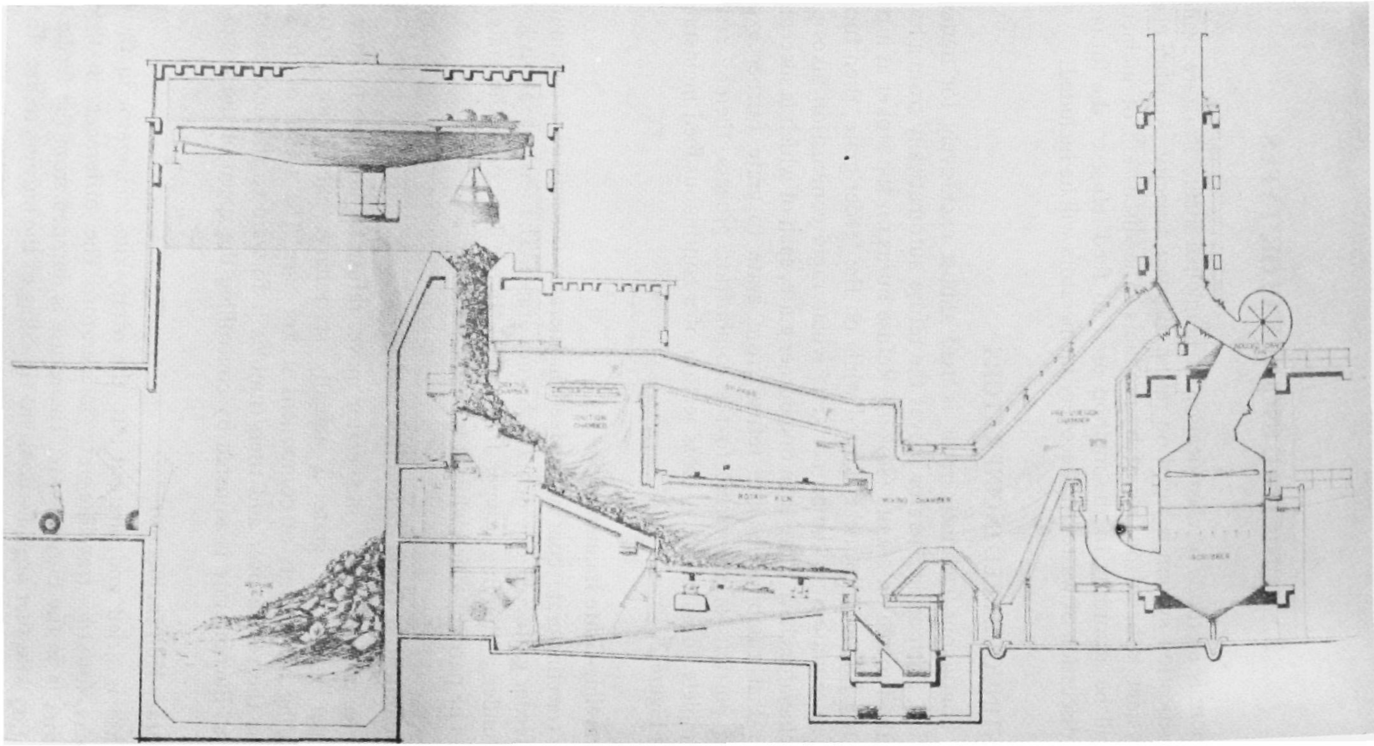


Figure 2. Cross section of typical municipal incinerator.

2.1.4 Barrel-Grate Incinerator

The barrel-grate incinerator is relatively new in design. Refuse is burned as it is moved by a series of rotating barrels. One such incinerator is now in operation in Dusseldorf, Germany (see Figure 3).

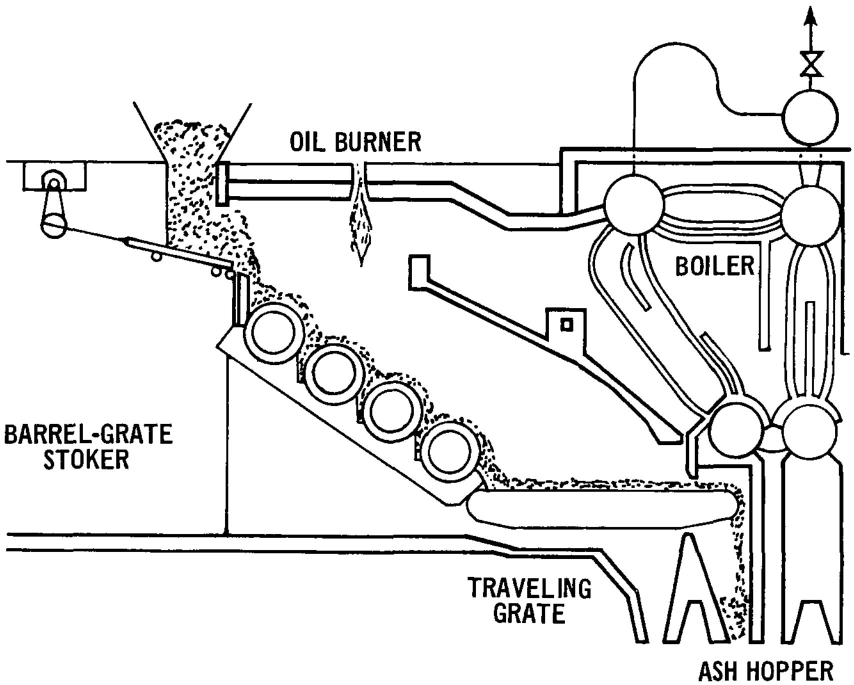


Figure 3. Municipal incinerator in the city of Dusseldorf, Germany. Garbage is first burned on barrel grates, then delivered to a traveling-grate stoker.[14]

2.2 BATCH-FEED INCINERATOR

The batch-feed incinerator is as its name implies, noncontinuous. Refuse is charged to the furnace through the furnace roof at periodic intervals to allow the previous batch to be almost completely burned, when a new batch is introduced. The residue is normally removed from the furnace in the batch method, but at a frequency much lower than the batch charging. Some installations have provisions for automatic removal of residue and incombustible components. Automatic agitators often provide constant overturning and mixing of the burning refuse to allow a minimum of hand stoking.

Cell incinerators, used more extensively in Great Britain and Europe than in other countries, can be considered batch incinerators. Normally, the furnace (see Figure 4) is made up of from two to six cells.[15] Each cell receives a premeasured charge of refuse through the charging gate. This refuse is then dropped onto the

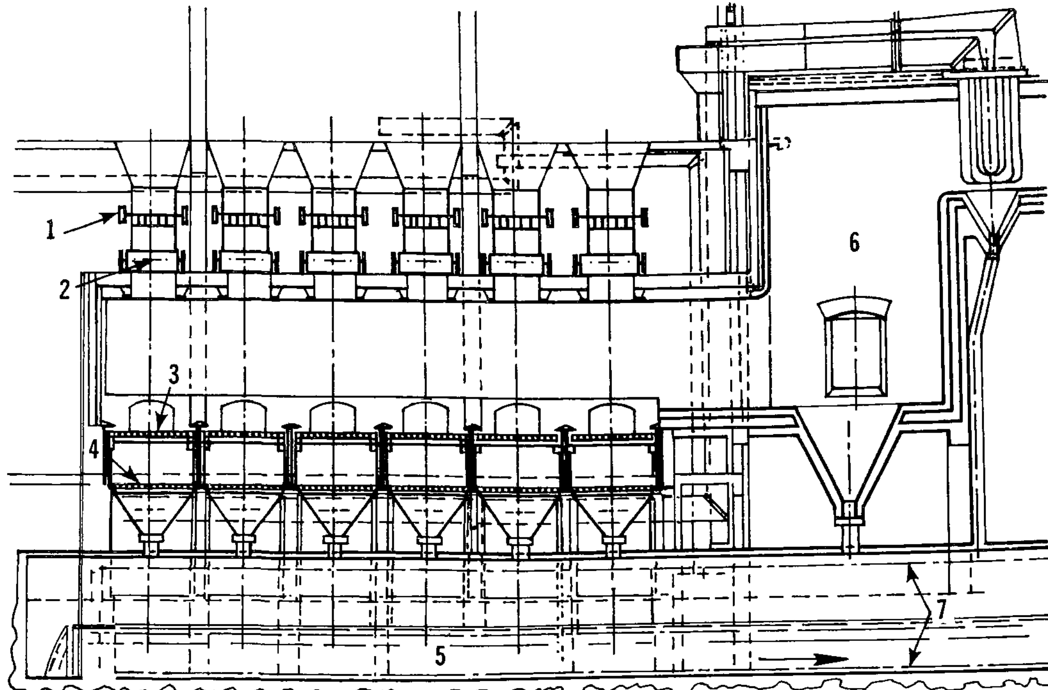


Figure 4. Longitudinal section of a cell furnace: (1) charging gate; (2) sliding cover; (3) horizontal grate; (4) clinker grate; (5) refractory lined drum; (6) combustion chamber; (7) ash conveyor.[15]

horizontal gate where it can be stoked by hand while burning. The grate is mechanically controlled for residue removal. Air for combustion is heated as it passes over the hot residue that has been removed from the horizontal grate. All cells are open to each other, and adjacent to the last cell in the direction of the combustion gas stream is a combustion chamber where the combustion of the gases is completed.

2.3 RAM-FEED INCINERATOR

The ram-feed incinerator uses a ram to move the refuse from a charging hopper to the burner grate. The burner grate then moves the burning refuse continuously through the furnace. Residue and noncombustibles are removed continuously at the end of the burner grate. A cross section of a ram-feed incinerator in Clearwater, Florida, is depicted in Figure 5.[16]

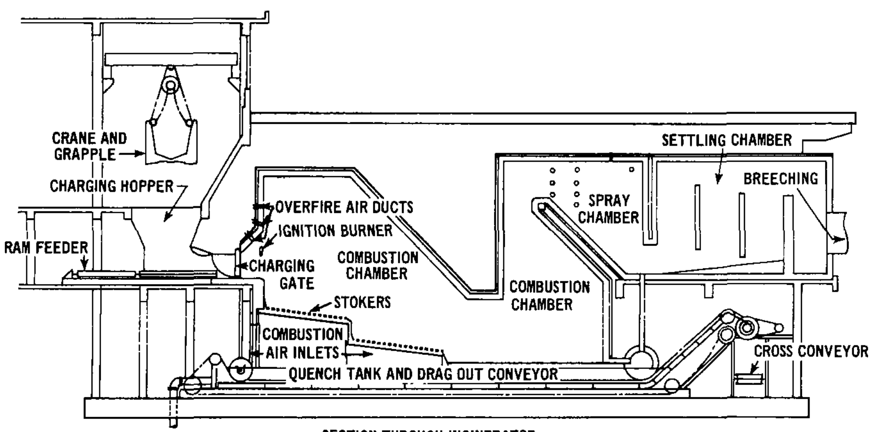


Figure 5. Cross section of ram-feed incinerator, Clearwater, Florida.[16]

2.4 METAL CONICAL INCINERATOR

Although of the "batch" type, conical incinerators are discussed separately because of their distinctive design and undesirability for municipal refuse incineration. Metal conical burners are similar in shape to an Indian tepee (see Figure 6). A survey of 15 burners in six states found that the size of the burners range from 10 feet in diameter by 12 feet high to 90 feet in diameter by 97 feet high.[17] The base of the conical incinerator is usually secured to a concrete ring foundation. Walls are usually made of 16-gauge steel. Some also have an inner lining of steel. The dome is usually fitted with a mesh wire for collection of large particles of flyash. Many draft doors are located at the base of the burner. Most conical burners are equipped with forced-draft blowers. Charging may be done by conveyor belt, bulldozer, or elevated truck chute.

Figure 6. Conveyor-fed municipal refuse burner during startup. Charge is dry paper, wood, and small amount of garbage. Represents peak emissions during field visits to this site.[17]

2.5 WASTE-HEAT-RECOVERY INCINERATORS

The calorific value of refuse in the United States averages about 5,000 Btu per pound. Of this amount, about 45 percent is usually released as waste heat to the atmosphere through the stack.[18] Only a very few incinerators in the United States are designed to recover waste heat. In Europe, however, most of the large modern municipal incinerators built since World War II are designed to recover waste heat. Waste heat is recovered by use of low-pressure boilers, high-pressure boilers, and, most recently, water-walls. Four elements that have made waste-heat recovery practical, efficient, and economical in Europe are:

1. Development of more effective and efficient incinerators to handle refuse that is difficult to burn and low in heat value.
2. Development of more effective heat-recovery systems.
3. Recognition of the considerable aid given to the alleviation of air pollution from the incineration of refuse. Approximately 50 percent of the particulate matter is removed by the average waste-heat system. Furnace gases of from 1,800° F are cooled to the required 400° to 500° F, and gas volumes are reduced by at least one-half.
4. Continued unavailability of economically competitive fuels.[18]

Recovered waste heat can be used to produce steam for heating or for the production of electricity and hot water for heating, personnel services, and process requirements. Waste heat can be used to dry sewage sludge, which can then be sold as a fertilizer, and at coastal sites it can be used to desalt salt water from the ocean to supply communities with potable water.

Waste-heat-recovery incinerators are generally of the continuous type that burn large amounts of refuse, the waste heat output of which is fairly constant and dependable.

2.5.1 Low-Pressure Boilers

Hot water can be generated in low-pressure boilers that are heated by hot gases that pass from the furnace to the boilers and then back to the stack. In refuse plants that use the hot water for internal heating and service requirements, only a small portion of waste heat is recovered. Because there is always a demand for hot water, external demands of municipal buildings and factories should not be overlooked.

2.5.2 High-Pressure Boilers

Early designs of waste-heat-recovery incinerators placed boilers in the combustion chamber with direct exposure to the burning refuse. The absorption of heat by the boiler, together with lower calorific value of refuse at that time, lowered furnace temperatures and thus the effectiveness of the combustion. To alleviate this problem, boilers built directly above the burning refuse are shielded to prevent excessive cooling of the furnace by radiation.

Many refractory incinerators that pass combustion gases through a series of boilers have been designed (Figure 7). Not only is waste heat recovered, but the volume of the combustion gases needing cleaning is reduced considerably. Boilers may be used to reduce flue gas temperature to within the range (482° to 572° F) that such high-grade dust collectors as electrostatic precipitators (to be discussed in Chapter 3) cannot be subjected.[19]

2.5.3 Water-Wall Furnace

Water walls are used in furnaces in various European incinerators, a practice that is not new. The only operational water-wall incinerator in the United States is located at the Norfolk, Virginia, Navy Base.

Water walls are constructed of interconnected steel tubes welded together to form an integral wall. Circulating water is converted to steam almost entirely by radiation supplemented by some convection. Obviously, many factors are involved in the amount of heat that is transferred from the furnace chamber to the water walls. If too much water-wall area is installed, the furnace may operate at temperatures below deoderizing temperatures, resulting in an undesirable situation.[20] As with boilers, the cooling of the furnace by water walls means a

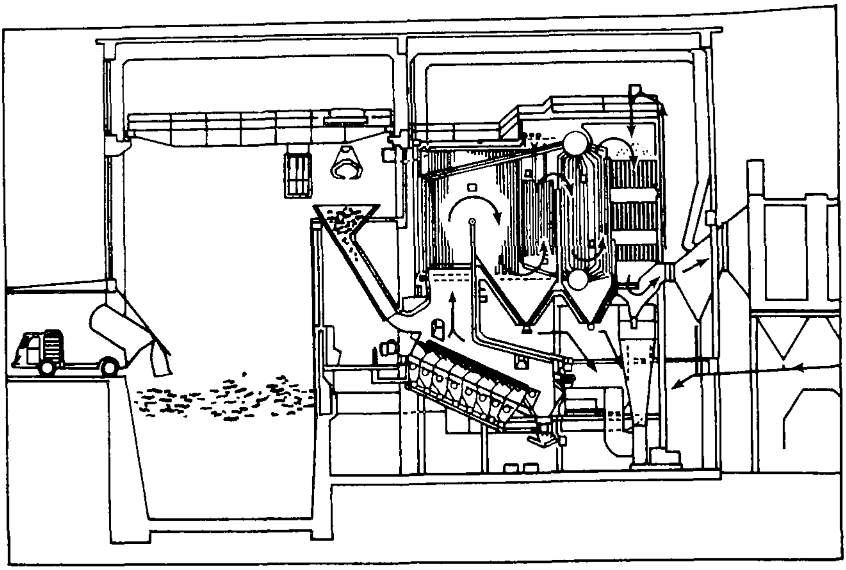


Figure 7. Cross-section of a large European incinerator, showing path of furnace gases through heat recovery boiler.[18]

lower requirement for the quantity of excess air, resulting in less flue gas requiring air pollution control treatment.

A cross section of the Norfolk refuse incinerator is shown in Figure 8. The specifications for each boiler-furnace unit are given in Table 10.

Table 10. SPECIFICATIONS FOR EACH BOILER-FURNACE UNIT IN WATER-WALL INCINERATOR, NAVY BASE, NORFOLK, VIRGINIA[20]

Mixed refuse capacity, tons/day	180
Heat content, Btu/lb as-fired	5,000
Moisture, percent	25
Noncombustible material, percent	12.5
Steam production	
With refuse at 5,000 Btu/lb, lb/hr	50,000
With drier refuse or with refuse plus oil, lb/hr	60,000
With oil only, lb/hr	50,000
Design stoker loading,	
lb refuse/ft^2-hr of effective grate surface	65
Heat release	
Btu/hr-ft^2 effective grate surface	325,000
Btu/ft^3 primary furnace volume maximum	25,000
Minimum gas temperature leaving primary furnace at 50 percent of rated load °F	1,400
Steam pressure, psig	275
Steam quality	Saturated
Feedwater temperature, °F	228
Exit gas temperature from boiler at design refuse capacity, °F	580

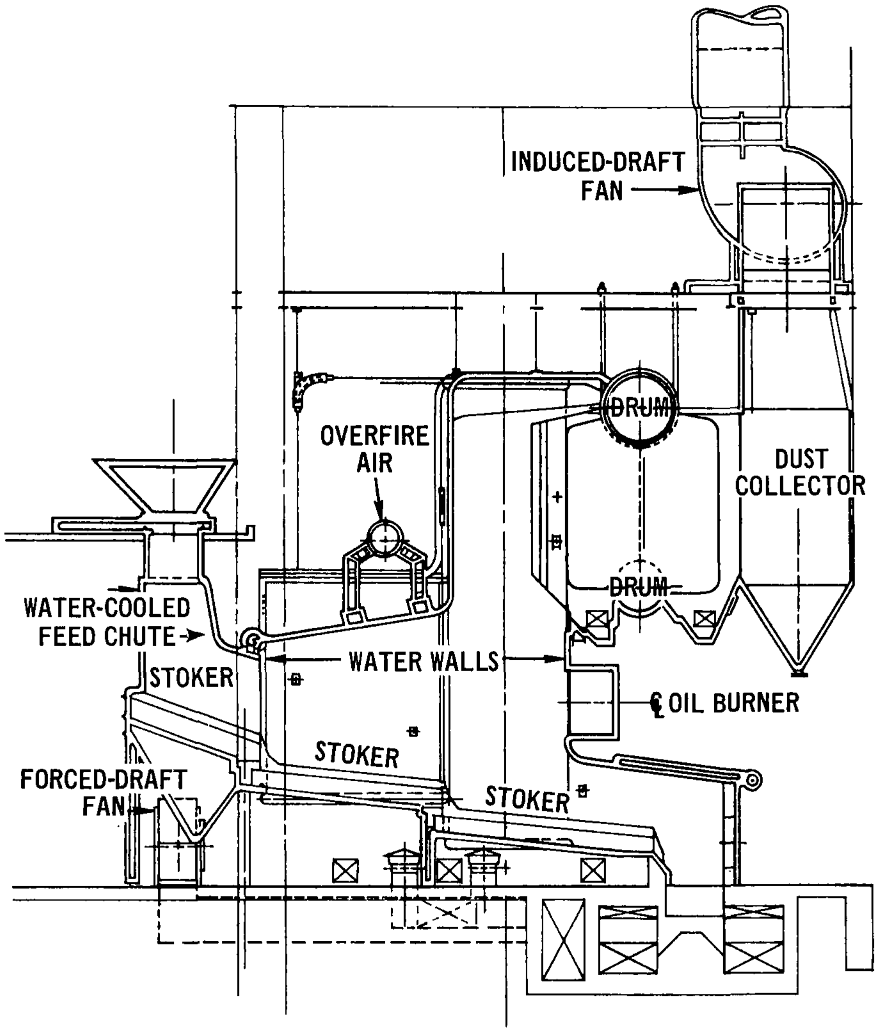


Figure 8 Water-wall incinerator at Navy Base Norfolk, Virginia[20]

A new water-wall incinerator that is noteworthy will soon be placed into service in Paris, France.[21] Steam produced will be used to generate electricity and heat for both internal use and sale to local consumers.

2.5.4 Salt Water Distillation

Waste heat can be used effectively to desalinate water. Its use in providing a future water supply for coastal areas should not be underestimated. Experience gained from the Oceanside Refuse Disposal Plant[22] shows that waste heat from the incineration of refuse from half a million people could supply one-fourth to one-third of their domestic water requirements.

The basic principle is that steam is generated from waste heat. The steam is used to convert the salt water, pumped from a nearby source, to steam. The salt water steam is then condensed to fresh water on tubes that are cooled with unheated salt water. A flow diagram of the Oceanside Refuse Disposal Plant is given in Figure 9.

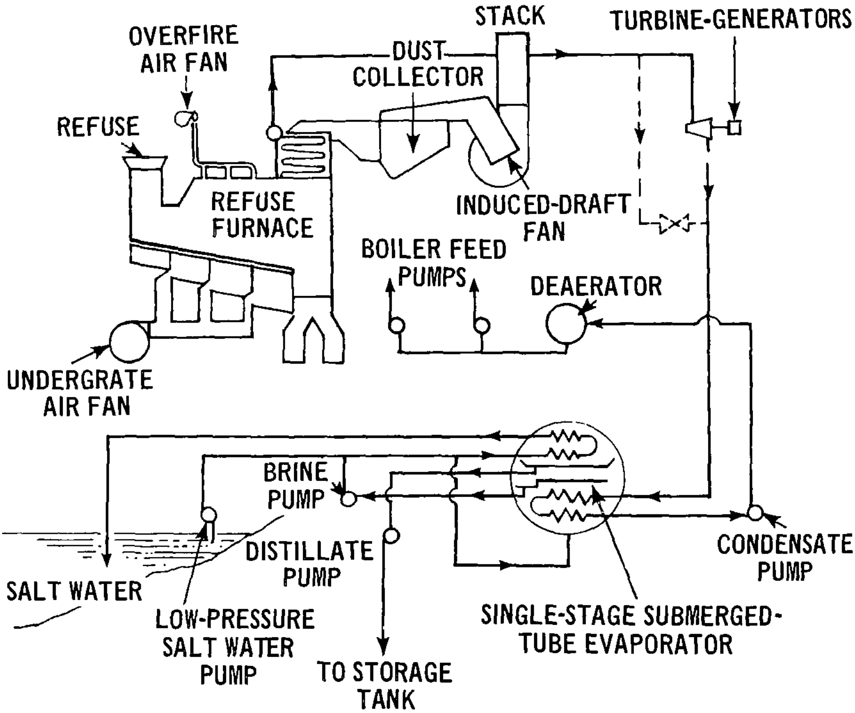


Figure 9. Flow diagram traces waste heat at work generating steam for power and desalting.

2.5.5 Sewage Sludge Disposal

Refuse incinerators can be located adjacent to sewage treatment plants where waste heat can be used to dry sludge or where dewatered sludge can be mixed with the refuse and burned. Dried sludge can be sold as a fertilizer. Effluent water can be used for cooling the incinerator furnace walls and for gas scrubbing. Raw sludge is dewatered by a vacuum filter. The resulting sludge cake contains 65 to 75 percent moisture.[23] The moisture content can be further reduced by storing the sludge for several days. Heating values, ash content, and percentage of volatile matter for a typical sludge cake are given in Table 11.

One such sludge-burning incinerator is located in a suburb of Philadelphia, Pa.[24] Oscillating conveyors are used for mixing the refuse and sludge. A performance test conducted on this incinerator showed that for 381.4 tons of refuse burned, 32.0 tons of sludge was burned. Combustible material that was not destroyed amounted to 4.36 percent.

Table 11. AVERAGE SEWAGE SLUDGE CHARACTERISTICS[23]

Moisture, percent of sludge cake	
Range	65 to 70
Average for design	70
Volatile matter including chemicals, percent of dry solids	
Range	50 to 85
Average for design	70
Ash content including chemicals and combustibles, percent of dry solids	
Range	50 to 15
Average for design	30
Heating values, Btu per pound	
Dry solids, range	5,600 to 10,000
Combustible, design average	11,500
Combustible in ash, percent of ash	
Maximum allowable	4

3. MUNICIPAL INCINERATOR DESIGN

3.1 BASIC INCINERATOR

Trucks deliver refuse to a storage pit at most modern municipal incinerators. Figure 10 illustrates a typical municipal incinerator. The size of the storage pit at such an incinerator is dependent on such factors as capacity of the furnace, emergency storage required in the event of furnace breakdowns, and refuse truck pickup schedules. The refuse trucks enter the tipping floor and normally back up to the pit and dump the refuse. Elevated cranes deliver the refuse to a charging hopper that feeds the refuse automatically through a chute to the feeder and drier stoker. The refuse is usually ignited on the feeder stoker before it is dumped onto the burner stoker. Air is supplied for combustion and temperature control through the grate, sidewalls, and roof of the combustion chamber. Residue is discharged from the end of the stoker into mechanical conveyors that transfer the residue to storage bins or trucks. Residue is wetted occasionally to control dust. In some incinerators, combustion gases are passed into a second combustion chamber (secondary combustion chamber) to complete combustion of gases and entrained solids. Combustion gases are then cleaned prior to exhausting through the stack.

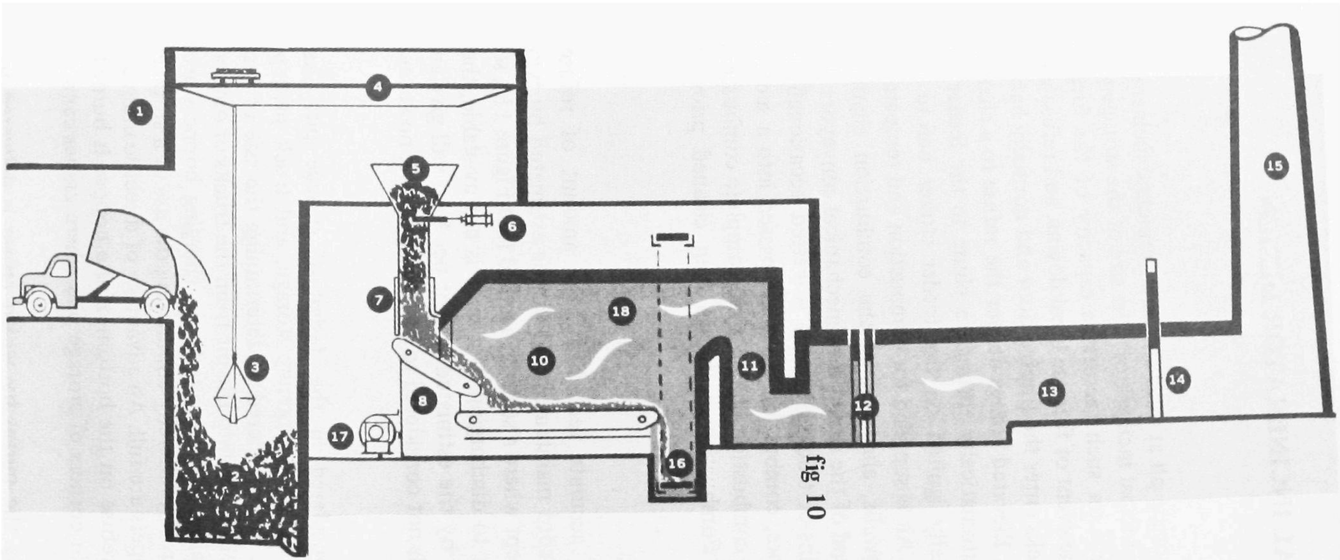
3.1.1 Scales

Many incinerators maintain accurate records of the amount of refuse processed. Weight is the usual record maintained and can be estimated by two methods. An accurate record is kept where a scale is installed (see Figure 11), so that trucks can be weighed prior to discharging. If a scale is not available, the number of truck loads multiplied by the estimated weight per load will give an approximate figure. This method is not considered to be good practice, however.

3.1.2 Storage Pits

Several factors must be considered in the design of storage pits. As previously mentioned, furnace capacity, emergency storage, and truck pickup schedules are important factors to be considered in determining the size of the storage pit. Refuse can be dumped directly into the pit from the trucks or onto a conveyor belt that carries the refuse to the pit. Some charging hoppers are designed to receive truck loads directly, thereby eliminating the use of a storage pit except when the charging hoppers are full. An advantage of direct loading of the charging hoppers is that old refuse on the bottom of the hopper is burned first. Refuse would not build up in corners of storage pits where cranes cannot reach.

Trucks are almost exclusively the means by which refuse is delivered to



1. INCINERATOR
2. STORAGE PIT
3. GRAB BUCKET
4. BRIDGE CRANE
5. CHARGING HOPPER
6. HOPPER GATE
7. WATER-COOLED HOPPER
8. FEEDING AND DRYING STOKER
9. BURNING STOKER
10. PRIMARY COMBUSTION CHAMBER
11. SECONDARY COMBUSTION CHAMBER
12. GAS-CLEANING CHAMBER
13. FLUE
14. DAMPER
15. CHIMNEY
16. ASH CONVEYOR
17. FORCED-DRAFT FAN
18. REFRACTORY ENCLOSURES

Figure 10. Schematic of Typical Municipal Incinerator.

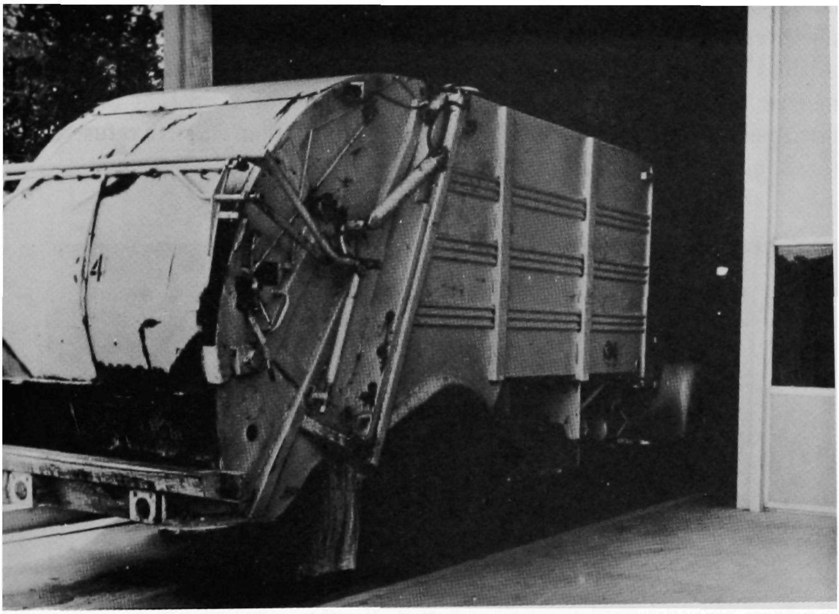


Figure 11-A. Refuse truck being weighed upon entering the tipping floor.

Figure 11-B. Operator reads scales.

municipal incinerators in the United States. In foreign countries, however, refuse is delivered to some plants by ships and railroad cars. So many additional variables exist in the design of receiving systems for ships and railroad cars that there is no one generalized design. An example of a custom design is the turntable and car dumper illustrated in Figure 12 that empties refuse into the storage pit at the Stuttgart incinerator.[26]

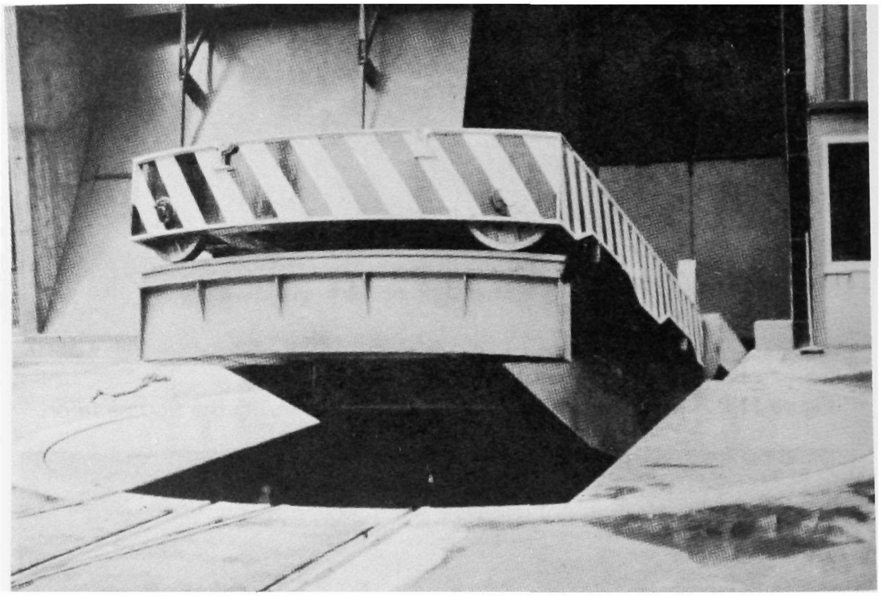


Figure 12. Combination turntable and car dumper empties refuse from railroad cars into the storage bin of the Stuttgart incinerator.[26]

Dust generated during refuse dumping, crane loading, and hopper charging can be troublesome. Some plants furnish their employees with breathing masks if dust control methods are not used or are ineffective. Exhaust hoods over dumping areas (illustrated in Figure 13) can reduce the dust. Another method uses air inlet ports around the top and bottom of the pit.[27] The upper ports draw in dust-laden air and the lower ports (near the bottom of the pit) "drain off" dangerous gases that occasionally form in the bottom of pits.

3.1.3 Cranes

Refuse is transferred from the storage pit to the charging hoppers by means of overhead, traveling cranes that can be equipped with either grapple or clamshell buckets. The refuse can be rearranged in the storage pits to permit truck dumping space. In the United States, grapples are more widely used than

Figure 13. Dust control at the Govan Incinerator in Glasgow includes hoods over the dumping area; the ductwork leads to a large bag house that removes the dust from air before discharge to the atmosphere.[26]

clamshell buckets are. Clamshells do not have the grappling ability of grapples but are useful for cleaning the bottom of the pit. Buckets must have sufficient digging ability to pick up the refuse, and cranes should provide a means of preventing bucket twist and have a desirable operating speed. A steel grating in the floor can provide a wearproof parking place for buckets not in use.[27]

In Europe both orange peel (polyp) and clamshell buckets are used, but polyp buckets are the more popular.[28] Polyp buckets are more expensive, but have the ability to pick up different types of refuse more positively. Bucket capacities of European incinerators range from 5 to 7 cubic yards, which is larger than the 2- to 3-cubic-yard capacity of buckets in the United States. European cranes work at slower operating cycles, which may cause them to use less power. This slower speed results in less damage to pit walls and hoppers, and makes a crane-weighing operation more practical.

At least two cranes are needed for the average refuse incinerator. The need for a third crane as a standby is stressed by some, debated by others, and denied by still others.[28,29] Emergency crane repairs can be made in a short time by a well-trained crew with available spare parts.

There are two different types of crane installations. The bridge crane affords the most versatility by allowing movement in both directions over the storage pit and charging-hopper area. The second type, the more inexpensive monorail crane, moves only in one direction, that is, along the centerline of the bin. The width of the bin for this type of crane should not exceed by 2 or 3 feet the width of the bucket in its wide-open position.[30]

The value of a good crane operator must not be overlooked. He can select the refuse from the pit to provide the most suitable mixture for incineration when the pit refuse is usually nonhomogeneous. He can remove large pieces of refuse that may not feed or burn satisfactorily. In some instances, the number of crane loads are counted or a crane is fitted with a scale to determine the amount of refuse fed to the incinerator.

3.1.4 Charging Hoppers and Gates

The charging hopper is the beginning of the completely mechanized portion of the incinerator. Hoppers of either metal or concrete are constructed in such a manner that they "funnel" the refuse by gravity through a chute to the furnace-charging mechanism. The flow of refuse can be shut off or regulated by a charging (hopper) gate (see Figure 10). Hoppers can be fitted with eccentrically weighted rotors that make the hoppers oscillate, thereby controlling the flow of refuse to the furnace-charging mechanism.[30] This method is particularly appropriate in ram-fed incinerators where the oscillating hopper can be syncronized with the furnace-charging cycle.

In continuous-feed furnaces the refuse in the charging hopper and chute seals off the heat of the furnace. To prevent fires in the charging hoppers the lower portions of the hoppers are connected to a water-cooled feeding chute through which the refuse passes to the charging grate.

3.1.5 Furnace Grates

The grates in a furnace are one of the most important parts of a continuous-feed incinerator. If refuse were merely dumped on a grate and burned without turning or agitation, burning would take place only on the top. Refuse not exposed to the flame and that next to the grate would leave the furnace incompletely burned. Well-designed grates turn and agitate refuse as they move it through the furnace so that (1) a high percentage of the moisture is evaporated, (2) volatiles are gasified, (3) burnable solids are heated to ignition temperature, and (4) nonburnable refuse is heated to approximately 1,500° F to make it nonputrescible.[31]

3.1.5.1 Traveling Grates

Traveling grates, perhaps used more widely in the United States than elsewhere, provide movement of refuse through the furnace by means of continuous, conveyor-type movement (see Figures 14 and 15). They are installed in line, usually in numbers of two or more.

The first section of a traveling-grate system is sometimes called the feeder

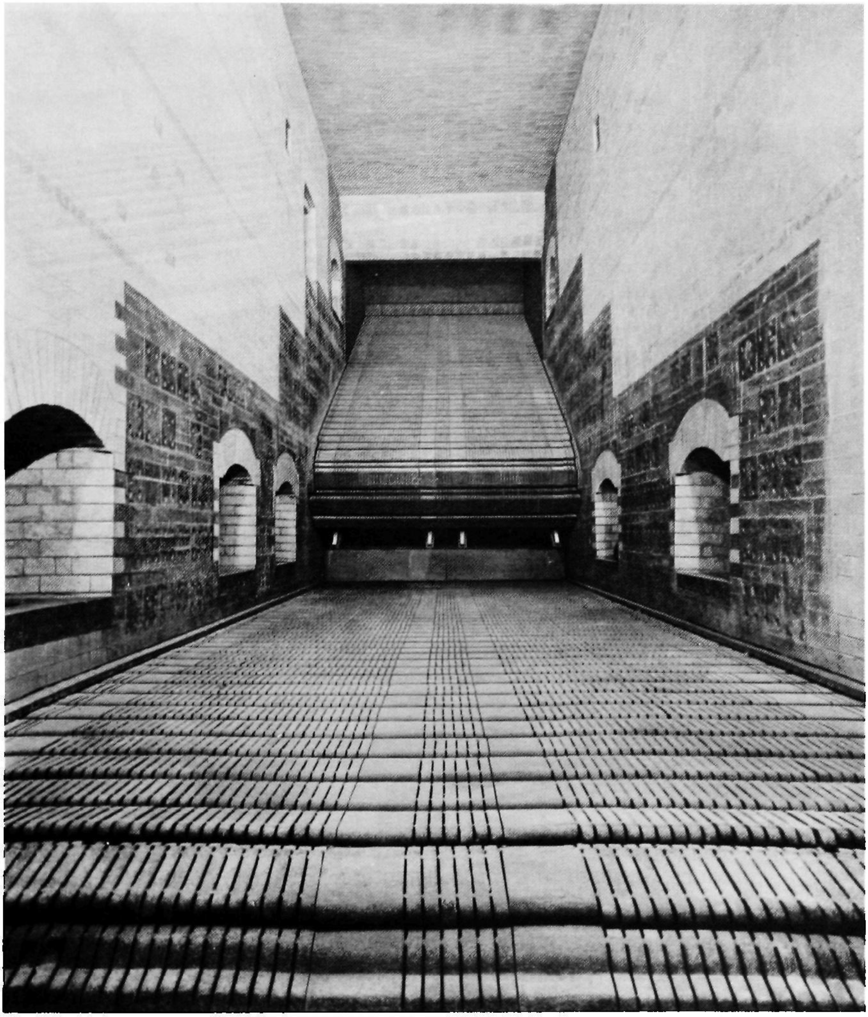


Figure 14. Traveling-grate stoker.
(Courtesy Combustion Engineering, Inc.)

grate. It is inclined and drops the refuse onto the burner grate (the second section) to provide turning and agitation of the refuse. Ignition of the refuse on the feeder grate normally takes place at about the middle of the grate. The speed of the feeder grate is controlled to provide sufficient drying and timely ignition of the refuse.

The burner grate (or grates) is horizontal; its speed is adjustable to fit the combustion nature of the refuse. The speed can be adjusted independently of the feeder grate. One of the later developments in traveling grates has been the

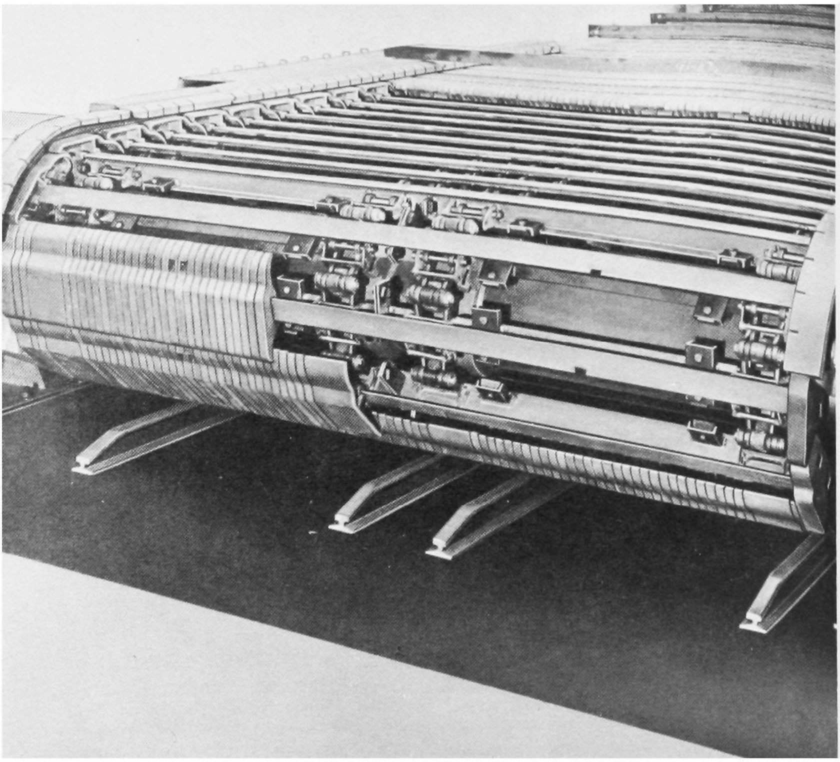


Figure 15. Partially assembled traveling-grate stoker. Overlapping cast iron keys reduce sifting of refuse through grate. (Courtesy Combustion Eng., Inc.)

addition of more burner grates to provide additional dropoffs, and thus additional turnover to provide more complete combustion.[31] An incinerator with an inclined feeder grate and three burner grates is shown in Figure 16.

3.1.5.2 Reciprocating Grate

Another popular grate is the reciprocating grate, which advances and agitates the refuse by means of alternate rows of grates sliding back and forth over a stationary row of like grates. An interior view of a 250-ton-per-day reciprocating-grate incinerator is shown in Figure 17.

The Von Roll System, which is widely used in Europe, uses a reciprocating grate. Because improvements are constantly being made in each new installation, no one installation can be classified as typical. In a recent installation, the drying stoker is inclined 20 percent. There is a 5-foot drop from the drier stoker to the first burner stoker, which is inclined 30 percent. Another drop of 5 feet moves

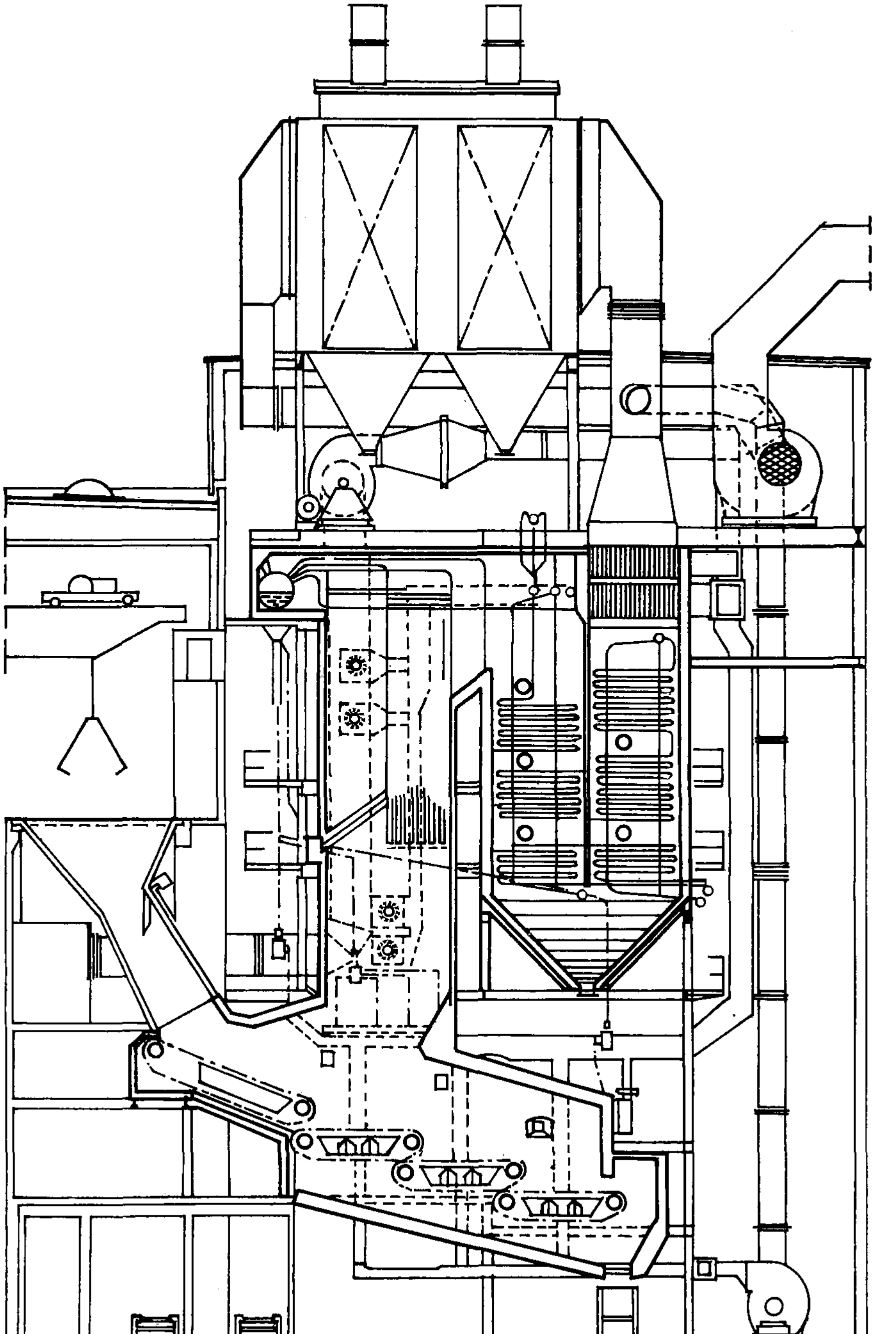


Figure 16. Boiler with multiple traveling-grate stoker.[31]

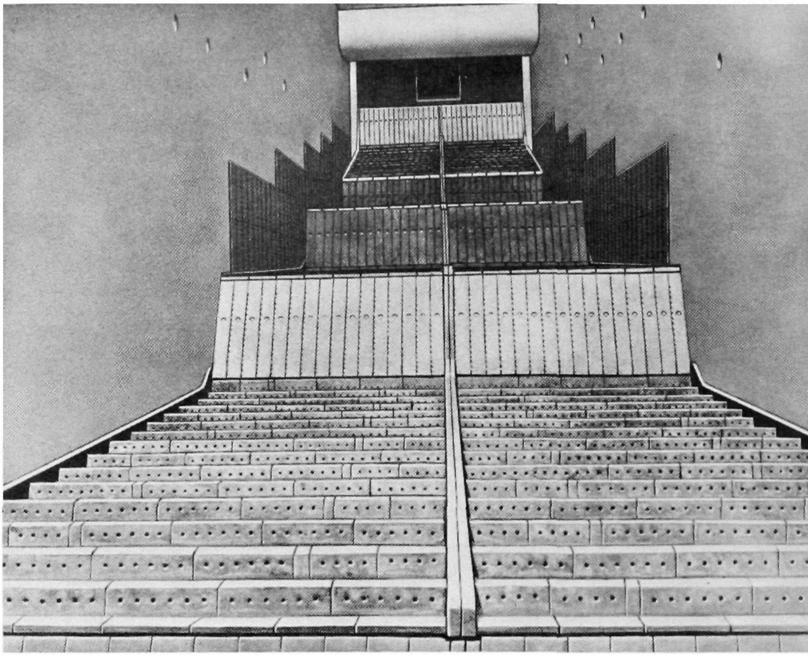


Figure 17. Reciprocating stoker of American incinerator.
(Courtesy Detroit Stoker Company)

the refuse to the second burner grate, which is inclined 33 percent. Rogus[28] states:

> The three stokers or grates are comprised of stepped-down special-cast steel pallets. These are alternately of solid and perforated bar key construction. The solid pallets have large swiveled arched inserts. The slow reciprocating downward movement, about a 5- to 6-inch stroke, of the individual pallets combined with the relative motion between them is augmented by the upward lifting action of the normally recessed segments. The overall effect provides a thorough intermixing and agitating action which promotes a near-complete burndown of the refuse. The siftings that pass through the grate system are discharged into zoned hoppers and thence through gravity chutes into the underlying residue troughs.

Another European grate design, known as the Martin System, is a reverse reciprocating-grate system.[28] This grate has a high efficiency, permitting the use of a single grate per furnace. The drying and burning is accomplished on a single short, but wide inclined grate. The stepped-down grate is sloped at an angle of approximately 30 degrees. The grate consists of heavy serrated cast-steel bars of chrome iron that can withstand temperatures up to 1,600° to 1,700° F. The grate consists of alternate reciprocating and stationary bars. The stoking bars actually push the refuse uphill against the downhill, gravity-induced movement of the refuse. This system has been used successfully in many countries with refuse of several types and widely varying calorific value and composition.

3.1.5.3 Rocker-Arm Grates

Rocker-arm stokers consist of rows of grates that pivot up from the horizontal through an angle of 90 degrees and then back to the horizontal. The pivoting motion is alternated between odd and even numbered rows, which provides agitation and movement of the refuse through the furnace.

3.1.5.4 Barrel Grate (Drum Grate)

One of the more recent designs that is being used in Europe is the barrel-grate incinerator. In an incinerator in Dusseldorf, Germany,[28] each furnace is equipped with seven contiguous cylinders set at progressively lower levels toward the discharge end at a slope of about 30 degrees from the horizontal. Figure 3 depicts a similar grate system except the traveling grate is replaced by drums. In actuality, this design simulates a series of traveling grates, equal in length to the exposed perimeter of the barrel grate. The speed of the barrels is independently variable; the first grate rotates at a speed of 50 feet per hour and the last grate rotates at 15 feet per hour. The grates are 5 feet in diameter and 10 feet long. They are made of serrated cast iron arched segements that are keyed to a structural steel frame.

3.1.5.5 Rotary-Kiln Grate

Rotary kilns can be used for both drying and burning refuse. The refuse is constantly tumbled as it moves slowly under the action of gravity through inclined rotating kilns. Rotary kilns are used in combination with other types of grates, such as in the incinerator depicted in Figure 18, where the refuse is dried and partially burned on a reciprocating grate that then delivers the burning refuse to a rotary kiln for final burning.[14]

3.1.5.6 Batch Incinerator Design

There are many grate designs, particularly for batch-feed incinerators, which, although not discussed previously, should be mentioned. Batch-feed furnaces are usually equipped with one of five different grate designs: manually stoked, circular manually stoked, rocking cell, reciprocating, and oscillating.[32]

3.1.5.7 Trends in Grate Design

The results of a survey of 204 municipal incinerator installations designed from 1945 through 1965 and those under construction as of November 1965 are shown in Figure 19.[32]

Some generalizations concerning United States incinerators are in order. The concept of municipal incineration grew rapidly following World War II. Batch-feed incinerators were built more often than continuous-feed incinerators until 1963, after which the trend was reversed. The three most popular continuous-grate designs are the traveling grate, reciprocating grate, and the rocking grate. The most significant trends for batch-feed grates are the replacement of the hand-stoked grates with mechanically stoked reciprocating and rocking grates.

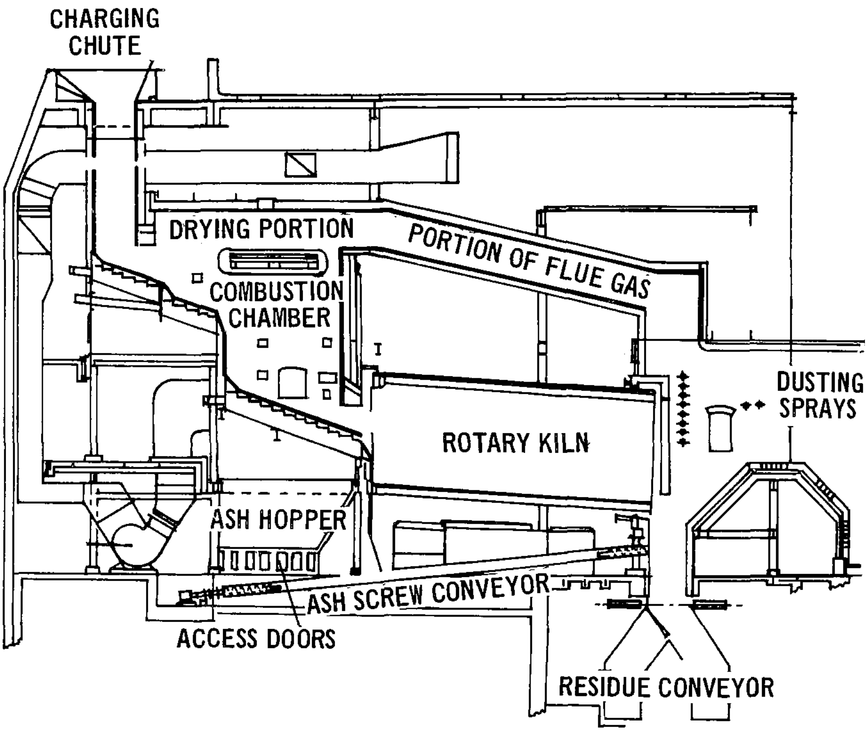


Figure 18. Incineration of garbage that has been dried and partly burned on reciprocating-grate stoker.[14]

3.1.5.8 Grate-Burning Rate

The burning rate for grates is determined by the amount of refuse that can be burned per unit grate area per unit time and is commonly expressed as pounds of refuse per square foot per hour. The Incinerator Institute of America has adopted a burning rate of 60 to 65 pounds per square foot per hour as being a "generally allowable" standard.[33] Table 12 presents grate-burning rates for 157 municipal incinerators of various design in the United States.[32] The year-to-year column gives the first and latest year of incinerator design for which a burning rate was reported.

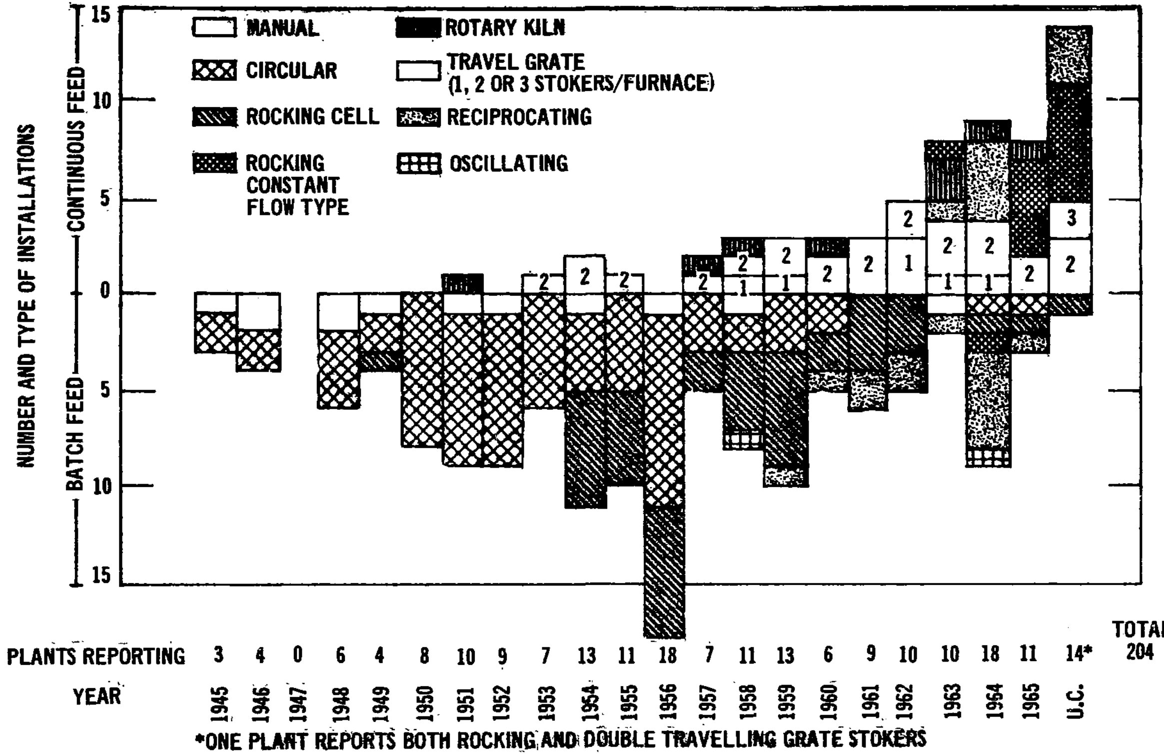


Figure 19. Stoker type and furnace feed.

Table 12. GRATE-BURNING RATES[32]

Stoker type	Feed type	Year to year	Number reporting	Refuse burned, lb/ft² grate surface-hr Max.	Min.	Median	Average
Manual	Batch	1946 - 1958	8	91	37.7	47/67	59
Circular	Batch	1945 - 1965	59	110	45.4	84	83.3
		1961 - 1965	2	70	70	–	70
Rocking	Batch	1949 - U.C.	37	71	32.4	57.5	56.8
		1961 1965	10	60	43	57/57.5	56.0
Rocking	a	1963 - U.C.	9	67.5	50	58	58.7
Traveling	a	1954 - U.C.	23	70	55.5	65	64.3
		1961 - U.C.	15	70	55.5	65	63.7
Reciprocating	Batch	1959 - 1965	11	87	35	57	57
		1961 - 1965	9	60	35	57	53.6
Reciprocating	a	1963 - U.C.	8	75	55.5	60	62.9
Oscillating	Batch	1958 - 1964	2	69.5	60	–	64.8
		1961 1964	1	–	–	69.5	–

aContinuous feed.

3.1.6 Combustion Chambers

There are basically two types of furnace wall construction, refractory and water-cooled structural steel, the choice of which can depend to a large extent on the sophistication of the gas-cleaning equipment used and on whether a large amount of waste heat is to be recovered. For these reasons, refractories have been used almost exclusively in the United States, while other countries with sophisticated gas-cleaning equipment and more emphasis on waste-heat recovery have made extensive use of structural steel (water walls). There are, of course, many other considerations in the choice between these two types of furnace wall construction.

3.1.6.1 Water-Walled Combustion Chamber

Combustion chambers of water-walled furnaces, as mentioned in an earlier section, are normally lined with structural steel tubes through which water is circulated for the generation of steam. In most incinerators the tubes are welded together to form an integral wall. Water walls are heated almost entirely by radiation supplemented by some convection, and their presence has a tremendous cooling effect on furnace temperatures and substantially reduces the amount of excess air required for cooling the furnace. Incinerators in which the stoker and boiler are coordinated can require as little as 30 percent excess air.[31] The use of small amounts of excess air has two major advantages. The first advantage is that the temperature of combustion of the refuse increases with decreasing amounts of excess air as illustrated in Figure 20. Obviously, the higher the temperature the more complete will be the combustion of the refuse. From Figure 20, the combustion temperature for 30 percent excess air is approximately 2,500° F, which is substantially higher than that for refractory furnaces requiring larger amounts of excess air for cooling. A second advantage is that small amounts of excess air mean smaller amounts of gases that must be expensively cleaned in areas with strict air pollution control codes.

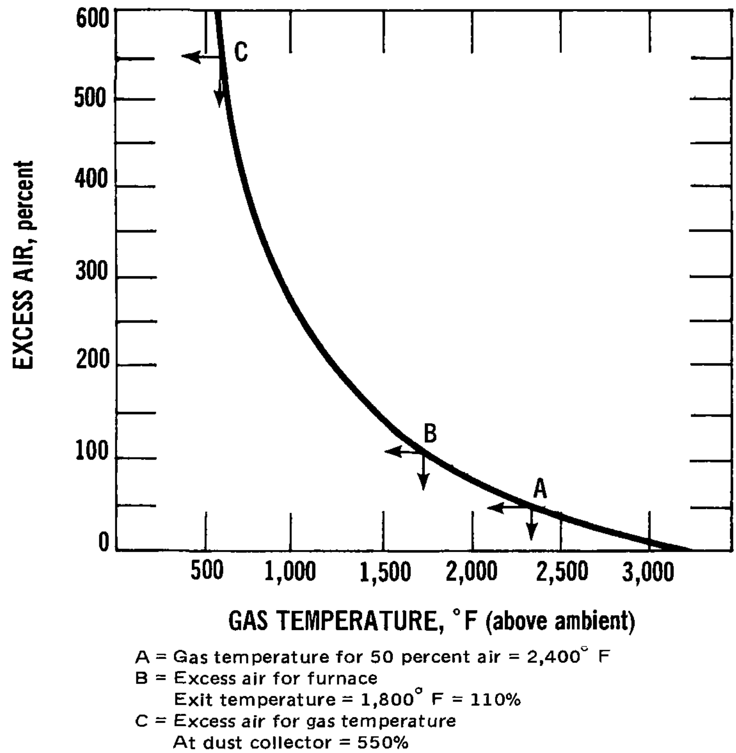


Figure 20. Chart showing gas temperature versus excess air rates for municipal refuse.

A cost comparison study of a water wall versus a refractory furnace for the Norfolk, Virginia, Naval Base installation showed that initial cost for the water-wall installation using 100 percent excess air was nearly equal to the initial cost of a refractory furnace using 200 percent excess air.[20] Steam production from a given amount of refuse can be increased by approximately 38 percent with water walls.

The use of water walls in other countries is extensive principally because of the requirement of low gas temperature for sophisticated gas-cleaning equipment (electrostatic precipitators) and the emphasis on waste-heat recovery. A relatively large water-wall incinerator built at Issy-Les-Moulineaux, a suburb of Paris, uses four 17-ton-per-hour furnaces.[21] Another noteworthy, water-wall incinerator that will soon be placed into operation at Ivry, a suburb of Paris, is discussed in Chapter 2.

3.1.6.2 Refractory Combustion Chamber

As with the water-wall combustion chamber, the primary function of the refractory combustion chamber is to provide an enclosure wherein controlled combustion of refuse can take place. Because of the increasing size of today's municipal incinerators, refractory enclosures for large installations become quite large and sophisticated in design.

Widely fluctuating temperatures inside the combustion chamber, resulting for the most part from the varying calorific value of charged refuse, cause uneven expansions and contractions resulting in thermal shocks to the refractory lining. Measurements of the temperature variations of the refractory lining at

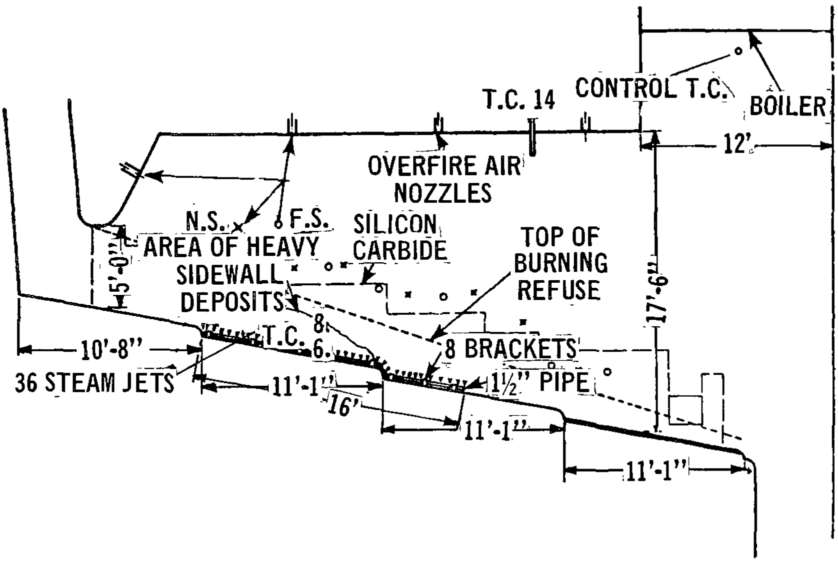


Figure 21. Locations of temperature-measuring instruments in the Oceanside Refuse Disposal Plant, New York.[34]

various locations (see Figure 21) in the Oceanside Refuse Disposal Plant, New York, show that variations of several hundred degrees Fahrenheit (see Figure 22) do indeed occur in periods of less than 1 hour and that temperature differences from one location in the furnace to another frequently amount to several hundred degrees.[34]

Refractories in common use are super-duty fireclay, high alumina, chrome magnesite, and plastics. Plastics are made from clays similar to those used in bricks. However, the plastics are prepared at the factory and shipped in a wet mix form. After the plastics are placed in the incinerator they are uniformly heated to a specified temperature during which time they develop into a ceramic-like structure and bond. For all refractories, uneven expansion and contraction can and must be appropriately accounted for. The refractory can be either self-supporting or be hung from a structural steel superstructure. Arches and walls supported by structural steel superstructures have proven successful in large incinerators.[35] Refractories can be constructed in sections so that the load for each section is independently carried through support castings to the superstructure, eliminating cumulative loading. Expansion joints for each section permit independent expansion and contraction eliminating the accumulation of thermal stresses. In the sectional design, refractory thickness is not required for wall stability and support; it is determined basically by temperatures and the operating conditions of the furnace. Thicker refractories are used when higher temperatures occur and when heat storage is necessary to control widely fluctuating temperatures. Refractory linings can be either air-cooled or insulated. Air-cooled walls can be used as ducts for delivery of "over-fired" air into the combustion chamber.

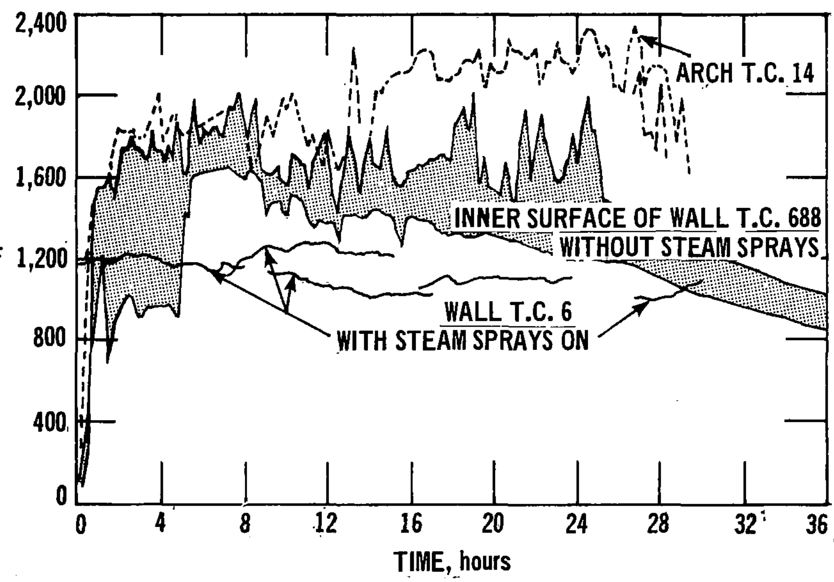


Figure 22. Typical refractory temperature versus time chart for selected locations in the Oceanside Refuse Disposal Plant, New York.[34]

3.1.6.3 Incinerator Slag

The buildup of slag on the side walls of combustion chambers of refractory incinerators has become an increasing problem with the advent of continuous-feed incinerators. Long operating periods of several days at a time result in high wall temperatures that enhance slag buildup. Slag buildup is greatest on the lower, side walls of the furnace where it causes obstruction of the grates and burning refuse. The composition of slag varies over a wide range from one incinerator to another. This fact is apparent from a chemical analysis of slags from 25 incinerators in the New York, New Jersey, and Connecticut area.[36] Tables 13 and 14 give the average and range of spectrochemical analysis for the 25 slag samples tested.

Table 13. AVERAGE SPECTROCHEMICAL ANALYSIS OF ALL INCINERATOR SLAGS TESTED[36]

Chemical	Average analysis of 25 slag samples, percent
Silica (SiO_2)[a]	44.73
Alumina (Al_2O_3)	17.44
Titania (TiO_2)	2.92
Iron oxide (Fe_2O_3)	9.26
Copper oxide (CuO)	Trace
Calcium (CaO)	10.52
Magnesia (MgO)	2.1
Sulfate (SO_3)	3.69 (Avg. 6)
Zinc oxide (ZnO)	1.54 (Avg. 6)
Lead oxide (PbO)	Trace
Phosphorus pentoxide (P_2O_5)	1.52
Soda (Na_2O)	6.09
Potash (K_2O)	1.99
Lithia (Li_2O)	0.06
Manganese oxide (MnO_2)	0.29
Barium oxide (BaO)	Trace

[a]All samples reported on a calcined basis.

Table 14. RANGE OF SPECTROCHEMICAL ANALYSIS OF ALL INCINERATOR SLAGS TESTED[36]

Chemical	Range of analysis of 25 slag samples, percent
Silica (SiO_2)[a]	20.9 – 76.0
Alumina (Al_2O_3)	0.2 – 28.3
Titania (TiO_2)	0.33 – 4.9
Iron oxide (Fe_2O_3)	1.8 – 40.0
Copper oxide (CuO)	Trace
Calcium (CaO)	7.3 – 17.0
Magnesia (MgO)	1.1 – 2.6
Sulfate (SO_3)	0.17 – 20.4 (Avg. 6)
Zinc oxide (ZnO)	0.20 – 6.3 (Avg. 6)
Lead oxide (PbO)	Trace
Phosphorus pentoxide (P_2O_5)	0.6 – 2.2 (Avg. 6)
Soda (Na_2O)	0.6 – 11.6
Potash (K_2O)	0.3 – 8.1
Lithia (Li_2O)	0.03 – 0.13
Manganese oxide (MnO_2)	0.04 – 0.9
Barium oxide (BaO)	Trace
Change on Ignition	-2.9 – +5.7

[a]All samples reported on a calcined basis.

Several methods for reducing or preventing the formation of slag deposits on furnace walls have been used. Silicon carbide in conjunction with air cooling of the furnace walls has been used in some incinerators.[37] The use of steam spray nozzles in a steam pipe mounted just above the grate has proven successful at the Oceanside Refuse Disposal Plant.[34] Water walls in some of the European incinerators have alleviated this problem.[31]

3.1.7 Heat-Recovery Boilers

Boilers placed in the path of combustion gases can be both an effective and economical method of cooling the gases. For example, heat absorption by water-walled furnaces with well-designed boilers can cause a gas temperature reduction of from 2,500° to 450° F.[31]

There are two basic boiler sections in the modern water-wall, waste-heat-recovery incinerator.[31] The first of these is the convection section, which is located immediately beyond the combustion chamber. In this section the gases move vertically upward passing through a series of boiler tubes. The velocity of the gases normally does not exceed 30 feet per second in this section. Since there is still a large amount of entrained flyash, and temperatures are high, the boiler tubes must be spaced far enough apart to prevent foul bridging across the tubes. On leaving the convection section, the gases have been reduced in temperature to nearly 1,000° F and are then usually channeled to move downward through the second boiler section, which is called the economizer. The tubes in the economizer are much more closely spaced because the fouling problem is reduced (flyash is less sticky) at the lower gas temperature. On leaving the economizer, the gases are ready for the gas-cleaning operation.

3.1.8 Auxiliary Heat

Auxiliary heat is sometimes used to attain high temperatures for the drying, ignition, and complete combustion of high-moisture-content refuse. Auxiliary burners may be installed in waste-heat-recovery incinerators to augment steam production on an as-needed basis when steam production from refuse drops below a specified amount. Oil and gas, and sometimes coal, are used for fuel. No one location for the burner is universally accepted. It may be located directly in the incinerator furnace as illustrated in Figure 23, or installed in a separate combustion chamber as in Figure 24, in which case the combustion gases from the burner and the incinerator come together at the boiler inlet.

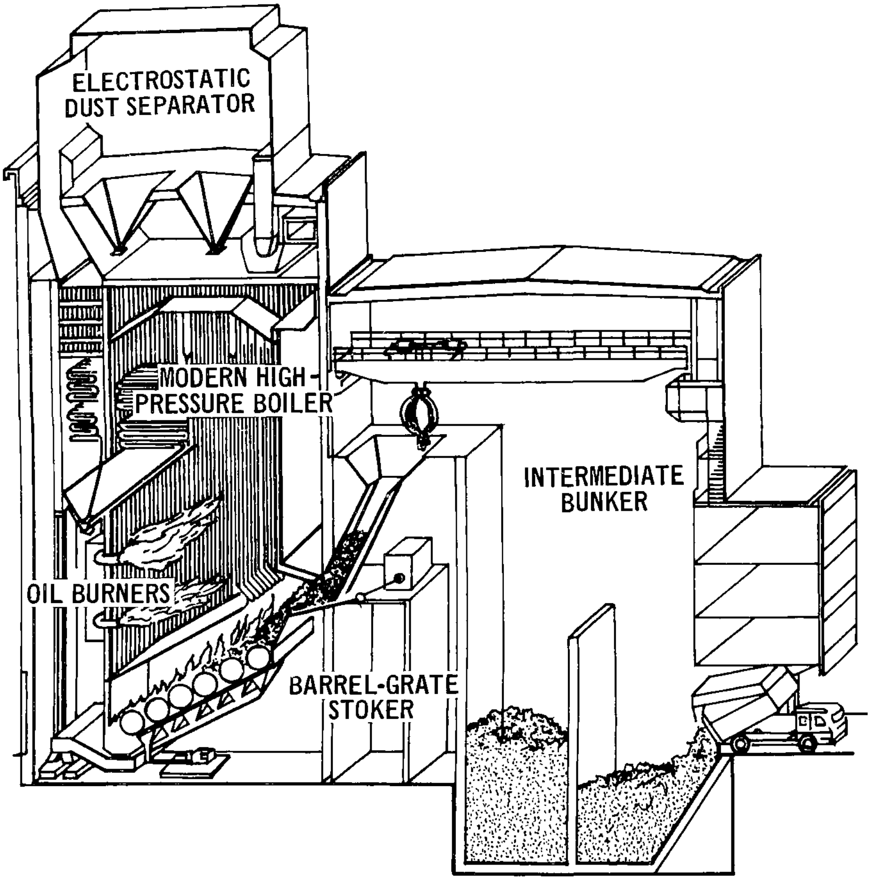


Figure 23. Elaborate boiler with auxiliary oil burners in Dusseldorf, Germany, incinerator.[14]

1 REFUSE PIT, 5,300-yd^3 CAPACITY
2 HOPPER AND FEEDING CHUTE
3 MARTIN STOKER
4 MARTIN RESIDUE DISCHARGER
5 APRON AND BELT CONVEYORS FOR RESIDUE
6 OPERATING FLOOR
7 COMBUSTION CHAMBER, NO. 1
8 COMBUSTION CHAMBER, NO. 2
9 PULVERIZED COAL BURNERS
10 STEAM SUPERHEATERS
11 STEAM RESUPERHEATERS
12 ECONOMIZER AND PREHEATER
13 ELECTROSTATIC PRECIPITATOR
14 OIL-FIRED BOILER FOR HEATING
15 TURBINE ROOM (TURBINES NOT SHOWN)
16 TURBINE-DRIVEN BOILER FEED PUMP
17 DEAERATOR

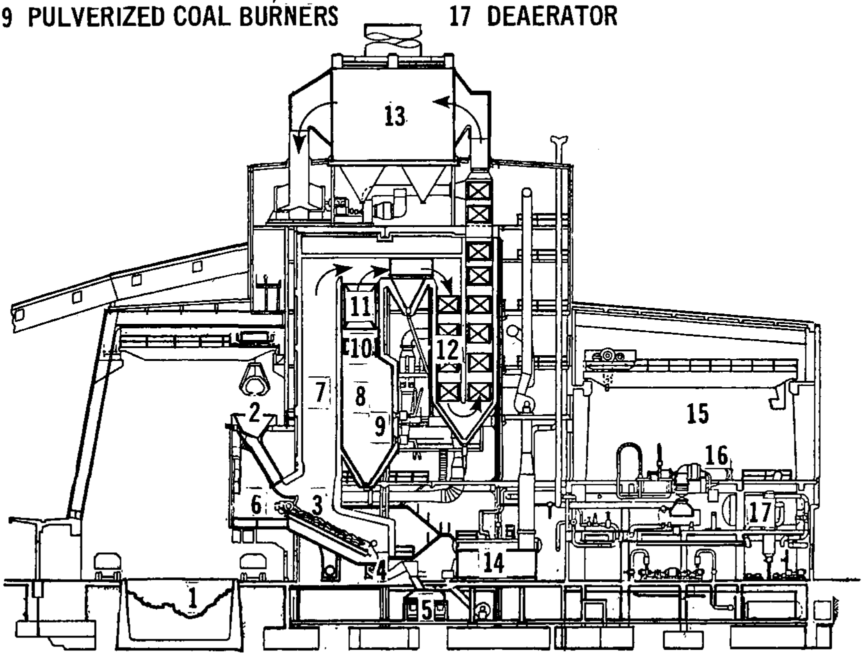


Figure 24. Power plant in Munich uses auxiliary burners to combine refuse incineration and pulverized-coal burning.[3]

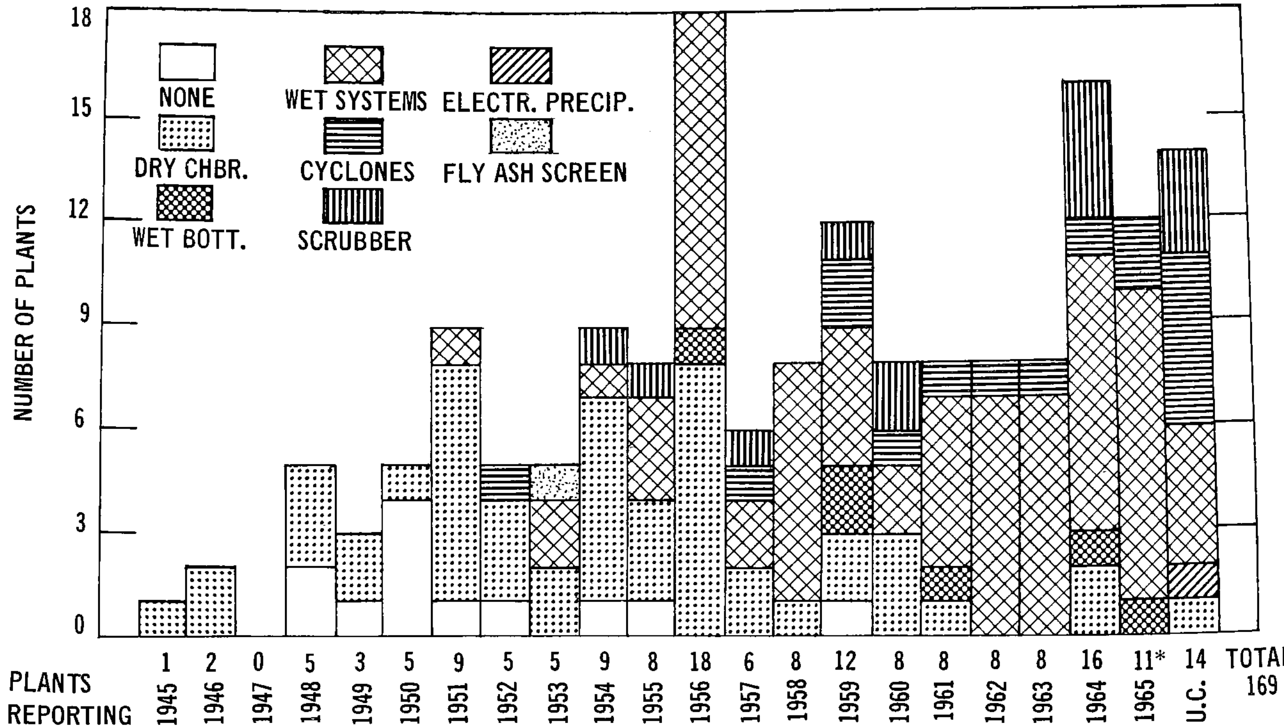
4. AIR POLLUTION CONTROL EQUIPMENT

Up to this point we have been concerned with the municipal incineration process from the generation and collection of refuse to the burning of refuse and recovery of waste heat. Incineration of refuse always produces at least two waste products, residue and combustion gases. Except for low "burnout" of the refuse, the residue is usually not a significant disposal problem because it is low in volume, sterile, and its offensive odors have been removed. Sufficient landfill areas are usually available to handle the residue produced. The combustion gases, however, can be a significant problem because of their contribution to air pollution. The primary air pollution concern is with particulate emissions rather than gases and odors. At present, air pollution control devices are basically designed for the removal of particulate matter, with some incidental removal of pollutant gases by certain types of control processes.* Stephenson and Cafiero,[32] in an extensive survey of incinerators, presented a summary of primary flyash removal facilities, shown in Figure 25.

4.1 SETTLING CHAMBER (EXPANSION CHAMBER)

A settling chamber, one of the early and simple methods for flyash control, is located immediately beyond the combustion chambers. Large particles of flyash settle out if the gas expansion chamber is large enough in size to substantially lower the gas velocity. For example, a 30-micron particle settles at the rate of 10 feet per minute, and a 1-micron particle settles at ¼ inch per minute.[40] It is apparent from these figures that, from a practical viewpoint, settling chambers are effective only for the extremely large flyash particles. The chambers are constructed of either refractory brick or steel, and are designed and fitted with devices to keep internal turbulence to a minimum to keep flyash from becoming reentrained in the gas stream. Reentrainment can also be reduced by using a wet bottom chamber. Deflecting dampers are installed in some wet bottom chambers to force the flyash-laden air against the water surface. Gravity settling is effective only for particle sizes of 200 microns or more,[39] and settling chamber efficiency usually averages only 15 to 25 percent. Such chambers are therefore desirable only for the removal of large particles prior to further cleaning by more sophisticated devices. Such a scheme is used in the North Hempstead incinerator, which uses two other gas-cleaning devices in addition to a wet bottom settling chamber (see Figure 26). In anticipation of more stringent codes, provisional space was provided for more efficient cleaning equipment.

*A third waste product, effluent water, can be a problem for municipal incinerators that utilize wet gas-cleaning devices. In areas where water pollution is a major consideration, it may be well to emphasize dry gas-cleaning systems rather than wet systems.



*ONE PLANT REPORTS SPRAY CHAMBER FOR RUBBISH FURNACE, CYCLONE FOR REFUSE FURNACES

Figure 25. Primary flyash removal facilities.[32]

A – DUAL CRANES
B – HOPPER WITH LARGE OPENING
C – FEED CHUTE
D – SAFETY JACKET
E – HIGH-TEMPERATURE REFRACTORY
F – GRATE
G – FURNACE
H – RESIDUE HOPPER
I – SECONDARY COMBUSTION CHAMBER AND DOWNPASS FLUE
J – FINAL BURNING AND SETTLING CHAMBER
K – NOZZLE-CLEARED WET BOTTOM
L – HIGH-PRESSURE OPPOSED SPRAY CURTAIN
M – FLYASH SLUICEWAYS
N – "FAIL-SAFE" DAMPER ARRANGEMENT
O – SEQUENTIAL CYCLONE COLLECTORS
P – FLYASH HOPPER
Q – INDUCED-DRAFT FAN
R – BYPASS FLUE
S – PROVISION FOR ADDED FILTERS OR PRECIPITATORS
T – CHIMNEY

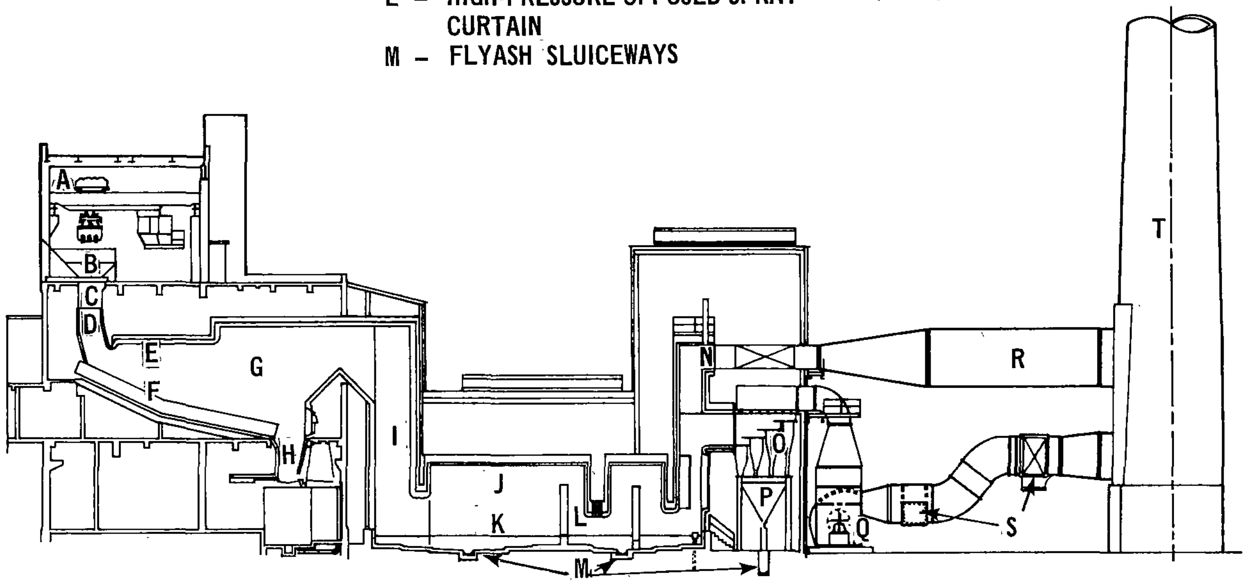


Figure 26. Special features of the North Hempstead incinerator include an unusual amount of air pollution control equipment, provision for additional equipment if needed, and an emergency bypass flue.[37]

4.2 BAFFLED COLLECTORS

In some incinerators, baffled collectors are installed separately from settling chambers. They are usually made of brick or metal and can be either wet or dry.[18] There are many collector designs and collectors can be placed in several locations within the post combustion chamber area of the incinerator. Particles are removed by direct impingement, velocity reduction, or centrifugal action. Removal efficiencies are quite low and only larger flyash particles, mostly 50 microns or larger can be removed.

4.3 SCRUBBERS

Scrubbers clean the combustion gases by carrying wetted flyash to the bottom of the scrubber. To be incorporated into the water, flyash particles must impact on a water droplet. The impaction efficiency is primarily a function of the relative velocity between the flyash particle and the water droplet, the size and density of the flyash, the number of water droplets, and the fineness of the water spray. Most of these factors are a function of the pressure drop in the scrubber and the energy input to the scrubber system.[38] In some incinerators, fresh water is used continuously for the scrubbing process, which necessitates disposal of the slurry leaving the scrubber. Because the amount of water required by scrubbers is high, however, and economy is of interest, the scrubber water can be recirculated after removal of the wetted flyash. Corrosion from the acidity of the scrubber water, caused by the absorption of acid-forming combustion gases, can be a serious design and maintenance problem. Some installations use the slurry for quenching the hot residue as it falls from the burning grate. After the quenching, the slurry may or may not be recirculated.

Scrubbers are usually made of stainless and carbon steels. Maintenance usually consists of repair and replacement of spray nozzles or flow valves. Efficiency is related to the pressure drop in that higher efficiencies require higher pressure drops. In the venturi scrubber, pressure drops of from 20 to 40 inches of water can be required.[40]

White stack plumes are common, particularly in cold weather when efficiently scrubbed gases are laden with large amounts of moisture added during the scrubbing process. Indicative of moisture, rather than pollutants, the plume has the appearance of being a pollutant, and codes with given opacity requirements can require elimination of such a plume. The most obvious method for elimination of the steam plume is to use a dry gas-cleaning method. Many methods have been suggested for suppression of the steam plume. Some of them are: electrostatic precipitation of the water droplets, mechanical separation of the water droplets, absorption or adsorption of water vapor, mixing of the moist gases with relatively dry heated air, condensation of the moisture by direct contact with water on cold surfaces, and reheat of scrubber exhaust gases. Studies show that costs of these steam plume suppression methods, when the ambient air temperature is above 20° F can be as much as the cost of a wet scrubber system.[41]

4.3.1 Spray "Walls"

Perhaps the simplest scrubber design (some may question its classification as a scrubber) consists of a water spray "wall" in which the spray is arranged to permit maximum contact between the water and the dirty gas. The sprays can be placed in several locations, such as the settling chamber, the baffle collector, the breaching ducts, or a chamber specifically designed for scrubbing.

4.3.2 Venturi Scrubber

Both flyash and gaseous pollutants are removed in a venturi scrubber in which water is supplied peripherally at the top of the venturi (see Figure 27). Gases passing through the venturi tube are accelerated at the throat to a velocity that fragments the water into a mass of fine droplets. Impaction efficiency is high because of high relative velocities, small water droplet size, and large number of droplets in the throat of the venturi tube. Downstream from the throat, the cleaned gases decelerate and the water droplets agglomerate to a size easily separated from the gas stream.

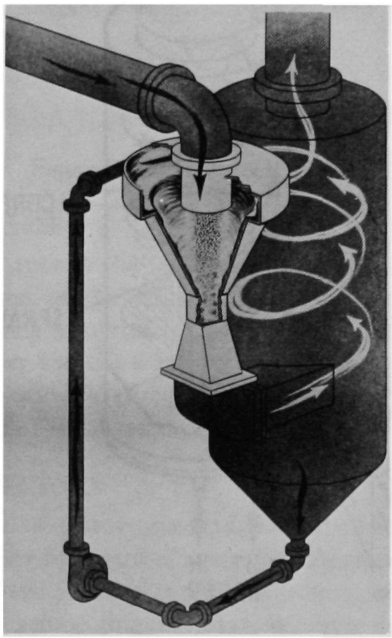


Figure 27. Venturi scrubber. (Courtesy Chemico)

Venturi scrubbers have a high collection efficiency, usually 90 percent or greater, and can process untreated gases directly from the combustion chamber. Recirculation of scrubber water permits less consumption of water and ensures a minimum, but concentrated production of slurry.

4.3.3 Cyclonic Spray Scrubber

The configuration of one style of cyclonic spray scrubber is illustrated in Figure 28. Gases enter the lower portion of the scrubber peripherally and make a helical motion through a water spray until they exit the top of the scrubber. Water is supplied to a spray manifold, which is located in the center of the scrubber. Slurry is drained from the bottom of the scrubber. Impaction efficiencies here depend on the velocity of the gases and the atomization of the water by the spray manifold. Efficiencies of cyclonic scrubbers range from 85 to 94 percent.[39]

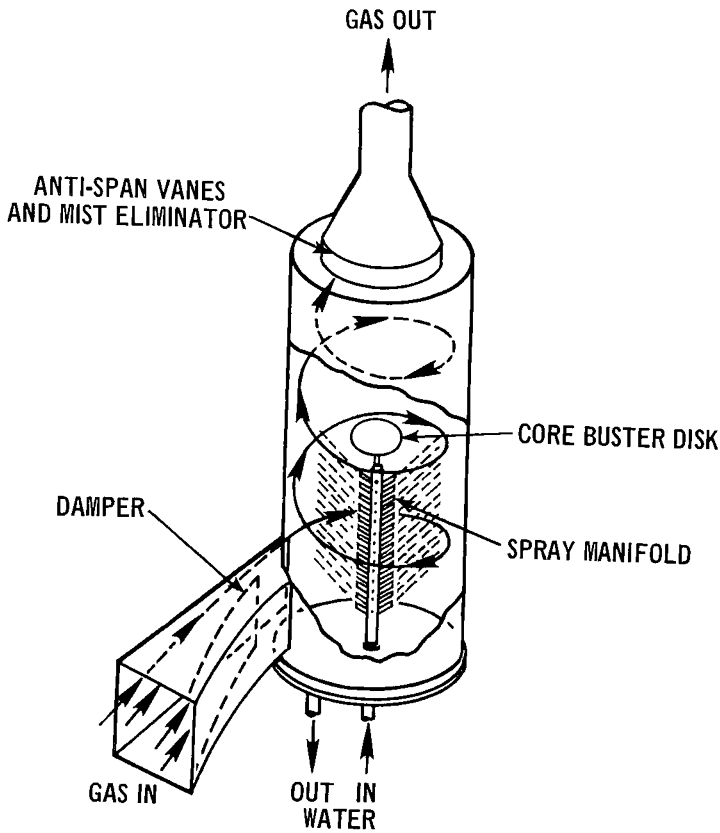


Figure 28. *Cyclonic spray scrubber.

4.3.4 Packed Scrubber

Packed scrubbers clean gases by the same process as other scrubbers but achieve impaction of the flyash with water in a unique way. Gases enter the cover portion of the scrubber (see Figure 29) and pass through a series of packed beds that are wetted from the top by water sprays. Flyash is carried to the bottom of the scrubber where it is removed.

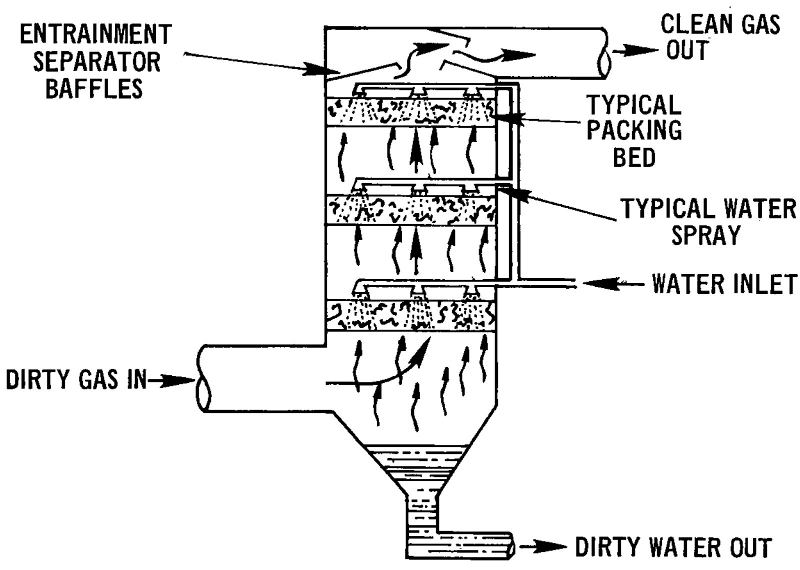


Figure 29. Packed scrubbers.[38]

4.3.5 Flooded-Plate Scrubber

Another scrubber type is the flooded-plate scrubber shown in Figure 30. Gases enter the bottom of the scrubber and pass through a series of water-flooded plates containing a myriad of water-covered holes. Clean gases exit at the top of the scrubber and the slurry is drained from the bottom. Collection efficiency ranges from 90 to 95 percent and water requirements range from 3 to 5 gallons for 1,000 cubic feet of gas treated.[40]

4.4 CYCLONE COLLECTORS

Cyclones are able to remove particulate matter from the exhaust gases without the use of water by means of centrifugal separation of the particles and gases. There are two basic types of cyclone collectors, the multicyclone (Figure 31) and the involute cyclone (Figure 32). Gases must be cooled to within the range of 400° to 700° F to permit standard construction of cyclone collectors and induced-draft fans.

4.4.1 Multicyclone Collector

Polluted gases enter the collector through a spinning vane, which sets up an intense vortex. Particles are centrifugally thrown against the walls of the collector and fall to the bottom where they are removed. The cleaned gases exit

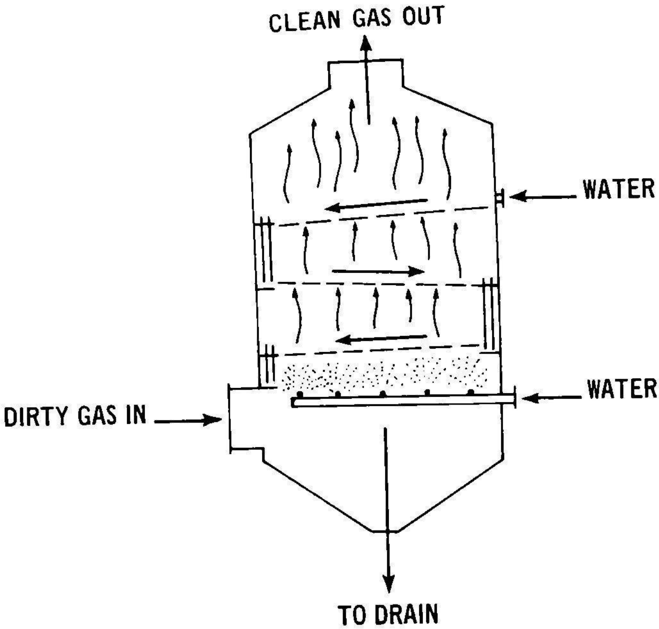


Figure 30. Flooded-plate scrubber.

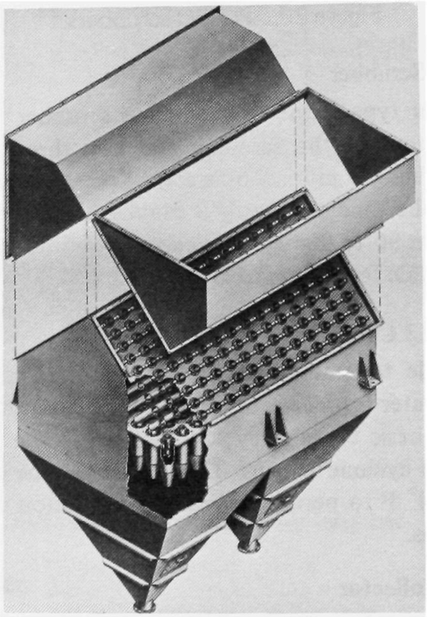


Figure 31. Multicyclone collector.

vertically through the outlet tube. The tubes of a multicyclone collector are usually from 9 to 10 inches in diameter and are mounted in two common tube sheets. One sheet is for incoming dirty gases and the second tube sheet is for the exit of the cleaned gases.

Multicyclones are more efficient for larger particles than they are for smaller particles. Efficiency drops off rapidly for particles smaller than 20 microns.[38] For 10-micron particles, only 35 percent (by weight) can be collected. For a pressure drop of 3.5 inches of water, a multicyclone collector can obtain an efficiency of about 80 percent.[38] Plugging of the cyclone, which can be a serious problem in this type of collector, can lower efficiency significantly.

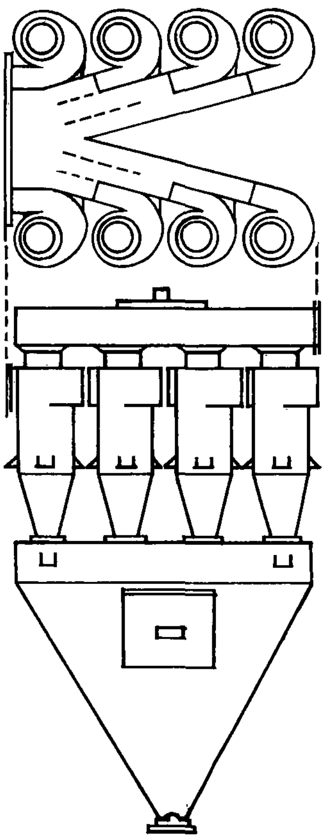


Figure 32. Cyclone dust collector, involute. (Courtesy of Research-Cottrell, Inc.)

4.4.2 Involute Cyclone

Involute cyclones, which are much larger than multicyclones, are usually 2 to 5 feet in diameter. They operate on the same principle as the multicyclone, but are not subject to the plugging. Erosion of the lower cone can occur and is usually corrected by ceramic lining or water flushing to remove collected flyash.[40] One particular model of the involute cyclone solves this problem by introducing water peripherally at the top of the cyclone wall. An additional advantage of this design is that it permits the water to carry the flyash down the walls, eliminating reentrainment of the ash. In addition, the temperature of the gas may be reduced by as much as 200 Fahrenheit degrees by passing the gas through a wet cyclone. The moisture added to the gas is usually not sufficient to create a steam plume.

4.5 FABRIC FILTER COLLECTORS

Fabric filter collection of flyash from incinerators has potential of being an effective and appropriate method of flyash control, but at present the method is still in its preliminary stages of development. Slow development can be attributed to the high-temperature gases that must be filtered and the characteristics of the flyash.[38] The efficiency of fabric filtration is high. Fabric filters cannot be overloaded during periods of excessive dust loadings as is common with other types of control equipment. Tests of fabric filters installed at an incinerator in Pasadena, California, show that they have an efficiency of 99.77 percent.[42] The filters are usually arranged as tubular bags so that they can be cleaned by shaking, bag collapse, reverse jet blowing, and reverse flow backwash. The bags are connected to a dust hopper into which the caked dust falls for removal (see Figure 33). Pressure losses for bag filters range from 3 to 7 inches of water. Glass

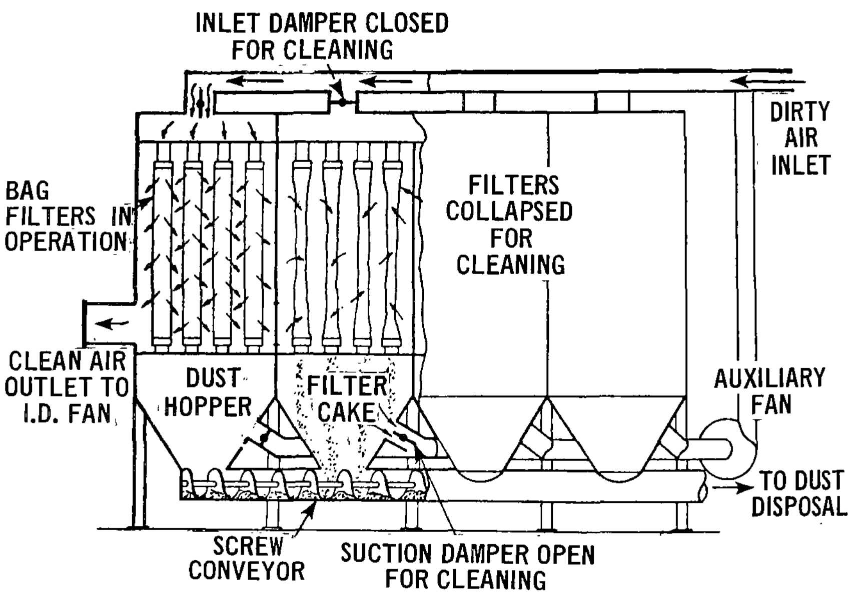


Figure 33. Fabric filter dust collector.[38]

fabrics used can withstand temperatures up to 500° F. A disadvantage of fabric filters is that they require more room than any other one air pollution control device. The initial cost of such filters and their maintenance is high.[38] Extensive gas conditioning and control is required for proper performance of the filter fabric.

4.6 ELECTROSTATIC PRECIPITATOR

What is perhaps the first electrostatic precipitator installed in an incinerator was installed in the late 1920's in Zurich, Switzerland. Since that time electrostatic precipitators have become widely used throughout most of Europe. All municipal incinerators located in large cities in Japan use electrostatic precipitators for gas cleaning.[44] England has used electrostatic precipitators in only a few of its incinerators to date, but the planned Deephams' Refuse Disposal Works in London, with a planned capacity of 1,667 tons per day, will be equipped with electrostatic precipitators.[45] The first two incinerators in the United States to be equipped with electrostatic precipitators are located in New York City.[46] As a pilot project, two precipitators will be supplied by two different manufacturers and placed in two different existing incinerators. Only one furnace at each of the two New York incinerators will be equipped with the new cleaning device. The city of Montreal, Canada is following the lead of the Europeans in the design of a 1,200-ton-per-day capacity incinerator that will be equipped for steam production and will use an electrostatic precipitator for each of its four furnaces.[47]

4.6.1 Operating Principles

The basic process by which electrostatic precipitators separate dust or moisture from a gas stream is relatively simple and has been quite adequately and briefly described by Robert L. Bump:[43]

> An electrostatic precipitator consists of discharge wires of relatively small diameter and collecting surfaces, such as plates or tubes, between which gases pass carrying entrained particles. The discharge wires are the pole of negative polarity while the collecting surfaces are positive and at ground potential. A unidirectional, high-potential field is set up between them. At and above a critical voltage, a corona discharge takes place near the surface of the negative wire. The corona is a visible manifestation of the ionization of the gas between the poles resulting in the formation of positive and negative gas ions in the region near the negative wires. These ions are attracted to the pole of opposite polarity. In moving toward the opposite pole the ions attach themselves to the dust particles entrained in the gas, charging the particle positive or negative as the case may be. The particles themselves are then attracted to the pole of opposite polarity on which they are deposited. Since the ions are formed in the immediate vicinity of the negative wire the

negative ions have a much longer distance to travel; hence, more entrained particles are charged negative than positive, resulting in a greater collection on the positive collecting surfaces than on the negative wires. On reaching the collecting surface, the particles give up their charge and adhere to it lightly until dislodged by rapping. From this it can be seen that there are four steps necessary for electrostatic precipitation: (1) charging the particles by means of gaseous ions or electrons; (2) transporting the charged particles through the gas to the collecting surfaces; (3) discharging the charged particles; and (4) removing the precipitated material from the wires and collecting surface.

4.6.2 Combustion Gas Conditioning

Combustion gas must be properly conditioned prior to entering electrostatic precipitators. Design criteria of precipitators limit the temperature of the inlet gases to a range of from 450° to 600° F. Another factor is the efficiency of a precipitator, which is related to the temperature and moisture content of the gases. In installations using waste heat boilers, the temperature reduction is handled by the heat recovery process. Installations not incorporating a waste-heat recovery process can condition the gases in three ways.[48] The first system is a separate evaporation cooling tower that is installed immediately following the last combustion chamber. Cooling of the gases is accomplished entirely by water. The second method is an air-water system in which air and water infiltrate and cool the gases. The third system cools entirely by water that is injected at the end of the furnace rather than in a separate cooling tower. A comparison of the "water only" and "water and air" conditioning systems for a typical 250-ton furnace is given in Table 15.

The table indicates that the "water and air" conditioning system results in 57 percent more gas volume to be treated. This factor, in addition to the effect of the dew point on the precipitation process in the "water only" system, results in a precipitator that is 77 percent larger for a "water and air" system than for a "water only" system. The dust load at the precipitator outlet for the "water and air" system must be lower to account for the effect of the "diluting air."

4.6.3 Efficiency

Electrostatic precipitators can be designed for nearly any efficiency required, with a pressure drop of only 0.5 to 1 inch of water.[38] Experience with precipitation of flyash from American refuse incineration is limited to only one pilot plant for which test results yielded a collection efficiency (by weight and 50 percent excess air) of up to 94.4 percent.[49] The precipitators that will be installed in New York are designed for 95 percent efficiency.[48] In Europe, because of more stringent codes or the anticipation of more stringent codes, installations with guaranteed efficiencies of over 99 percent are common.[43]

Table 15. COMPARISON OF CONDITIONING SYSTEMS[48]

System	Water only	Water and air
Incinerator exhaust		
Gas volume, cfm	169,500	169,500
(250-ton furnace)	at 1310 °F	at 1310 °F
H_2O dewpoint, °F	104	104
Dust load, g/acf	0.241	0.241
Conditioning system		
Spray water, gpm	80	40
Ambient air, cfm	—	45,400 at 68 °F
Precipitator inlet		
Gas volume, cfm	130,150 at 560 °F	205,200 at 572 °F
H_2O dewpoint, °F	150	120
Dust load, g/acf	0.314	0.20
Precipitator size	x	x times 1.77
Precipitator outlet		
Gas volume, cfm	130,150 at 560 °F	205,200 at 572 °F
H_2O dewpoint, °F	150	120
Dust load, g/acf (Residual dust)	0.018	0.010
Power required — Precipitator fans, pumps	350 kW	640 kW

Table 16 presents some of the basic design elements for 52 precipitator units that are installed in 27 European incinerators. The range of efficiency is 92.0 to 99.5 percent, but the average is 98.0 percent.[18]

Table 16. DESIGN ELEMENTS OF EUROPEAN ELECTROSTATIC PRECIPITATORS[18]

27 incinerator plants
52 precipitator units

Characteristic	Range	Average median
Size of furnaces, tpd	42 to 1,060	270
Raw gas volume, cfs	350 to 7,200	1,450
Dust load in raw gas, lb/1,000 lb	2.7 to 12.3	5.43
Gas entry temperature, °F	285 to 520	490
Overall particulate cleansing efficiency, percent	92.0 to 99.5	98.0

4.6.4 Physical Characteristics

Electrostatic precipitators are quite large. Except for fabric filter baghouses, they are perhaps the largest control devices used for municipal incineration. In view of the increased concern with air pollution, when such devices are not made a part of the original design, designers of new plants should consider making allowances for their future installation. The arrangement of the collecting plates and hoppers is shown in Figure 34.

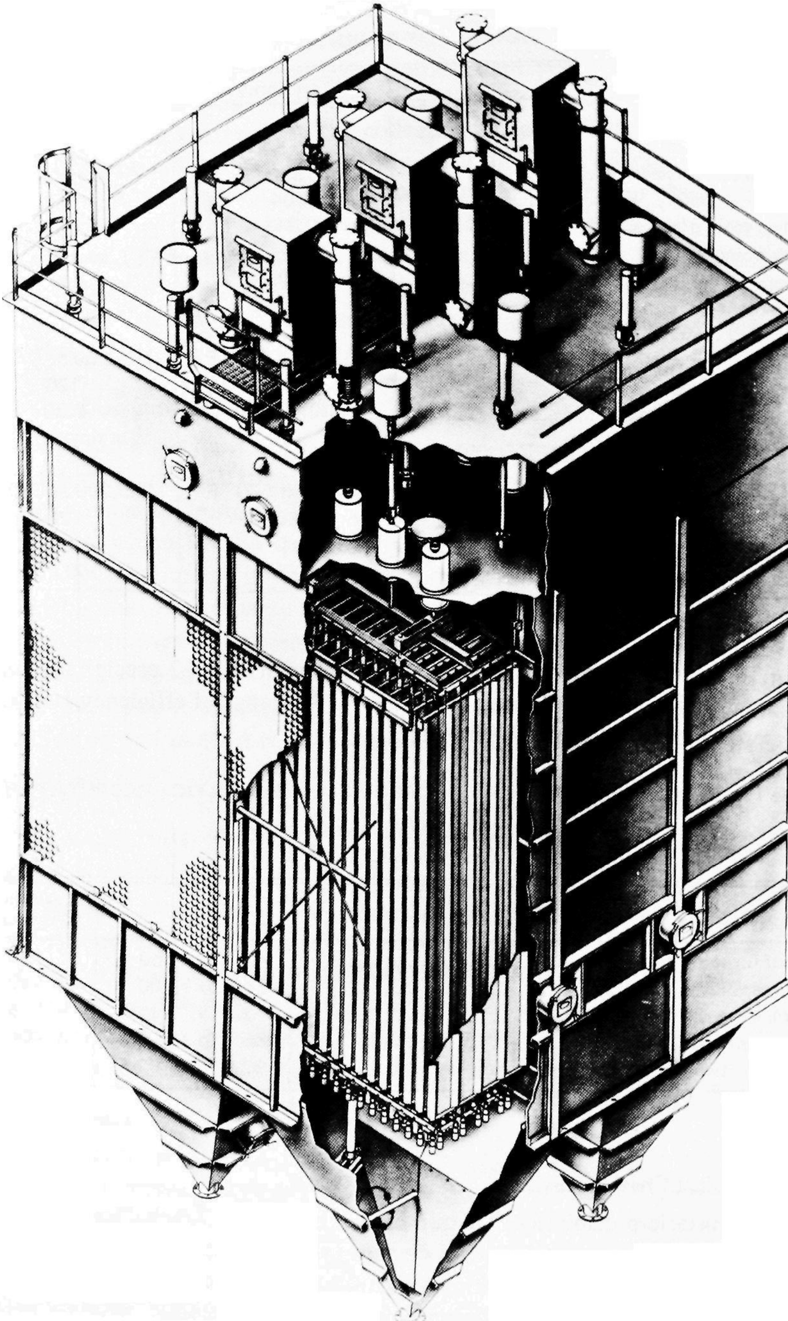


Figure 34. Electrostatic precipitator. (Courtesy of Research-Cottrell, Inc.)

4.7 COMPARISON OF AIR POLLUTION CONTROL EQUIPMENT

Innumerable comparisons may be made among air pollution control devices. One comparison may point out the advantage of system A over system B while another comparison may point out the advantage of system B over system A.

Perhaps in the end, the single most important element of a control device is its collection efficiency. From previous discussions, perhaps a relative rating of efficiencies can be surmised. Figure 35 presents the ranges of collection efficiency for the various classes of control devices.[38] This figure also presents the stack emissions for a given dust loading and collector efficiency.

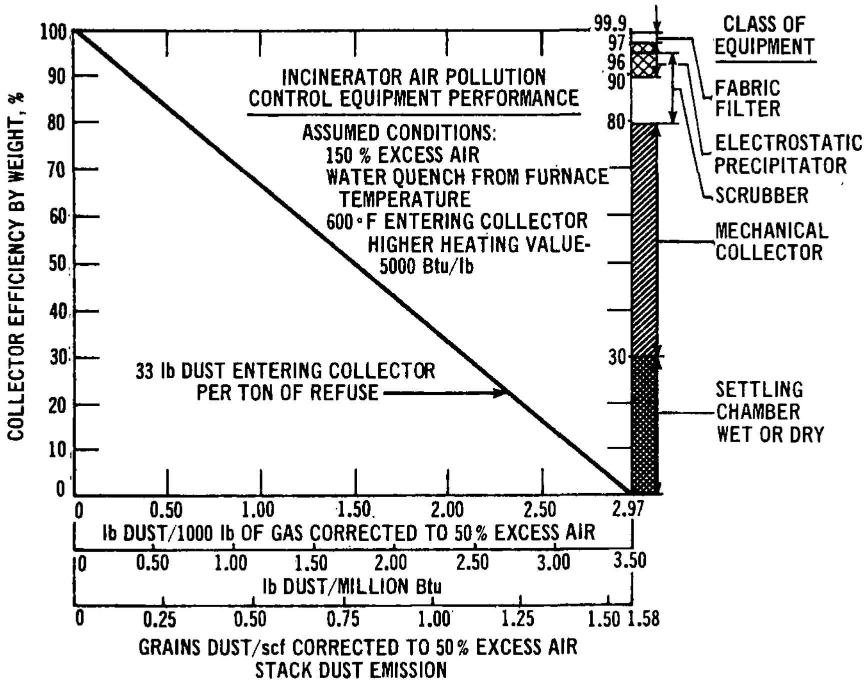


Figure 35. Collector efficiency versus stack dust emissions.

Costs of control equipment are difficult to estimate because of variations among manufacturers, the effect of efficiency and reliability on the cost, and differences in design permitted by local climate. Gas-cleaning costs generally depend on the amount of excess air used, the inlet gas temperature, and the heating value of the refuse.[38] One of the most recent rule-of-thumb estimates of costs of gas-cleaning equipment is presented in Table 17.[50] These figures are based on collectors constructed of mild steel. It has been suggested[38] that, because of the difficulties encountered with the collection of flyash from

Table 17. ESTIMATED COSTS OF GAS-CLEANING EQUIPMENT[50]
($/cfm)

Type of collector	Equipment	Erection	Yearly maintenance and repair
Mechanical	0.07 - 0.25	0.03 - 0.12	0.005 - 0.02
Electrostatic precipitator	0.25 - 1.00	0.12 - 0.50	0.01 - 0.025
Fabric filter	0.35 - 1.25	0.25 - 0.50	0.02 - 0.08
Wet scrubber	0.10 - 0.40	0.04 - 0.16	0.02 - 0.05

incinerators, air pollution control equipment costs would be found in the higher ranges given in Table 17. The economics of decrease in price per volume of gas treated with increase in unit size is reflected in this table. Table 18 compares the relative cost, space, efficiency, water usage, pressure drop, and operating costs for the various types of incinerator air pollution control equipment. It can be seen that in some instances initial cost savings can be lost to high operating costs. High pressure drops mean higher costs because of increased fan loading. Water usage or space requirements can make an otherwise attractive device become quite unattractive.

Table 18. COMPARATIVE AIR POLLUTION CONTROL DATA FOR MUNICIPAL INCINERATOR[38]

Collector	Relative capital cost factor (F.O.B.)	Relative space, %	Collection efficiency, %	Water to collector, gpm/1,000 cfm	Pressure drop, in. water column	Relative operating cost factor
Settling chamber	Not applicable	60	0 - 30	2 - 3	0.5 - 1	0.25
Multicyclone	1	20	30 - 80	None	3 - 4	1.0
Tangential inlet Cyclones to 60-in. diameter	1.5	30	30 - 70	None	1 - 2	0.5
Scrubber[a]	3	30	80 - 96	4 - 8	6 - 8	2.5
Electrostatic precipitator	6	100	90 - 97 ,	None	0.5 - 1	0.75
Fabric filter	6	100	97 - 99.9	None	5 - 7	2.5

All of these estimates and comparisons are first approximations that must be used only in that respect. More meaningful estimates can be quoted by architects, engineers, and equipment manufacturers when a certain type of incinerator is under consideration.

5. AUXILIARY EQUIPMENT

5.1 RESIDUE-HANDLING EQUIPMENT

From 5 to 25 percent by weight of the refuse charged into an incinerator remains as residue after combustion.[2] Devices to handle this residue differ, depending on the type and design of the incinerator.

Batch-feed furnaces are usually fitted with ash hoppers located directly below the grates. The hoppers are usually large enough to store the residue from several hours' burning. The residue is usually quenched or sprayed with water to reduce fire hazards and to control its entrainment in the air. Many incinerators are designed to allow dump trucks to load the residue directly from the hoppers for delivery to a landfill or other disposal site.

The residue from continuous-feed furnaces falls from the burning grate into ash removal devices that are usually automated. The residue is usually quenched in a bath for dust and fire control. A drag or apron pan conveyor then carries the wet residue to dump trucks that deliver the residue to the disposal site. Figures 36 and 37, respectively, show a drag bottom conveyor carrying wet, steaming residue and a dump truck receiving the residue from the conveyor belt. Figure 38 is a view of an operational residue landfill site.

5.2 AIR AND FAN REQUIREMENTS

Forced-draft and induced-draft fans required for air supply and exhaust of the combustion gases are a most important factor in the design of municipal incinerators. Air requirements are difficult to calculate because of the heterogeneous nature of refuse. Required air can usually best be estimated by analyses of representative refuse samples. The amount of theoretical air needed for combustion of various materials on a moisture- and ash-free basis is given in Table 19.

Table 19.

AIR REQUIRED FOR COMBUSTION OF SELECTED MATERIALS[2]

(lb/lb of refuse)

Paper	5.9
Wood	6.3
Leaves and grass	6.5
Wool rags	6.7
Cotton rags	5.4
Garbage	5.5
Rubber	9.4
Suet	12.1

Air supplied to the combustion chamber can be classed as either primary or secondary air. Primary air is supplied under the grates and, basically, controls the rate of burning. Primary air can be preheated if the moisture content of the refuse is high enough to make it desirable. Generally, heating of the primary air is not required because of the higher values of today's refuse. Instead, excess air is usually required to cool the furnace to a temperature compatible with the furnace lining.

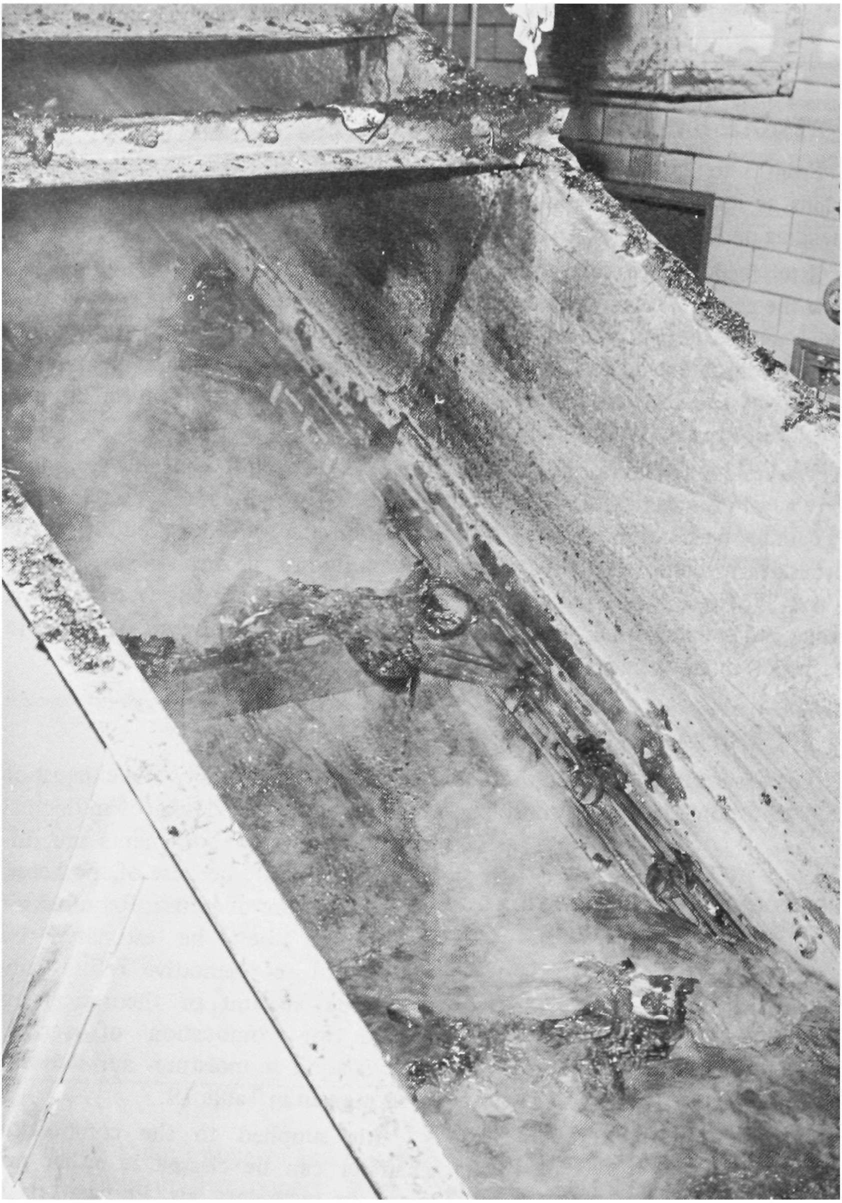


Figure 36. Drag bottom residue conveyor carrying steam-wetted residue.

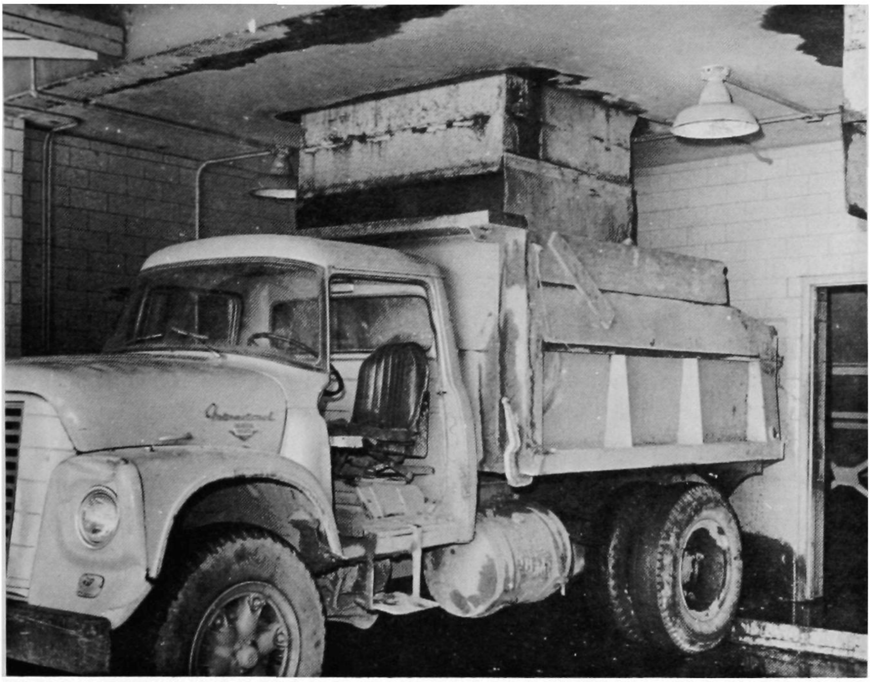


Figure 37. Dump truck receiving residue from conveyor.

Figure 38. Residue landfill site.

Secondary air is supplied above the burning refuse to provide turbulence and oxygen for furthering the combustion of combustible gases, vapors and particles within the combustion chamber. Secondary air can also be used as excess air for temperature control of the furnace.

Induced-draft fans are extremely large fans that provide air to move combustion gases through the furnace, through the gas-cleaning devices and breachings, and out the stack. Figures 39 and 40 show the electric motor and fan enclosure for one of the 350-ton-per-day furnaces at the Montgomery County incinerator in Rockville, Maryland.

Performance "characteristics" of both induced-draft and forced-draft fans for incinerator application are discussed in a report by Silva.[51] The formulas and guidelines presented in the report can be helpful in plant design and modification.

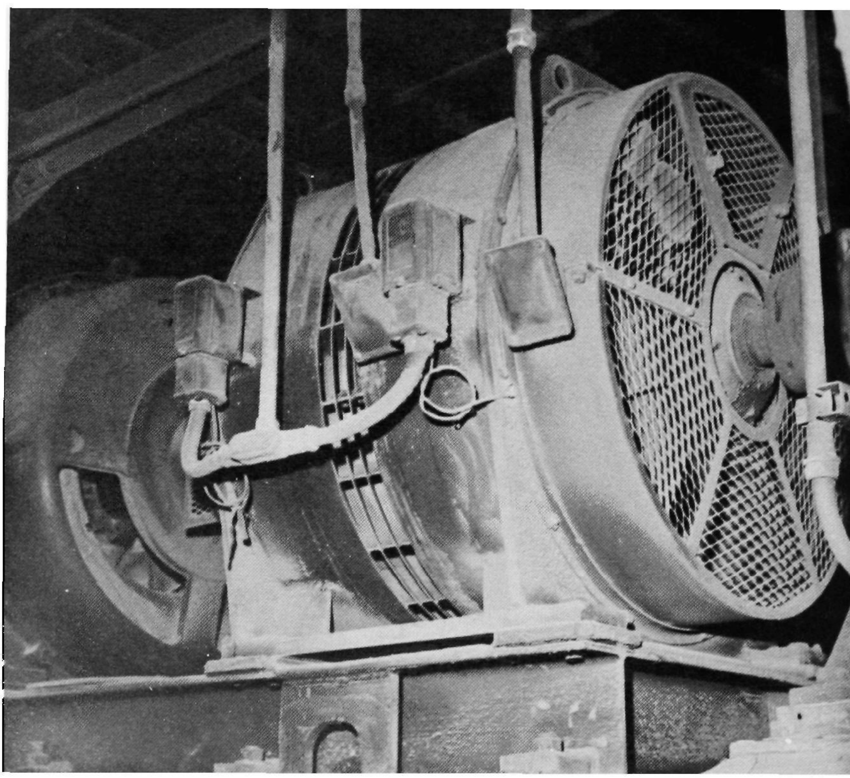


Figure 39. Electric motor of induced-draft fan.

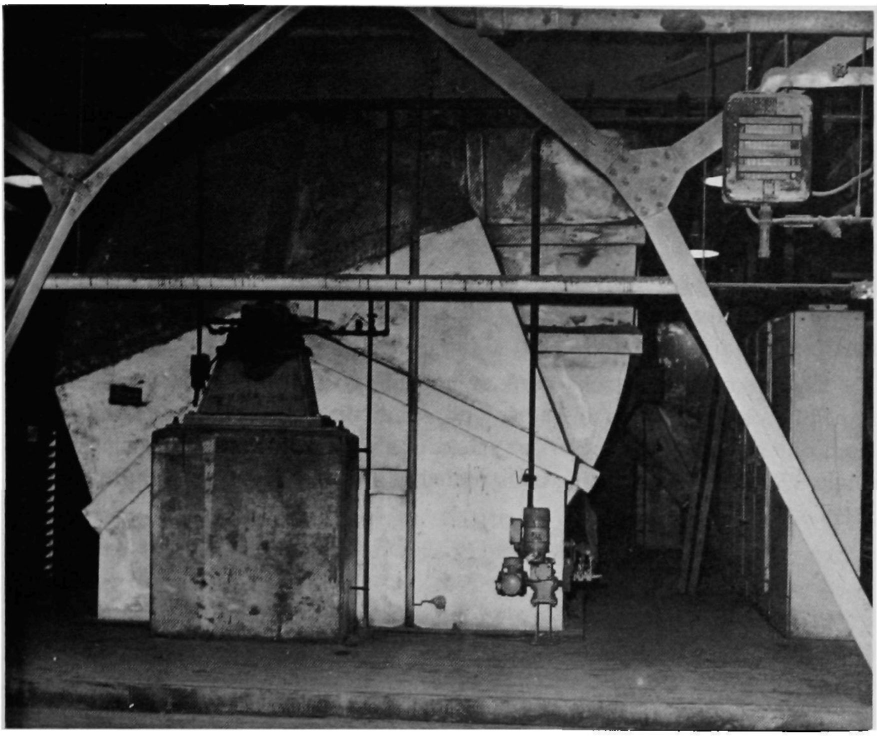


Figure 40. Induced-draft fan enclosure elevated platform is mounted on springs for vibrational control.

5.3 INCINERATOR STACKS

An incinerator stack is a vertical flue that transports combustion gases to a level in the atmosphere where the gases can be emitted, hopefully, with minimum pollution of the immediate environs of the stack. The height of the stack as a factor in air pollution control is an extensive subject in its own right. In some incinerators with highly sophisticated gas-cleaning equipment, the stack height is not significant except in considering air pollution in the immediate vicinity of the plant. A stack should be high enough to permit sufficient dispersion of the effluent pollutants before they reach a receptor in objectionable concentrations. The local meteorological elements and topography and their interactions are a major factor in the dispersion of the stack effluent. Generally, high stacks are good draft producers and less power is required to operate draft fans. Three types of stacks are used for incinerators: steel, masonry, or concrete. Masonry and steel chimneys are the most widely used.

Masonry construction is used extensively for high, natural-draft chimneys. Masonry chimneys can be attractively designed to blend with building architecture and ruggedly constructed to support their weight and withstand high winds. Masonry chimneys usually consist of an outer structural shell and a heat-resistant lining that can withstand temperatures up to 1,000° F, depending on the incinerator.[2] The outer shell and inner lining are usually separated by an annular air space.

Steel chimneys are much less expensive and usually require less space than masonry chimneys. Because tall steel chimneys require unsightly guy wires for structural support, short steel self-supporting chimneys (see Figure 41) with induced-draft fans have become popular.

Stack height and diameter are dependent on the temperature, velocity, and amount of flue gas to be handled.

The number of stacks used at a plant is basically a matter of design. Recently constructed incinerators and some that are under construction use from one stack per furnace to one stack for all the furnaces of the incinerator. A single 328-foot stack is being constructed at the Ivry Plant in a suburb of Paris, France.[21]

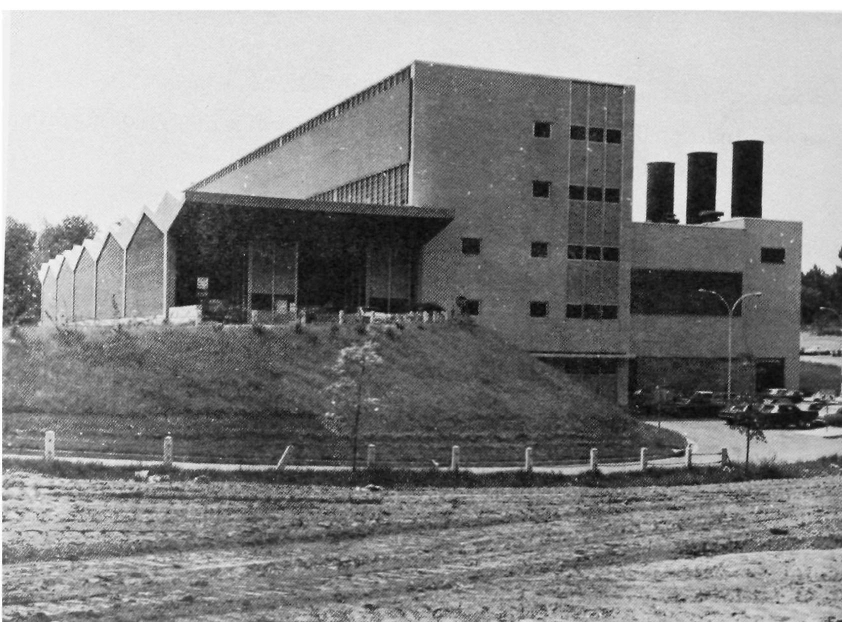


Figure 41. Attractive steel stacks used at the Montgomery County incinerator in Rockville, Maryland..

5.4 CLOSED-CIRCUIT TELEVISION

Closed-circuit television (CCTV) has many uses and advantages at large municipal incinerators where a multitude of operations that must be closely coordinated take place on four or five floors. The use of CCTV in municipal incinerators is obviously a rather recent innovation that has not yet found wide acceptance. What is perhaps the first CCTV installed in a municipal incinerator is in use at the newer Oyster Bay, New York, incinerator.[52] In this plant, television cameras are located on the charging floor to monitor the storage bin and crane operation, and two cameras, one for each of two furnaces, are located in the rear walls of the furnaces to monitor the final grate section, which is the best indicator of the furnace performance. By viewing the television monitor, the supervisor can affect the critical operations of the plant by use of fingertip controls.

The advantages of such a CCTV system are, indeed, immediately apparent. The Oyster Bay plant installed the complete CCTV system for $25,000 and eliminated two men per shift (a total of six men per 24-hour day) from the operating floor. The speed of the grates can be varied when the furnace monitor shows either insufficient or excess burning time. Large pieces of incombustible material that can jam the grates or residue conveyors can be detected and removed before damage occurs. In the future, monitoring cameras may be used to monitor residue conveyors, stack emissions, weighing stations, and other activities at incinerators.

5.5 BUILDING AND FACILITIES

The trend toward large, mechanized incinerators with flyash control over the past 15 to 20 years has brought about changes in building design to accommodate larger furnaces and flyash-removal equipment. Building sites close to the refuse source are becoming more difficult to find because of scarcity of land, sensitivity of a community to the very thought of a refuse disposal facility in their community, and community sensitivity to air pollution.

Many objections to a municipal incinerator can be lessened by enclosing objectionable operations within an attractive well-designed building (see Figure 42). Landscaping and litter policing can be used to make the grounds attractive.

Another interesting trend is the increasing similiarity of design of incinerators. There are, of course, still major differences, but increased communication among design engineers and consultants has brought about a more universal design that does not include previous design mistakes and inadequacies.

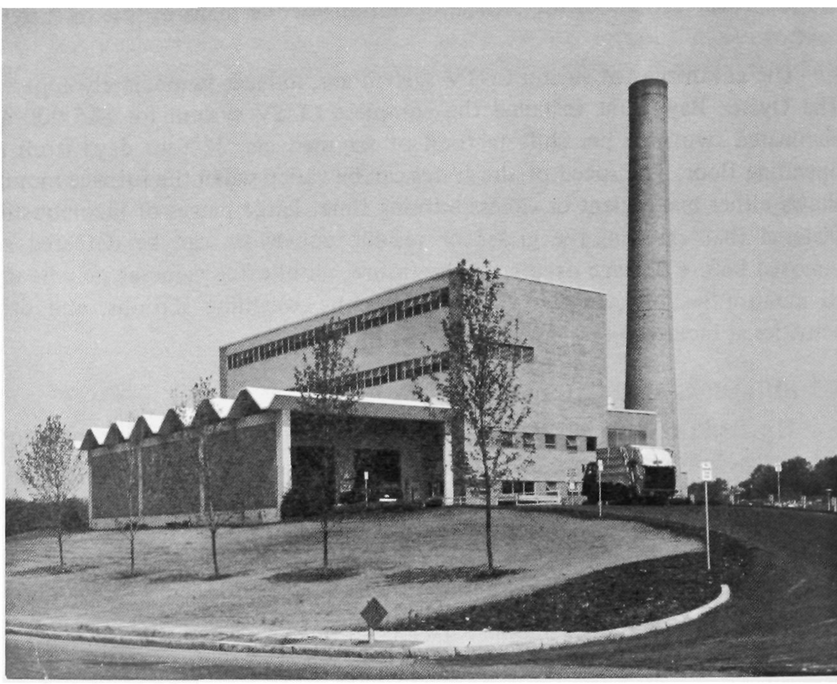


Figure 42. Modern municipal incinerator. (Courtesy Combustion Engineering, Inc.)

6. OPERATION OF MUNICIPAL INCINERATORS

6.1 OPERATING TEMPERATURES AND THEIR MEASUREMENT

Actual flame temperature inside of the combustion chambers of municipal incinerators is approximately 2,400° F.[53] The "furnace temperature" commonly referred to is the temperature of combustion gases exiting the combustion chamber. Except in water-walled furnaces, furnace temperature is usually controlled to the range of 1,800° F to 2,000° F.[53] If truck loads of refuse with unusually high or low calorific value are not mixed with the normal refuse by the crane operator, this approximate range of temperatures can be several hundred degrees too low or too high. "A load of sawdust in a charge, for example, could increase the normal operating temperature of 1,800° to over 2,000° F in approximately 15 seconds. While this temperature fluctuation may be most prevalent in batch-feed furnaces, it also exists in continuous-feed furnaces."[53]

When furnace temperatures are referred to, the precise location at which the temperature is taken in the furnace should be noted. As already discussed, furnace temperatures are usually controlled by using excess air, that is, air in excess of that needed to completely burn the combustible portion of the refuse. The effect of excess air on furnace temperatures for various moisture contents is shown in Figure 43.[54]

From the combustion chamber, the gases enter either a waste-heat boiler area, gas-cleaning devices, or cooling towers. At this point, the gas has cooled usually to within the range from 1,400° to 1,800° F.[53] In incinerators equipped with waste-heat boilers or cooling towers, the temperature of the gases is from 500° to 700° F after passing through the device. On leaving the gas-cleaning devices, the temperature of gases that have not previously been cooled by waste-heat recovery or by passage through cooling towers is usually less than 1,000° F.

Incinerator temperatures are usually measured with either electrical or filled-bulb sensing devices. Among the electrical types applicable to incinerators are the thermocouple, thermopile, radiation pyrometer, and thermistor. The thermocouple and the thermopile, which is made of thermocouples arranged to produce a higher electrical output, are perhaps the most widely used temperature-measuring devices used in incinerators. They can measure temperatures of from 2,000° to 2,300° F. Radiation pyrometers can withstand higher temperatures than thermocouples, and are, therefore, normally used for measuring actual flame temperature in the combustion chamber. Pyrometers normally have effective temperature-sensing ranges of from 1,000° to 4,000° F. Thermistors of platinum wire are applicable for temperatures ranging from 400° to 1,000° F.

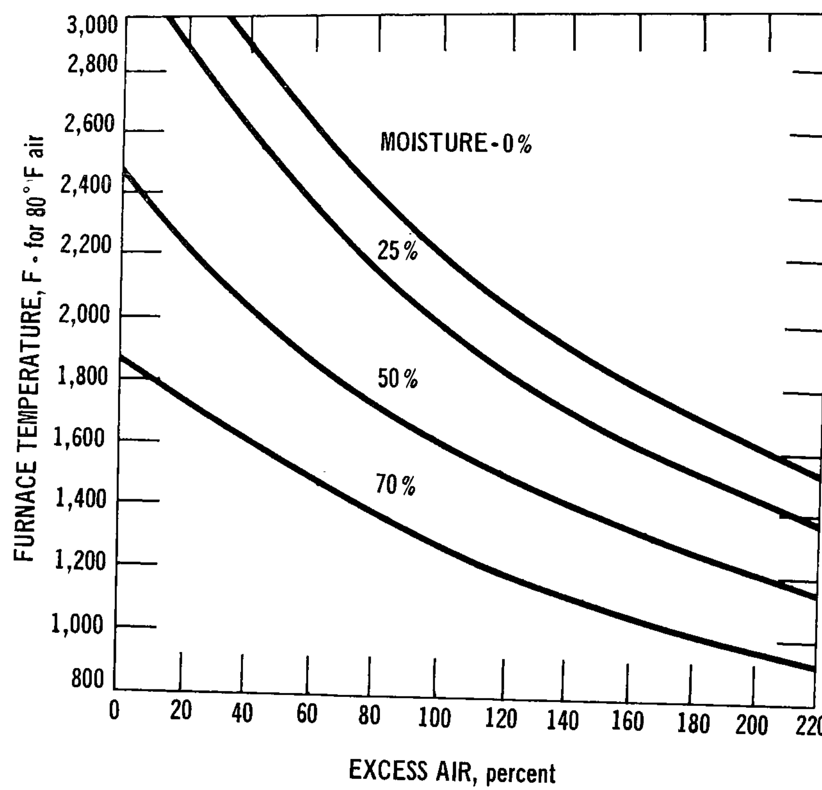


Figure 43. Relationship of moisture, excess air, and furnace temperature.[54]

Filled-bulb temperature-sensing devices using the expansion properties of a liquid, vapor, or gas are not used as widely as electrical-sensing devices in incinerators. Compared to the electrical devices, they are quite large and bulky and require extensive shielding to protect them from corrosion, erosion, and deposition. Filled-bulb devices can measure temperatures up to 1,200° F.

Thermocouples are usually recommended for temperature measurements at the combustion chamber exits and in the flues just prior to waste-heat boilers or cooling towers. Protecting wells must be provided for the thermocouple. The wells are often coated with silicon carbide to protect them from corrosion from slag.

Thermistors and filled-tube devices can be used between either waste-heat boilers or gas-cleaning devices and stacks.

Pyrometers are the only practical devices for measurement of actual flame temperature. Because pyrometers are expensive and the relationship among fire temperature, refractory life, and combustion is not well understood, the fired temperatures are not usually measured.

6.2 OPERATING PRESSURES AND DRAFT REQUIREMENTS

The air supply and combustion gases in incinerators are controlled by forced, natural, and induced drafts. A forced draft is created by the pressure difference generated by a mechanical device that supplies air at a pressure greater than atmospheric pressure. Forced drafts are used to supply primary combustion air to the drier and burner grates of incinerators. Natural draft results from the pressure difference created by a stack and is a function of the stack height and temperature difference between the flue gases and the ambient air.[33] Natural drafts are normally neither sufficient nor consistent enough to remove combustion gases from large incinerators, particularly those that are equipped with gas-cleaning devices.

Induced drafts are the result of the pressure difference created by a mechanical device located between the furnace and the top of the stack. Short stacks require induced drafts. Air pollution control devices have various ranges of pressure drops that must be taken care of by induced-draft fans. The draft requirements for air pollution control equipment are shown in Table 18 in inches of water column.

Operational pressures differ from one incinerator to another in such a manner that average pressures would have little meaning. Draft gauges are usually located to measure primary and secondary air pressure, furnace pressure, induced-draft suction pressure, and pressures at the inlet and outlet of various air pollution control devices.

6.3 MANAGEMENT

6.3.1 Schedules

Municipal incinerators are routinely operated for periods of from 8 to 24 hours a day and for 5, 6, or 7 days per week. A survey in which 154 incinerators in the United States reported operating schedules is summarized in Table 20.[32]

Table 20. SUMMARY OF OPERATING SCHEDULES OF 154 INCINERATORS

Operating period, hr/day	Number of plants	Percent of total
8	55	36
9	2	1
10	2	1
12	1	1
16	9	6
18	1	1
20	2	1
24	82	53

The current trend in operating schedules is toward 24-hour-a-day operation.[32] Table 21 shows operating schedules of two groups of incinerators, based on year of construction. The table indicates that this trend perhaps began around the year 1964.

Table 21. DAILY OPERATION OF 154 MUNICIPAL INCINERATORS[32]

Year of incinerator construction	Number of plants reporting	8 hours		9 - 20 hours		24 hours	
		Number	Percent	Number	Percent	Number	Percent
1945 through 1963	117	48	41	13	11	56	48
1964 through 1966	37	7	19	4	11	26	70

6.3.2 Personnel

The number and types of personnel vary with the operating schedule, design, and degree of automation of the incineration plant. One versatile maintenance man can sometimes perform tasks normally requiring knowledge in two or more diverse fields.

Operating personnel of some modern incinerator plants are discussed in the following paragraphs.

6.3.2.1 Rockville, Maryland, Incinerator

The Montgomery County, Maryland, (Rockville) incinerator has a capacity of 1,050 tons per day. It operates 24 hours a day, 6 days a week. The 44 operating personnel include:

1 Plant supervisor
4 Foremen
9 Equipment operators (bulldozer and crane operators)
3 Truck drivers
8 Furnace stokers
12 Laborers
1 Clerk
1 Weighmaster
1 Electrician
1 Plumber
1 Mason
1 General maintenance man
1 Janitor

6.3.2.2 Detroit, Michigan, Incinerator

Northwest Incinerator Plant at Detroit has two furnaces, each of which is capable of burning 425 tons of refuse every 24 hours. The plant operates three shifts a day, 5 days a week. The 51 employees at the plant include:[55]

Operating crew per shift
- 1 Incinerator foreman
- 3 Electric crane operators
- 6 Incinerator firemen
- 1 Charging floor man
- 1 Ash tunnel man
- 3 Semi-truck drivers

Additional personnel on day shift
- 1 Scaleman
- 1 Tipping floor man
- 1 Mechanical tradesman
- 3 Janitors

6.3.2.3 Milwaukee, Wisconsin, Incinerator

The Lincoln Avenue Plant in Milwaukee, Wisconsin, has a rated capacity of 300 tons per 24 hours. The plant is operated on a 5-day-a-week schedule. Machinery operator service is provided on a 7-day-a-week basis. Table 22 shows how personnel at the plant are used.

Table 22. LINCOLN AVENUE PLANT OPERATING PERSONNEL[55]

Job title	Number of employees		
	1st shift	2nd shift	3rd shift
Operating engineer II	1	1	1
Craneman	1	1	1
Furnacemen	3	3	3
Disposal division laborers	4	3	3
Machinery operator	1	1	1
Collection division laborers	2		
Electrical mechanic	1		
Maintenance mechanic	1		
Truck driver	1	1	
Mechanic helper		1	1
Total	15	11	10

Engineer-in-charge – In charge of all Disposal Department activities. Asst. Engineer-in-charge – Assistant to above, and directly responsible for all maintenance and repair. Firebrick Mason – Maintenance and repair of all refractories. Electrical Mechanic – Maintenance and repair of all electrical equipment. Operating Engineer II – In charge of one plant shift. Maintenance Mechanic Foreman – In charge of all maintenance and repair activities. Boiler Repairman – Maintenance and repair of waste-heat boilers. Craneman – Operation of overhead traveling cranes. Machinery Operator – Operation of waste-heat boilers, feed water pumps, oil burners, etc. Maintenance Mechanic I – Maintenance and repair of all mechanical equipment. Furnaceman – Operation of furnaces, dampers, temperature controls, draft fans, charging gates, etc. Truck Driver – Operation of incinerator ash removal truck. Mechanic Helper – Assistant to maintenance mechanic, electrical mechanic, boiler repairman, or firebrick mason.[55]

6.3.2.4 Washington, D. C., Incinerator

Mount Olivet incinerator in Washington, D. C. has a 500-ton capacity. The incinerator consists of four 125-ton furnaces of the mutual-assistance type with rocking grates. It has a peak capacity of 700 tons.

Table 23. MOUNT OLIVET INCINERATOR OPERATING PERSONNEL

Job title	8-4	4 - 12	12 - 8
Plant foreman	1	1	1
Mechanic	1		
Overhead crane operators	2	2	2
Incinerator firemen	4	4	4
Equipment lubricator	1		
Weighmaster	1	1	
Laborer (hopper)	2	2	2
Laborer (ash tunnel)	2	2	2
Laborer (janitor)	1		
Laborer (watchman)	1	1	1
Refuse transfer operator (platform)	1		
Incinerator drivers	2	2	
Total	19	15	12

The St. Quen incinerator in Paris, France, consists of four furnaces with a total annual capacity of 407,000 tons and recovers waste heat. Approximately 160 people are employed.[21] The Stuttgart incinerator in Germany, with an annual capacity of 220,000 tons, has a staff of 55 employees.[56]

Municipal incineration is usually organized under a municipal government but is occasionally a function of a county government or an autonomous incinerator authority operating under a governmental charter. Usually plant supervisors, and sometimes the maintenance men, are hired during the planning or construction phases so that they become intimately familiar with the plant.

Immediately prior to the opening of a plant at least one person for each job classification is hired and instructed on the operation of the plant. Actual performance tests are usually made by the manufacturer on the individual pieces of equipment.

6.4 MAINTENANCE

6.4.1 Plant Maintenance

Neatness and proper maintenance of building and grounds are at least as important to the aesthetic quality of incinerators as they are to the aesthetic quality of other industrial buildings. Refuse disposal facilities are not generally held in esteem by any community, and a littered, unmaintained facility can provide justification for such sentiment.

Janitors are usually a part of the full-time staff at most incinerators. Their duties are usually routine, but very important to the cleanliness of the plants since incinerators' environments can be quite dusty. Some plants use a central vacuum system (see Figure 44), with connecting outlets throughout the building. The central vacuum system can be connected so that it disposes of collected wastes directly into the residue-handling system.

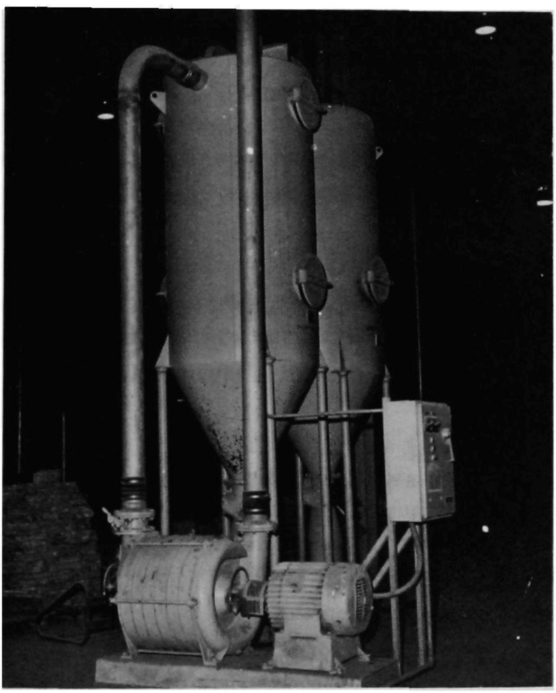


Figure 44. Central vacuum system installed at a municipal incinerator.

6.4.2 Maintenance Facilities

Some incinerators are equipped with maintenance shops that are fully equipped with the power tools and equipment necessary to repair various types of incinerator equipment. Spare parts for cranes, stokers, fans, and motors, which are not always readily available as shelf items, are sometimes kept on hand. Most operational maintenance is performed by regular staff employees.

6.4.3 Preventive Maintenance

Serious problems can be prevented by frequent preventive maintenance. Weekend shutdowns provide an excellent opportunity to inspect for and detect future problem areas. Refractory maintenance, boiler care, slag removal, and grate maintenance are just a few of the important areas that should be serviced frequently. The maintenance facility of the plant is usually able to perform routine preventive maintenance.

6.4.4 Plant Safety

Plant safety is a continuing concern of incinerator designers and supervisors. Serious accidents, including loss of life, have occurred at some older plants. Incinerator hazards have been attacked on two fronts. One method of attack is to incorporate safety design features into the construction of the plant. Some of the safety features included when plants are constructed are:[57]

1. Brick and concrete building materials, automatic or manual sprinkler systems for storage pits and charging floors, and fire hose stations at strategic locations for fire protection.
2. More space on stoking floors to avoid crowded conditions.
3. More adequate lighting from large windows and artificial lights.
4. Lunch rooms, locker rooms, and showers for more sanitary conditions for employees.
5. Drinking fountains with salt tablet dispensers to reduce the number of cases of heat exhaustion during warm weather.
6. Better pitching of floors with adequate drains to aid in cleanliness and prevent falls.
7. Improved building ventilation. The use of outdoor suction intakes for forced-draft fans avoids the possibility of creating a vacuum on stoking floors that can cause blow-outs of flame through the stoking doors of ignition chambers with serious hazard to employees.
8. Chimneys equipped with airplane lights, lightning rods, and safety ladders as standard equipment.
9. Two-way radio systems for signaling between the charging and stoking floors to supplement other signaling devices and avoid confusion and mistakes in directions. For safe operation it is important that the charging doors be closed when stoking.

10. Refuse storage pits with access ladders, and either forced fresh air inlets or mechanical exhaust systems with air ports located near the bottom of the pits. Decomposing garbage may deplete the oxygen necessary for life and cause oxygen deficiency in men entering such pits. Pit drains are also standard practice to permit hosing of pits for thorough cleaning to avoid nuisance and free the pits of vermin.
11. Elevators to carry heavy equipment from one floor to another and for employee convenience.
12. Stationary vacuum pumps having port outlets at convenient locations for suction cleaning of floors, stairs, and flues.

The second method for attacking safety hazards is to practice and enforce such operational safety practices as:

1. Keeping truck stops at the tipping edge of refuse storage pits in good repair, and prohibiting employees or others from standing on them when trucks are unloading.
2. Using mechanical ventilation when refuse pits containing decomposing refuse must be entered by employees. Portable air blowers are used when provisions for mechanical ventilation have not been provided. (Safety belts should be worn when persons are descending long ladders.)
3. With floor-charge furnaces, protecting the men charging the furnaces with safety belts or guards placed around the charging openings.
4. Using an alarm in the crane housing of bucket-charged furnaces to warn employees, as necessary, of descending loads of refuse.
5. Wearing of protective clothing, including safety shoes, heavy gloves, and goggles or face shields by stokers.
6. Restricting entrance of flues for removal of flyash to times when the temperature is below 100° F. Respirators are worn for comfort.
7. Providing first-aid kits and posting emergency instructions for employee information.
8. Proper housekeeping.

7. INCINERATOR EMISSIONS

Municipal incinerator emissions, especially particulate emissions, are being scrutinized more closely as new and more stringent air pollution codes are being formulated and put into effect in many states and municipalities. This increasing scrutiny is perhaps due in part to two factors: (1) emissions from incinerators can make a substantial contribution to air pollution, and (2) these emissions can be reduced effectively by some of the air pollution control devices now available on the market. The very nature of the particulate and gaseous pollutants emitted and the methods by which they are sampled and measured are the basis for the following discussion.

7.1 PARTICULATE EMISSIONS

7.1.1 Particle Size

Particulate matter that has been identified in incinerator effluents consists of smoke, soot, flyash, grit, dirt, carbonaceous flakes, aldehydes, organic acids, esters, fats, fatty materials, phenols, hydrocarbons, and polynuclear hydrocarbons. The size of the particles ranges from less than 5 microns to 200 microns and larger. The ease with which the large particles break up during and after capture makes their measurement difficult. Very limited data have been published on incinerator emissions. Walker and Schmitz[58] performed extensive studies on emissions from three incinerators, each with a different grate system. Furnace capacity ranged from 120 to 250 tons per day.

Table 24 gives the breakdown of particle size and other physical properties of particulate matter gathered in the area between the combustion chambers and the gas-cleaning devices for the three test incinerators. Tests performed on another incinerator having a furnace capacity of 150 tons per day provide particle size data for stack gases that had been previously cleaned by a combustion settling chamber and wet baffle system.[59] The sizes of particles measured by a Coulter Counter are presented in Table 25.

Particle sizes recommended by Bump[43] for proper application of electrostatic precipitators to European incinerators are given in Table 26. In comparing Tables 25 and 26, several inconsistencies seem to appear. It is important to keep in mind, however, that Table 25 reports actual measurements from an incinerator stack in Milwaukee, Wisconsin, where the stack gases had been previously cleaned by a settling chamber and a wet baffle system, whereas Table 26 presents typical values, based on European data, of particle sizes that can be used for design of electrostatic precipitators. The particulate sizes in Table 26 are representative of those particles that have passed through a waste-heat-boiler system at some point just prior to entry into the precipitator.

Table 24. PHYSICAL PROPERTIES OF PARTICLES LEAVING FURNACE[58]

	Installation number		
	1	2	3
Total sample in cyclone, %	77.0	77.5	63.0
Total sample in bag, %	23.0	22.5	37.0
Specific gravity, g/cm^3	2.65	2.70	3.77
Bulk density, lb/cf	–	30.87	9.4
Loss on ignition @ 750° C, %	18.5	8.15	30.4
Analysis			
% by weight less than 2 microns	13.5	14.6	23.5
% by weight less than 4 microns	16.0	19.2	30.0
% by weight less than 6 microns	19.0	22.3	33.7
% by weight less than 8 microns	21.0	24.8	36.3
% by weight less than 10 microns	23.0	26.8	38.1
% by weight less than 15 microns	25.0	31.1	42.1
% by weight less than 20 microns	27.5	34.6	45.0
% by weight less than 30 microns	30.0	40.4	50.0

Table 25. SIZE AND DENSITY OF INCINERATOR STACK GAS PARTICLES[a59]

Microns	Percent by weight greater than stated size
30	31.3
20	52.8
10	79.5
5	94.0

[a]Density is 1.85 grams per cubic centimeter

Table 26. PARTICLE SIZE AND DENSITY FOR DESIGN OF ELECTROSTATIC PRECIPITATORS IN EUROPEAN INCINERATORS[43]

Particle diameter, microns	Percent
< 5	11.1
< 7	21.7
< 10	30.1
< 14	40.2
< 19	46.9
< 27	55.1
< 39	67.5
< 59	90.5
> 59	9.5

7.1.2 Particle Concentration Standards

Particle concentrations are normally expressed in one of three ways. Dust loading, a term frequently used, expresses particulate concentration in grains (7,000 grains equals 1 pound) per cubic foot of gas normally corrected to either 12 percent CO_2 or 50 percent excess air. A second method expresses dust loading in pounds per 1,000 pounds of gas corrected to either 12 percent CO_2 or 50 percent excess air. A third method is to express concentration in terms of weight of particulate matter emitted per weight of refuse burned. Carbon dioxide produced by the use of auxiliary fuels should be excluded from the calculation to 12 percent CO_2. Samplings of particulate matter can be taken at various gas temperatures and atmospheric pressures. To make various samples comparable, a correction to standard conditions of 68° F and 29.92 inches of Hg can be accomplished by use of the following equation:

$$D_1 = D_0 \quad \frac{(t + 460)}{(68 + 460)} \; \frac{(29.92)}{(P)} \qquad (1)$$

Where:

D_1 is the dust loading in grains per standard cubic foot (gr/scf), D_0 is the dust loading in grains per cubic foot (gr/cf), t is the sampling temperature in degrees Fahrenheit, and P is the atmospheric pressure in inches of mercury.

To connect dust loading in grains per cubic foot to pounds of dust per 1,000 pounds of flue gas at standard conditions the following formulas can be used:[60]

$$D_2 = D_0 \quad \frac{3.12 \; (t + 460)}{M \times P} \qquad (2)$$

Where:

D_2 is the number of pounds of dust per 1,000 pounds of flue gas at standard conditions and M is the molecular weight of the flue gas.

After a dust loading has been corrected to standard conditions, it must be further corrected to a standard amount of excess air. This is necessary because particle concentrations are dependent on the amount of excess air used. Quite obviously, as more excess air is used, a greater amount of dilution of the combustion gases occurs, which lowers the particulate concentration. Most air pollution control agencies now use a 50 percent excess air or 12 percent CO_2 correction standard. The dust loading correction to 50 percent excess air is accomplished by the equation:[60]

$$D_c = D_u \quad \frac{\text{lb flue gas/lb refuse (actual)}}{\text{lb flue gas/lb refuse (50\%) excess air)}} \qquad (3)$$

Where:

D_c is the corrected dust loading and D_u is the uncorrected dust loading.

The alternative method for correcting dust loading to 12 percent CO_2 can be accomplished by the following equation:[60]

$$D_c = D_u \quad \frac{(0.12)}{(CO_2)} \tag{4}$$

Where:

CO_2 is expressed in a decimal percentage.

7.1.3 Particulate Emission Control Regulations

Control regulations imposed by many state and local governments are much more strict than the earlier accepted value of 0.85 pound per 1,000 pounds of flue gas corrected to either 50 percent excess air or 12 percent CO_2 (excluding auxiliary fuel contributions). Many control agencies are watching the two electrostatic precipitators in New York City to see exactly what the capabilities of this type of control device are and whether this type of control system might be applicable to incinerators in their jurisdictions. Past and future development of cyclonic collectors, scrubbers, and perhaps baghouses will determine new and future trends in particulate emission regulations as applied to incinerators. A summary of some of the present particulate emission regulations for refuse burning equipment is given in Table 27.[61]

Table 27. SELECTED PARTICULATE MATTER EMISSION REGULATIONS FOR REFUSE-BURNING EQUIPMENT

Jurisdiction	Maximum particulate matter emission
Allegheny County, Pa.	0.2 lb per 1,000 lb of gas
Cincinnati, Ohio	0.4 lb per 1,000 lb of gas corrected to 12 percent CO_2
Detroit, Mich.	0.3 lb per 1,000 lb of gas corrected to 50 percent excess air
Los Angeles County, Cal.	0.3 grain per standard cubic foot of gas, corrected to 12 percent CO_2 (excluding CO_2 contributions by auxiliary fuels)
New York City	0.65 lb per 1,000 lb of dry gas corrected to 50 percent excess air or 13 percent CO_2, not to exceed 250 lb in any 60-minute period
San Francisco	0.2 grain per standard dry cubic foot of gas, corrected to 6 percent O_2
State of Illinois	0.2 grain per standard cubic foot corrected to 50 percent excess air

7.1.4 Particle Concentration Measurements

Measurements of particulate emissions are usually made at some point within the incinerator or in the stack. Air pollution control equipment manufacturers are concerned with particle concentrations at the combustion chamber outlets or at the location of the entrance to their gas-cleaning equipment. They are also interested in stack concentrations which indicate collection ability. Air pollution control authorities are primarily interested in the stack emissions rather than internal particulate measurements.

7.1.4.1 Particle Measurements at Furnace Outlet

Tests have been performed at the furnace outlets of several types and sizes of incinerators.[58, 59, 62] Table 28 summarizes particulate loadings corrected to 50 percent excess air.

The method of supplying air to the combustion chamber is one of the major factors affecting the creation of flyash. This factor is indeed apparent in Table 28, which shows, as previously found in experimental incinerators, that the greater the percentage of underfire air supplied, the higher the particulate loading.

Table 28. PARTICULATE EMISSIONS AT FURNACE OUTLET[2]

Furnace type	Excess air, percent	Underfire air, percent	Average dust loading, lb/ton of charge
50-ton-per-day batch	235	20	0.78
50-ton-per-day batch	110	50	1.04
50-ton-per-day batch	100	70	1.79
250-ton-per-day continuous	190	20	3.8 [a]
250-ton-per-day continuous	180	50	2.8
250-ton-per-day continuous	150	100	4.6
250-ton-per-day continuous (traveling grate)	(6.0% CO_2)	41.8 scfm/sq ft grate area	12.4
250-ton-per-day continuous (reciprocating grate)	(5.0% CO_2)	105 scfm/sq ft grate area	25.1
120-ton-per-day continuous (rocking grate)	(7.0% CO_2)	17.5 scfm/sq ft grate area	9.1
150-ton-per-day continuous (rocking grate)	—	—	30.8

[a]See original article for a special discussion and explanation of this unexpected value

European design and performance factors presented by Bump give a dust loading of from 0.8 to 4.0 grains per standard cubic foot at the entry point of the combustion gases into an electrostatic precipitator.[43] At this point, the gases have been cooled to 400° to 650° F by the waste-heat-recovery boilers. Some of the particles settle out or collect on the boiler tubes; this range of values is, therefore, not truly representative of the dust loading at the furnace outlet.

7.1.4.2 Stack Emission Measurements

Stack emission measurements are obviously very closely related to the excess air supplied to the furnace and the efficiency of the gas-cleaning equipment. Measurements of stack emissions are necessary to determine compliance with local codes and to check efficiency of the air pollution control equipment. The samples are generally taken from some convenient stack location. Some stack particulate matter measurements for incinerators equipped with various types of cleaning systems are presented in Table 29.[58, 59, 62]

Table 29. PARTICULATE MEASUREMENTS OF STACK GASES

Furnace type	Control equipment	Excess air, percent	Underfire air, percent	Average dust loading, lb/ton charge in stack gases
50-ton-per-day batch	Scrubber	235	20	0.57
50-ton-per-day batch	Scrubber	110	50	0.55
50-ton-per-day batch	Scrubber	100	70	0.61
250-ton-per-day continuous (reciprocating grate)	Settling chamber and wet baffle	—	—	11.8
120-ton-per-day continuous (rocking grate)	Settling chamber and wet baffle	—	—	8.2
150-ton-per-day continuous (rocking grate)	Wet baffle	—	—	8.24

7.1.5 Particle Chemical Composition

Very little data have been published on chemical composition of incinerator particulate matter. The few results that have been published show that flyash can consist of an average of from 5 to 30 percent organic matter and from 70 to 95 percent inorganic matter. A chemical analysis that gives the various inorganic constituents of incinerator flyash from the South Shore incinerator in New York City is presented in Table 30.[2]

Table 30. CHEMICAL ANALYSIS OF FLYASH SAMPLES FROM SOUTH SHORE INCINERATOR, NEW YORK CITY, BY SOURCE[2]
(percent by weight)

Component	Source of sample		
	Upper flue	Expansion chamber	Emitted
Organic	0.5	0.6	10.4
Inorganic	99.5	99.4	89.6
Silica as SiO_2	50.1	54.6	36.1
Iron as Fe_2O_3	5.3	6.0	4.2
Alumina as Al_2O_3	22.5	20.4	22.4
Calcium as CaO	7.9	7.8	8.6
Magnesium as MgO	1.8	1.9	2.1
Sulfur as SO_3	4.3	2.3	7.6
Sodium and potassium oxides	8.1	7.0	19.0

A rather detailed elemental analysis of ashed incinerator stack effluent and collector catch was presented by Jèns and Rehm.[59] The incinerator tested was equipped with an impingement wet baffle system. Results of two test runs are summarized in Table 31.

Jens and Rehm found the pH of stack effluents to be 7.7 and 8.3. A much higher pH of 12.3 was found for the collector catch.[59]

Table 31. SPECTROGRAPHIC ANALYSIS OF ASHED INCINERATOR PARTICULATE MATTER

Element	Stack effluent, percent ashed material	Collector catch, percent ashed material
Silicon	5+ –	10+ –
Manganese	0.1 – 1.0	0.1 – 1.0
Chromium	0.1 – 1.0	0.1 – 1.0
Nickel	1.0 – 10+	0.001 – 0.01
Copper	0.1 – 1.0	0.01 – 0.1
Vanadium	0.001 – 0.01	0.01 – 0.1
Iron	0.1 – 5.0	0.5 – 5.0
Tin	0.001 – 0.5	0.05 – 0.5
Aluminum	0.1 – 10	1 – 10
Zinc	1 – 10	1 – 10
Magnesium	1 – 10	1 – 10
Titanium	0.5 – 5.0	0.5 – 5.0
Silver	0.0001 – 0.01	0.001 – 0.1
Boron	0.01 – 0.1	0.01 – 0.1
Barium	0.1 – 1.0	0.1 – 1.0
Beryllium	0.001 – 0.01	0.001 – 0.01
Calcium	10+ –	10+ –
Sodium	1 – 10	1 –
Lead	0.01 – 0.5	0.1 – 1.0
Sulfur	–	0.620 –
Phosphorus	1.140 – 1.460	1.760 –
Silicate	5.4 –	–

7.2 GASEOUS EMISSIONS

Gaseous incinerator emissions are not, at least at the present, of primary concern as a source of air pollution. When compared to other gaseous emission sources, the contribution of incinerators is relatively small. It is for this reason that incinerator air pollution control equipment is adapted to the removal of particulate matter rather than gases. Some published data show that the wet collecting devices can remove small amounts of gases. The number of measurements of gaseous emissions, although not plentiful, is sufficient to provide some idea of the types and amounts of such emissions emitted from a municipal incinerator. Oxides of nitrogen, oxides of sulfur, aldehydes, hydrocarbons, and ammonia are emissions that have been detected and have been discussed in the literature.

7.2.1 Oxides of Nitrogen

Both batch- and continuous-feed incinerators emit nitrogen oxide (NO) in small amounts that are not significantly different for a given amount of charged refuse. Actual tests indicated amounts ranging from 1.4 to 3.3 pounds per ton of refuse charged for a 50-ton-per-day batch-feed incinerator and a 250-ton-per-day

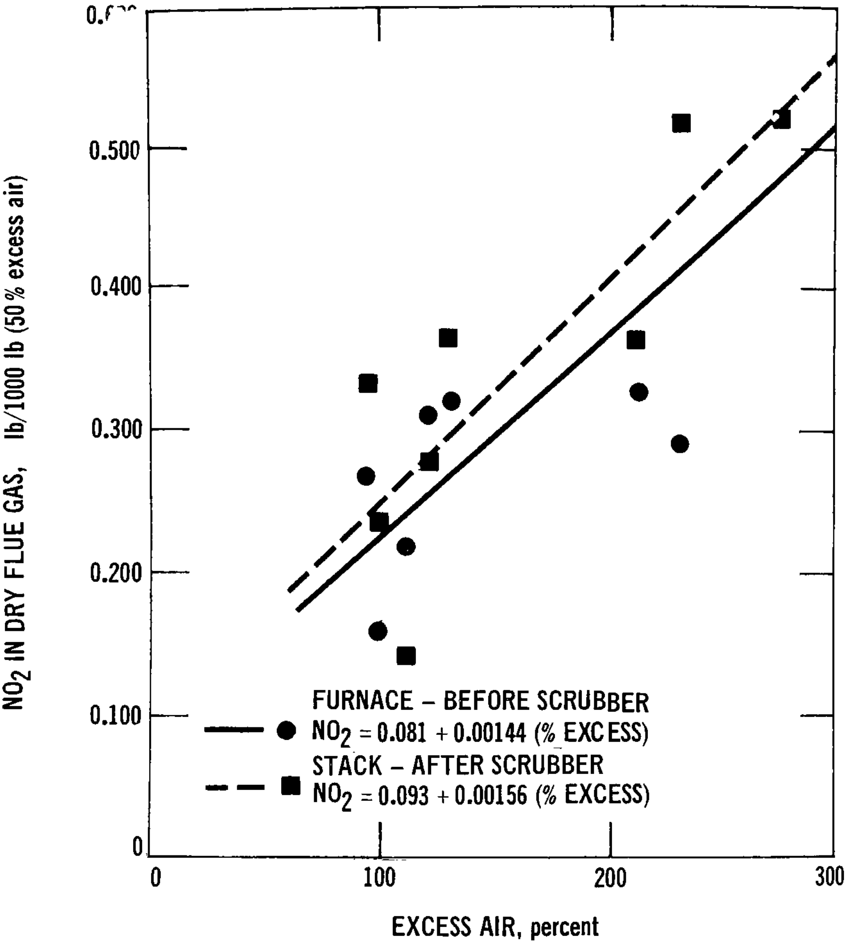


Figure 45. Relationship between oxides of nitrogen and excess air in 50-ton-per-day units.[62]

continuous-feed incinerator.[62] Nitrogen dioxide (NO_2) emissions increase with increasing amounts of excess air as shown in Figure 45. Wet cleaning processes tend to increase slightly the amount of NO_2 produced. The amount of underfire air has a significant effect on NO_2 production (see Figure 46), an occurrence that has been explained by Stenburg, et al. as being a result of the variance in oxygen consumption and its residence time with underfire air.[62]

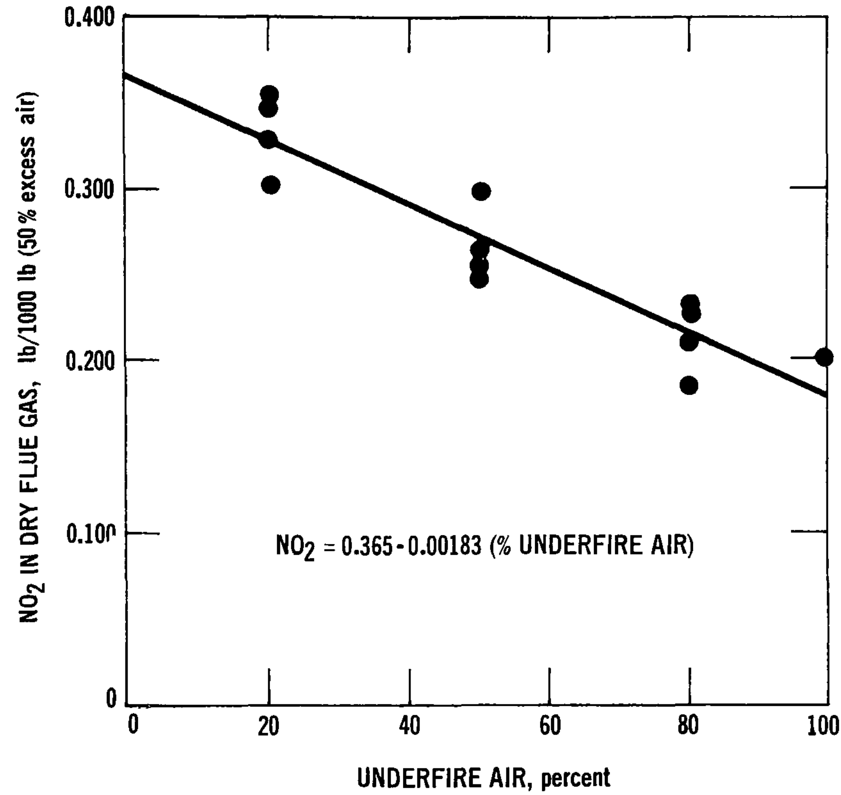


Figure 46. Relationship between oxides of nitrogen and underfire air in 250-ton-per-day unit.[62]

7.2.2 Carbon Dioxide

Stack emissions of carbon dioxide (CO_2) usually amount to only 1 to 6 percent of the dry volume.[9, 59] At the furnace exit, however, the amount of CO_2 is larger, ranging from approximately 4 to 16 percent.[9, 58] Carbon dioxide content in these concentrations is of little, if any, interest other than the information it can provide on the efficiency and rate of combustion of the refuse.

7.2.3 Carbon Monoxide

The concentration of carbon monoxide (CO) in gaseous incinerator effluents is so small that it is nearly impossible to detect. One of the largest recorded concentrations of carbon monoxide (1.0 lb per 1,000 lb of dry flue gas) was at a 50-ton-per-day batch-feed incinerator[62] during a firing that produced a low operating temperature. Carbon monoxide emitted from a 250-ton-per-day continuous-feed incinerator[62] ranged from 0.03 to 0.07 pound per 1,000 pounds of dry flue gas.

7.2.4 Oxides of Sulfur

Sulfur oxide (SO) emissions from municipal incinerators are practically negligible because the sulfur content in refuse generally averages only about 0.1 percent.[63] For comparison, the sulfur content of coals fired in power plants averages approximately 1.0 to 2.5 percent. If the stack gas concentration of sulfur dioxide (SO_2) is measured in parts per million by volume, the amount of diluting excess air supplied to the furnace will directly effect the concentration of the SO_2. Published data of SO_2 emissions from municipal incinerators range from 0 to 100 parts per million by weight. Figure 47 is a plot of SO_2 versus excess air data for incinerators in California and New York.[63] The solid line gives the relationship between the SO_2 emission and excess air assuming the refuse *contains 0.1 percent sulfur and conversion of sulfur into* SO_2 *is complete.* The data suggest, however, that only a fraction of the sulfur is converted into SO_2, assuming the 0.1 percent sulfur content is approximately correct. The remaining sulfur can be contained in the residue, as has been confirmed by analyses.

Incinerators equipped with auxiliary burners for either waste-heat-recovery boilers or for burning low-calorific-value refuse often use high-sulfur-content fuels such as coal and oil. In this type of incinerator, SO_2 emissions are considerably higher and can be of considerable concern.

7.2.5 Formaldehyde

Formaldehyde is generated in municipal incinerators in minute quantities. The amount generated has been shown to be related to the temperature of the furnace gases, which in turn is related to the amount of excess air supplied and the amount of underfire air.[62, 64] For a 50-ton-per-day batch-feed incinerator operating at 108 percent excess air, no formaldehyde was produced. However, when the excess air was increased, which decreased furnace temperature by 400° F, up to 0.021 pound of formaldehyde per ton of charged refuse was formed. For a 250-ton-per-day continuous-feed incinerator operating at 185 percent excess air, 0.0014 pound of formaldehyde per ton of refuse was formed.

7.2.6 Hydrocarbon

Hydrocarbon content of incinerator flue gases is usually well below the limit of detectability of the measuring instruments. Measurement of hydrocarbon emissions from a 50-ton-per-day batch-feed incinerator shows that less than 0.003 pound per 1,000 pounds of dry flue gas is emitted when 110 percent excess air is used.[62] For a 250-ton-per-day continuous-feed incinerator using 150 to 190 percent excess air, less than 0.08 pound per pound of dry flue gas was measured.[62]

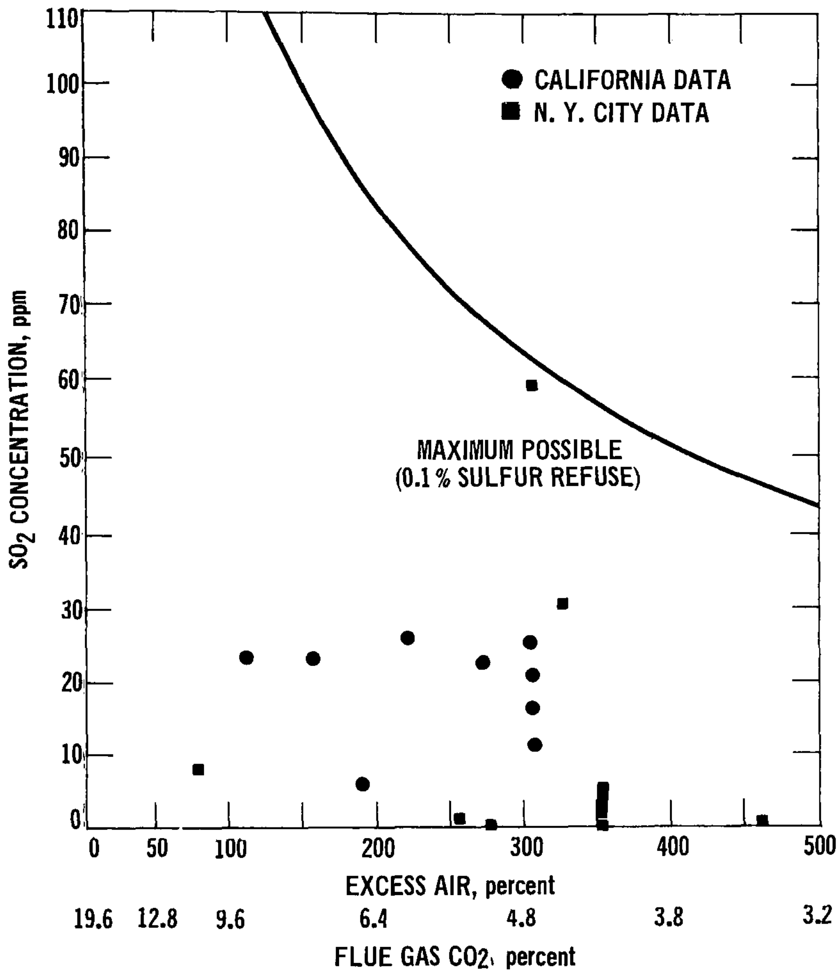


Figure 47. SO_2 concentration in municipal incinerator flue gases.[63]

Polynuclear hydrocarbons have been detected in incinerator flue gases.[64] Table 32 summarizes the measurements of the various emissions produced in a 50-ton-per-day and a 250-ton-per-day incinerator.

7.2.7 Chlorine

Chlorine has been found to be present in incinerator stack gases in rather minute quantities in the form of hydrogen chloride (HCl). Its concentration is dependent on the proportion of plastics (polyvinyl chloride) in the refuse, which proportion in turn may be influenced rather strongly by the amount of

Table 32. POLYNUCLEAR HYDROCARBON EMISSION SUMMARY BY INCINERATION SOURCES[64]

Type of unit	Sampling point	Group 1								Group 2			
		Benzo(a)pyrene[a]		Pyrene	Benzo(e)-pyrene	Perylene	Benzo-(g,h,i)-perylene	Anthan-threne	Coronene	Anthra-cene	Phenan-threne	Fluoran-thene	Benz(a)-anthra-cene
		µg/1000 m3	µg/lb of refuse charged										
Municipal													
250-ton/day multiple chamber	Breeching (ahead of settling chamber)	19	0.075	8.0	0.34		b		0.24		b	9.8	0.37
50-ton/day multiple chamber	Breeching (ahead of scrubber)	2,700	6.1	52	12		34		15		18	4.6	
	Stack (behind scrubber)	17	0.089	2.1	0.58		0.63		0.63		b	3.3	0.15
Commercial													
5.3-ton/day single chamber	Stack	11,000	53	320	45	3.1	90	6.6	21	47	140	220	4.6
3-ton/day multiple chamber	Stack	52,000	260	4,200	260	60	870	79	210	86	59	3,900	290

[a]Micrograms per 1,000 cubic meters of flue gas at standard conditions (70°F, 1 atmosphere).
[b]A blank in the table for a particular compound indicates it was not detected in the sample.

industrial refuse processed by an incinerator. Maximum HCl content in European municipal incinerators is abour 0.02 volume percent in wet flue gases.[19] An increase in use of polyvinyl chlorides would make this emission become of more concern in municipal incinerator operations.

7.3 MEASUREMENT METHODS

7.3.1 Smoke Measurement

There are basically two methods–Ringelmann and soiling index–for measurement of smoke. The Ringelmann method is a system whereby graduated shades of gray, ranging in five equal steps from white to black, may be accurately reproduced by means of a rectangular grill of black lines of definite width and spacing on a white background; these shades of gray are then compared to an actual smoke emission.[66] Many air pollution emission control regulations are based on the Ringelmann Chart even though the chart was not originally designed for regulatory purposes.

Several tests may be used to determine the soiling index. One is the Bacharach spot smoke test. In the test 2,250 cubic inches of stack gas is drawn through a filter paper by means of a hand pump.[65] The resulting soiled spot is compared to a chart containing nine shades of gray. A similar method, the A.I.S.I. automatic smoke filter, works on the same principle as the Bacharach method except the air is drawn through the filter paper automatically. The spot formed gives the average soiling for the sampling time, which is adjustable.

One of the most sophisticated new devices for smoke measurement is the Van Brand Recorder. The Van Brand System automatically filters the sampled gas through a filter tape that can be stationary or moving to provide either spot or trace soilings. The speed of the tape is adjustable and is marked for timing purposes. From one to three recording heads can be used simultaneously to sample smoke before and after control devices. The spot or traces are side by side on the filter tape so that comparisons can be easily made. The system can be fitted with a Rudds System device, which expresses the comparisons on a numerical basis that eliminates subjective and observational errors.

A photoelectric device also may be used for smoke measurement. Such devices have apparently had very little usage in the incinerator field. Some new, modern municipal incinerators, however, incorporate this type of measuring device into their designs.[67] It is expensive and lacks portability.

7.3.2 Particulate Matter and Gas Sampling

As previously discussed, particulate matter and gases can be sampled at various locations in municipal incinerators. They may be sampled anywhere from the combustion chamber exit to the top of the stack depending on the purpose of the sampling. Samples must be taken during normal operating conditions and be representative of the parent medium. Three fairly widely

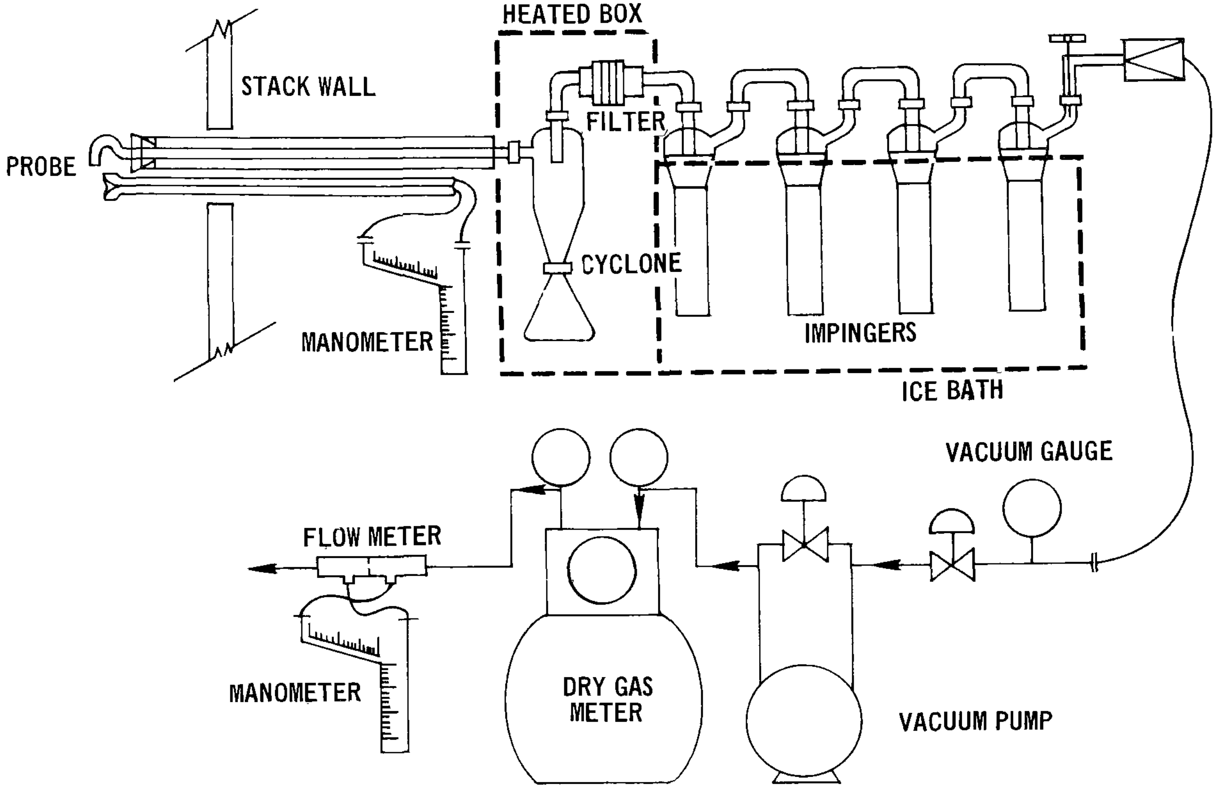


Figure 48. Particulate sampling train.[68]

accepted particulate testing guides are available. They are the American Society of Mechanical Engineers (ASME) Test Code, the WP-50 Bulletin of the Western Precipitation Corporation, and the Source Testing Manual of the Los Angeles County Air Pollution Control District. Rehm has discussed the ASME Test Code and the WP-50 Bulletin and their application to incinerator testing.[67]

When samples are taken, the sampling nozzle should be as large as possible, but not so large as to prevent isokinetic sampling. It is usually best to sample in vertical flow ducts to minimize errors caused by stratification. Water-jacketed stainless steel probes reduce errors caused by corrosion and reduce combustion losses of glowing particles.

Filtration inside of stacks is not recommended because of combustion losses that can result from high stack temperatures. Some of the considerations in the selection of a filtration device are the high-volume sampling rate required to obtain a fairly representative sample, low particulate concentrations, high moisture content of the combustion gases, the need for high efficiency at low pressure drop, the weight stability of the filter, the durability required for field use, portability required, and high gas temperatures.

The sampling train used for incinerator testing at Federal facilities is shown in Figure 48.[68] The train basically consists of a probe, cyclone, glass filter, four impingers, vacuum pump, dry gas meter, and flow meter.

Occasionally used is a dual filtration system in which a cyclone located just prior to the fabric filter precipitates the larger size particles and condensed moisture. This type of system, illustrated in Figure 49, substantially reduces

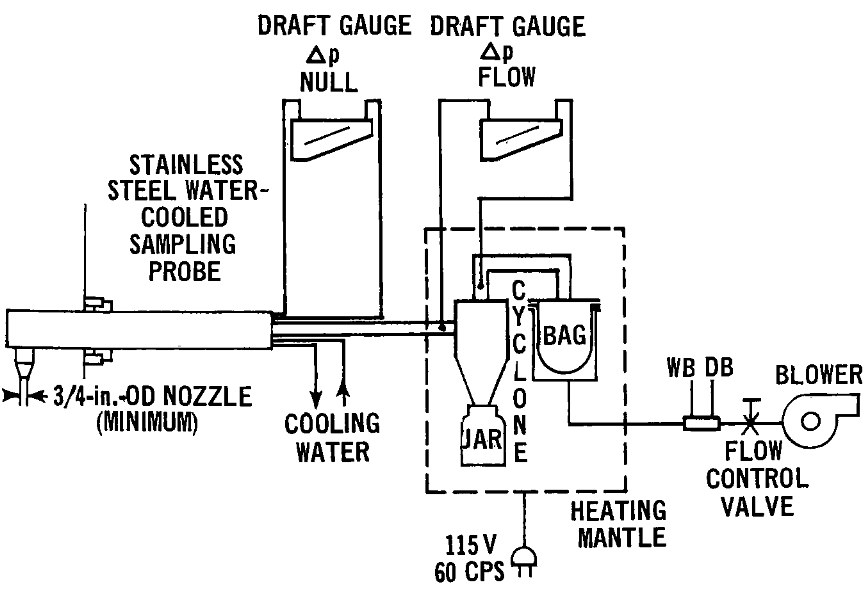


Figure 49. Furnace outlet particulate matter sampling arrangement.[58]

filter pressure buildup due to condensation. It is particularly useful in evaluating wet scrubber systems. Figure 50 illustrates a stack-sampling arrangement for particulate matter and humidity. Because of lower temperatures, the nozzle is not water-cooled. A provision for maintenance of isokinetic conditions is not included in the system. Sampling rates should be based on gas velocities determined by pitot tubes.

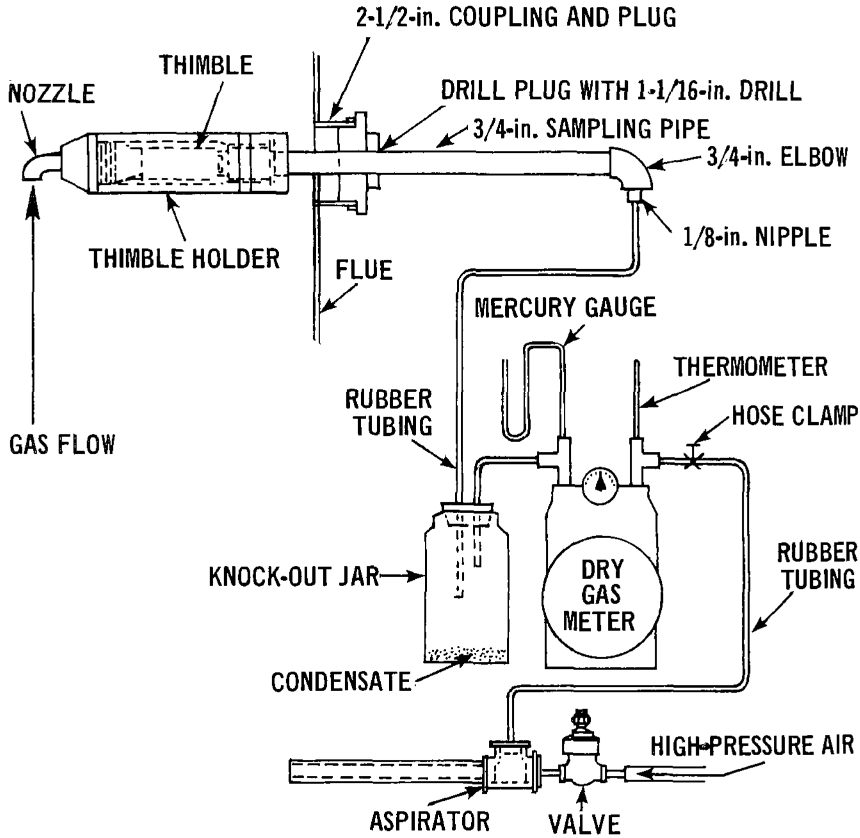


Figure 50. Stack particulate matter and humidity sampling arrangement.[58]

7.3.3 Particulate Matter and Gas Measurement

After particulate matter and gases have been sampled, they are collected using sampling trains suitable for the desired analyses. Measurement methods are not standardized. The selection of the method is the judgment of the tester. Table 33 summarizes some of the measurement methods that have been used for incinerator tests. No effort is made to describe the methods in detail because there are many references available on this subject.

Table 33. INCINERATOR EMISSION MEASUREMENT METHODS

Emission	Method of measurement
Particle mass	Filtration gravimetric
Particle size	Sieve analysis, coulter counter, microscopic analysis
Particle composition	Chemical analysis
Hydrocarbons	Infrared spectrophotometry, flame ionization analyzer
Polynuclear hydrocarbons	Separated by benzene extraction and column chromatography, and then analyzed by spectrophotometry, fluorometric
Organic acids	Acid-base titration
Aldehydes	Colorimetric (bisulfite analysis and modified Ripper's method
Ammonia (rarely present)	Modified Kjeldahl distillation method
Carbon dioxide	Orsat analysis, infrared analyzer
Carbon monoxide	Orsat analysis, infrared analyzer, gas detector
Oxides of sulfur	Gravimetric and volumetric analysis (barium perchlorite titration)
Oxygen	Orsat analysis, portable gas analyzer
Nitrogen	Indirect by Orsat analysis
Oxides of nitrogen	Saltzman, phenoldisulfonic acid method
Chlorine	Gravimetric (Volhard)
Water	Condensate method, wet and dry bulb thermometer (wetting temperature limitation)

7.4 RESIDUE

The characteristics of the residue can determine the means and location of its ultimate disposal. The residue should be of a nature, or disposed of in such a manner, that insect and rodent attraction, dust, odor, and water pollution from leaching are at a minimum.

Residue consists of siftings that fall through the grates, as well as the "burned-out" refuse that remains at the end of the burning grate. The amount of residue that sifts through the grates is obviously dependent on the design and type of the grate. Some grates such as the rocking grate are designed to achieve as much sifting through the grate as is possible. Other grates are designed only with underfire air supply in mind and have much lower sifting rates. A study performed by Kaiser, Zeit, and McCaffery on two 200-ton-per-day rocking-grate stokers showed that 177 pounds of siftings was produced per ton of refuse burned.[69] Table 34 summarizes the sifting weight and percentages for 325,100 pounds of fired refuse.

Table 34. SIFTING WEIGHTS AND PERCENTAGES[69]

Grate	Sifting weight, lb	Percent of refuse
Feeder	1,160	0.36
Burner	27,600	8.49
Total	28,760	8.85

The composition of siftings varies with the position along the grate at which the sifting took place. Less ash, clinker, glass, ceramic material, stone, and metal sift through the feeder grate that sift through the burner grate. Feeder grate siftings contain more combustible material, moisture, and organic matter than burning-grate siftings. Tables 35, 36, and 37[69] are results of the analyses of siftings from a feeder grate, a burner grate, and the combined feeder and burner grate system, respectively.

Table 35. SIFTINGS FROM FEEDER GRATE WITH NO UNDERFIRE AIR SUPPLY[69]

Residue	Sieve opening		
	> 1/4 in.	1/4 in. x 10 mesh	< 10 mesh
	Percent by weight		
Ferrous metal	1.08	1.35	3.14
Magnetic oxide	0.00	0.00	–
Nonferrous metal	0.32		
Glass + ceramic + stones	23.28		
Clinker	0.49		
Bones, shells	0.79		
Nonmagnetic	–	23.55	43.79
Combustible, including ash			
Nonputrescible	1.46		
Putrescible	0.75		
Total	28.17	24.90	46.93
Moisture	0.70	3.84	4.65
Dry organic (ash free)	6.03	31.70	29.00
Ash, glass, metal	93.27	64.46	66.35
Total	100.00	100.00	100.00

Combined analysis, percent: Moisture 3.34; dry organic 23.20; ash, glass, metal 73.46.

Table 36. SIFTINGS FROM BURNER GRATE SECTIONS[69]

Residue	Sieve opening		
	>1/4 in.	1/4 in. x 10 mesh	<10 mesh
	Percent by weight		
Ferrous metal	7.92	1.03	3.40
Magnetic oxide	0.00	1.56	
Nonferrous metal	1.98	0.99	
Glass + ceramics + stones	39.73	5.55	
Clinker	5.75	3.08	
Bones, shells	1.17	1.79	
Nonmagnetic			23.53
Combustible, including ash			
Nonputrescible	1.37		
Putrescible	0.19	0.96	
Total	58.11	14.96	26.93
Moisture	0.00	0.00	0.00
Dry organic (ash free)	1.60	1.61	5.35
Ash, glass, metal, etc.	98.40	98.39	94.65
Total	100.00	100.00	100.00

Combined analysis, percent: Moisture 0.00; dry organic 2.61; ash, glass, metal 97.39.

Table 37. COMBINED SIFTINGS FROM STOKER GRATES[69]

Residue	Sieve Opening > 1/4 in.	1/4 in. x 10 mesh	< 10 mesh
	Percent by weight		
Ferrous metal	7.65	1.04	3.39
Magnetic oxide	0.00	1.50	
Nonferrous metal	1.91	0.95	
Glass + ceramics + stones	39.06	5.33	
Clinker	5.54	2.95	
Bones, shells	1.15	1.72	
Nonmagnetic		0.95	24.35
Combustible, including ash			
Nonputrescible	1.38	0.92	
Putrescible	0.21		
Total	56.90	15.36	27.74
Moisture	0.03	0.16	0.19
Dry organic (ash free)	1.78	2.82	,6.31
Ash, glass, metal	98.19	97.02	93.50
Total	100.00	100.00	100.00

Combined analysis, percent: Moisture 0.10; dry organic 3.19; ash, glass, metal 96.71

The physical analysis of total residue from a 300-ton-per-day continuous-feed incinerator is presented in Table 38. The data presented in this table are not meant to represent average or typical residue compositions. Rather, they identify the residue constituents for one specific municipal incinerator. They can be useful

Table 38. CLASSIFICATION OF INCINERATOR RESIDUE[69]

	Dry weight, lb	Percent of total
Ferrous metal	943.97	15.75
Tin cans	(828.25)	(13.82)
Other	(115.72)	(1.93)
Magnetic flakes	227.32	3.80
Nonferrous metal	18.04	0.30
Glass over 1/4 inch	567.72	9.48
Ceramics, stones	90.53	1.51
Clinker over 3 inch	487.76	8.15
1/4 x 3 inch	956.50	15.96
Ash, nonmagnetic		
1/4 x 10 mesh	373.23	6.23
Minus 10 mesh	590.79	9.87
Combustible		
Paper, wood, char	107.43	1.79
Putrescible (visual)	4.11	0.07
Bones, pits	1.82	0.03
In conveyor water	1,620.90	27.06
Total	5,990.12	100.00
Less salt	−26.5	
Net residue	5,963.6	
Combustible-free residue	5,209.1	

as a "first guess" in estimating residue composition. Table 39 presents typical ranges of values for the various residual constituents.

Table 39. RESIDUE COMPOSITION
(percent)

Material	Range
Metals	19 to 30
Glass	9 to 44
Ceramics, stones	1 to 5
Clinkers	17 to 24
Ash[a]	14 to 16
Organic	1.5 to 9

[a]Exclusive of other materials listed.

Potential water pollution from residue landfill sites by leaching can be a major consideration in selecting a location for a site. From 4.75 to 5.75 percent (by dry weight) of the residue is water soluble.[70] Again, the variation can be the result of a complexity of factors such as incinerator design, incinerator operation, and refuse heteorogeneity. An analysis of the water-soluble portion of residue for a batch-and continuous-feed incinerator is presented in Table 40.

Table 40. AVERAGE ANALYSIS OF WATER-SOLUBLE PORTION OF RESIDUE[70]
(percent by dry weight of sample)

	Batch-feed incinerator	Continuous-feed incinerator
Hydrocarbon concentration	6.1666	9.1666
Alkalinity	0.1156	0.1865
Nitrate nitrogen x 10^{-4}	4.0078	3.48
Phosphate x 10^{-4}	2.75	4.416
Chloride	0.1221	0.0771
Sulfate	0.0813	0.2447
Sodium	0.04675	0.197
Potassium	0.04230	0.048
Iron	0.00617	0.015

7.5 EFFLUENT WATER

Water is used in various parts of the incineration process and, as it is used, it usually becomes contaminated with dissolved and suspended matter. The contamination of the waste water is generally great enough that the water must be treated prior to discharge to prevent or control pollution of rivers and underground water streams. Characteristics of waste water from five types of incinerators are given in Table 41. For comparison purposes some average characteristics of river water and sewage are also included in the table.

Cross and Ross reported interesting studies of scrubber effluent waters from incinerators in Jacksonville and Ft. Lauderdale, Florida.[72] For a batch-feed incinerator, they found that both the effluent water temperature and acidity

Table 41. CHARACTERISTICS OF INCINERATOR WASTE WATER[71]

Source	Odor[a]	pH	Alkalinity, ppm	Total solids, ppm	Total volatile suspended solids, ppm	Percent	5-day biochemical oxygen demand at 20°C, ppm
River	0	7.0	50	100	10	trace	2
Sewage	4M	6.8	100	500	300	50	200
Incinerator wastes							
Batch-fed incinerator (rectangular)							
Ash hopper	3M			1,327	69	70	700
Fly ash disposal	1M	7.2	50	11,846	11	31	3.2
Lagoon	2S	7.3	134	9,580	13	24	54
Continuous-feed traveling grate							
Residue conveyor	2M	11.6	424	1,830	236	71	618
Batch-fed (circular)							
Residue conveyor	3M	4.6	330	6,302	56	78	750
Continuous-feed rocking grates							
Residue conveyor	3M	–	–	–	45	47	560
Continuous-feed reciprocating grate							
Residue conveyor	1S	6.4	410	–	14	43	605

[a]M - Moldy; S - Sulfuretted; Scale of 1 (no odor) to 5 (very strong).

varied widely. The pH ranged from 3 to 5 and the water temperature fluctuated from 140° to 180° F. Maximum values of pH were noted when the temperature of the effluent water was at or near a minimum. Table 42 summarizes the contributions of various chemical constituents made by a scrubber system in the Ft. Lauderdale incinerator.[72]

Cyanide and phenols show the largest increase, with rather substantial increases in many of the other constituents.

Table 42. ANALYSES OF SCRUBBER WATER AT FT. LAUDERDALE INCINERATOR, BROWARD COUNTY, FLORIDA (JUNE 1966)[72]

Chemical constitutent	Raw water	Scrubber effluent	Contribution from incineration
Iron (Fe) (mg/l)	0.35	2.00	1.65
Barium (Ba) (mg/l)	0.0	5.0	5.0
Cyanide (CN) (μg/l)	210.0	5,400.0	5,190.0
Chromium (Cr) (mg/l)	0.0	0.13	0.13
Lead (Pb) (mg/l)	0.0	1.30	1.30
Phenols (μg/l)	5.0	1,726.0	1,721.0
Copper (Cu) (mg/l)	0.08	0.18	0.10
Zinc (Zn) (mg/l)	0.0	2.40	2.40
Manganese (Mn) (mg/l)	0.0	0.30	0.30
Aluminum (Al) (mg/l)	0.18	20.80	20.62

8. COSTS OF MUNICIPAL INCINERATION

There are innumerable ways in which cost data may be presented. The method that is best suited to the need at hand is usually chosen. Rather than try to interpret the needs of prospective readers, cost data will be discussed and presented in this chapter to a large extent in the manner in which they appear in the published literature. Certain precautions are necessary for users of such data. For comparative purposes, costs should be reduced to a base year to adjust for inflationary trends. Cost differences of utilities, materials, and labor from one area to another or one country to another should be taken into consideration. Design specifications such as control equipment emission criteria may have a very significant effect on the price of a plant. Sometimes expensive construction design is necessary because of unusual soil conditions or climate. The economy of building one large incinerator instead of two incinerators half the size can be significant even though transportation distance of the refuse may be increased and vulnerability of the overall operation to breakdowns is increased. These are just a few of many factors that make an accurate determination of costs, and comparisons of costs in one area of the country to those of another, difficult, if not impossible.

8.1 INITIAL PLANT CONSTRUCTION COSTS

Plant costs are most commonly given either as total cost or in cost per ton capacity per day. The total cost price can range anywhere from $52,000 for a simple 140-ton-per-week conical burner serving a town of approximately 15,000[73] to $30,600,000 for a 660,000-ton-per-year, steam-generating, continuous-feed incinerator.[21] Rogus presented some capital costs for recently constructed modern incinerators.[74] His figures were corrected to a 1965 index and are shown in Table 43. Added to this table are costs (uncorrected) of new incinerators either built or being built in Rockville, Maryland; Oyster Bay, New York; London, England; and Paris, France.

Many authors have given ranges for construction costs per ton dry plant capacity. Table 44 summarizes the ranges of combustion costs per ton dry plant capacity that have been reported in recent literature. Foreign costs have been directly converted to dollars and do not reflect the differences in purchasing power of the dollars in foreign countries. The high cost per ton-day of some foreign incinerators is because of their sophisticated gas-cleaning equipment and extensive waste-heat-recovery apparatus. These dual-purpose incinerators not only burn refuse but supply steam and electricity, the value of which more than recovers the extra construction costs.

Table 43. INCINERATOR PLANT CAPITAL COSTS

Location	Furnace types, number and size, tons/day	Supplementary fuels	Water-cooled walls	Refractory walls	Special auxiliaries: Waste-heat boilers	Electrostatic precipitators	Steam generating plant	Electric generating plant	Oversized weight equivalent	Residue and metals salvaged	Chimneys per plant	Capital cost: Total cost of plant	Unit cost per ton per day	Remarks[a]
Vienna	Van Roll 3 @ 200	Waste oil	–	X	X	X	X	X	–	X		$ 9,600,000	$16,000	Difficult foundations
Munich	Martin 2 @ 660	Pulverized coal	X	–	X	X	X	X	X	X	1			
	Martin 1 @ 1,060	Pulverized coal	X	–	X	X	X	X	X	X		21,750,000	9,100	Costs are approximate
Dusseldorf	Drum 4 @ 250	–	X	–	X	X	X	X	X	X	1	7,500,000	7,500	Cost includes building for total of six furnace units
Rotterdam	Martin 4 @ 385	–	X	–	X	X	X	X	X	X	2	9,250,000	6,000	Steam for on-site only, electric power generator: 10% for inc. balance sold
Paris (Issy-les-Moulineaux)	Martin 4 @ 450	–	X	–	X	X	X	X	–	X	2	20,000,000	11,100	Highly sophisticated
Lausanne	Von Roll 2 @ 200	–	–	X	X	X	X	X	–	X		4,000,000	10,000	Handsome plant in midst of apartment area
Montreal	Martin or Von Roll, 4 @ 300	–	X	–	X	X	X	–	X	X	2	12,000,000	10,000	Bids taken November 2, 1965
N.Y.C. (6 modern plants)	Traveling grate 4 @ 250	–	–	X	–	–	–	–	–	–	2	8,000,000	8,000	Large subsidence chambers
Rockville, Maryland	Traveling grate 3 @ 350	–	–	X	X	–	–	–	–	–	3	4,874,973[b]	4,640	Land cost ($297,580) included, completed 1965
Oyster Bay, N.Y.	Continuous-feed 2 @ 250	–	–	X	X	–	–	–	–	–	2	2,493,000[b]	5,000	Equipped with CCTV
London (Deephams)	1333 tons per day	Unknown	–	–	–	–	–	–	–	–	–	25,200,000[b]	18,900	Under construction
Paris (Ivry)	Martin 2 @ 330,000 tons per year	Unknown	X	–	X	X	X	X	Unknown	Unknown	1	30,600,000[b]	Unknown	Under construction

[a]All plants burn mixed, unsegregated refuse.
[b]Not corrected to 1965 index.

Table 44. RANGES OF INCINERATOR CONSTRUCTION – COSTS PER TON-DAY

Location	Cost, $
United Kingdom	1,500 to 18,900
W. Europe	6,000 to 16,000
United States	3,000 to 8,000+

8.1.1 Air Pollution Control Equipment Cost

The costs of air pollution control equipment are closely related to the efficiency of the equipment. It is the more sophisticated, high-efficiency equipment that is more costly. The rather simple nonmechanical types of control equipment such as settling chambers, baffle collectors, and scrubbers do not require pretreatment of the furnace gases and are generally less costly. Scrubbers, however, are perhaps the most expensive of the group. Cyclones, electrostatic precipitators, and fabric filters all require pretreatment of the furnace gases and are the most expensive, but most efficient type of control systems. Cyclones are not quite as expensive on the average as fabric filters and electrostatic precipitators. The first electrostatic precipitators to be installed in the United States had an estimated cost of approximately $450,000 each. Fife and Boyer have presented (Table 45) estimated construction costs in 1966 of several combinations of air pollution control equipment for a hypothetical 500-ton-per-day incinerator equipped with two 250-ton-per-day furnaces.[75] Dust loading to the collector was assumed to be 3.5 pounds of dust per 1,000 pounds of flue gas corrected to 50 percent excess air. Five combinations are given for refractory-lined furnaces and three combinations are given for steam-generating, water-walled furnaces. It can be seen that reduced gas volumes resulting from water-walled furnaces lower the costs of a given control system to less than one-half the value for a refractory furnace.

Table 45. COSTS OF CONSTRUCTING, OWNING, AND OPERATING AIR POLLUTION CONTROL EQUIPMENT TO MEET MUNICIPAL INCINERATOR STACK EMISSIONS[75]

Equipment	Average construction cost, dollars	Unit cost, dollars/ton of refuse burned	Stack emissions, lb/1,000 lb flue gas at 50% excess gas
Baffled spray chamber	$188,200	$0.77	1.75
Spray chamber-cyclone collector	270,360	1.23	0.77
Wet scrubber	400,900	2.10	0.14
Spray chamber-electrostatic precipitator	501,770	1.21	0.175
Spray chamber-fabric filter	712,190	2.00	0.035
Water-cooled furnace-cyclone	91,800	0.38	0.77
Water-cooled furnace-electrostatic precipitation	210,300	0.39	0.175
Water-cooled furnace-fabric filter	243,000	0.65	0.035

8.1.2 Land Cost

Land cost is sometimes one of the reasons a community decides to adopt municipal incineration as opposed to a landfill for its refuse disposal. Incineration reduces substantially the volume of the refuse to be disposed, but the desire to locate an incinerator as close as possible to the source of the refuse still requires the purchase of expensive land. Some municipalities have been able to buy state- or county-owned land for as little as $1.00 while other municipalities have not been as fortunate and have had to pay current real estate market values. When choosing among several sites, the costs of long hauling distances must be carefully weighed against some of the other factors involved, such as overall community acceptance.

8.2 REFUSE INCINERATION COSTS

The overall cost of incineration usually consists of personnel, maintenance, repair, replacement, utility, and amortization costs.

Rogus has summarized personnel costs for four European incinerators and six incinerators in the United States.[28] His computations of cost in man-hours per ton of refuse are given in Table 46. All of the European incinerators are equipped with by-product recovery and salvaging operations for which extra man-hours are required.

A comparison of the overall costs from this limited data strongly indicates that, on the average, European operating costs are substantially lower than operating costs in the United States. This is even more indicative when income from by-product recovery and salvage operation is included.

An earlier cost analysis (1958 cost index) for refuse incineration is presented in Table 47. Improvements that have been made in continuous-feed incinerator design may make these figures obsolete; however, the various cost factors involved and their relative magnitudes are of interest.

8.3 EXPANSION AND REMODELING COSTS

Substantial savings can be realized by remodeling and expanding some of the older incinerators in lieu of replacement with new installations. Many of the recently constructed incinerators have allotted space for the installation of additional furnaces and air pollution control equipment. In such an installation, there is no question as to whether it is more economical to expand and remodel or to build a new plant. It appears from the published literature that rehabilitating old plants can be economically attractive. The New York Department of Sanitation operates 11 incinerators that were built between 1934 and 1962.[77] Four of these are batch-feed units built before 1938. Two of the batch-feed furnaces will be converted to continuous-feed furnaces and the remaining 7 continuous-feed incinerators are being rehabilitated. Construction costs for sophisticated air pollution control systems are estimated to range from $1 to $1½ million.

Table 46. PERSONNEL REQUIREMENTS OF PLANTS BURNING MIXED, UNSEGREGATED REFUSE

Plant[+]	Design capacity per plant, tons/day	Operating period, hr/week	Operating factor[a]	Refuse processed, tons/working day	Manpower, man-hours/ working day	Cost/man-hr-ton, $	Cost,[b] dollars/ton
			European				
A	600	168	70	420	384	0.91	–
B	1,000	168	85	850	564	0.66	–
C	1,540	126	70	980	592	0.60	2.50 net
D	400		50	200			3.50 gross 1.50 net
			U. S. A.				
6 modern continuous-feed plants[c]	1,000	128	80	800	576	0.72	4.30

Note: All European incinerators are equipped and operated to include steam and power generation, residue processing, and metal salvage.

[a]Operating Factors = Average actual production ÷ Design Capacity.

[b]Total cost exclusive of amortization.

[c]Average values per plant for 6 modern plants for 3 years of 300 working days each—refuse incineration only.

Table 47. COST OF REFUSE DISPOSAL BY INCINERATION[76]
(dollars per ton of refuse destroyed—1958 Cost Index)

	Average of three continuous-feed, modern, mechanized incinerators	Average of four batch-fed, manually-stoked incinerators
Total cost per ton-day of design capacity (exclusive of land)	$5,500.00	$3,750.00
Unit costs		
Direct operating costs (exclusive of residue disposal)	$2.40	$4.20
Maintenance and repair	1.05	1.05
Administration and supervision	0.50	0.65
Pensions	0.60	0.90
Fuel and utilities	0.05	0.05
Amortization	0.95	0.65
Total unit costs	$5.55	$7.50

The city of Philadelphia is presently considering the conversion of some of its batch-feed incinerators to a continuous-feed type.[78] The city presently is operating two continuous-feed and four batch-feed incinerators. Rehabilitation and conversion of the batch-feed incinerators will cost an estimated $2.1 to $2.2 million.[79] Replacement of one of the batch-feed units will cost approximately $6 to $7 million, assuming a capacity of 600 tons per day.

The city of Kenosha, Wisconsin, is studying the possibility of converting its city incinerator plant from a garbage-only incinerator operation to a modern, mixed-refuse incineration plant.[5] An entirely new 240-ton-per-day incinerator plant, including air pollution control equipment, would cost approximately $1.7 million, but cost estimates for rehabilitation of the old plant range from only $333,200 to $661,900, depending on design features and air pollution control equipment.

8.4 BY-PRODUCT RECOVERY

Waste heat, metals, slag, and residue can all be valuable by-products of municipal incineration. Refuse as a fuel is quite attractive. It is free and, in contrast to other fuels, contains small amounts of sulfur. Nearly 2 pounds of steam can be generated per pound of refuse incinerated.[21] The new Ivry Plant being built in Paris, France, will produce 277,000 pounds of steam per hour at 1,378 pounds per square inch and 878° F.[21] Thus a rather significant income can result from the sale of steam or electricity to a nearby market. A modern refuse incinerator in Germany[56] receives $1.99 per ton of refuse incinerated from the sale of steam. Sale of steam from a 720-ton-per-day incinerator in Chicago, Illinois, is estimated to net $125,000 to $150,000 annually. Waste-heat recovery on a smaller scale for internal use only by the incinerator plant is fairly common throughout the United States. This type of operation can be reflected in significant savings in utility bills. The use of incineration waste heat for the desalinization of salt water is another cost recovery method for incinerators located in coastal areas. The Oceanside Refuse Disposal Plant in New York[22] desalts ocean water for internal use. Table 48 summarizes the uses of waste heat for 43 municipal incinerators in the United States.[32] Each use, except the preheating of combustion air, has direct economic value resulting in lower total incineration cost.

Salvage of residue and metal is perhaps more widely practiced in foreign countries than it is in the United States. The price received for salvage metal in Europe and England ranges from $2.15 to $18.50 per ton.[26] Similar variations in the price of salvage metals in the United States are common.

With increasing flyash collection in municipal incineration, sintering operations to produce building blocks, such as those found at some power companies, may find wider application. Further profitable uses of residue and flyash are the objectives of some current research programs. Some incinerator salvage operations in the United States have had to be abandoned because they were not economically practical. Many incinerators have successful salvaging operations, however, such as one incinerator in Chicago, Illinois, that burns 500 tons of refuse per day, of which approximately 170 cubic yards of reclaimable metal is sold daily.[81] Based on 1 year of operational data, 38 cents worth of metal per ton of raw refuse is recovered. Tin cans account for 23 cents per ton and the remaining 15 cents per ton is received from the sale of scrap metal.[82] Cinders are sold for fill, and the remaining residue can be mixed with lime to form a product that is used in the construction of streets, parking lots, and playgrounds. This product, even though proven useful, has not been financially successful.

Table 48. INCINERATOR WASTE HEAT UTILIZATION[32]

Construction year	Plants reporting use	Heat use								
		Building heat and/or hot water	Electric power	Sewage sludge drying	Steam production				Preheat combustion air	Other use
					For sale	Outside heating	Other use	Use not stated		
1945–1950	2	1	1	0	0	0	0	0	0	0
1951–1955	10[a]	4	2	2	1	0	0	2	1	0
1956–1960	17[b]	10	1	3	0	1	d, g	1	1	e, f
1961–1965	14[c]	9	1	1	1	1	h	1	0	i
Total	43	24	5	6	2	2	3	4	2	3

[a]One plant reports building heat, hot water, and preheating combustion air. Another reports building heat and sludge drying.
[b]One plant each reports: hot water and power generation, hot water and air preheating, hot water and sludge drying, and steam for equipment drives and heating nearby hospital.
[c]One plant reports building heat and steam for sale. One reports power generation and desalination.
[d]Equipment drives.
[e]Sludge furnace.
[f]Heat for sludge digester.
[g]For sewage treatment plant.
[h]Desalination of sea water.
[i]Tubuler gas reheater cools combustion-chamber outlet gas and rehats scrubber exit gas.

9. LOCATIONS OF MUNICIPAL INCINERATORS

9.1 SITE LOCATION

Municipal incinerators are usually located as near as feasible to the population centers served, except for instances in which bias is sometimes given in the direction of the maximum projected population growth. Convenient road access to the incinerator from all areas to be served is important. If a decision must be made between a "close-in" site or a more remote site, hauling distances can be a major consideration. Normally, residue is more economical to haul than raw refuse, if great distances are involved. Industrial areas are usually more receptive to incinerators than are nonindustrial areas. Purchase of a generous amount of acreage assures room for future expansion and is usually a good investment. Locating incinerators near sewage plants for sludge treatment or incineration of odorous gases emitted during sewage treatment can have its merits. Municipal burning of refuse at sea has been under consideration in Boston.[83] Such a plan requires, among other things, a determination of the possible effects of the residue on marine environment.

9.2 GEOGRAPHICAL LOCATION

Municipal incineration is practiced rather widely throughout the United States, England, Japan, and most of the western European countries, and may be practiced in other countries for which little or no technical information is available. Information on extensive studies or surveys of incinerator locations other than in the United States and Canada has not been found; therefore, the following discussion will be limited to the countries for which information on studies is available.

In November 1965, 289 incinerators that burn municipal refuse in the United States were identified.[32] Incinerators that were installed prior to 1945 and not rebuilt or added to since 1945 were not included. The Appendix presents, in its entirety, Stephenson and Cafieros' plant summary for all 289 incinerators.[32] At the time of Stephenson and Cafieros' survey, there were approximately 1,000 to 1,250 noncaptive sanitary landfills and 17,500 to 21,300 noncaptive open dumps.[84]

The estimated distribution of incinerators by states is given in Table 49.[84] Most of the municipal incinerators are found in the eastern United States with New York, New Jersey, and Ohio having the largest percentages of all the states.

The estimated distribution of incinerators, by community size as of 1965, is given in Table 50.[84] Cities with a population of 1 million or more have the lowest percentage of incinerators, while cities with populations of 10,000 to 24,900 have the highest—25.2 percent.

Table 49. ESTIMATED DISTRIBUTION OF INCINERATORS IN 1965 BY STATE[84]

State	Percent of total	State	Percent of total
Alabama	1.6	Nebraska	0.5
Connecticut	4.3	New Jersey	11.9
District of Columbia	0.2	New York	15.1
Florida	3.7	North Carolina	2.1
Georgia	1.6	North Dakota	0.5
Hawaii	0.5	Ohio	9.2
Illinois	4.8	Oregon	0.5
Indiana	1.6	Pennsylvania	7.6
Iowa	1.0	Rhode Island	1.6
Kentucky	2.1	South Carolina	0.5
Louisiana	2.1	Tennessee	1.0
Maryland	2.1	Texas	1.6
Massachusetts	6.0	Virginia	3.7
Michigan	2.7	Washington	0.5
Minnesota	1.6	West Virginia	1.6
Missouri	0.5	Wisconsin	5.4
Total for states with less than 0.1 percent of the U. S. totals			0.3
Total			100.0

Source: APWA estimates and calculations.

Table 50. ESTIMATED DISTRIBUTION OF THE NUMBER OF INCINERATORS BY COMMUNITY SIZE IN 1965[84]

Community population, thousands	Number of communities in United States, 1960	Percentage of communities with incinerators	Average number of incinerators per community	Distribution of incinerators by community size	
				Number	Percent
1,000 or over	5	80.0	4	16	5.1
500 to 999.9	16	75.0	2	24	7.6
250 to 499.9	30	50.0	1.5	22	7.0
100 to 249.9	81	30.0	1	24	7.6
50 to 99.9	201	25.0	1	50	15.9

10. EVALUATION OF MUNICIPAL INCINERATION

Many factors are involved in the evaluation of municipal incineration as a basic refuse disposal method. Some of the factors are dependent on the city in which an incinerator is used, and the remaining factors are an inherent part of the basic incineration process. Municipal incineration is generally considered to be an economical, nuisance-free, sanitary refuse disposal method. The determination of whether incineration is the best solution to a city's refuse problem is perhaps best reached after a careful consideration of its advantages and disadvantages, followed by an investigation of the advantages and disadvantages of other refuse disposal methods.

10.1 ADVANTAGES OF MUNICIPAL INCINERATION

Many of the advantages of municipal incineration are apparent from a review of the previous chapters. There are ten basic advantages expressed by various authors in the refuse disposal field:

1. Municipal incinerators require relatively small plots of land as compared to sanitary landfills.
2. Incinerators can usually be located in industrial areas near the center of the service area and near collection routes.
3. The incinerator operation is not interrupted by inclement weather.
4. The operating time of a municipal incinerator can range up to 24 hours a day to accommodate the variations in refuse generation.
5. The residue from an incinerator is generally stable and nearly inorganic.
6. An incinerator can be designed to be inconspicuous to allow it to be located in or near residential areas.
7. Incinerators located near sewage treatment plants can complement the plants by burning malodorous gases and drying and burning sludge.
8. Incinerators can be less expensive than sanitary landfills.
9. Incinerators can burn practically any kind of refuse.
10. Income can be realized if there is a market for steam, hot water, electricity, salvage metals, residue, and incineration service to industry.

Other advantages undoubtedly have been realized in municipal incineration.

10.2 DISADVANTAGES OF MUNICIPAL INCINERATION

Little has been written on the disadvantages of municipal incineration, which indicates the disadvantages may be few.

Perhaps the biggest disadvantage to incineration is the high initial cost of an incinerator facility. Even though long-term landfill cost has been reported to be as much or more than incineration, the initial cost of a plant can be a substantial burden to a municipality.

Municipal incinerators emit pollutants into the atmosphere. Adherence to air pollution control requirements are becoming mandatory nearly everywhere in the world. Efficient means to control air pollutants released to the atmosphere are available, but are relatively expensive.

Operating costs are relatively high. Although the number of employees required to run an incineration plant may be smaller than it is for other methods of disposal, the wages for the skilled employees who operate, maintain, and repair an incinerator are higher, for instance, than for men who work on a landfill. Maintenance and repair costs may be high because of the high temperatures necessary for the burning and the dirty and damaging nature of the refuse and residue. Equipment and machinery are frequently damaged by wires; tramp metals; and fusible, abrasive, and explosive objects in the refuse. The combination of large capital investment, higher labor costs, and costly maintenance and repairs can produce a cost per ton for refuse disposal greater than for other acceptable methods.

It is sometimes difficult to get a site for an incineration plant because refuse disposal operations in any form are offensive to many people. Moreover, truck traffic to and from the plant may be considered a hazard and a nuisance, particularly in residential neighborhoods.

Incineration is not a complete disposal method. Ash and other residue from the burning process, including flyash, must be disposed of by other means.[2]

10.3 OTHER DISPOSAL METHODS

A brief review of dumping, open burning, sanitary landfill, composting, burial at sea, disposal in sewer, and hog-feeding will provide some perspective in the evaluation of municipal incineration. Some of these methods could provide for the complete disposal of municipal refuse while others would provide disposal of only a fraction of the refuse.

10.3.1 Dumping

One of the first refuse disposal methods used was open dumping of refuse on land. This method is still widely used and is obviously very inexpensive, but extremely objectionable and offensive in and near populated areas. Such a site is a breeding ground for insects and rodents; odors can pollute the air for considerable distances from the dump. Long hauling distances are required to reach areas where few people live, and even then objections still arise.

10.3.2 Open Burning

Open burning has all of the disadvantages of dumping without burning, except that the volume of the refuse is reduced and less land is required. The insect and rodent problem is reduced somewhat; however, the burning produces extensive amounts of smoke and increased odors.

10.3.3 Sanitary Landfill

A sanitary landfill can be an economical and nuisance-free method of refuse disposal. A sanitary landfill involves burying refuse in a sanitary manner. Unsightly refuse is hidden from view by a layer of earth that controls the insect and rodent problem found in open dumps. Sufficient land at a reasonable price and in close proximity to the refuse collection area must be available to make a landfill successful. Public acceptance is sometimes difficult to achieve because a sanitary landfill is often associated with open burning and dumps or landfill operations that are not sanitary. Sanitary landfills can be an excellent method for filling depressions, canyons, tidal areas, swamps, and marshes. Some of the problems associated with landfills are adverse weather conditions, dust, odors, water pollution due to leaching, settlement of the landfill, and formation of explosive gases in the decomposing section of the fill. A completed landfill can be successfully used for recreational purposes, parking areas, and construction provided some important precautions are taken.

10.3.4 Composting

Composting is the biochemical degradation of organic materials to a sanitary, nuisance-free, humus-like material.[2] Composting has potential as a refuse disposal method, but has not been used extensively enough to permit an evaluation of its operational effectiveness. Advantages of composting based on pilot plants operating in Europe and the United States during the 1950's are as follows:[2]

1. A composting plant produces a usable end product that may be sold, thus either paying for, or at least reducing, costs.
2. Composting can be used to dispose of such industrial wastes as those from meat packing plants, paper mills, saw mills, tanneries, stockyards, and canneries. Dewatered sewage solids, especially if they are mixed with ground refuse, may be disposed, and cans and bottles that have no salvage value can be economically ground with the remaining refuse. When large grinders are used (plants capable of processing more than 100 tons a day), even large, bulky objects may be handled. A municipal refuse composting plant can dispose of all these wastes.
3. Normally, composting offers favorable conditions for salvage of rags, glass, cardboard, paper, cans, and metals.
4. A well-located refuse composting plant may reduce the cost of hauling refuse to the point of disposal.
5. Flexibility of operation permits a 100 to 200 percent overload in design capacity for several days by increasing the time the receiving bins and grinders operate.
6. Weather does not affect an enclosed composting plant, although heavy rain adversely affects most kinds of outdoor composting.

Disadvantages to composting include:[2]

1. Capital and operating costs apparently are relatively high.
2. Marketability of composted refuse has not yet been proved and seasonal use of the end product may require special marketing procedures or outdoor storage.
3. Trained personnel to operate composting plants are not readily available.
4. Refuse that damages grinders, such as tires, pipes, heavy stones, and mattresses, must be removed and disposed of separately.
5. If cans and bottles have no local salvage value, they must either be removed and disposed of separately or ground with the organic matter, thus somewhat reducing the quality of the finished compost.
6. Site procurement for a composting plant is difficult because any type of refuse disposal facility is considered a nuisance in most neighborhoods.
7. Odors can become a problem during periods when a compost plant is not functioning properly.

10.3.5 Dumping at Sea

Dumping of raw refuse at sea was practiced rather widely prior to 1953 by New York City and other communities. After many communities were recipients of floating refuse, however, a United States Supreme Court decision in 1953 prohibited dumping of the raw refuse at sea. Some consideration has been given in recent years to incineration aboard ships at sea, with residue disposal in the sea. Unknown effects of the residue on sea life and the possibility of floating debris make this method questionable.

10.3.6 Disposal in Sewer

This method, which is practiced ever more widely in private homes, consists of grinding the refuse on a municipal scale, metal and glass excluded, and then disposing the ground refuse into a city's sewage system. This method is generally not considered to be very feasible. Most sewage systems are already overburdened. Additional equipment and experimentation that would have to be performed to put such a system into operation would be quite costly.

10.3.7 Unit Trains

The use of a special train carrying only refuse as cargo (unit train) has potential as a city's refuse disposal system. Such a train would carry the refuse to an unpopulated area such as a desert, swamp, or mountainous area where it would be dumped. This type of system may still meet with some of the serious problems encountered with local open dumps.

10.3.8 Swine Feeding

Feeding of cooked food wastes to swine can accommodate only a fraction of the total refuse produced by a municipality. Opposition to hog-feeding has grown, as evidenced by increased zoning restrictions and the elimination of this garbage disposal method in many areas. All garbage must be cooked before it is fed to swine to help prevent vesicular exanthema, hog cholera, and enteritis diseases.[2] A high correlation exists between trichinosis in humans and the feeding of raw garbage to swine.[2]

10.3.9 Nuclear Energy

Perhaps future nuclear technology will provide an answer to the increasing problems of waste disposal faced by the entire world. At present there are no practiced means to use this method for disposal of solid wastes.

11. INCINERATOR RESEARCH AND PILOT PROJECTS

This chapter is a review of some current incinerator demonstration, pilot, and research projects. Many of these are either demonstration grants, research contracts, or research grants awarded by the Public Health Service to various universities and to state, county, and city governments. Although some literature has been published on some of these projects, no effort is made herein to present any of the research findings.

11.1 INCINERATION AT SEA

The idea of burning refuse aboard ships at sea and disposing of the residue there originated at Harvard University, where the idea is being researched. The ability of the atmosphere 10 to 30 miles off shore to diffuse the incinerator emissions without coastal pollution is being studied. The deposition and distribution of residue on the ocean floor, as well as its possible effects on marine life, are being investigated. The application of systems analysis and operations research methods in the overall operation is also being studied.

11.2 BASIC INCINERATION PROCESSES AND EMISSIONS

A study of basic incineration processes such as combustion, gasification, heat transfer, and furnace aerodynamics that take place in a full-scale incinerator and in laboratory models, is being performed by Pennsylvania State University in an effort to provide the necessary information for the design of incinerators with higher performances and lower stack emissions. An additional expectation is that this research may lead to the development of analytical and control instrumentation that will make good incinerator control possible at a feasible cost.

New York University is conducting research in an effort to establish engineering design data for the handling, charging, and smokeless burning of bulky refuse. It is planned that additional data will be obtained on refuse composition, bulk density, calorific values, residue flyash, and the location of overfire air jets for the combustion of hydrocarbons. Tests on a batch-feed prototype incinerator will be performed. Available incinerators will also be observed while burning bulky refuse.

New York University is also studying the composition of stack effluents from domestic municipal incinerators and has compiled an annotated bibliography of foreign and domestic publications relevant to municipal incinerator emissions.

The City of San Francisco plans to design, develop, and construct a 100- to 150-ton-per-day incinerator that will meet the requirements of the several air pollution control districts along the Pacific Coast with a minimum amount of air pollution control equipment. Various features that will be studied, developed, fabricated, and tested include:

1. A mechanical grate that is capable of operating with a low amount of excess air.
2. A secondary chamber located to provide sufficient turbulence for complete burnout of gases.
3. Air jets for inducing turbulence and mixing at the entrance of the secondary chamber.
4. A flyash scrubber in conjunction with other gas-cleaning components to provide compliance with air pollution emission regulations.

Information on construction, maintenance, and operating costs will also be provided.

Another research project at New York University will endeavor to investigate a wide range of characteristics of a modern continuous-feed incinerator. The incinerator has rocking-grate stokers and cyclone dust collectors. Waste-heat boilers are incorporated for generation of electricity and conversion of sea water to potable water. The composition of refuse, residue, slag, flyash, and waste water will be studied also. A material balance will be made to include residue, flyash, slag deposits, waste-water pollutants, and flue gas emissions. A furnace heat balance will be determined, and air pollution control efficiencies will be calculated for this incinerator.

11.3 PILOT AND DEMONSTRATION INCINERATORS

The City of Bridgeport, Connecticut, is experimenting with a brush burner and an open-pit incinerator to study the feasibility of disposing of those components of municipal refuse that cannot be burned in conventional incinerators. Information will be gathered as to the practicability, safety, costs, hazards, and the types of materials that can be incinerated in such a device.

The possibility of using fluidized beds for the disposition of refuse and sewage sludge is being investigated by West Virginia University. The process of using a fluidized bed will be evaluated by using a pilot plant.

The feasibility and costs of incorporating such special features as advanced air pollution control devices, heat-recovery boilers, a metal-recovery operation, a control laboratory, a chipper installation, and a compression press into the construction and design of an incinerator are being determined by the District of Columbia. The feasibility of using a Melt-Zit high-temperature incinerator for the municipal refuse of Brockton, Massachusetts, is being determined by using a pilot incinerator at Whitman, Massachusetts. In Shippensburg, Pennsylvania, an effort is being made to demonstrate that a mechanically stoked rotary-grate incinerator can be a feasible means of municipal refuse disposal that can meet air pollution regulations for a small community. Western Jefferson County, Wisconsin, is determining the feasibility of a joint solid waste disposal system for five communities. Projections of population and refuse and a review of available methods of disposal, including incineration, will be included.

The demonstration incinerator being constructed in San Francisco to show that an incinerator can meet air pollution control regulations in a feasible manner has already been discussed. The adaptation of electrostatic precipitators to two incinerator furnaces in New York City is also considered a research project that will demonstrate the feasibility of this type of control system for domestic incinerators.

11.4 SYSTEMS ANALYSIS

Santa Clara County is making a systems analysis approach to demonstrate whether a solid waste disposal system that basically employs incineration can be a feasible method for solid waste disposal on a county-wide basis.

Systems analysis is a fairly recent development, particularly as it is applied to refuse disposal. Wolf and Zinn have presented a block diagram for solid waste management, which is shown in Figure 51. In addition, they state:[85]

> Systems analysis can provide the means for the officials responsible for solid waste management in metropolitan areas, counties, and states with the information necessary to develop a comprehensive disposal plan. Knowing the costs and benefits associated with a wide range of alternatives, they can seek public support for their recommendations with full confidence that their proposals are not simply reactions to immediate, pressing problems, but rather represent the combination of waste disposal methods that offers the greatest long-term benefit to the community.

11.5 RESIDUE ANALYSIS AND CLASSIFICATION

Several studies of incinerator residue are secondary objectives of some of the previously discussed projects. Drexel Institute has performed several studies primarily concerned with incinerator residue. The studies include the classification, chemical composition, and biological properties of residue. Biological studies include, for the purpose of control, determining nutrient thresholds necessary for propagation of flies and rats.

11.6 PYROLYSIS OF REFUSE

New York University is undertaking a project of which the main objectives are: (1) the gasification potential of refuse components; (2) the development and demonstration of continuous refuse gasification with air; and (3) the determination of energy necessary to dry, heat, and ignite refuse components.

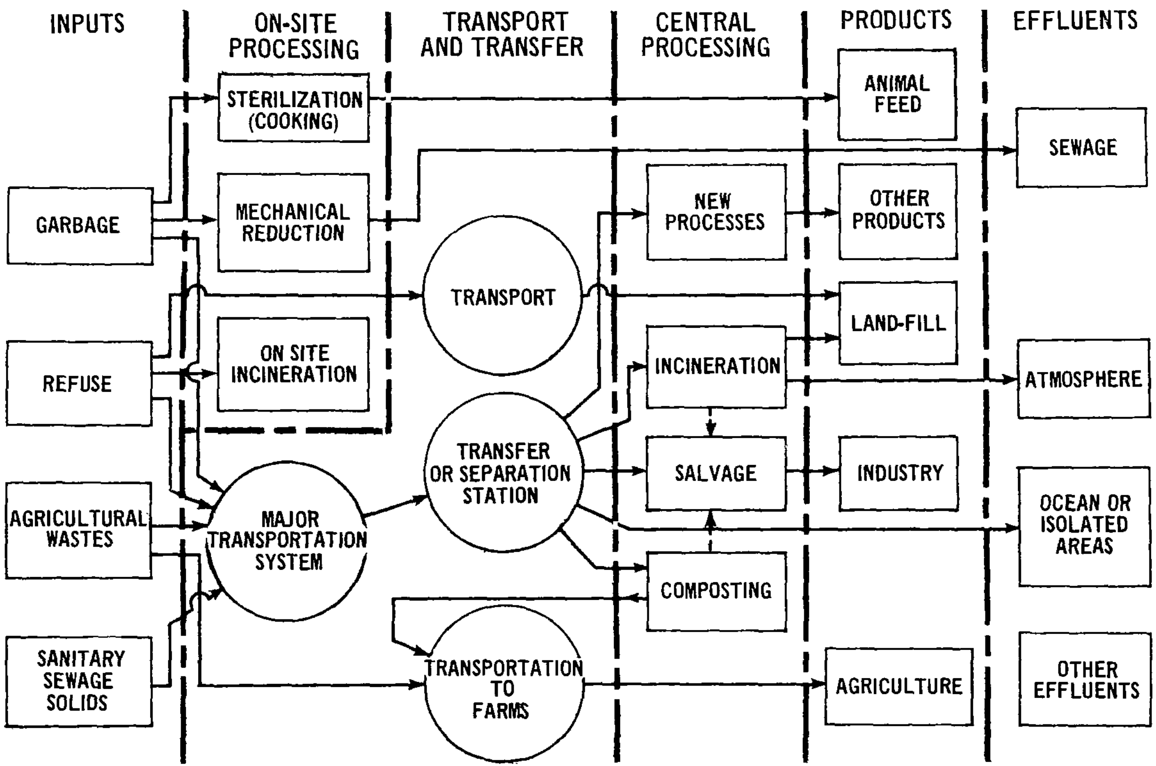


Figure 51. Block diagram for solid waste management shows alternative paths that may be followed. Note that transportation may take place between any two stages; only those transportation systems requiring major investment are shown.

11.7 REFUSE CRUSHING

The city of Buffalo, New York, in its proposal to install a bulk-refuse crusher as an addition to its municipal incinerator, has begun a demonstration to determine the feasibility of pre-sizing bulky municipal refuse prior to incineration. Accurate records will determine if this procedure is economically feasible for other communities with the problem of excessively bulky refuse.

11.8 INCINERATOR WATER TREATMENT SYSTEM

The Whitemarsh Township Authority, Lafayette Hill, Pennsylvania, has been concerned with the effectiveness of a waste-water treatment system. Such a system would permit the reuse of waste water. The construction of a new treatment system may demonstrate that waste water, indeed, can be successfully treated and reused.

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13. GLOSSARY

The following glossary is compiled from four sources: Incinerator Institute of America Incinerator Standards,[33] Lexicon of Incinerator Terminology by Dan Schwartz,[86] Chapter 11 of the New Jersey Air Pollution Control Code,[87] and Chapter 2 of "Control Techniques for Particulate Air Pollutants," National Air Pollution Control Administration Publication No. AP-51.[88]

-A-

AIR

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

1. Air jets–Streams of high velocity air issuing from nozzles in the incinerator enclosure to provide turbulence. Air jets, depending on their location, may be used to provide excess, primary, secondary, and overfire air.
2. Excess air–Air remaining after a fuel has been completely burned, or that air supplied in addition to the theoretical quantity.
3. Overfire air–Any air controlled with respect to quantity and direction, supplied beyond the fuel bed, as through ports in the walls of the primary combustion chamber, for the purpose of completing combustion of combustible materials in the gases from the fuel bed, or to reduce operating temperatures within the incinerator. (Sometimes referred to as secondary air.)
4. Primary air–Any air controlled with respect to quantity and direction, forced or induced, supplied through or adjacent to the fuel bed for the purpose of promoting combustion of the combustible materials in the fuel bed.
5. Secondary air–Any air controlled with respect to quantity and direction, supplied beyond the fuel bed, as through ports in the walls or bridge wall of the primary combustion chamber (overfire air) or the secondary combustion chamber for the purpose of completing combustion of combustible materials in the gases from the fuel bed, or to reduce operating temperature within the incinerator.
6. Theoretical air–The exact amount of air required to supply oxygen for complete combustion of a given quantity of a specific fuel.
7. Underfire air–Any air controlled with respect to quantity and direction, forced or induced, supplied beneath the grate, that passes through the fuel bed.

ABRASION

Wearing away of refractory surfaces by the scouring action of moving solids such as refuse, residue, or flyash.

ABSORPTION

The ratio of the weight of water a refractory can absorb to the weight of the dry refractory. The ratio is expressed as a percentage.

ABUTMENT

In furnace construction, the structural member that withstands the thrust of an arch. In general, an abutment consists of a brick skewback and a steel supporting member.

ALUMINA

Al_2O_3, the oxide of aluminum. In combination with H_2O alumina forms the minerals bauxite, diaspore, and gibbsite. In combination with SiO_2, alumina forms kaolinite and other clay minerals.

ANCHOR

A metal or refractory device inserted between the outer supports and the refractory wall, arch, or roof to hold the refractory lining in place.

APRON CONVEYOR

A conveyor with steel pans suspended between two strands of chain with rollers, having fixed vertical sides to contain the material inside the extended chain side bars.

ARCH

The roof of a furnace, chamber or flue.

1. Bonded arch–A sprung arch in which the transverse joints are staggered to tie the construction together.
2. Flat arch–An arch in which both outer and inner surfaces are horizontal.
3. Ignition arch–A refractory roof over or in a furnace near the zone of fuel entrance that promotes ignition by reflection of heat.
4. Jack arch–A flat arch held in place by compressive forces from the edges, similar to a sprung arch.
5. Sprung arch–An arch that is supported by abutments at the sides or end only. A cross section of a sprung arch, taken at right angles to its axis, usually consists of a segment of a circular ring, in which the inner and outer arch surfaces are represented by arcs of concentric circles.
6. Relieving arch–A sprung arch in a wall to reduce the gravity load over a section below.
7. Ring arch–A sprung arch formed of separate courses or rings not bonded together.
8. Wall arch–A relieving arch or an arch over a door opening or port in a wall.

ASH

Solid mineral remains after complete burning of refuse.

ASHES

Residue from solid-fuel fires used for cooking and on-site incineration usually containing some combustible constituents. (When collected with municipal refuse, ashes are part of the refuse charged to municipal incinerators.)

ASH GATE

A horizontal gate used to close the bottom of ash hoppers. Such a gate is normally supported on rollers. Some ash gates have a special drain arrangement to allow quenching water to be retained to provide an air seal for the furnace.

ASH PIT

A pit or hopper located below a furnace in which residue is accumulated and from which it is removed at intervals.

AUTOMATIC (RECYCLING) BURNER

A burner that is purged, started, ignited, modulated, and stopped automatically and recycles on a preset operating range.

AUXILIARY FUEL

Fuel other than waste materials used to attain temperatures sufficiently high (1) to dry and ignite waste materials, (2) to maintain ignition thereof, and (3) to effect complete combustion of combustible solids, vapors, and gases.

AUXILIARY-FUEL-FIRING EQUIPMENT

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

AUXILIARY GIRDER

A girder on a crane (parallel to the main girder) for supporting the platform, motor base, operator's cab, and control panels to reduce the torsional forces such loads would otherwise impose on the main girder.

AVAILABLE HEAT

The quantity of useful heat per unit of fuel available from complete combustion after deducting dry flue gas and water vapor losses.

-B-

BAFFLE

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

BAFFLE CHAMBER

A chamber designed to promote the settling of flyash and coarse particulate matter by changing the direction and/or reducing the velocity of the gases produced by the combustion of refuse.

BAROMETRIC DAMPER

A hinged or pivoted balanced blade, placed so as to admit air to the breeching, flue connection, or stack, thereby automatically maintaining a constant draft in the incinerator.

BATCH-FED INCINERATOR

An incinerator that is charged with refuse periodically, the charge being allowed to burn down or burn out before another charge is added.

BATTER

The decrease in thickness of a wall as it ascends. Also, the slope of the face of a wall; the angle at which the face of a wall slopes from the vertical.

BLAST GATE

A sliding metal damper in a duct, usually used to regulate the flow of forced air.

BLOWER

A fan used to force air under pressure.

BODY

(1) A ceramic shape; (2) the blend of raw materials used for the production of a ceramic shape; (3) more specifically, the most important mineral constituent of a ceramic shape.

BOND

1. Ceramic bond—The mechanical strength developed by a heat treatment that causes cohesion of adjacent particles.
2. Hydraulic bond—The mechanical strength developed in a ceramic material by the combination of water with the mineral to form hydrate crystals.

BREECHING OR FLUE CONNECTION

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

BRIDGE

That part of an overhead crane consisting of girders, trucks, end ties, walkway, and drive mechanism, which carries the trolley and travels in a direction parallel to the runway.

BRIDGE WALL

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

BRITISH THERMAL UNIT

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

BUCKSTAYS

Pairs of vertical steel beams, one on each side of a furnace or flue and connected near the top, for the purpose of sustaining the thrust of a sprung arch.

BULKY REFUSE OR BULKY WASTE

Waste unsuitable for charging into conventional incinerators because of its size.

BURNER

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

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

BURNING AREA

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

BURNING RATE

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

BUTTERFLY DAMPER

A plate or blade installed in a duct, breeching, flue connection, or stack, which rotates on an axis in its plane to regulate flow.

BYPASS

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

-C-

CALCINING

The heat treatment of raw refractory materials for the purpose of eliminating volatile chemically combined constituents and for reducing volume changes.

CALORIFIC VALUE

See heating value.

CAPACITY

The amount of waste incinerated, usually expressed in pounds per hour, with the characteristics or type of waste stipulated.

CARBONACEOUS MATTER

Carbon compounds or pure carbon associated with the fuel or residue of a combustion process.

CASTABLE REFRACTORY

A hydraulic-setting refractory suitable for casting, ramming, or gunniting into heat-resistant shapes or walls.

CHAIN-GRATE STOKER

A stoker that has a moving chain as a grate surface; the grate consisting of links mounted on rods to form a continuous surface that is usually driven by sprockets on the front shaft.

CHARGE

The quantity of refuse introduced to the furnace at one time, as in a batch-fed incinerator.

CHARGING CHUTE

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

CHARGING CUTOFF GATE

A modification of charging gate used in continuous-feed furnaces that do not have high temperatures near the charging hopper. It consists of a steel cutoff plate at the bottom of the charging hopper that closes on a machined seat at the top of the charging chute.

CHARGING GATE

A horizontal, moving cover that closes the charging opening on top-charging furnaces. It usually consists of a steel cutoff plate for sealing the charging hopper, a refractory-lined cover that fits into the frame in the top of the furnace, and mechanical means for opening and closing.

CHARGING RAM

A reciprocating device to meter and force refuse into a furnace.

CHECKERWORK

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

CHIMNEY, STACK, OR FLUE

A vertical passage for conducting products of combustion to the atmosphere.

CHUTE-FED INCINERATOR

A multiple-chamber, Class IIA incinerator. The incinerator is top charged through a charging chute extending two or more floors above the incinerator.

CLINKER

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

CLOSING MOTION

The hoist motion that closes and opens the bucket or grapple and also is used in raising and lowering the load.

COLD SET

The hardening or "setting" of a mortar that takes place at room temperature. See mortar, air-setting.

COMBUSTION

The rapid reaction of the combustible material with oxygen, with the resultant generation of heat.

COMBUSTION CHAMBER

In municipal incinerators, the chamber immediately following the furnace in which gaseous and suspended particles continue to burn. In other incinerators, the furnace or primary combustion chamber.

COMBUSTION GASES

The mixture of gases and vapors produced in the furnace and combustion chamber.

CONTINUOUS-FEED INCINERATOR

An incinerator into which refuse is charged in a nearly continuous manner so as to maintain a steady rate of burning.

CONSTRUCTION WASTE

Scrap lumber, pipe, and other discarded materials from new construction and remodeling.

CONTROLLER

A device for regulating in a predetermined way the power delivered to a motor or other equipment.

CONTROL POINT

The value of the controller variable which the controller operates to maintain.

COMPLETE COMBUSTION

The complete oxidation of the fuel, regardless of whether it is accomplished with an excess amount of oxygen or air or the theoretical amount required for perfect combustion.

COOLING AIR

Ambient air added to the combustion gases for cooling by dilution. Also called "tempering air."

COOLING SPRAYS

Water sprays directed into the flue gases for the purpose of cooling the gases and, in most cases, to effect a partial separation of flyash from the gases.

CORBEL

In a wall, the projection from the vertical formed by placing each course beyond the course just below.

CORE WALL

In a battery wall, those courses of brick, none of which are exposed on either side.

COURSE

A horizontal layer or row of bricks in a structure.

1. Header course—A course laid flat with the longest dimension of the bricks perpendicular to the face of the wall.
2. Row lock course—A course laid on edge with the longest dimension of the bricks perpendicular to the face of the wall.
3. Soldier course—A course with bricks set vertically.
4. Stretcher course—A course laid flat with its length parallel to the face of the wall.

CRANE STOP

A block secured to the runway to limit movement of the crane.

CROWN

The highest point of an arch. Also, a dome-shaped furnace roof.

CURTAIN WALL

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

-D-

DAMPER

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

1. Barometric damper—A hinged or pivoted balanced blade placed to admit air to the breeching, flue connection, or stack, thereby automatically maintaining a constant draft in the incinerator.
2. Butterfly damper—A plate or blade installed in a duct, breeching, flue connection, or stack, which rotates on its axis.
3. Guillotine damper—An adjustable blade installed vertically in a breeching or flue connection, arranged to move vertically across the breeching or flue connection, usually counterbalanced for easy operation.
4. Sliding damper—An adjustable blade installed in a duct, breeching, flue connection, or stack, arranged to move horizontally across the duct, breeching, flue connection, or stack.

DEAD PLATE GRATE

A stationary grate through which no air passes.

DEAD PLATES

Castings supporting walls and extending into door openings to provide sills.

DEMOLITION WASTE

Construction materials from the razing of buildings and structures.

DESTRUCTIVE DISTILLATION

The heating of organic matter when air is not present, resulting in the evolution of volatile matter and leaving solid char consisting of fixed carbon and ash.

DESTRUCTOR

A Class III, Class IV, Class VI, or Class VII incinerator.

DEVITRIFICATION

The change from a glassy to a crystalline condition.

DIRECT-FEED INCINERATOR

A Class I, Class IA, Class III, Class IV, Class VI, or Class VII incinerator. The incinerator may be side, end, and/or top charged. When top charged, the charging chute shall serve not more than one floor.

DOME

See Crown.

DOWNPASS

Chamber or gas passage placed between two chambers to carry the products of combustion in a downward direction.

DRAFT

The pressure difference existing between the incinerator or any of its component parts and the atmosphere, which pressure difference causes a continuous flow of air and products of combustion through the gas passages of the incinerator to the atmosphere.

1. Forced draft—The pressure difference created by the action of a fan, blower, or ejector that supplies primary combustion air at more than atmospheric pressure.
2. Induced draft—The pressure difference created by the action of a fan, blower, or ejector located between the incinerator and the stack or at the stack exit.
3. Natural draft—The pressure difference created by stack or chimney because of its height and the temperature difference between the flue gases and the atmosphere.

DRAFT CONTROLLER

An automatic device to maintain a uniform furnace draft by regulation of an internal damper.

DRAG CONVEYOR

A conveyor normally used for residue, consisting of vertical steel plates known as flights, fastened at intervals between two strands of chain.

DRAG PLATE

A plate beneath a traveling- or chain-grate stoker used to support the returning grates.

DROP ARCH

Any vertical refractory wall supported by arch construction, which serves to deflect gases in a downward direction. (Sometimes referred to as a curtain wall.)

DRY-PRESS PROCESS

A method of forming brick from slightly moistened granular materials by charging the materials into molds and compressing by machines into rigid shapes.

DUMP PLATE

An ash-supporting hinged plate from which ashes may be discharged by rotation from one side of the plate.

DUST LOADING

The amount of dust in a gas, usually expressed in grains per cubic foot or pounds per thousand pounds of gas.

DUTCH OVEN

A combustion chamber built outside of and connected to a furnace.

-E-

EFFLUENT

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

ELECTRIC OVERHEAD TRAVELING CRANE

An electrically operated machine for lifting, lowering, and transporting loads, consisting of a movable bridge carrying a fixed or movable hoisting mechanism and traveling on an overhead runway structure.

ELECTROSTATIC PRECIPITATOR

A device for collecting dust from a gas stream by placing an electrical charge on the particle and removing that particle onto a collecting electrode.

EROSION

The wearing away of refractory surfaces by the washing action of moving liquids, such as molten slags or metals; or the action of moving gases.

EXCESS AIR

The air supplied to burn a fuel or refuse in addition to that theoretically (stoichiometrically) necessary for complete combustion. Usually expressed as a percentage of theoretical air, as "130 percent excess air." (See Air.)

EXPANSION OR SETTLING CHAMBER

Any chamber designed to reduce the velocity of the products of combustion to promote the settling of flyash from the gas stream.

FIREBRICK

Refractory brick of any type.

FIRE CLAY

A sedimentary clay containing only small amounts of fluxing impurities, but high in hydrous aluminum silicates, and therefore capable of withstanding high temperature.

FIRECLAY BRICK

A refractory brick manufactured substantially or entirely from fire clay.

1. Alumina-diaspore fireclay brick–Brick made essentially of diaspore or nodule clay and having an alumina content of 50, 60, or 70 percent plus or minus 2.5 percent.
2. Low-duty fireclay brick–Fireclay brick that have a pyrometric cone equivalent (PCE) not lower than Cone 19.
3. Intermediate-duty fireclay brick–Fireclay brick that have a PCE not lower than Cone 29, or that deform not more than 3 percent at 2460° F (1350° C) in the standard load test.
4. High-duty fireclay brick–Fireclay brick that have a PCE not lower than Cone 31 to 32, or that deform not more than 1.5 percent at 2460° F (1350° C) in the standard load test.
5. Super-duty fireclay brick–A fireclay brick having a PCE not lower than Cone 33 on the fire product, and not more than 1 percent linear shrinkage in the permanent linear ASTM change test, Schedule C (2910° F) and not more than 4 percent loss in the panel spalling test (preheated at 3000° F).

FIRECLAY REFRACTORY

Brick, shapes or specialties made principally or entirely of fire clays.

FIXED CARBON

The ash-free combustible matter remaining in a sample of refuse after the sample has been heated by a prescribed method to red heat in a closed crucible.

FIXED GRATE

A grate that does not move. A stationary grate.

FLAREBACK

A burst of flame from a furnace in a direction opposite to the normal flow, usually caused by the ignition of an accumulation of combustible gases.

FLIGHT CONVEYOR

A conveyor often used as a drag conveyor, but having rollers interspersed in the chains to eliminate friction.

FLUE, STACK, OR CHIMNEY

A vertical passage for conducting products of combustion to the atmosphere.

FLUE-FED INCINERATOR

A single-chamber Class II incinerator. The incinerator is charged through a vertical flue that also serves as a charging chute.

FLUE CONNECTION OR BREECHING

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

FLUE-GAS WASHER

Equipment for removing flyash and other objectionable materials from the products of combustion by such means as sprays and wet baffles.

FLUE GAS

All gases that leave the incinerator by way of the flue, including gaseous products of combustion, water vapor, excess air and nitrogen. (Sometimes referred to as the products of combustion.)

FLYASH

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

FLYASH COLLECTOR

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

FORCED DRAFT

Pressure greater than atmospheric pressure created by the action of the fan or blower that supplies the primary air.

FORCED-DRAFT FAN

A fan supplying air under pressure to the fuel-burning equipment.

FURNACE

The chamber of the incinerator into which the refuse is charged, ignited, and burned. The primary combustion chamber.

FURNACE VOLUME

The amount of space within the furnace above the grate, expressed in cubic feet.

FUSION POINT

The temperature at which a particular complex mixture of minerals becomes sufficiently fluid to flow under the weight of its own mass. As most refractory materials have no definite fusion points, but soften gradually over a range of temperatures, the conditions of measurement have been standardized by the American Society for Testing and Materials. (See Pyrometric Cone Equivalent.)

-G-

GAS WASHER OR SCRUBBER

Equipment for removing flyash and other objectionable materials from the products of combustion by such means as sprays and wet baffles.

GAGE PRESSURE

The pressure above atmospheric pressure.

GARBAGE

Vegetable and animal food wastes from the preparation, cooking, and serving of food; market wastes; and wastes from handling, storage, and sale of produce.

GASES

Formless fluids that occupy the space of enclosure and that can be changed to a liquid or solid state only by the combined effect of increased pressure and decreased temperature.

GRAINS PER CUBIC FOOT

The term for expressing dust loading in weight (grains) per unit of gas volume (cubic foot). 7,000 grains equals 1 pound.

GRAPPLE

Used for the same purpose as the grab bucket, but has long tines for better digging action.

GRATE

Surface with suitable opening to support the fuel bed and permit passage of air through the burning fuel. It is usually located in the primary combustion chamber and is designed to permit removal of unburned residue, and may be horizontal or inclined, stationary or movable.

GROG

Calcined fire clay or clean broken fireclay brick, ground to suitable fineness. It is added to a refractory batch to reduce shrinkage in drying and firing.

GUILLOTINE DAMPER

An adjustable blade installed vertically in a breeching and arranged to move vertically across the breeching; usually counter-balanced for easy operation.

GUNNITING

The placement of hydraulic setting refractory concrete at a high velocity by compressed air.

-H-

HEARTH

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

1. Cold hearth—A surface on which waste material is placed to dry and/or burn, aided by the action of hot combustion gases passing only over the waste material.
2. Hot hearth—A surface on which waste material is placed to dry and/or burn by the action of hot combustion gases that pass first over the waste materials and then under the hearth.

HEAT OF COMBUSTION

The heat released by combustion of a unit quantity of waste or fuel, measured in British Thermal Units.

HEAT RELEASE RATE

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

HEATING VALUE

The heat released by combustion of a unit quantity of waste or fuel, measured in British Thermal Units.

HIGH-ALUMINA REFRACTORIES

Refractory products containing 47.5 percent or more of alumina.

HOT DRYING HEARTH

A surface on which wet material is placed to dry by the action of hot combustion gases that pass successively over the wet material and under the hearth.

HYDRAULIC FLYASH HANDLING

A system using water-filled pipes or troughs in which flyash is conveyed by means of gravity, water jets, or centrifugal pumps.

-I-

INCINERATION

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

INCINERATOR

An engineered apparatus capable of withstanding heat and designed to efficiently reduce solid, semi-solid, liquid, or gaseous waste at specified rates, and from which the residues contain little or no combustible material.

INCINERATOR CLASSES

Class I – Portable, packaged, direct-feed incinerator with a capacity of up to 25 pounds per hour of Type 1 or Type 2 refuse.

Class IA – Portable, packaged, or site assembled direct-feed incinerator with a capacity of from 25 to 100 pounds per hour of Type 1 or Type 2 refuse.

Class II – Chute-fed apartment house incinerator in which the refuse chute also acts as the flue for the products of combustion.

Class IIA– Chute-fed apartment house incinerator having a separate refuse chute and a separate flue for the products of combustion.

Class III – Direct-feed incinerator with a burning rate of 100 pounds or more per hour, suitable for Type 1 or Type 2 refuse.

Class IV – Direct-feed incinerator with a burning rate of 75 pounds or more per hour, suitable for Type 3 refuse.

Class V – Municipal incinerator with a burning rate of 1 ton or more per hour.

Class VI – Crematory and pathological incinerator suitable for only Type 4 refuse.

Class VII– Incinerator designed for specific Type 5 or Type 6 by-product waste.

INCINERATOR STOKER

A mechanically operable moving-grate arrangement for supporting, burning and transporting the refuse in a furnace and discharging the residue. A mechanical stoker for the burning of refuse in an incinerator.

INDUCED DRAFT

The pressure less than atmospheric pressure created by the action of a blower or ejector that is located between the incinerator and the stack or at the stack exit. Induced draft is measured in inches of water column (in.w.c.).

INDUCED-DRAFT FAN

A fan exhausting hot gases from the heat-absorbing equipment, dust collector, or scrubber.

INSULATION

A material having a low thermal conductivity used on the exterior of heated constructions and capable of withstanding the temperatures to which it is subjected.

1. Insulating (backup) block–A shaped product having a low thermal conductivity and a bulk density of less than 70 pounds per cubic foot, suitable for lining industrial furnaces.
2. Insulating firebrick–A firebrick having a low thermal conductivity and a bulk density of less than 70 pounds per cubic foot, suitable for lining industrial furnaces.
3. Plastic insulation–Insulation, plastic enough when mixed with water, to adhere to outer furnace walls to be placed over arches.

-J-

JAMB

The vertical or upright structural member forming the side of a door or other opening in a furnace wall. Also a brick shape with one short edge rounded.

JOINT

1. Buttered joint–In laying up firebrick, a joint formed by troweling mortar on the faces of the brick.
2. Dip joint–In laying up firebrick, a joint formed by dipping the brick into the mortar and either rubbing or tapping the brick into place.
3. Expansion joint–An open joint left for thermal or permanent expansion of refractories. Also, small spaces or gaps built into a refractory structure to permit sections of masonry to expand and contract freely and to prevent distortion or buckling of furnace structures from excessive expansion stresses. These joints are built in such forms as to permit movement of masonry but to limit or prevent air or gas leakage through the masonry.

-K-

KEY

In furnace construction, the uppermost or the closing brick of a curved arch.

K-FACTOR

The thermal conductivity of a material, expressed in Btu per hr (sq ft) (° F) (in.).

-L-

LEDGE PLATE

A form of plate that is adjacent to, or overlaps, the edge of a stoker.

LIFT

Maximum safe vertical distance through which a crane bucket can move.

LINTEL

A horizontal structural member spanning an opening to carry a superstructure.

LIPIDS

The oils, greases, fats, and waxes in a refuse sample as determined by Soxlet extraction with anhydrous ethyl ether.

LOW-GAS-PRESSURE SWITCH

A pressure-actuated device arranged to effect a safety shutdown of a burner or prevent it from starting when the gas supply pressure falls to below a predetermined low supply pressure.

LUMNITE CEMENT

A tri-calcium aluminate with hydraulic setting properties.

-M-

MANOMETER

A U-shaped tube or an inclined tube filled with a liquid used to measure pressure difference.

MANUAL BURNER

A burner that is purged, started, ignited, modulated, and stopped manually.

MATERIAL BALANCE

An accounting of the weights of material entering and leaving a process, such as an incinerator, usually on an hourly basis.

MINERAL WOOL

An artificial product composed of fine, fused, silicate fibers used as insulation and soft packing.

MIXING CHAMBER

Chamber usually placed between the primary combustion chamber and the secondary combustion chamber where thorough mixing of the products of combustion is accomplished by turbulence created by increased velocities of gases, checkerwork and/or turns in direction of the gas flow.

MOISTURE CONTENT OF REFUSE

The weight loss on drying a sample to constant weight under standard conditions, tentatively 75° C for refuse.

MONOLITHIC LINING (OR CONSTRUCTION)

A refractory lining construction made in large sections on the site without the conventional layers and joints of brick construction. The lining or construction may be formed by casting, gunniting, ramming, or sintering of a granular material into place.

MORTARS

A combination of fine-grained refractory materials, which, on mixing with water, develops a plasticity that makes it suitable for spreading easily with a trowel or for dipping and adhering to brick.

1. Air-setting refractory mortar—A finely ground refractory material that forms a wet mortar that will, on drying, develop a strong air-set bond between refractory shapes and maintain a bond when heated to working furnace temperatures.
2. Cold-setting refractory mortar—Same as air-setting refractory mortar.
3. Fireclay mortar—A mortar of high-fusion-point fire clay and water, often used to fill joints to stop air or gas leakage without forming a strong bond.
4. Grout—A mortar thin enough to flow into unfilled joints in firebrick construction.
5. Heat-setting refractory mortar—A mortar in which the bond is developed

by relatively high temperatures. The hardening of the mortar is the result of the vitrification of part of its constituents.

6. Hot-setting refractory mortar—Same as heat-setting refractory mortar.
7. Hydraulic-setting mortar—A mortar that hardens or sets as a result of hydration, a chemical reaction with water. As the working furnace temperature is applied, the water evaporates and a ceramic bond develops.

MULTICYCLONE

A dust collector consisting of a number of cyclones, operating in parallel, through which the volume and velocity of gas can be regulated by means of dampers to maintain dust-collectorefficiency over the load range.

MUNICIPAL INCINERATOR

An incinerator owned or operated by government or by a person who provides incinerator service to government or others, that is designed for and used to burn waste materials of any and all types, 0 to 6 inclusive.

-N-

NATURAL DRAFT

The negative pressure difference created by a stack or chimney because of its height and the temperature difference between the flue gases and the atmosphere.

-O-

ODORANT

A gaseous nuisance that is offensive or objectionable to the olfactory sense.

OPERATOR'S CAB

The operator's compartment from which movements of the crane are controlled.

ORSAT

An apparatus used for analyzing flue gases volumetrically by measuring the amounts of carbon dioxide, oxygen, and carbon monoxide.

OSCILLATING GRATE STOKER

A stoker, the entire grate surface of which oscillates to move the refuse and residue over the grate surface.

OVERFIRE AIR JETS

Streams of high-velocity air issuing from nozzles in the furnace enclosure to provide turbulence and oxygen to aid combustion or to provide cooling air.

PANEL SPALLING TEST

A standardized test to provide an index to the spalling behavior of refractories.

PARTICULATE MATTER OR PARTICULATES

(As related to control technology) any material, except uncombined water, that exists as a solid or liquid in the atmosphere or in a gas stream at standard conditions.

PEEP DOOR

A small door usually provided with a shielded glass opening through which combustion may be observed.

PEEP HOLE

A small observation port with cover on an incinerator door.

PENETRATION OF SLAG

The action of slag in soaking into a refractory.

PILOT

A burner smaller than the main burner that is ignited by a spark or other independent and stable ignition source, and that provides ignition energy required to immediately light off the main burner.

PILOT TUBE

An instrument that will sense the total pressure and the static pressure in a gas stream. It is used to determine gas velocity.

PLASTIC REFRACTORY

A blend of ground fire clay materials in plastic form, suitable for ramming into place to form monolithic linings or special shapes. It may be air-setting or heat setting, and is available in different qualities of heat resistance.

PNEUMATIC ASH HANDLING

A system of pipes and cyclone separators that conveys flyash or floor dust in an air stream to a bin.

POLLUTANTS

Any solid, liquid, or gaseous matter in the effluent that tends to pollute the atmosphere.

POTENTIOMETER

A temperature-measuring device made of a number of turns of resistance wire wound in a cylindrical form and constructed with three connections; the center connection is a movable finger or wiper that rides over the length of the coil completing the circuit wherever it touches.

POWER PRESSING

The forming, in molds by means of high pressures applied vertically, of refractory brick shapes from ground refractory material containing an optimum amount of added water.

PRESSURE-COMPENSATED PUMP

A rotary-vane pump with variable displacement by means of a pressure compensating governor that enables the pump to maintain relatively constant pressure from zero to rated volume capacity without the use of a relief valve or other bypass arrangement.

PRIMARY AIR

Any air controlled with respect to quantity and direction, forced or induced, supplied through or adjacent to the fuel bed for the purpose of promoting the combustion of combustible materials in the fuel bed.

PRIMARY COMBUSTION CHAMBER

See Furnace.

PUFF

A minor combustion explosion within the furnace.

PURGE

Scavenging of the furnace and boiler passes with air. Purge airflow must reach not less than 70 percent of the airflow required at maximum continuous capacity of the unit and be sufficient for at least eight air changes.

PUTRESCIBLE MATTER IN RESIDUE

Unburned organic matter in the residue that is fermentable or capable of decaying or assimilation by animals and microorganisms.

PYROMETER

An instrument for measuring and/or recording temperature.

-R-

RADIATION PYROMETER

A pyrometer that determines temperature by measuring the intensity of radiation from a hot body.

RAMMING MIX

A ground refractory material mixed with water to a stiff consistency and rammed or hammered into place to form monolithic furnace linings or patches.

RATED LOAD

The maximum load a crane is designed to handle safety.

RECIPROCATING GRATE

A forced-draft grate, the sections of which move continuously and slowly, forward and rearward, for the purpose of agitating, compressing, moving, and burning refuse material from the charging end to the discharge end of an incinerator furnace.

REFRACTORY (REFRACTORIES)

Nonmetallic substances capable of enduring high temperatures and used in linings of furnaces. While their primary function is resistance to high temperature, they are usually called on to resist one or more of the following destructive influences: abrasion, pressure, chemical attack, and rapid temperature change.

REFUSE

All waste composed of garbage, rubbish, liquids, gases, and noncombustible material.

RESIDUE

Solid materials remaining after burning comprised of ash, metal, glass, ceramics, and unburned organic substances.

RESIDUE CONVEYOR

A conveyor, usually drag- or flight-type, running in a water-filled trough that quenches and dewaters as it elevates the residue to a discharge point.

RINGLEMANN CHART

A series of four rectangular grids of black lines of varying widths printed on a white background, and used as a criterion of blackness for determining smoke density.

ROCKING GRATE

An incinerator stoker with moving (and stationary) trunnion-supported grate bars. In operation, the moving bars oscillate on the trunnions, imparting a rocking motion to the bars, and thus agitating and moving the refuse and residue along the grate.

RUBBISH

All solid waste having combustibles, exclusive of garbage.

RUBBISH CHUTE

A pipe, duct, or trough through which waste materials are conveyed by gravity from the upper floors of a building to a storage room below preparatory to burning.

RUNWAY

The rails, beams, brackets, and framework on which the crane operates.

RUNWAY CONDUCTORS

The conductors mounted on or parallel to the runway that supply current to the crane.

RUNWAY RAIL

The rail supported by the runway beams, on which the bridge of the crane travels.

-S-

SCRUBBER OR GAS WASHER

Equipment for removing flyash and other objectionable materials from the products of combustion by such means as sprays and wet baffles.

SECONDARY AIR

Any air, controlled with respect to quantity and direction, supplied beyond the fuel bed, for the purpose of completing the combustion of combustible materials in the gases from the fuel bed, or to reduce the operating temperature within the incinerator.

SECONDARY COMBUSTION CHAMBER

Chamber where unburned combustible materials from the primary chamber are completely burned.

SEPARATION CHAMBER

A chamber beyond the combustion chamber in which particulate matter may be removed from the gas stream by gravity and reversal of gas flow.

SETTLING OR EXPANSION CHAMBER

Any chamber designed to reduce the velocity of the products of combustion to promote the settling of flyash from the gas stream.

SILICA

SiO_2, the oxide of silicon, a major constituent in fire clay refractories, alone or in chemical combinations.

SILICON CARBIDE

SiC, a refractory material of high melting point, high density, high thermal conductivity, and high resistance to abrasion.

SINTERING

A heat treatment that causes adjacent particles of material to cohere at a temperature below that of complete melting.

SLAG

A liquid mineral substance formed by chemical action and fusion at furnace operating temperatures.

SLAGGING OF REFRACTORIES

Destructive chemical action on refractories at high temperatures, resulting in the formation of slag. Also, the coating of refractories by ash particles, that form a molten or viscous slag on the refractories.

SLIDING DAMPER

An adjustable blade installed and arranged to move in a horizontal plane across a duct, breeching, flue connection, or stack to control the flow of flue gases.

SPALLING OF REFRACTORIES

The breaking or crushing of a refractory unit by thermal, mechanical, or structural causes, thus presenting newly exposed surfaces or the residual mass.

1. Mechanical Spalling – Spalling resulting from stresses caused by rapid heating of wet refractory, abuse in removing slag and clinkers, no provision for expansions, and pinching.
2. Thermal Spalling – Spalling caused by stresses set up in a refractory body during heating and cooling, vitrification, contamination by slags and fluxes, tightness of joints, and degree and uniformity of reversible thermal expansion.
3. Structural Spalling – Spalling caused by materials in joints, degree of burning, and shrinkage.

SPARK ARRESTER

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

STACK, CHIMNEY, OR FLUE

A vertical passage for conducting products of combustion to the atmosphere.

STATIONARY GRATE

A grate with no moving parts. A fixed grate.

-T-

THEORETICAL AIR

The exact amount of air (stoichiometric air) required to supply the oxygen necessary for the complete combustion of a given quantity of a specific fuel or refuse.

THERMAL CONDUCTIVITY

The specific rate of heat flow per hour through refractories, expressed in Btu per square foot of area, for a temperature difference of one degree Fahrenheit, and for a thickness of one inch. Btu/(ft^2) (hr) (°F). (in.)

THERMAL SHOCK RESISTANCE

The ability of a refractory to withstand sudden heating or cooling or both without cracking or spalling.

THERMOCOUPLE

Two lengths of wire, made from different metals, connected to form a complete electric circuit that develops an electromotive force (emf) when one junction is at a different temperature than the other.

THERMODYNAMICS

The science that deals with the mechanical actions or relations of heat.

TIPPING FLOOR

Unloading area for vehicles that are delivering refuse to an incinerator.

TRASH

Waste materials small enough for conventional incineration.

TRAVELING-GRATE STOKER

A traveling-grate stoker consists of an endless grate similar to a chain grate, but with grate keys mounted on transverse bars. The lead nose of each key on one bar overlaps the rear end of the keys on the preceding bar. The transverse bars are mounted on chains and are driven by sprockets.

TROLLEY

The unit that carries the crane-hoisting mechanism and travels on the bridge rails.

TUYERES

Air openings or ports in a forced-draft grate.

TYPE O WASTE

Trash. A mixture of highly combustible waste such as paper, cardboard cartons, wood boxes, and combustible floor sweepings containing approximately 10 percent moisture and 5 percent incombustible solids, having a heating value of approximately 8500 Btu per pound as fired, derived from commercial and industrial activities. The mixtures contain up to 10 percent by weight of plastic bags, coated paper, laminated paper, treated corrugated cardboard, oily rags, and plastic or rubber scraps.

TYPE 1 WASTE

Rubbish. A mixture of combustible waste such as paper, cardboard cartons, wood scraps, foliage, and combustible floor sweepings containing approximately 25 percent moisture and 10 percent incombustible solids, having a heating value of approximately 6500 Btu per pound as fired, derived from domestic, commercial and industrial activities. The mixture contains up to 20 percent by weight of restaurant or cafeteria waste, but contains little or no treated paper, plastic, or rubber wastes.

TYPE 2 WASTE

Refuse. An approximately even mixture by weight of rubbish and garbage containing up to 50 percent moisture and approximately 7 percent incombustible solids, having a heating value of approximately 4300 Btu per pound as fired, commonly derived from apartment and residential occupancy.

TYPE 3 WASTE

Garbage. Animal and vegetable wastes containing up to 70 percent moisture and up to 5 percent incombustible solids, having a heating value of approximately 2500 Btu per pound as fired, derived from restaurants, cafeterias, hotels, hospitals, markets, and similar installations.

TYPE 4 WASTE

Human and animal remains. Carcasses, organs, and solid organic wastes from hospitals, laboratories, abattoirs, animal pounds, and similar sources, consisting of up to 85 percent moisture and approximately 5 percent incombustible solids, having a heating value of approximately 1000 Btu per pound as fired.

TYPE 5 WASTE

By-product waste. Gaseous, liquid, or semi-liquid materials such as tar, paints, solvents, sludge, and fumes from industrial operations.

TYPE 6 WASTE

Solid by-product waste such as rubber, plastics, and wood waste, from industrial operation.

-U-

UNDERFIRE

Any air, controlled with respect to quantity and direction, that is supplied beneath the grate and that passes through the fuel bed.

-V-

VAPOR PLUME

The stack effluent consisting of flue gas made visible by condensed water droplets or mist.

VITRIFICATION

A process of permanent chemical and physical change in a ceramic body at high temperatures, with the development of a substantial proportion of glass.

VOLATILE MATTER OF REFUSE

The weight loss of a dry sample on heating to red heat in a closed crucible.

-W-

WALL

A vertical side or end of a chamber including refractory, insulation, brick, and steel.

1. Air-cooled wall – A wall in which there is a lane for the flow of air directly in back of the refractory.
2. Battery wall – A double or common wall between two incinerators, both faces of which are exposed to heat.
3. Bridge wall – The furnace wall that separates the fuel-burning portion from the rest of the furnace or system. Also, a partition wall between chambers over which the combustion gases flow.

4. Core wall – In a battery wall, those courses of brick none of which are exposed on either side.
5. Gravity wall – A wall supported directly by the foundation or floor of a structure.
6. Insulated wall – A wall in which insulation is placed directly behind the refractory.
7. Supported wall – A furnace wall that is anchored to and has its weight transferred to a structure (usually steelwork and castings) outside of the high-temperature zone.
8. Unit suspended wall – A furnace wall or panel that is supported by hanging from overhead steel.

WORKABILITY

The combination of properties that permits refractory mortars, plastic refractories, and ramming mixes to be placed or shaped with a minimum of effort.

WHEEL LOAD

The load on any crane wheel with the trolley and lifted load (rated capacity) positioned on the bridge to give maximum loading.

WINDBOX

A chamber below the grate or surrounding a burner, through which air under pressure is supplied for combustion of the fuel.

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15. APPENDIX

INCINERATOR PLANT SUMMARY

Data reported in questionnaires and from manufacturers' installation lists for 289 new and rebuilt plants and plant additions are included in this Appendix. A blank space or (-) indicates no information given in questionnaire.

To fully understand this Appendix, please see Legend and Notes at end of Appendix.

Table A-1. INCINERATOR PLANT SUMMARY

Line	Location	Plant	Year built	Source of data	Status	Capacity, tons/24 hr	Refuse handling	Cranes No.	Cranes Type	Buckets	Tipping floor enclosed	Furnaces No.	Furnaces Capacity, tons/24 hr	Furnaces Feed	Furnaces Stoker type	Separate combustion chamber	Spray or expansion chamber	Cooling chamber	Chimneys-height, ft No.	Chimneys-height, ft Total	Chimneys-height, ft Above grates	Mechanical draft	Fly ash removal	Water Treatment	Water Disposal	Waste heat use	Residue handling	Salvage	Notes
1	Jacksonville, Fla.	South Side	1945	QB	New	120	FD	-	-	-	-	1	120	Batch	Circ.	1	-	-	-	-	-	Yes	-	-	-	-	Dir. Dump		
2	Winnipeg, Man.		1945 (D)	QD	New	400	B & C	-	Br.	Bu.	Yes	4	100	Batch	Circ.	4	2	-	1	175	-	Yes	D	-	-	-	Dir. Dump		
3	Youngstown, Ohio		1945	QM	New	200	FD	-	-	-	Yes	2	100	Batch	Man.	-	-	-	-	-	-	-	-	-	-	None	-		
4	Babylon, N. Y.		1946	PD-1	New	90	FD	-	-	-	Yes	1	90	Batch	Circ.	-	-	-	1	-	-	-	-	-	-	-	Manual		
5	Liberty, N. Y.		1946	QD	New	30	FD	-	-	-	Yes	1	30	Batch	Man.	-	-	-	1	70	-	-	-	-	-	-	Dir. Dump		x
6	Racine, Wisc.	Garbage	1946	QM	Re-built	220	FD				Yes	2	80	Batch	Man	2	0	0		139.5	135.5	I	D				Manual		
												1	60	Batch	Man.	1													
7	Warwick, R.I.		1946	QB	New	100	FD				Yes	1	100	Batch	Circ.	1	0	0					D						
No plants reported for 1947																													
8	Carmel, N. Y.		1948	QD	New	40	FD	-			Yes	1	40	Batch	Circ.	1	0	0	1	80	-	U	None	-	-	None	Dir. Dump		
9	Cleveland Hts., Ohio		1948	QD	New	150	FD	-	-	-	Yes	2	75	Batch	Circ.	2	1	0	1	100	85	U	D	None	None	None	Dir. Dump		
10	Jefferson Parish, La.	Marrero	1948	QD	New	90	B & C	1	Br.	Bu.	No	1	90	Batch	Circ.	1	1	0	1	80	70	U	D	-	-	None	Dir. Dump		
11	Pittsfield, Mass.		1948	QM	New	180	B & C	1	Br.	Bu.	Yes	2	90	Batch	Man.	2	2	0	1	165	140	-	D	-	-	BH	Dir. Dump	None	x
12	Providence, R.I.	Field Point	1948	QM	Addition	160	B & C	-	Br.	Bu.	No	1	160	Batch	Man.	1	0	0	1	150	147	Yes, I	None	-	-	E	Dir. Dump		x
13	West Bend, Wisc.		1948	QB	New	30	FD	-	-	-	Yes	1	30	Batch	Circ.	1	-	-	1	-	-	-	-	-	-	-	Dir. Dump		
14	Meadville, Penna.		1949	QB	New	80	FD	-	-	-	Yes	1	80	Batch	Circ.	1	-	-	1	-	-	U	D	-	-	-	Dir. Dump		
15	Mt. Kisco, N. Y.		1949	QD	New	40	FD	-	-	-	Yes	1	40	Batch	Man.	1	0	0	1	80	-	U	None	-	-	None	Dir. Dump		x
16	Mt. Vernon, N.Y.		1949	QB	New	600	FD	-	-	-	Yes	4	150	Batch	Circ.	2	-	-	2	-	-	U	-	-	-	-	Dir. Dump		
17	St. Louis, Mo.	South Side	1949 (D)	QD	New	400	B & C	2	Br.	Bu.	Yes	4	100	Batch	Rock	4	4	-	2	175	-	Yes	D	-	-	-	Dir. Dump		x
18	Alhambra, Calif.		1950	PD-2	New	150	FD	-	-	-	-	1	150	Batch	Circ.	1	1	-	1	-	125	U, I	-	-	-	-	Dir. Dump		
19	Ft. William, Ont.		1950	QB	New	144	FD	-	-	-	Yes	2	72	Batch	Circ.	1	0	0	1	125	-	U	None	None	None	None	Dir. Dump		
20	Gretna, La.		1950	QD	New	100	B & C	-	Br.	Bu.	No	2	50	Batch	Circ.	1	0	0	1	100	90	U	D	-	-	None	Dir. Dump		
21	Middletown, Conn.		1950	P & S	Addition	60	FD	-	-	-	Yes	1	60	Batch	Circ.	1	0	0	1	-	-	U	None	-	-	None	Manual		
22	Moncton, N.B.		1950	QB	New	96	FD	-	-	-	Yes	1	96	Batch	Circ.	1	0	0	1	125	140	U	None	None	None	None	Dir. Dump		
23	North York, Ont.		1950	QM	New	480	B & C	2	Br.	Bu.	Yes	4	120	Batch	Circ.	2	-	-	2	160	170	U	-	-	-	None	Dir. Dump	None	
24	Philadelphia, Penna.	Southeast	1950	QM	New	300	B & C	-	-	-	-	2	150	Batch	Circ.	-	-	-	-	-	-		-	-	-	-	-		
25	Port Arthur, Ont.		1950	QB	New	96	FD	-	-	-	Yes	1	96	Batch	Circ.	1	0	0	1	125	140	U	None	None	None	None	Dir. Dump		
26	Atlanta, Ga.	Mayson	1951	QD	Addition	350	B & C	-	Br.	Bu.	No	2	175	Contin.	Rot. Kiln	2	0	0	1	200	190	U, O, I	D	None	None	SO	Conveyor	Metal	x
27	Buffalo, N.Y.	West Side	1951 (D)	QD	New	400	B & C	2	Br.	Gr.	-	3	133	Batch	Circ.	3	1	-	1	185	-	Yes	D	-	-	-	Dir. Dump		
28	Calgary, Alta.		1951 (D)	QD	New	240	B & C	1	Br.	Bu.	Yes	2	120	Batch	Circ.	2	1	-	1	125	-	Yes	D	-	-	-	Dir. Dump		x
29	Lakewood, Ohio		1951	QD	New	150	FD	-	-	-	Yes	2	75	Batch	Man.	2	1	0	1	110	105±	Yes	D	None	None	None	Dir. Dump		
30	Los Angeles, Calif.	Gaffey St.	1951 (D)	QD	New	200	B & C	1	Br.	Bu.	No	2	100	Batch	Circ.	2	2	-	1	146	-	Yes	D	-	-	-	Dir. Dump		
31	Miami, Fla.		1951	QD	New	900	B & C	2	Br.	Bu.	Yes	6	150	Batch	Circ.	6	-	-	2	150	-		WB,S,SB	Settling	Sewer	Steam	Dir. Dump		x
32	Pomona, Calif.		1951	QM	New	225	FD	-	-	-	-	2	112.5	Batch	Circ.	2	-	-	1	90	-		-	-	-	-	Dir. Dump		x
33	Port Chester, N.Y.		1951	QD	New	120	B & C	1	Br.	Bu.	No	2	60	Batch	Circ.	2	1	0	1	120	-	U	D, F	None	None	BH,BHW, P	Dir. Dump		x
34	Windsor, Ont.		1951	QB	New	72	FD		-	-	Yes	1	72	Batch	Circ.	1	0	0	1	125	116	U	None	None	None	None	Dir. Dump		
35	Yonkers, N.Y.		1951	QD	New	450	B & C		Br.	Bu.	Yes	3	150	Batch	Circ.	3	1	-	2	185	160	Yes	D	-	-	None	Dir. Dump		
36	Bloomsburg, Pa.		1952	QD	New	60	FD		-	-	Yes	1	60	Batch	Circ.	1	-	-	1	78	75	Yes	-	-	-	SD	Dir. Dump		x
37	Brookline, Mass.		1952	QD	New	300	B & C		Br.	Bu.	Yes	2	150	Batch	Circ.	2	1	0	1	169	150	Yes	D	-	-	None	Dir. Dump		
38	Glendale, Calif.		1952	PD-3, A	New	90	B & C		Br.	Bu.	No	1	90	Batch	Circ.	-	-	-	-	-	-		-	-	-	-	Dir. Dump		
39	Hempstead, N.Y.	Merrick	1952	PD-4	New	700	B & C	2	Br.	Bu.	Yes	4	175	Batch	Circ.	2	0	0	2	Stub	-	Yes, I	C	-	-	E	Conveyor		
40	Lawrence, Mass.		1952	QD	New	300	B & C	1	Br.	Bu.	Yes	2	150	Batch	Circ.	2	1	0	1	167	150±	Yes	D	-	-	None	Dir. Dump		

Table A-1 (continued). INCINERATOR PLANT SUMMARY

Line	Location	Plant	Year built	Source of data	Status	Capacity, tons/24 hr	Refuse handling	Cranes		Buckets	Tipping floor enclosed	Furnaces				Separate combustion chamber	Spray or expansion chamber	Cooling chamber	Chimneys-height, ft			Mechanical draft	Fly ash removal	Water		Waste heat use	Residue handling	Salvage	Notes
								No.	Type			No.	Capacity, tons/24 hr	Feed	Stoker type				No.	Total	Above grates			Treatment	Disposal				
41	Kitchener, Ont.		1952	QB	New	216	FD	-	-	-	Yes	3	72	Batch	Circ.	1	0	0	1	130	120	U	None	None	None	None	Dir. Dump		
42	Regina, Sask.		1952 (D)	QD	New	240	B & C	1	Br.	Bu.	Yes	2	120	Batch	Circ.	1	1	0	1	150	-	Yes	D	-	-	-	Dir. Dump		
43	Santa Monica, Calif.		1952	PD-5	New	300	FD	-	-	-	Yes	4	75	Batch	Man.	4	-	Yes	1	129	-	U,O,I	-	-	-	-	Dir. Dump		
44	Waterbury, Conn.		1952	QD	New	300	B & C	1	Br.	Bu.	No	2	150	Batch	Circ.	2	1	No	1	120	100	U	-	-	-	BH,SD	Conveyor		
45	Edmonton, Alta.		1953 (D)	QD	New	360	B & C	1	Br.	Bu.	No	3	120	Batch	Circ.	3	0	-	1	150	-	Yes	-	-	-	-	Dir. Dump		
46	Harrison, N.Y.		1953	QD	New	150	FD	-	-	-	Yes	2	75	Batch	Circ.	1	0	0	1	100	85	U	F	-	-	None	Dir. Dump		
47	Milwaukee, Wisc.	Green Bay	1953	QM	New	300	B & C	1	Br.	Bu.	Yes	2	150	Batch	Circ.	2	0	0	1	175	-	U,O	SB	None	Sewer	BH,BHW	Dir. Dump		
48	New York City	Gansevoort	1953	QE	New	1,000	B & C	-	Br.	-	Yes	4	250	Contin.	Trav. 2	-	-	-	-	-	-	-	-	-	-	-	Conveyor		
49	Niagara Falls, N.Y.		1953 (D)	QD	New	240	B & C	1	Br.	Bu.	Yes	3	120	Batch	Circ.	2	1	-	1	175	-	Yes	D	-	-	-	Dir. Dump		
50	S.E. Oakland County (or Cty.), Mich.		1953 (D)	QD	New	450	B & C	2	Br.	Bu.	Yes	3	150	Batch	Circ.	3	1	-	1	175	-	Yes	D	-	-	-	Dir. Dump		
51	Westmount, Que.		1953	QM	New	150	FD	-	-	-	Yes	2	75	Batch	Circ.	1	-	0	1	150	-	U	SB	None	None	None	Dir. Dump		
52	Alexandria, Virginia		1954 (D)	QD	New	200	B & C	1	Br.	Bu.	Yes	2	100	Batch	Rock	2	1	-	1	175	-	Yes	D	-	-	-	Dir. Dump		x
53	Cincinnati, Ohio	West Fork	1954	QM	New	500	B & C	2	Br.	Bu.	Yes	4	125	Batch	Circ.	4	4	-	2	175	-	-	D	-	-	None	Dir. Dump	None	x
54	Ft. Lauderdale, Fla.		1954	QD, PD-6	New	250	B & C	1	Br.	Bu.	No	2	125	Batch	Circ.	2	2	-	1	100	-	-	-	-	-	-	Dir. Dump		
55	Hartford, Conn.		1954	QD	New	600	B & C	2	Br.	Bu.	Yes	4	150	Batch	Circ.	4	2	0	2	179.5	165±	U	D	-	-	None	Dir. Dump		
56	New York City	South Shore	1954	I, PD-7	New	1,000	B & C	2	Br.	Gr.	Yes	4	250	Contin.	Trav. 2	4	4	0	2	200	-	U,O	D,F	-	-	-	Conveyor		
57	Omaha, Neb.		1954	QD	New	375	B & C	1	Br.	Bu.	No	3	125	Batch	Rock	3	1	-	1	150	-	U,O	D	-	-	None	Dir. Dump		x
58	Philadelphia, Penna.	Harrowgate	1954	QM	Re-built	300	-	-	-	-	-	2	150	Batch	Circ.	-	-	-	-	-	-	-	-	-	-	-	-		
59	Providence, R.I.	Field Point	1954	QM	Re-built	160	-	-	-	-	No	1	160	Contin.	Trav. 2	1	0	-	-	-	-	Yes,I	-	-	-	E	Conveyor		x
60	Racine, Wisc.	Rubbish	1954	QM, MD	New	60	FD	-	-	-	Yes	1	50	Batch	Rock	2	1	0	1	[illegible]	[illegible]	U	D,WB,S SB	Settling	Sewer	None	Manual		
61	St. Louis Park, Minn.		1954	QD	New	150	FD	-	-	-	Yes	2	75	Batch	Rock	-	-	-	1	125	120±	Yes	-	-	-	-	Dir. Dump		x
62	South Euclid, Ohio		1954	QD	New	100	FD	-	-	-	Yes	2	50	Batch	Rock	2	0	0	1	80	75±	U	None	None	None	None	Dir. Dump		
63	Washington, D. C.	#3 Mt. Olivet	1954	QM	New	500	B & C	3	Br.	Bu.	Yes	4	125	Batch	Rock	4	4	0	2	165	145	U	D	-	-	None	Dir. Dump		
64	Youngstown, Ohio		1954	QM	Addition	100	FD	-	-	-	Yes	1	100	Batch	Man.	-	1	-	-	-	-	Yes,I	D,SC	-	Recirc.	None			
65	Abington, Penna.		1955	P & S, PD-8	New	200	B & C	1	Br.	Bu.	No	2	100	Batch	Rock	2	1	-	1	125	-	U,O	D	-	-	None	Dir. Dump		
66	Evanston, Ill.		1955 (D)	QD	New	180	B & C	1	Br.	Bu.	No	2	90	Batch	Rock	2	2	-	1	175	-	Yes	C	-	-	-	Dir. Dump		
67	*Framingham, Mass.*		1955	QM	New	200	B & C	1	Br.	Bu.	Yes	2	100	Contin.	Trav. 1	0	0	0	-	-	-	U,I	S,Sc	Settling	Run-off	None	Conveyor		x
68	Huntington, N.Y.		1955	PD-9	New	150	B & C	1	Br.	Bu.	No	1	150	Batch	Rock	1	1	-	1	125	-	Yes	-	-	-	-	Dir. Dump		
69	Merrill, Wisc.		1955	QM	New	35	FD	-	-	-	-	1	35	Batch	Rock	1	1	-	1	80	81	Yes	D	None	None	-	Dir. Dump		x
70	Milwaukee, Wisc.	Lincoln Ave.	1955	QM	New	300	B & C	1	Br.	Bu.	Yes	2	150	Batch	Rock	2	1	0	1	175	-	U,O	SB	Settling	Recirc.	BH	Dir. Dump		x
71	Philadelphia, Penna.	Bartram	1955	QM	Addition	250	-	-	-	-	-	2	125	Batch	Circ.	-	-	-	-	-	-	-	-	-	-	-	-		
72	Philadelphia, Penna.	Southeast	1955	QM	Addition	300	-	-	-	-	-	2	150	Batch	Circ.	-	-	-	-	-	-	-	-	-	-	-	-		
73	Port Arthur, Ont.		1955	QE	Addition	96	FD	-	-	-	-	1	95	Batch	Circ.	1	0	0	Existing		-	U	None	None	None	None	Dir. Dump		
74	Quebec, P.Q.		1955	QM	New	360	B & C	2	Br.	Bu.	Yes	3	120	Batch	Circ.	3	1	-	-	-	-	-	S	-	-	-	Dir. Dump	Metal	x
75	Rochester, N.Y.	West Side	1955	I, PD-10	New	450	B & C	1	Br.	Gr.	Yes	3	150	Batch	Circ.	3	1	0	1	165	-	-	WB,S, B,F	-	-	-	Dir. Dump		
76	Babylon, N.Y.		1956	PD-1	Re-built	390	B & C		Br.	Bu.	No	1 2	90 150	Batch Batch	Circ. Circ.	-	Yes		1 1	- -	- -		D			BHW	Conveyor		x
77	Baltimore, Md.	#4	1956	QD	New	800	B & C	3	Br.	Bu.	Yes	4	200	Batch	Rock	4	2	0	2	170.5	150	U,O	D	-	-	None	Dir. Dump	None	
78	Binghamton, N.Y.	Stow Flats	1956	PD-11, 14	New	300	B & C	1	Br.	Bu.	No	2	150	Batch	Circ.	2	1	-	1	145	-	U	D	-	-	-	Dir. Dump		
79	Chicago, Ill.	Medill	1956	PD-12	New	720	B & C	3	Br.	2 Bu., 1 Gr.	Yes	4	80	Batch	Rock	4	-	-	2	250	-	Yes	S	-	-	P	Dir. Dump		
80	East Hartford, Conn.		1956	PD-13	New	200	B & C	-	Br.	Bu.	No	2	100	Batch	Rock	2	1	-	1	100	-	J,O	D	-	-	-	Dir. Dump		

Table A-1 (continued). INCINERATOR PLANT SUMMARY

Line	Location	Plant	Year built	Source of data	Status	Capacity, tons/24 hr	Refuse handling	Cranes No.	Cranes Type	Buckets	Tipping floor enclosed	Furnaces No.	Furnaces Capacity, tons/24 hr	Furnaces Feed	Furnaces Stoker type	Separate combustion chamber	Spray or expansion chamber	Cooling chamber	Chimneys-height, ft. No.	Chimneys-height, ft. Total	Chimneys-height, ft. Above grates	Mechanical draft	Fly ash removal	Water Treatment	Water Disposal	Waste heat use	Residue handling	Salvage	Notes
81	Euclid, Ohio		1956	P & S,I	New	200	B & C	1	Br.	Bu.	Yes	2	100	Batch	Rock	2	2	0	2	125	-	U, O	WB	Lagoon	Sewer	None	Dir. Dump		
82	Forest Hill, Ont.		1956	QB	New	180	FD	-	-	-	Yes	2	90	Batch	Circ.	1	1	-	1	167	146	U	WB,S, SB	Settling	Storm Sewer	None	Dir. Dump		
83	Glendale, Calif.		1956	PD-3, MD	Addition	90		-				1	90	Ram	Rock			-	-	-		U, I	WB,S		-		Dir. Dump		x
84	Los Angeles, Calif.	Lacy St.	1956	QM	New	320	B & C	1	Br.	Gr.	No	2	160	Batch	Man.	2	2	2	1	170	170	O, I	D,WB, S,SB	Settling	Recirc.	None	Dir. Dump		
85	Montreal, Canada	Dickson St.	1956	QD	New	500	B & C	2	Br.	Bu.	Yes	4	125	Batch	Circ.	2	2		2	125	125	U	D,WB,S	Settling	Sewer	BH	Dir. Dump	None	
86	New Canaan, Conn.		1956	QD	Re-built	50	B & C	1	M	Bu.	No	1	50	Batch	Circ.	1	1	0	1	100	101	U	D	None	None	None	Dir. Dump	None	x
87	Oyster Bay, N.Y.	Bethpage	1956	QD	New	500	B & C	2	Br.	Bu.	No	4	125	Batch	Rock	4	2	-	2	125	-	U, I	WB,S	Settling	-	E,BH, BHW	Sluice		x
88	Philadelphia, Penna.	Northeast	1956	QM	New	600	B & C	2	Br.	Bu.	No	4	150	Batch	Circ.	2	2	-	2	166.5	148	U,I	D,WB,S,SB	Settling	-	-	Dir. Dump		
89	Poughkeepsie, N.Y.		1956	P & S,I	Re-built	200	B & C	1	M	Bu.	No	2	100	Batch	Circ.	1	1	-	1	100	-	U	D	None	None	None	Dir. Dump	None	
90	Rochester, N.Y.	East Side	1956	I, PD-10	New	600	B & C	2	Br.	Gr.	Yes	4	150	Batch	Circ.	4	2	0	2	204	-		WB,S SB,F	-	-	-	Dir. Dump		
9	Toronto, Canada	Commissioners St.	1956	QB	New	900	B & C	3	Br.	Bu.	Yes	6	150	Batch	Circ.	6	6		3	175	160	U	D				Dir. Dump		
92	West Hartford, Conn.		1956	QD	New	350	B & C	-	Br.	Bu.	Yes	2	125	Batch	Circ.	2	1	0	1	175	160±	U	D	None	None	BH	Dir. Dump		
93	White Plains, N Y.		1956	QD	New	400	B & C	1	Br.	Bu.	Yes	2	200	Batch	Rock	2	2	0	1	175	160±	U	WB,S,SB	Cyclone	-	None	Dir. Dump		
94	Coral Gables, Fla.		1957	PD-6	New	300	B & C	1	Br.	Bu.	No	2	150	Batch	Circ.	-	-	-	1	160	-		SB	-	-	-	-		
95	Jersey City, N.J.		1957	PD-15, I	New	600	B & C	2	Br.	1 Bu., 1 Gr.	Yes	4	150	Batch	Circ.	4	2	0	2	127	-	U	Sc	-	-	BH	Dir. Dump		
96	Lexington, Ky.		1957	QD	New	200	B & C	1	Br.	Bu.	Yes	2	100	Batch	Circ.	2	1	-	1	175	-	Yes	D	-	-	-	Dir Dump		x
97	Louisville, Ky.		1957	PD-16, 17, I	New	750	B & C	2	Br.	1 Bu., 1 Gr.	Yes	3	250	Contin.	Rot. Kiln	3	3	0	2	200	-	-	S	-	-	SD	Conveyor	Cans	x
98	New York City	73rd St.	1957	QD	Re-built	660	B & C	2	Br.	Gr.	Yes	3	220	Contin.	Trav. 2	0	0	3	1	154	214.5	U,O,I	C	-	-	BH,BHW	Conveyor		x
99	Parma, Ohio		1957	I	New	225	B & C	1	Br.	Bu.	Yes	2	112.5	Batch	Rock	2	0	0	-	114	125	U	-	-	-	None	Dir. Dump		x
100	Tonawanda, N.Y.		1957	QB	Re-built	80	FD	-	-	-	-	2	40	Batch	Rock	1	0	-	1	-	-	I	D	-	-	-	Dir. Dump		x
101	Bridgeport, Conn.	Bostwick Ave.	1958	QM	New	300	B & C	1	Br.	Bu.	No	2	100	Batch	Circ.	2	1	0	1	183	154	U,O	WB,S,SB	-	-	BH	Dir. Dump		x
102	Durham, N.C.		1958	PD-18	Addition	340	FD	-	-	-	No	2	170	Batch	Man.	2	-	-	1	115	-	U	-	-	-	-	-		x
103	Halifax, N.S.		1958	QD	New	400	B & C	1	Br.	Bu.	Yes	2	200	Contin.	Trav. 2	0	0	0	1	175	160±	U,O	D	-	-	None	Dir Dump		
104	Hollywood, Fla.		1958	PD-19	New	450	FD	-	-	-	Yes	2	225	Batch	Osc.	2	2	-	2	65	-	Yes	WB,S	-	-	-	Conveyor		
105	Indianapolis, Ind.		1958	PD-20	New	450	B & C	1	Br.	Bu.	-	3	150	Batch	Circ.	-	Yes	1	1	195	-	-	WB,SB	-	-	SD	Dir. Dump		x
106	Marblehead, Mass.		1958	QD	New	90	B & C	1	M	Gr.	No	1	90	Batch	Rock	1	1	-	1	85	85	U	S,SB	None	None	None	Dir. Dump		
107	Neenah-Menasha, Wisc.		1958	MD	New	300	-	-	-	-	-	2	150	Contin.	Trav.1	-	-	-	-	-	-	-	-	-	-	-	-		
108	New Orleans, La.	Florida Ave.	1958	QD	New	400	B & C	1	Br.	Gr.	No	2	200	Batch	Rock	1	1	-	-	150	130	U	D,S	-	Wasted	None	Dir. Dump		x
109	Racine, Wisc.	Rubbish	1958	QM,MD	Addition	60	FD	-	-	-	Yes	1	50	Batch	Rock	2	1	0	1	86	83	U	S,SB	Settling	Sewer	None	Manual		
110	Shorewood, Wisc.		1958	QM	New	60	FD	-	-	-	-	2	30	Batch	Rock	2	0	0	1	125	117	U,O	WB,SB	Settling	Sewer	None	Dir. Dump	None	
111	Stickney, Ill.	Private	1958	MD	New	500		-				2	250	Contin.	Rot. Kiln	.			-			-				Boilers			
112	Belmont, Mass.		1959	PD-21	New	150	B & C	1	Br.	Bu.	No	2	25	Batch	Circ.	2	-	2	1	-	-	I	C	-	-	-	Dir. Dump		
113	Boston, Mass.	South Bay	1959	QD	New	900	B & C	3	Br.	Bu.	Yes	6	150	Batch	Rock	6	3	6	3	175	160±	U,I	C	-	-	SO,SE	Dir. Dump		x
114	Chicago, Ill.	Calumet	1959	PD-22	New	1200	B & C	3	Br.	-	Yes	6	200	Batch	Rock	Yes	Yes	-	3	250	-	-	WB,S,SB	Clarifiers	Recirc.	BH	Dir. Dump		
115	New Albany, Ind.		1959	QD	New	160	B & C	1	Br.	Bu.	No	2	80	Contin.	Trav. 1	2	0	0	1	150	94.5	U,O	D	None	None	SD	Dir. Dump		
116	New York City	Betts Ave	1959	MD	Re-built	1000	B & C	-	Br.	-	Yes	4	250	Contin.	Trav. 2	-	-	-	-	-	-	-	-	-	-	-	Conveyor		
117	New York City	Greenpoint	1959	QD	New	1000	B & C	2	Br.	Gr.	Yes	4	250	Contin.	Trav. 2	0	4	0	2	200	177	U,O	S	-	-	BH,BHW	Conveyor		
118	Rye, N.Y.		1959	QM, PD-23	New	150	B & C	1	M	Gr.	No	2	75	Batch	Circ.	1	0	0	1	100	100	U	WB	Lagoon	L.I. Sound	None	Conveyor		
119	Scarsdale, N.Y.		1959	QM	New	150	B & C	1	M	Bu.	No	2	75	Batch	Circ.	1	1	-	1	119	110.5	U	WB	Settling	-	-	Conveyor		
120	Stamford, Conn.		1959	QM	Addition	125	B & C	-	-	-	Yes	1	125	Batch	Rock	1	1	-	1	135	125	U	WB,S	-	-	BH,SD	Dir. Dump		

Table A-1 (continued). INCINERATOR PLANT SUMMARY

Line	Location	Plant	Year built	Source of data	Status	Capacity, tons/24 hr	Refuse handling	Cranes No.	Cranes Type	Buckets	Tipping floor enclosed	Furnaces No.	Furnaces Capacity, tons/24 hr	Furnaces Feed	Furnaces Stoker type	Separate combustion chamber	Spray or expansion chamber	Cooling chamber	Chimneys-height, ft No.	Chimneys-height, ft Total	Chimneys-height, ft Above grates	Mechanical draft	Fly ash removal	Water Treatment	Water Disposal	Waste heat use	Residue handling	Salvage	Notes
121	Wauwatosa, Wisc.		1959 (D)	QD	New	165	B & C	1	Br.	Gr.	Yes	2	82.5	Batch	Rock	2	1	-	1	175	-	Yes	WB,SB	-	-	-	Dir. Dump		
122	Wellesley, Mass.		1959	QD	New	150	B & C	-	Br.	Bu.	No	2	75	Batch	Rock	2	-	-	1	146	131	Yes	None	None	None	None	Dir. Dump		
123	Whitemarsh, Penna.		1959	PD-24, 1	New	300	OSC	-	-	-	Yes	1	300	Batch	Recip.	0	1	0	2	Stub	-	U,O,I	S,Sc	-	Recirc.	None	Conveyor		x
124	Winnipeg, Man.		1959 (D)	QD	Addition	200	B & C	-	Br.	-	Yes	1	200	Batch	Rock	1	1	-	1	175	-	Yes	D	-	-	-	Dir. Dump		
125	Bradford, Penna.		1960	QD	New	200	B & C	1	Br.	Bu.	Yes	2	100	Batch	Rock	2	1	-	1	150	130	U,O	D	-	-	SF	Dir. Dump		
126	Cleveland, Ohio	Ridge Road	1960	I	New	500	B & C	2	Br.	Bu.	Yes	4	125	Batch	Rock	4	4	-	4	-	-	Yes,I	SB	Settling	Recirc.	-	Dir. Dump		
127	Delaware, County, Pa.	#1	1960	PD-25	New	500	B & C	2	Br.	Gr.	Yes	2	250	Contin.	Trav. 2	0	2	-	1	160	-	U,O	D,F	-	-	None	Conveyor		
128	Miami, Fla.	Coconut Grove	1960	QD	New	300	B & C	1	Br.	Bu.	Yes	1	300	Contin.	Rot. Kiln	1	1	1	1	200	-	U,O	WB,S, SB	Lagoon	Recirc.	-	Conveyor		x
129	Philadelphia, Pa.	Northwest	1960	QM	New	600	B & C	2	Br.	1 Bu., 1 Gr.	No	2	300	Contin.	Trav. 2	-	-	2	2	40	98	U,O,I	S,C	-		-	Dir. Dump		
130	Somerville, Mass.		1960	PD-26	New	450	B & C	1	Br.	Gr.	Yes	3	150	Batch	Circ.	3	1	-	1	175	-	-	D,Sc	-	-	-	Dir. Dump		
131	Winchester, Ky.		1960	QD	New	100	FD	-	-	-	Yes	2	50	Batch	Recip.	2	2	2	1	5	-	I	Sc	-	-	None	Conveyor		
132	Woonsocket, R.I.		1960	QD	New	160	B & C	1	Br.	Bu.	No	2	80	Batch	Circ.	2	1	0	1	150	138±	U	D	None	None	None	Dir. Dump		
133	Dedham, Mass.		1961	QD	New	100	B & C	1	M	Bu.	No	2	50	Batch	Rock	2	1	-	1	125	109	U,O	WB,S,SB	-	Wasted	None	Dir. Dump		
134	Delaware County, Pa.	#2	1961	PD-25	New	500	B & C	2	Br.	Gr.	Yes	2	250	Contin.	Trav. 2	0	2	-	1	155	-	-	WB	Lagoon	Creek	None	Conveyor		
135	Honolulu, Hawaii	Kewalo	1961	QE	New	220	-	-	-	-	-	2	110	Batch	Recip.	-	-	-	-	-	-	-	-	-	-	-	-		
136	New York City	S.W. Brooklyn	1961	QD	New	1000	B & C	2	Br.	Gr.	Yes	4	250	Contin.	Trav. 2	0	4	0	2	200	127	U,O	S	-	-	BH,BHW	Conveyor		
137	Norwood, Ohio		1961	QD	New	150	B & C	1	Br.	Bu.	Yes	2	75	Batch	Recip.	2	1	1	1	80	60	U,O,I	S	Settling	Sewer	None	Dir. Dump	None	
138	Portsmouth, Va.		1961 (D)	QD	New	350	B & C	1	Br.	Gr.	No	2	175	Batch	Rock	2	2	-	1	175	-	Yes	WB,SB	-	-	-	Conveyor		
139	Sharonville, Ohio	Private	1961	QD	New	225	B & C	1	Br.	Bu.	No	1	225	Contin.	Trav. 2	0	1	1	1	40	35	Yes,I	WB,S,SB	-	-	None	Conveyor	None	
140	Washington, D.C.	Ft. Totten	1961	QM	New	500	B & C	3	Br.	Bu.	Yes	4	125	Batch	Rock	4	4	0	2	165	145	U	D	-	-	None	Dir. Dump		
141	Winchester, Mass.		1961	QD	New	100	B & C	1	Br.	Bu.	No	2	50	Batch	Rock	2	1	1	1	60	44	U,O,I	WB,S,C	-	Recirc.	None	Dir. Dump		x
142	Darien, Conn.		1962	QD	Addition	70	B & C	1	M	Bu.	No	1	70	Batch	Rock	1	1	0	Exist.		-	U	WB,S,SB	Settling	Stream	None	Conveyor		x
143	Delaware County, Pa.	#3	1962	PD-25, 27	New	500	B & C	2	Br.	Gr.	Yes	2	250	Contin.	Trav. 2	0	2	-	1	250	-	U,O	WB,SB	Settling	Recirc.	None	Conveyor		
144	Eastchester, N.Y.		1962	QD	New	200	B & C	1	Br.	Bu.	Yes	2	100	Batch	Rock	2	1	-	1	140	-	U	WB,S	-	-	BH,BHW	Dir. Dump		x
145	East Kildonan, Man.		1962	MD	New	100	-	-	-	-	-	1	100	Batch	Recip.	-	-	-	-	-	-	-	-	-	-	-	-		
146	Honolulu, Hawaii	Kapalama	1962	QE	New	220	-	-	-	-	-	2	110	Batch	Recip.	-	-	-	-	-	-	-	-	-	-	-	-		
147	Islip, N.Y.	Hauppauge	1962	PD-28	New	300	B & C	1	Br.	Gr.	No	2	150	Contin.	Trav. 1	-	0	2	2	-	-	U,O,I	-	-	-	-	Dir. Dump		
148	New Orleans, La.	7th St.	1962	QD	New	400	B & C	2	Br.	Gr.	No	2	200	Batch	Rock	1	1	-	2	125	106	U	D,S	-	Sewer	None	Dir. Dump		x
149	New York City	Hamilton Ave.	1962	QD	New	1000	B & C	2	Br.	-	Yes	4	250	Contin.	Trav. 2	0	4	0	2	-	-	U,O	S	-	-	BH,BHW	Conveyor		
150	Norwalk, Conn.		1962	QD	New	360	B & C	1	Br.	Gr.	No	2	180	Contin.	Trav. 1	0	2	0	1	140	137	U,O	WB,S,SB	Settling	Recirc.	-	Conveyor		
151	Valley Stream, N.Y.		1962	MD, I	New	200	B & C	1	Br.	Gr.	No	2	100	Contin.	Trav. 1	2	1	-	1	130	-	Yes	WB,SB	-	-	-	Dir. Dump		
152	Atlanta, Ga.	Hartsfield	1963	QD	New	500	B & C	2	Br.	Bu.	No	2	250	Contin.	Rot. Kiln	2	2	-	1	200	190	U,O	WB,S,SB	-	-	None	Conveyor	Metals	x
153	Chicago, Ill.	Southwest	1963	PD-29	New	1200	B & C	3	Br.	Gr.	Yes	4	300	Contin.	Rot. Kiln	-	-	-	2	250		U,I	WB,S,SB	Settling	Recirc.	BH,SO	Conveyor	Metals	
154	Garden City, N.Y.		1963	QD	New	175	B & C	1	Br.	Bu.	No	2	87.5	Contin.	Recip.	2	1	0	1	140	150	U,O	WB,S	-	-	BH,BHW	Conveyor		
155	Greenwich, Conn.		1963	QD	Addition	250	B & C	1	Br.	Bu.	No	1	250	Contin.	Rock C	1	1	0	1	130	137	U,O	WB,S	-	Recirc.	BH,BHW	Conveyor	None	x
156	Monroe, Wisc.		1963	QM,MD	Addition	60	FD	-	-	-	-	2	30	Batch	Man.	2	2	-	2	55	-	-	-	-	-	-	Manual		
157	New Haven, Conn.		1963	QD	New	720	B & C	2	Br.	Gr.	No	3	240	Contin.	Trav. 2	0	3	0	1	153	150	U,O,S	WB,S,SB	Settling	Recirc.	None	Conveyor	None	
158	New Orleans, La.	Algiers	1963	QD	New	200	B & C	1	Br.	Gr.	No	1	200	Contin.	Trav. 2	0	1	1	1	40	67	U,O,S,I	C	-	-	None	Conveyor		x
159	Rocky River, Ohio		1963	QE	Addition	60	FD	-	-	-	Yes	1	60	Batch	Recip.	-	-	-	-	-	-	-	-	-	-	None	Dir. Dump		
160	S.E. Oakland County (or Cty.), Mich.		1963	QD	Re-built	600	-	-	-	-	-	2	300	Contin.	Trav. 2	0	2	0	2	175	160±	U,O	WB,S,SB	Cyclones	-	BH	Dir. Dump		
161	Stratford, Conn.		1963	QD	New	240	B & C	1	Br.	Gr.	No	2	120	Contin.	Trav. 1	0	2	-	1	143	140	U,O,S	WB,S,SB	Settling	Recirc.	None	Conveyor	None	
162	Beacon, N.Y.		1964	QD	New	100	B & C	1	Br.	Gr.	No	2	50	Batch	Rock	2	2	0	1	150	134	U,O	WB,S,SB	Lagoon	-	None	Dir. Dump	None	
163	Bloomington, Ind.		1964	QD	New	100	B & C	1	Br.	Gr.	Yes	1	100	Batch	Recip.	1	1	1	1	48	46	U,I	WB,S,SB	-	-	-	Conveyor		

Table A-1 (continued). INCINERATOR PLANT SUMMARY

Line	Location	Plant	Year built	Source of data	Status	Capacity, tons/24 hr	Refuse handling	Cranes No.	Cranes Type	Buckets	Tipping floor enclosed	Furnaces No.	Furnaces Capacity, tons/24 hr	Furnaces Feed	Furnaces Stoker type	Separate combustion chamber	Spray or expansion chamber	Cooling chamber	Chimneys-height, ft. No.	Chimneys Total	Chimneys Above grates	Mechanical draft	Fly ash removal	Water Treatment	Water Disposal	Waste heat use	Residue handling	Salvage	Notes
164	Broward County, Fla.	#1	1964	QD	New	300	B & C	1	Br	Gr.	Yes	2	150	Contin	Recip.	2	2		2	100	90	U,O,I	WB,S,SB, Sc	See Note	Recirc.	None	Conveyor	Metal	x
165	Broward County, Fla	#2	1964	QD	New	300	B & C	1	Br.	Gr.	Yes	2	150	Contin.	Recip.	2	2		2	100	90	U,O,I	WB,S,SB, Sc	See Note	Recirc	None	Conveyor	Metal	x
166	Canajoharie, N.Y.		1964	QB	New	50	FD	-	-	-	Yes	1	50	Batch	Circ.	1	1	-	1	46	82	U	WB,S,SB	None	None	None	Dir. Dump		x
167	Charleston, W. Va.		1964	QD	New	300	B & C	1	Br	Bu	Yes	2	150	Batch	Recip.	2	2	-	1	35	50	U,O,I	WB,S,SB, Sc	Fly Ash Rem.	River	None	Dir. Dump		
168	Clearwater, Fla.		1964	QD	New	300	B & C	1	Br.	Gr.	Yes	2	150	Contin.	Recip.	1	1	-	1	62	67	U,O,I	WB,S,SB	-	S.T.P.	-	Conveyor		x
169	Dearborn Heights, Mich	Central Wayne Cty. Sanitation Auth.	1964	QD	New	500	B & C	2	Br.	1 Bu., 1 Gr.	Yes	2	250	Contin.	Recip.	2	-	-	2	120	100	U,O,I	WB,S,SB	None	Sewer	None	Dir. Dump		x
170	DeKalb County, Ga.		1964	QD	New	600	B & C	2	Br.	Bu.	No	2	300	Contin.	Rot. Kiln	2		-	1	200	189	U,O	WB,S,SB	-		None	Conveyor		x
171	Ewing Township, Pa.		1964	QD	New	240	B & C	1	Br.	Gr.	No	1	240	Contin.	Trav. 1	0	1	-	1	175	158	U,O	D	-	-	None	Dir. Dump		
172	Frankfort, Ky.		1964	QD	New	150	FD	-	-	-	Yes	2	75	Batch	Recip.	2	2	2	1	5	-	I	WB,S,SB, Sc	-	-	None	Conveyor		
173	Freeport, N.Y.		1964	QD	Re-built	150	B & C	1	M	Gr.	No	2	75	Batch	Rock C	2	0	0	1	90	86	U,O	WB	-	-	None	Conveyor		x
174	Jefferson Parish, La.	East Bank	1964	QD	New	400	B & C	2	Br.	Gr	No	2	200	Contin.	Trav. 2	0	2	2	2	15	72	U,O,S,I	C	-	-	None	Conveyor		x
175	Lowell, Mass.		1964	MD	New	400	-	-	-	-	-	2	200	Contin.	Trav. 2	-	-	-	-	-	-	-	-	-	-	-	-		
176	Nekoosa, Wisc.		1964	QB	New	60	FD	-	-	-	-	1	60	Batch	Recip.	3	1	0	1	85	82	U	WB,S	-	-	None	Conveyor		
177	Orlando, Fla.		1964	QB	New	250	B & C	1	Br.	Bu.	No	1	250	Batch	Osc.	1	1	0	1	70	70	U,O	WB,S,SB	Settling	Recirc	None	Conveyor		
178	Pawtucket, R.I.		1964	MD	New	400	-	-	-	-	-	2	200	Contin.	Trav. 2	-	-	-	-	-	-	-	-	-	-	-	-		
179	Roanoke, Va.		1964	QB	Re-built	200	B & C	1	M	Bu.	Yes	2	100	Batch	Recip.	2	-	-	1	-	-	U,O	D	-	-	-	Dir. Dump		
180	Cincinnati, Ohio	Center Hill	1965	QD	New	500	B & C	2	Br.	1 Bu., 1 Gr	Yes	2	250	Contin.	Trav. 2	0	2	2	2	200	196	U,O	SB	Settling	Recirc.	None	Conveyor		
181	Hempstead, N.Y.	Oceanside	1965	PD-30	New	750	B & C	2	Br.	Bu.	Yes	1 2	150 300	Contin. Contin.	Rock C Rock C	1 0	1 -	- -	1 2	- -	- -	U,O,I U,O,I	WB,SB C	- -	- -	None E,Des	Dir. Dump Conveyor	None	x x
182	Huntington, N.Y.	#3	1965	QE	New	150	B & C	1	Br.	-	Yes	1	150	Contin.	Rock C	1	2	0	1	125	105	U,O	D,WB	Lagoon	-	None	Dir. Dump		
183	Louisville, Ky.		1965	QM	Addition	250	B & C	-	-	-	Yes	1	250	Contin.	Rot. Kiln	1	1	0	Exist.		-	Yes	WB,S,SB	-	-	SD	Conveyor	Cans	
184	Montgomery Cty., Md.		1965	QD	New	1050	B & C	3	Br.	2 Bu., 1 Gr.	Yes	3	350	Contin.	Trav. 2	3	3	3	-	Stub	-	U,O,I	C	Settling	Recirc.	BH	Conveyor		x
185	Newburgh, N.Y.		1965	QD	New	240	B & C	1	Br.	Gr.	No	2	120	Contin.	Rock C	0	2	0	1	143	140	U,O,S	WB,S,SB	Settling	River	None	Conveyor	None	
186	Oyster Bay, N.Y.		1965	QD	New	500	B & C	2	Br.	Gr.	No	2	250	Contin.	Rock C	2	2	0	2	145	125	U,O	WB,S,SB	Strainers	-	None	Dir. Dump		x
187	Port Washington, Wisc.		1965	QB	New	75	FD	-	-	-	Yes	1	75	Batch	Recip.	2	0	Yes	1	55	39	U,I	WB,S,SB	-	-	None	Dir. Dump	None	x
188	Ramapo, N.Y.		1965	QD	Addition	200	B & C	1	Br.	Bu.	Yes	1	200	Batch	Rock	1	1	0	1	165	150	Yes	WB,S,SB	Cyclone	-	None	Dir. Dump		x
189	Sheboygan, Wisc.		1965	QD	New	240	B & C	1	Br.	Bu.	-	2	120	Contin.	Rock C	1	3	-	1	175	168	U,O	WB,S	Lagoon	-	None	Dir. Dump	None	x
190	Weymouth, Mass.		1965	QD	New	300	B & C	1	Br.	Bu.	Yes	2	150	Batch	Circ.	2	1	0	1	166	147.5	U	WB,S,SB	Cyclone	-	BH	Dir. Dump		
191	Alexandria, Va.	#2	U.C.	QD	New	300	B & C	1	Br.	Gr.	Yes	2	150	Contin.	Rock C	2	1	-	1	200	185±	U,O	SB	-	-	-	Conveyor		
192	Babylon, N.Y.	#2	U.C.	QE	New	400	B & C	2	Br.	Gr.	No	2	200	Contin.	Rock C	2	1	-	1	-	-	U,O	S	-	-	-	Dir. Dump		
193	Ft. Lauderdale, Fla.		U.C.	QD	New	450	B & C	1	Br.	Gr.	No	2	225	Contin.	Recip.	0	-	-	2	100	85	U,O,I	Sc	Lagoon	-	None	Conveyor		x
194	Houston, Texas	Holmes Rd.	U.C.	QD	New	800	B & C	2	Br.	Gr	No	2	400	Contin.	Trav. 3	2	See Note	-	2	150	145	U,O,I	WB,S,SC	Settling	Recirc	See Note	Conveyor		x
195	Lexington, Ky.		U.C.	QD	Addition	150	-	-	-	-	Yes	1	150	Batch	Rock	1	-	-	Exist.		-	U,O	D	-	-	-	Dir. Dump		x
196	Montreal, Quebec	Descarrieres	U.C.	QD	New	1200	B & C	2	Br	Bu.	Yes	4	300	Contin	Recip.	0	0	0	1	250	225	U,O,I	E	-	-	See Note	Conveyor		x
197	New Orleans, La.	C	U.C.	QD	Re-built	400	B & C	2	Br.	Gr.	No	2	200	Contin.	Trav. 2	0	1	-	1	55	52	U,O,I	S,C	-	Wasted	-	Conveyor		
198	Newton, Mass.		U.C.	QD	New	500	B & C	2	Br.	Bu.	Yes	2	250	Contin.	Trav. 3	0	2	0	1	175	166	U,O	WB,SB	Cyclone	Recirc.	None	Conveyor	None	
199'	Norfolk, Va.	Navy Yard	U.C.	QD	New	360	B & C	1	Br.	Bu.	Yes	2	180	Contin.	Recip.	0	0	0	2	20	-	U,O,I	C	None	-	SO	Conveyor		x
200	North Hempstead, N.Y.		U.C.	QE	New	600	B & C	2	Br.	-	Yes	2 1	200 200	Contin. Contin.	Rock C Trav. 2	2 1	- -	2 1	1 -	- -	- -	I I	C C	Lagoon Lagoon	Recirc. Recirc.	- -	Dir. Dump Dir. Dump		x x
201	Philadelphia, Pa.	East Central	U.C.	QM	New	600	B & C	2	Br.	1 Bu., 1 Gr.		2	300	Contin.	Trav. 2	-	-	2	-	-	-	I		-	-	-	Dir. Dump		
202	St. Petersburg, Fla.		U.C.	QB	New	500	B & C	1	Br.	Gr.	Yes	2	250	Batch	Rock C	1	3	1	-	-	-	U,O,I	WB,S,SB	-	Sewer	None	Conveyor		
203	West Haven, Conn.		U.C.	QE	New	300	B & C	-	-	-	-	2	150	Contin.	Rock C	2	0	-	2	Stub	-	U,O,I	WB,S,C	-	-	-	Conveyor		
204	Whitemarsh, Pa.		U.C.	QD	Re-built	300	B & C	1	Br	Bu.	No	1	300	Contin.	Rock C	0	0	0	-	-	-	U,O,I	Sc	Cyclone	-	None	Conveyor		
205	New Orleans, La.	E. New Orleans	U.C.	QD	New	400	B & C	1 or 2	Br.	Gr	No	2	200	Contin.	Rock or Recip.	2	2	2	2	25	60	U,O,S,I	D,C	Settling	-	-	Conveyor		x

Table A-2. ADDITIONAL INCINERATOR INSTALLATIONS, 1945 TO DATE[a]

New and Rebuilt Plants and Plant Additions

City	Plant	Year	Capacity, tons/day	Number of furnaces	Type stoker
Amarillo, Tex.		U.C.	250	2	Reciprocating
Ambridge, Pa.		1960	150	2	Rocking
Amsterdam, N.Y.		1946	120		Manual
Arlington Co., Va.		1949	300		Circular
Arlington Co.		1955	300		Circular
Bedford, O.	Garbage	1946	60		Circular
Bedford, O.	Rubbish	1954			
Beverly Hills, Calif.		1946	300		Circular
Berea, O.			50	1	Manual
Bessemer, Ala.		1946	60		Manual
Cheektowaga, N.Y.		1946	150		Circular
Cheviot, O.		1953	60		
Collingswood, N.J.		1949	60		Circular
Columbus, O.		1948	150		Circular
Corning, N.Y.		1947	80		Circular
DePere, Wisc.		1961	75	1	Rocking
Derby, Conn.					
Detroit, Mich.	24 St.	1955-56	510	2	Rocking
Detroit	24 ST	1963	235	1	Rocking
Detroit	Northwest	1956-57	850	2	Rocking
Detroit	St. Jean	1957	300	1	Rocking
Detroit	Central	'58, '60, '61	1,200	4	Rocking
East Cleveland, O.		1946	100		Circular
Ecorse, Mich.		1954	90	1	Circular
Erie, Pa.		1953	200		Circular
Ft. Worth, Tex.		1951	245	2	Circular
Ft. Worth		1955	190	2	Circular
Ft. Worth	Berry St.	1958	125	2	Rocking
Fall River, Mass.		U.C.	600	2	
Gloucester City, N.J.		1950	60		Circular
Green Bay, Wisc.		1963	60		
Huntington, N.Y.		1958	150	1	Rocking
Jacksonville, Fla.	5 St.	1947	350		Circular
Jacksonville	Riverside	1950	300		Circular
Kenosha, Wisc.		1952	120		
Kowaskum, Wisc.		1954	24		Circular
Long Beach, N.Y.		1951	200		Circular
Lima, O.		1953	200		
Lachine, Que.			150	2	Reciprocating
Lexington, Va.		1945	30		Manual
Maple Heights, O.		1955	150	2	Rocking
Mimico, Ont.			150	2	Reciprocating

Table A-2 (continued). ADDITIONAL INCINERATOR INSTALLATIONS, 1945 TO DATE[a]

City	Plant	Year	Capacity, tons/day	Number of furnaces	Type stoker
Morgan City, La.		1950	30		Manual
Melrose Park, Ill.	VanDerMol		400	2	Impact
North Tonawanda, N.Y.		1958	100		Reciprocating
North Hempstead, N.Y.		1952	200	2	Circular
New Rochelle, N.Y.		1959	150	1	Rocking
New Milford, Conn.					
North York, Ont.		U.C.	450	3	Circular
Newton, Mass.		1954	240	2	Rocking
Oshkosh, Wisc.			36	1	Manual
Providence, R.I.		1949	160		
Pennsaucken, N.J.		1952	60		Circular
Princeton, N.J.		1954	100		
Paris, Ky.		U.C.	100	2	Reciprocating
Philadelphia, Pa.	Bartram	1950	200		Circular
Red Lion Borough, Pa.		1954	60	1	Circular
River Rouge, Mich.		1961	60	1	Rocking
Regina, Sask.		1961	150	1	Rocking
Rocky River, O.		1952	50		
St. Louis, Mo.	North Side	1956	400	4	Rocking
Salisbury, Md.		1949	125		Circular
Sidney, O.		1946	50	1	Circular
Staunton, Va.		1948	60	1	Circular
Skokie, Ill.			150	2	Impact
Sharonville, O.	Clark's	U.C.	150	2	Reciprocating
Shelton, Conn.					
Tonawanda, N.Y.		1944	100		Circular
Tonawanda, N.Y.	Town	1948	90	1	Circular
Tonawanda	Town	1950	90	1	Circular
Troy, N.Y.		1947	250		Circular
Trenton, Mich.		1963	100		Reciprocating
Troy, O.					
Tampa, Fla.		U.C.	1,200	4	Rotary kiln
Woodbridge, N.J.		1954	300		
Worcester, Mass.		1953	450		Circular
Watertown, Mass.		1958	250		Circular
West Seneca, N.Y.		1949	60	1	Circular
Warren, O.		1949	195		
Wash. Sub. San. Dist., Md.		1946	150		Circular
Wash. Sub. San. Dist.		1950	75		Circular
West Allis, Wisc.		1955	200	2	Rocking
Waltham, Mass.		1959	150	2	Rocking
Woodville, O.			12	1	Manual

[a]The above data are largely from manufacturers' installation lists. The years shown are, in most cases, the year of equipment order, usually one to two years prior to completion of construction. All the above are believed to be batch feed except Amarillo (ram feed), Fall River (continuous), and Tampa (continuous).

LEGEND AND NOTES

Year Built – Reported year of completion, except (D) indicates reported year of design and U.D. indicates under construction, under contract, or in bidding stage as of November, 1965.

Source of Data

A	*Proc. ASCE,* Vol. 80, Separate No. 497, Sept. 195-.
I	Plant inspection and/or interview with operating personnel or municipal officials.
MD	Equipment manufacturer's data sheets.
P&S	Examination of plans and specifications.
QB	Questionnaire completed by incinerator builder.
QD	Questionnaire completed by designer including municipal officials where plant was designed by municipal personnel.
QM	Questionnaire completed by municipal personnel other than as noted for QD.
PD–1	"433% Larger," *The American City,* Feb. 1956.
PD–2	L. C. Larson, "Mechanically Stoked Incinerator Alhambra's Waste," *Public Works,* Jan. 1950.
PD–3	"New Incinerator Promises Less Smog" Engineer News-Record, Oct. 11, 1956.
PD–4	"The Incinerator Has to be Big and It has to be Tidy", *The American City,* July 1953.
PD–5	M. M. King. "A Double Grate Incinerator," *The American City,* Nov. 1952.
PD–6	W. H. Sleeger, "Three Florida Incinerators," *The American City,* July 1957.
PD–7	Tour information sheet prepared by New York City Department of Sanitation.
PD–8	C. F. Hettenbach, "An Extra Feature Incinerator," *The American City,* July 1957.
PD–9	G. H. Scudder, "The Town of Huntington Looks Ahead–With Incineration," *The American City,* April 1956.
PD–10	Lewis & Nussbaumer, "Two New Incinerators," *The American City,* Sept. 1956.
PD–11	Leonard S. Wegman, "Binghamton's Incinerator After One Year," *Civil Engineering,* June 1958.
PD–12	P. Gerhardt, "Chicago Completes First of Four Incinerators," *The American City,* June 1958.
PD–13	"Incinerator Near Residential Area Is Nuisance-Free," *Public Works,* June 1958.
PD–14	R. F. Sternitzke, "Municipal Incinerator Trends," *Public Works,* Sept. 1958.
PD–15	F. J. Lynch, "Jersey City Solves Its Refuse Disposal Problem," *The American City,* Sept. 1959.
PD–16	J. W. Leake, "Louisville Incinerator Operates on Production Line Basis," *The American City,* Nov. 1957.

PD–17 H. J. Cates, "Operation of Louisville's New Incinerator," *Public Works*, April 1958.

PD–18 C. F. Wheeler, "Direct Charge Incinerator Can Do A Good Job," *The American City*, May 1959.

PD–19 J. W. Watson, "A Custom Designed Incinerator," *The American City*, Feb. 1959; and J. W. Watson, "New Incinerator Designed to Reduce Fly Ash Emission," *Public Works*, April 1958.

PD–20 D. O. Bender, "We Incinerate Our Refuse Now," *The American City*, April 1958.

PD–21 J. L. Hayden, "Belmont, Mass. Incinerator Gives Complete Fly Ash Control," *The American City*, Jan. 1960; and J. L. Hayden, "New Incinerator Gives Complete Fly Ash Control," *Public Works*, Oct. 1959.

PD–22 "Calumet Incinerator–Chicago's Second, Nation's Largest," *The American City*, Feb. 1960.

PD–23 Vincent Baum, "Something Different in Incinerator Design," *The American City*, Nov. 1960.

PD–24 I. M. Chace, Jr., "A New Type of Municipal Incinerator," *The American City*, Nov. 1959; and "Whitemarsh," Publication of Dravo Corp.

PD–25 R. I. Mitchell, "Penna. County Selects Incineration Over Landfill Operation," *Refuse Removal Journal*, Aug. 1963; and E. B. Fox, Jr., "49 Municipalities Join in County-Wide Incineration Plan," *Public Works*, 1963.

PD–26 "Sumerville Builds An Incinerator," *The American City*, May 1960.

PD–27 "Tour Information," prepared by Delaware County Disposal Department.

PD–28 Gordon Gewecke, "Built To Fit The Site," *The American City*, June 1963.

PD–29 M. A. Noel, "Southwest Incinerator," National Incinerator Conference, May 1964; and Paul Gerhardt, Jr., "Incinerator to Utilize Waste Heat for Steam Generation," *Public Works*, May 1963.

PD–30 C. R. Velzy and C. O. Velzy, "Unique Incinerator Develops Power & Provides Salt Water Conversion," *Public Works*, April 1964; C. R. Velzy, "An Incinerator With Power and Other Unusual Features," ASME Winter Annual Meeting 1964, Paper No. 64-WA/PID-2; "Hempstead-Oceanside Refuse Disposal Plant," Printed description of ASME tour, Dec. 1, 1964.

Refuse Handling

B&C Bin and crane

FD Floor Dump

Osc Direct dump to oscillating conveyor

Cranes

Br Bridge crane

M Monorail Hoist

Buckets

Bu Clamshell bucket

Gr Grapple

Stokers

Circ.	Circular, mechanically stoked
Man.	Manually stoked
Osc.	Oscillating grate
Recip.	Reciprocating grate
Rock	Rocking grate, constant flow type
Rot. Kiln	Rotary kiln
Trav. 1	*Single travelling grate*
Trav. 2	Double travelling grate
Trav. 3	Triple travelling grate

Mechanical Draft

Yes	Forced draft reported, but distribution not indicated
U	Forced underfire. Includes cone cooling air for circular furnaces.
O	Forced overfire
S	Forced side fire
I	Induced draft

Flyash Removal

C	Cyclones
D	Dry expansion chamber
E	Electrostatic precipitators
F	Flyash screen
S	Water sprays
SB	Spray or wet baffles
Sc	Scrubber
ST	Spray towers
WB	Water bottoms or ponds in chambers

Water Treatment and Disposal

Recirc.	Recirculated
S.T.P.	Discharged to nearby water pollution control plant

Waste Heat Use

BH	Building heat
BHW	Building hot water
Des	Steam used in desalination units
E	Generating electricity
P	Preheating combustion air
SD	Sewage sludge drying
SE	Steam for equipment drives

NOTES

Line	Plant	
5	Liberty	Nye odorless incinerator.
11	Pittsfield	Plant no longer operating.
12	Providence	Power from waste heat drives sewage pumps and S.T.P. blowers.
15	Mt. Kisco	Ash to carts on tracks to disposal area, later removed.
17	St. Louis	North side plant is similar to South Side.
26	Atlanta	Annual revenue from sale of steam and reclaimed metal approximately $200,000.
28	Calgary	Stack sized for 360-ton capacity.
30	Los Angeles	Operation indefinitely suspended.
31	Miami	Daily steam production 1,500,000 lb. Use of steam not reported.
33	Port Chester	Special hearth at base of combustion chamber for disposal of dead animals and bulky, slow burning materials.
36	Bloomsburg	Monorail hoist for ash buggy.
52	Alexandria	Stack sized for 300-ton capacity.
53	Cincinnati	Residue conveyors installed 1960.
57	Omaha	Metal now reclaimed from residue by private operator.
59	Providence	This unit replaced a 1936 unit. By-pass provided around boiler and ID fan.
61	St. Louis Park	Residue used for land filling.
67	Framingham	Water-cooled furnace walls.
69	Merrill	Use of waste heat abandoned because of availability only 7 hours per day. Use of steam not reported.
70	Milwaukee	Waste heat also used for heating adjacent garage and for hot water for truck washing and sanitary use.
74	Quebec	Metal salvaged from residue dump.
76	Babylon	Waste heat hot water also used to heat nearby sludge digestion tanks.
83	Glendale	Ram feed to furnace. Spray tower between combustion chamber and spray chamber.

84	Los Angeles	DeCarie basket grate plant rated 32 T/day with 7500 Btu/lb refuse, and 400 T/day with 6000 Btu/lb refuse. Operation indefinitely suspended.
86	New Canaan	Expansion chamber and stack designed for 100-ton capacity.
87	Oyster Bay	Small bin provided for unburnables. Ash removal system includes clarifier and 1,000,000 gallon reservoir. Forced draft air drawn from refuse pit area for dust control.
89	Poughkeepsie	Original chimney used with new furnaces. Tipping area enclosure added later.
96	Lexington	Stack sized for 300-ton capacity.
97	Louisville	Stacks and building designed for 1000-ton capacity. Plant has hammermill and chipper to reduce bulky materials before burning.
99	Parma	Plant has provision for direct charge from trucks.
100	Tonawanda	Ash dumped to carts which are lifted to grade.
101	Bridgeport	Sewage treatment plant effluent used in flyash removal system. Residue used for fill.
102	Durham	"Beehive" furnaces.
105	Indianapolis	Steam used in sewage treatment plant.
108	New Orleans	Ash conveyors added later.
113	Boston	Heat used for adjacent hospital. By-passes around boilers through cooling chambers.
123	Whitemarsh	Water-cooled refractory furnace walls.
128	Miami	Water recirculation unsatisfactory due to clogging.
141	Winchester, Mass.	Apron conveyor, for receiving refuse during peak delivery period, discharges to pit.
142	Darien	New monorail hoist and bucket serves 130T plant, replacing two old hoists with single line buckets. Existing 75 ft chimney serves new 70T and two existing 30T furnaces.
144	Eastchester	Tubular conveyor for flyash removal from expansion chamber.

148	New Orleans	Ash conveyors added later.
152	Atlanta	Residue used for fill and road sub-base. Reclaimed metal sold for +$6.00/ton.
4	Garden City	Two refuse bins. Forced draft air drawn from bins for dust control. Water sprays in bins for dust control.
155	Greenwich	New bin and crane serve new furnace. Existing bin and crane serve two existing furnaces. Tubular conveyor for flyash removal. Bin ventilation and sprays for dust control. Animal hearth in combustion chamber.
158	New Orleans	Automatic control of furnace draft and temperature, forced draft pressure, and ID fan inlet temperature. Adjustable set points in all controls.
164	Broward County No. 1	Ram feed to furnaces. Preliminary settling of water in quench tank followed by rotary screen, then pressure filter. Magnetic separation of metal in ash.
165	Broward County No. 2	Ram feed to furnaces. Preliminary settling of water in quench tank followed by rotary screen, then pressure filter. Magnetic separation of metal in ash.
166	Canajoharie	Vertical monohearth. Spray chamber and stack also serve multiple-hearth sludge furnace.
168	Clearwater	Ram feed to furnaces.
169	Dearborn Heights	Combined combustion and flyash removal chamber for each furnace. Building has provision for third furnace.
170	DeKalb County	Residue is good fill and road sub-base material.
173	Freeport	Existing stack retained.
174	Jefferson Parish	Automatic control of furnace draft and temperature, forced draft, and ID fan inlet temperature.
181	Hempstead	Two 300-ton refuse furnaces with waste-heat boilers and one 150-ton rubbish furnace.
184	Montgomery County	Flyash settling chambers designed for cleaning by front end loader.
186	Oyster Bay	Closed-circuit TV for observing fire bed and charging floor.

187	Port Washington	By-pass stack for startup and shut-down, sized for future unit.
188	Ramapo	New crane and stack serve 300-ton total plant capacity.
189	Sheboygan	Flyash from spray areas to lagoon.
193	Ft. Lauderdale	Ram feed to furnaces.
194	Houston	Spray chambers integral with combustion chambers. Tubular gas reheaters cool combustion chamber outlet gas and heat scrubber outlet gas. Screen separator at conveyor discharge.
195	Lexington	New furnace utilizes existing expansion chamber and stack. Furnace designed with standby capacity.
196	Montreal	Designed for Martin or VonRoll (Canada) stokers. One boiler unit integrally with each furnace. Use of steam not reported.
199	Norfolk	Salvage fuel boiler plant with water-wall furnaces and waste-heat boilers. Steam to be used on destroyer and submarine piers and general heating distribution system for base. Recirculated water used to convey flyash to conveyor troughs.
200	North Hempstead	Two rocking-grate refuse furnaces and one double travelling-grate rubbish furnace.
205	New Orleans	Number of cranes and type of stoker not determined when questionnaire submitted.