An Evaluation of Seven Incinerators

W.C. ACHINGER and L.E. DANIELS

ABSTRACT

In an evaluation of seven incinerators that process municipal solid waste, data have been gathered on (1) the quality and quantity of solid waste processed, residue, and gasborne particulate emissions, (2) the quality of the fly ash collected and the wastewater produced, and (3) the economics involved in incineration. These data are compared and the study results summarized. The sampling procedures being used and the problems encountered during their evolution are also described.

INTRODUCTION

The 1965 Solid Waste Disposal Act (PL 89-272) created a federal solid-waste management program to join air- and water-pollution programs in a national effort to combat environmental pollution. Realization of the rapidly increasing types and amounts of solid waste being generated in this country had prompted this federal action and the creation of a program, the Bureau of Solid Waste Management, to lead and coordinate planning and research activities in solid-waste management on a nationwide level. The broad objective of the Bureau is to act as a catalyst in the initiation and utilization of methods of solid-waste disposal that are effective and economic. Technical and financial assistance is provided to state and local governments and interstate agencies for planning, developing, and conducting solid-waste management.

Because meaningful data are scarce on incineration, this program for testing municipal incinerators was conceived and initiated by the Bureau's division of technical operations.

The first phase of this testing program was designed to develop reliable sampling methodology and accumulate basic data that identify the results of the incineration process. The intention was to identify the operating characteristics of the various incinerator designs, not to downgrade or promote any particular design. This first phase is nearing completion. The next phase will involve refining and expanding the sampling methodology developed in the first phase and continuing the studies of various incinerator designs.

The sampling procedures now used and the results of the first seven incinerator studies are given here. The incinerator designs studied were the rotary kiln, conical burner (pilot-plant size), traveling grate, rocking grate, modified reciprocating grate, and reciprocating grate.

SAMPLING PROCEDURES

At the beginning of this testing program, sampling procedures for evaluating municipal incinerators were neither widely published nor accepted. As a result, the existing sampling procedures have been considerably modified since the start of this program in an effort to develop better testing methods. Additional modifications are expected as further data become available.

The sampling procedures presently used, reported in this paper, are designed to obtain information on (1) the efficiency of the incinerator as a reduction device, (2) the potential impact of the incinerator operation on the environment as indicated by the quality and quantity of the solid, liquid, and gaseous effluents discharged to the environment, and (3) the cost of incinerating solid wastes.

Under development are procedures for identifying the bacteriologic quality of all influents and effluents and for determining the quantity of gaseous pollutants, primarily: hydrocarbons, hydrogen chloride, sulfur oxides, carbon monoxide, and nitrogen oxides emitted to the atmosphere.

The incinerators are evaluated at their "operating" capacity (operated in the way the plant would be operated if it were not being tested) because, at present, the charging rate on a short-term (hourly) basis cannot be determined. Evaluating a particular incinerator at different conditions to determine the capacity at which it achieved the best overall operation is no longer done because of the resources required.

Incoming Solid Waste

Burning Rates

Because design burning rates are sometimes inaccurate in relation to actual operation at a given time, it is necessary to determine true burning rates before waste-reduction efficiencies, particulate-grain loadings, and other factors can be determined. Burning rates are determined indirectly by measuring the charging rate and are most useful if determined on an hourly basis.

Initially, strain gages mounted on the crane cables were considered as a means of determining the hourly charging rate, but this procedure was not attempted because of anticipated problems associated with installation. Weighing grapples full of waste on a platform scale to determine the weight of an average grapple charge proved unsatisfactory because it was difficult to keep the cables slack and at the same time prevent material from falling out of the grapple during the weighing process.

At present, a weekly charging rate is determined by emptying the pit before the study, weighing all materials dumped during the study week, emptying the pit at the conclusion of the study, and recording the time it takes to charge the material received during the study week. This procedure is followed on a daily basis in those plants that operate less than 24 h/day. When the plant operation permits, sufficient wastes to charge the furnaces for about 8 h is weighed and set aside. During a testing day, the time required to charge the material is recorded and used to determine a daily charging rate. Although neither of these latter two procedures yield an hourly charging rate, they do provide data more reliable than the other procedure.

Composition and Characteristics

To determine the composition of the incoming waste for the test period, eight grab samples weighing between 200 and 300 lb each are manually sorted into nine categories. The combustible categories include: (1) food waste, (2) garden waste, (3) paper products, (4) plastic, rubber, leather, (5) textiles, and (6) wood. The noncombustible categories include (7) metals, (8) glass and ceramics, and (9) and ash, rocks, dirt, etc. The amount in each category is weighted. Portions of four of the eight grab samples are collected for laboratory analyses. To obtain a 15- to 20-lb laboratory sample, a proportionate amount of material is taken from each of the nine separated categories. The combustible and noncombustible materials are placed in separate plastic bags and sent to the laboratory. Before any other processing is attempted, the moisture content of the samples is determined. The combustible portion of all four samples is then analyzed for heat, volatile (material driven off at 600°C), and ash contents and for elemental composition (carbon, hydrogen, oxygen, nitrogen, sulfur, and chlorine).

Size and Number of Samples

During the first study made under this program, the effect of sample size on the precision of the data was ascertained. Statistical analysis of the resulting data indicated no difference in the precision of composition data based upon sample size, the results were as precise with "small" (i.e., 200- to 300-lb) samples as with "large" (1400- to 1700-lb) samples if the grab samples were representative (based upon appearance).

The first study also determined that 12 grab samples are required to obtain the percentage of any component with a precision of plus or minus two percentage points. Because of the manpower and time required to sort these samples manually, only eight samples are collected during the course of a study. This loss of precision is not deemed critical.

A more comprehensive treatment of this statistical analysis was presented by Carruth and Klee [1].

Distribution of Sampling

The sampling study period of 1 week, which was shortened to 3 days for Study E, introduced a problem when trying to characterize the composition of the solid waste. During Study E, the eight samples for composition analysis were taken unevenly over the study period: three samples were taken on the first day, four on the second, and one sample on the last. Comparison of the data obtained from the samples (Table 1) indicates that the wastes delivered to the facility on different days had different compositions and that sampling to determine composition must be distributed throughout the week if the average composition is to be representative of the material delivered to the facility during any one week. Analysis of the data from other plants similarily indicates the necessity of distributing the sampling over the entire study week.

Moisture Content

In the first two studies, the moisture content of the combustible fraction of the composition samples was erratic and unexpectedly low, ranging from 9 to 23 percent. Visual examination of samples indicated higher moisture contents because the samples were quite wet. These samples were placed inside 6-gal plastic cans with the plastic lid sealed with tape, and analysis of the samples occurred some time after the samples were taken. When this apparent loss of moisture during transport and storage became evident, extra precautions were taken on subsequent studies to seal the samples securely. Samples are now placed inside two independently knotted plastic bags. Moisture contents of the combustible portions of samples sealed in this manner have ranged from 22 to 43 percent.

In all of these studies, the moisture content of the noncombustible fraction of the solid-waste samples has been assumed to be zero, since moisture determinations were not practical with the equipment available. Grinding the noncombustible fraction to homogenize the sample for moisture analysis was considered impractical because of the abrasive properties of these materials. Arrangements have been made to have the moisture content of the entire combustible and noncombustible laboratory samples determined in larger capacity ovens in future studies.

Table 1

Daily Solid-Waste Composition for Plant E (Percent by Weight)

Component	Monday*	Tuesday†	Wednesday‡	Average§
Combustibles:				
Food waste	7.2	14.6	18.1	12.2
Garden waste	1.8	1.9	0.3	1.6
Paper products	57.8	60.3	54.1	58.7
Plastic, rubber, leather	2.7	2.8	4.9	3.0
Textiles	1.6	1.7	2.9	1.8
Wood	0.3	0.5	0.3	0.4
Total	71.4	81.8	80.6	77.7
Noncombustibles:				
Metal	8.8	8.0	10.0	8.6
Glass, ceramics	14.9	7.4	8.2	10.3
Ash, rock, and dirt	4.9	2.8	1.2	3.4
Total	28.6	18.2	19.4	22.3

* Average of three samples.
† Average of four samples.
‡ One sample.
§ Average of all eight samples.

Residue and Fly Ash

All the residue accumulated during the study period is weighed, and the information is used to determine reduction efficiencies, as is discussed later in the section on study results.

To determine the quality of the residue, five grab samples each weighing approximately 50 lb are collected during the study period. A statistical analysis was not made of the number and size of the residue samples required because, at a given facility, the composition of the residue does not vary as much as that of the solid waste. Four of the five samples are manually sorted into four categories: (1) metals (2) rocks, glass, and ceramics, (3) unburned combustibles, and (4) fines (unidentifiable material passing through a 0.5-in. sieve).

The fifth sample is returned to the laboratory for determination of moisture content. The fines and the unburned combustibles of the other four samples are placed into two independently sealed plastic bags and returned for laboratory analyses similar to that of the incoming solid waste.

Where possible, a 2- to 10-lb sample of fly ash is collected from the air-pollution-control device. This is returned to the laboratory to determine the moisture, heat, ash, and volatile contents.

A material balance of the metals from the solid waste and from the residue may not be calculated because a considerable portion of the fines in the residue contain metal that is not removed during the current separation procedure. In one study, for example, the plant received 2300 tons of solid waste that contained 8.5 percent (195.5 tons) metal. The 660 tons of residue weighed contained 16.8 percent (110.9 tons) metal. From these data, it would seem that 84.6 tons of metal disappeared during incineration. In preparing the laboratory sample of the fines for analysis, however, 13.7 percent of the fines were removed with a magnet. This magnetic material accounts for another 71.8 tons of ferrous metal in the residue to reduce the apparent loss of metal to 12.8 tons, which is within the accuracy of our sampling procedures. The residue separation procedures are being modified to include removal of ferrous metals from the fine category.

Liquid Effluents

Each wastewater source is sampled to determine pertinent physical and chemical characteristics. The major sources sampled are the incoming water, scrubber water, residue quench water, and plant effluent. Two 500-ml grab samples are collected from each source during each stack test and combined. The temperature and pH of all samples are measured immediately after collection. After the samples are returned to the laboratory, they are analyzed for alkalinity, chlorides, hardness, sulfates, phosphates, conductivity, and solids [2].

Stack Effluents

Particulate Emissions

The sampling train (Fig. 1) and methods developed by the National Air Pollution Control Administration (NAPCA) are used for measuring particulates emitted from the stack [3]. The major elements of this sampling train are the (1) stainless-steel button-hook probe tip, (2) glass-lined or all metal probe, (3) cyclone and collection flask, (4) 2.5-in. glass-fiber filter, (5) electrically heated enclosed box, (6) series of four modified Greenburg-Smith impingers (the first impinger has the tip replaced with a 0.5-in i.d. glass tube and is filled with 100 ml distilled water; the second impinger (unmodified) is filled with 100 ml distilled water, the third impinger is modified like the first and is left dry; and the fourth impinger is also modified like the first and contains about 175 g of dry silica gel, (7) box containing an ice bath, (8) dial thermometer, (9) check valve, (10) flexible vacuum tubing, (11) vacuum gauge, (12) needle valve, (13) leakless vacuum pump, (14) bypass valve, (15) 1 ft^3/r dry gas meter, (16) calibrated orifice, (17) inclined-vertical manometer, and (18) Type S pitot tube.

Gas Composition

The effluent gases are sampled and analyzed for moisture, carbon dioxide, carbon monoxide, and oxygen. To determine the moisture content, water vapor is condensed in the impingers of the particulate sampling train, and then the gases are passed

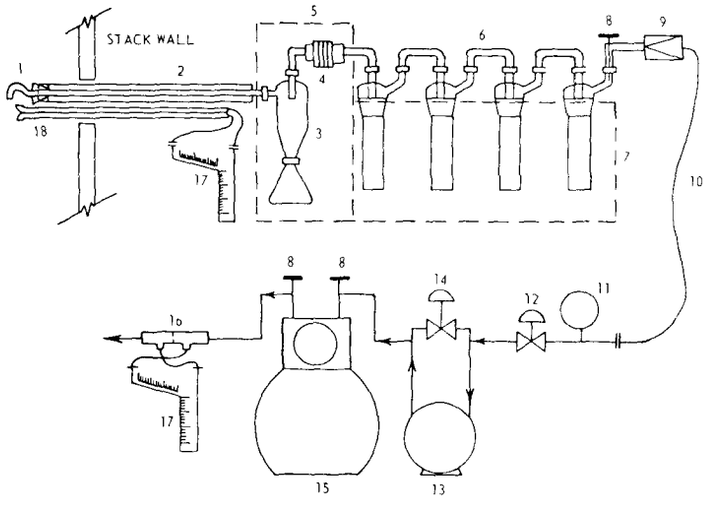


Fig. 1 Particulate Sampling Train

through silica gel to dry. The condensate in the impingers and the weight gain in the silica gel (assumed to be moisture adsorption) are measured to indicate the moisture content of the stack gases. To determine the carbon dioxide, carbon monoxide, and oxygen concentration, integrated gas samples are collected in a flexible bag sampler during each stack test and then analyzed with the use of an Orsat analyzer. To check the carbon dioxide data, a series of instantaneous grab samples are also taken during each stack test and analyzed with the use of a manual wet-chemistry carbon-dioxide indicator.

Probe Corrosion

Some municipal incinerators have large-diameter stacks, sometimes with double walls, that require the use of long probes when sampling the effluent gases. Because of handling difficulties and breakage, it is impractical to use glass-lined probes over 7 ft in length. In these situations, unlined, unheated metal probes have been used.

Type 304 stainless steel was initially selected as the probe material when the use of all-metal probes was necessary. These probes were used in two studies spaced about 5 months apart. Some visible evidence of corrosion was noted during the first study. Because of the natural reddish-brown color of the particulate collected on the filter, corrosion could not be established definitely without a thorough laboratory analysis, which did not seem justified at the time. Reddish-brown material was also noted in the probe washings collected during the second study. Since the natural color of the material collected on the filters was black, oxidation of the probe metal probably occurred. Visual inspection of the inside walls of the probes revealed this possibility. The reddish-brown residue remaining after evaporation of the acetone wash in this study was qualitatively analyzed for iron and indicated a high iron concentration, but the particulate material collected on the filter showed only a faint trace of iron. This indicates the iron came from the probe rather than the incinerator. Even though the iron from the probe adds some to the total particulate collected, visual inspection did not indicate it to be a significant amount.

The corrosion is caused by condensation occurring in the probe. Because the metal probes were not heated, considerable amounts of liquid (up to 135 ml) have condensed in the all-metal probe and cyclone through which the gases pass before entering the particulate filter (Fig. 1). The gases cool sufficiently in the length of the probe to condense even though they enter the probe at approximately 500 to 600°F. It is suspected that acidic gases, particularly hydrogen chloride, are absorbed in this condensed water and create a very corrosive solution. In subsequent studies, the pH of the water removed from the impingers was measured and found to vary between 2.5 and 3.5.

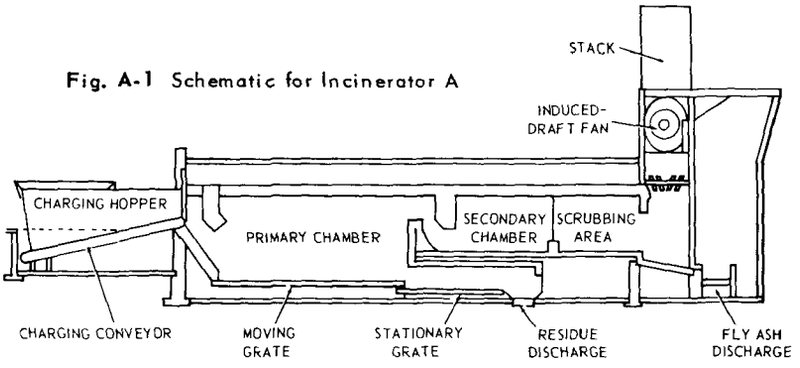
Two alternatives were considered for correcting the corrosion problem in metal probes. The probes could be heated, or more corrosion-resistant materials could be used. Because of the problems involved in shielding the heating wire or tape, it was decided to try more resistant probe materials.

Two alloys, Incoloy 825 (approximately 40 percent nickel, 30 percent iron, and 20 percent chromium) and Monel 400 (approximately 65 percent nickel, 30 percent copper, and 1 percent iron), were investigated because of their reported resistance to corrosion by acidic gases. The two different materials were used simultaneously in one study. The Incoloy 825 probes seemed to be more resistant to corrosion, the washings were generally clear, and inspection of the inside walls showed no indication of corrosion. The washings from the Monel probes were yellow and contained greenish material that indicated the presence of copper compounds. The inside walls showed visible signs of corrosion. Although the Incoloy 825 seems promising in its ability to resist corrosion by incinerator stack gases, it is too early to make a positive conclusion. The use of heated glass-lined probes is recommended whenever possible.

Filter Plugging

Filter plugging due to particulate buildup or to moisture condensing on the filter has also been a problem in testing. Rather than attempting to develop a larger filter assembly that would require extensive modification of the sample collection box, the sampling train is merely shut down for a few minutes while the filter assembly is changed. In some cases, as many as four filter changes were necessary to complete a test. This method of operation is rapid and has proven satisfactory during the studies.

Fig. A-1 Schematic for Incinerator A



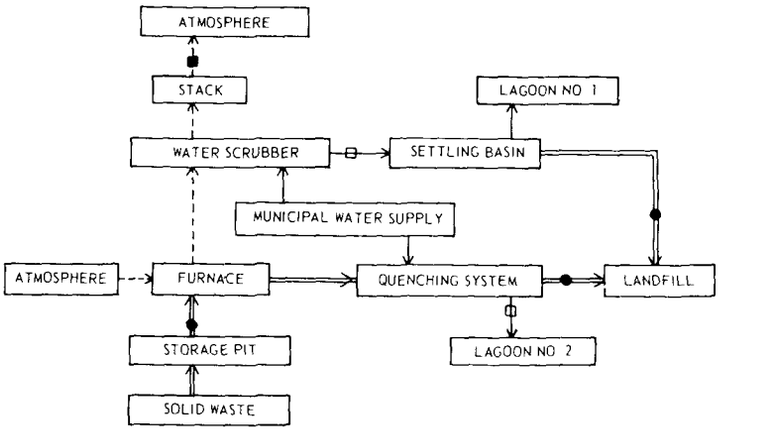
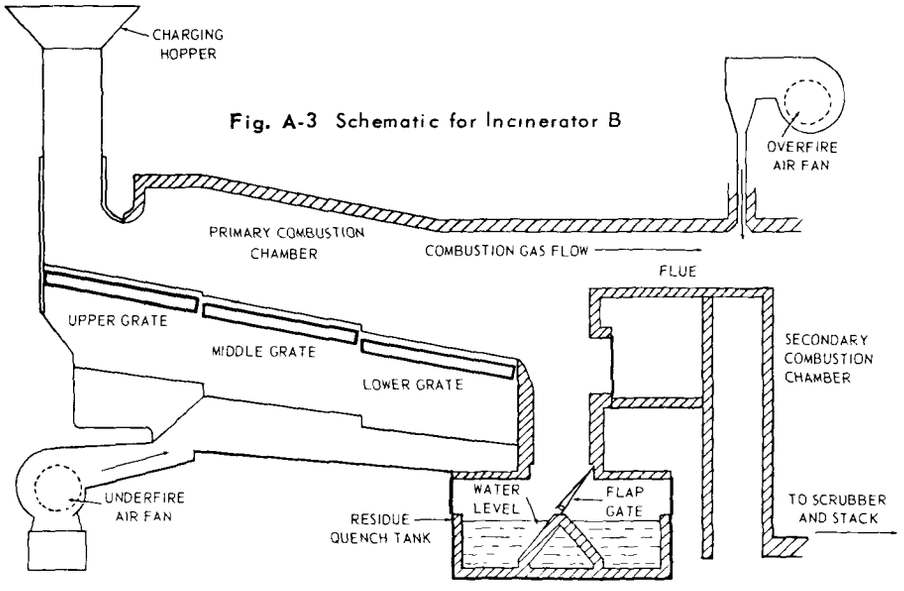


Fig. A-2 Flow Diagram for Incinerator A

Fig. A-3 Schematic for Incinerator B



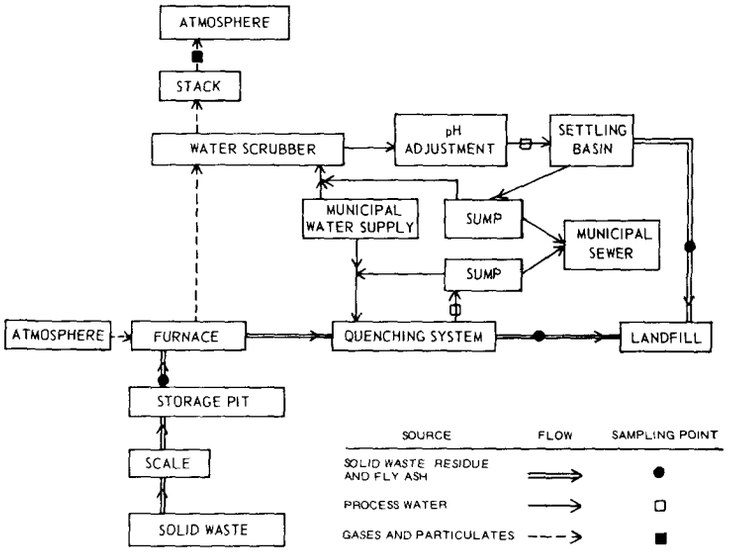


Fig. A-4 Flow Diagram for Incinerator B

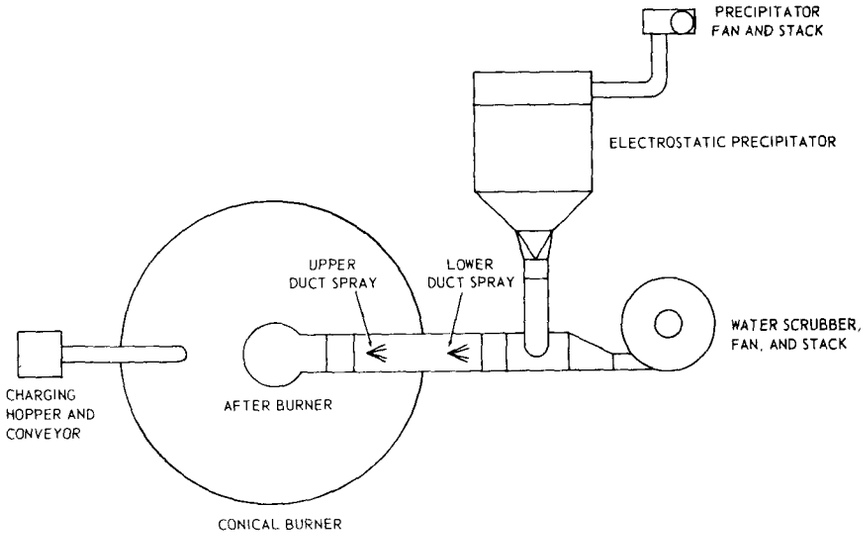


Fig. A-5 Plan View for Incinerator C

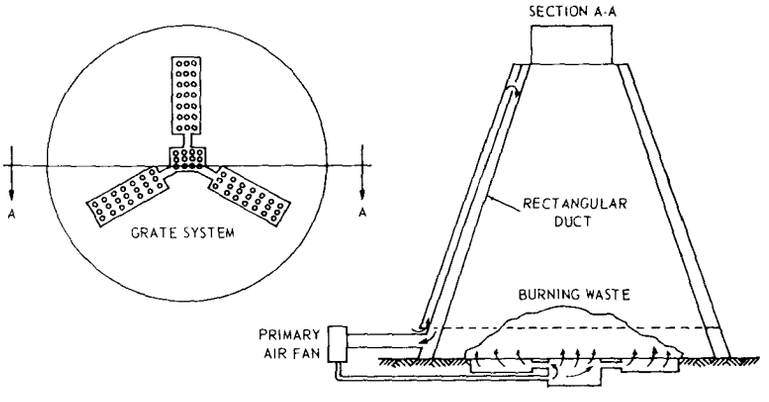


Fig. A-6 Underfire-Air System for Incinerator C

Cost Data

The objective of collecting cost data is to determine the true costs at each plant studied, which includes costs for residue disposal, facility amortization, bond interest, site improvement, etc. In addition to obtaining overall operating and capital costs, the operating costs are divided into solid-waste receiving, volume-reduction, and effluent-treatment "cost centers."

The cost data are obtained by checking all cost records kept by the plant and any administrative group keeping pertinent records. In addition, to verify and apply the cost data to the cost accounting procedure correctly, discussions were held with the personnel who maintain cost records. This cost accounting procedure has been described by Zausner [4], and the computerized cost-analysis technique used in the studies has been described by Zausner and Helms [5].

The cost analysis is presently being expanded to include a capital cost breakdown according to cost centers. Unfortunately, capital cost information, when available, is not easily allocated to the cost centers because the data are not available in a form that lends itself to the cost-center concept.

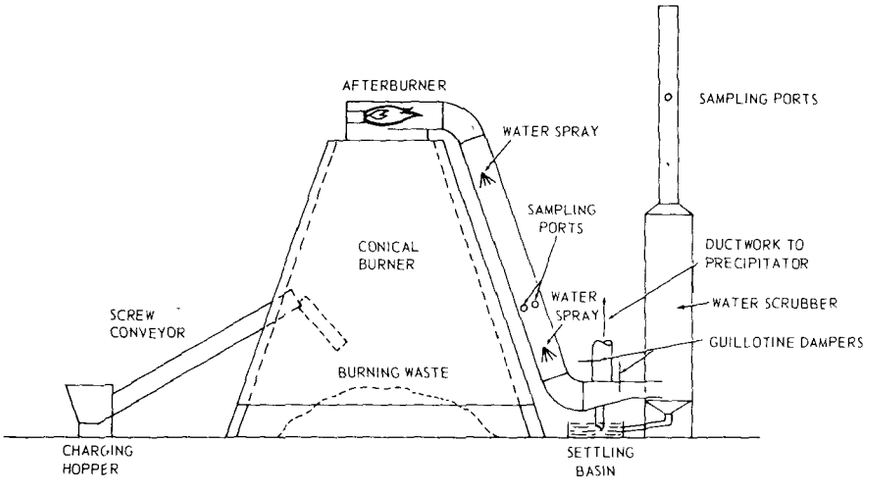


Fig. A-7 Water Scrubber and Afterburner Ductwork for Incinerator C

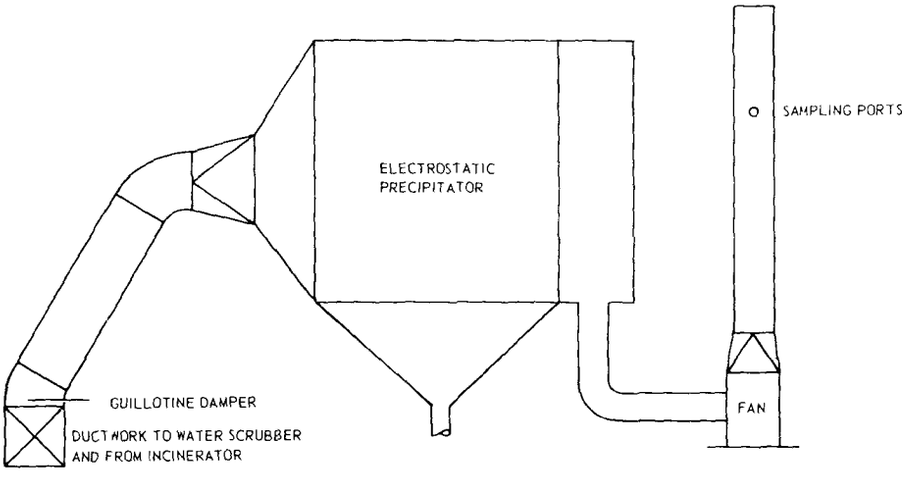


Fig. A-8 Electrostatic-Precipitator Ductwork for Incinerator C

In addition to breaking down capital costs according to cost centers, future studies under this program will include cost analysis according to subsystems within each cost center. For the "Receiving and Handling" cost center, costs are assigned to the scales, pit and tipping area, and the crane and charging floor; for the "Volume Reduction" cost center, to the furnace enclosure, grates, combustion-air systems, and instrumentation; and for the "Effluent Handling and Treatment" cost center, to residue, wastewater, and gas-treatment systems.

STUDY RESULTS

Facility Descriptions

Incinerator A was built in 1966 with a design capacity of 300 tons/day. Each furnace contains a modified reciprocating grate and a stationary grate. A wetted-column water scrubber is used for air-pollution control. Incinerator B was built in 1966 with a design capacity of 300 tons/day. Each furnace

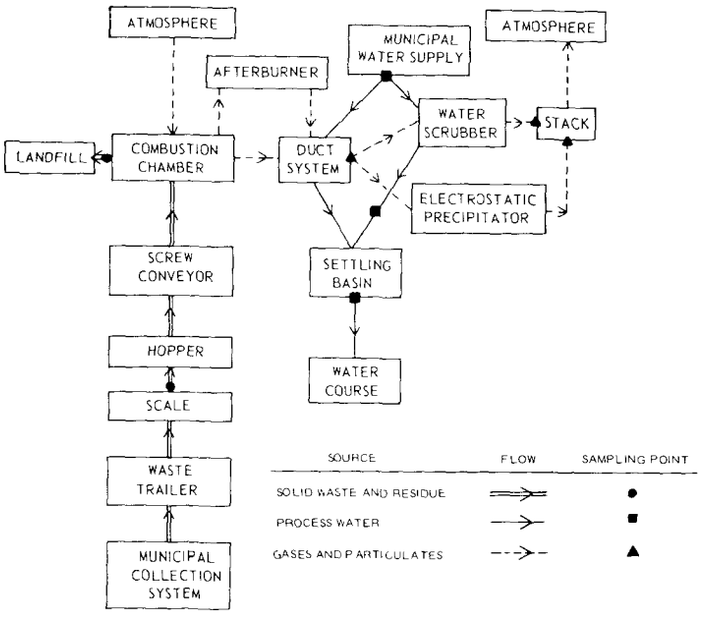


Fig. A-9 Flow Diagram for Incinerator C

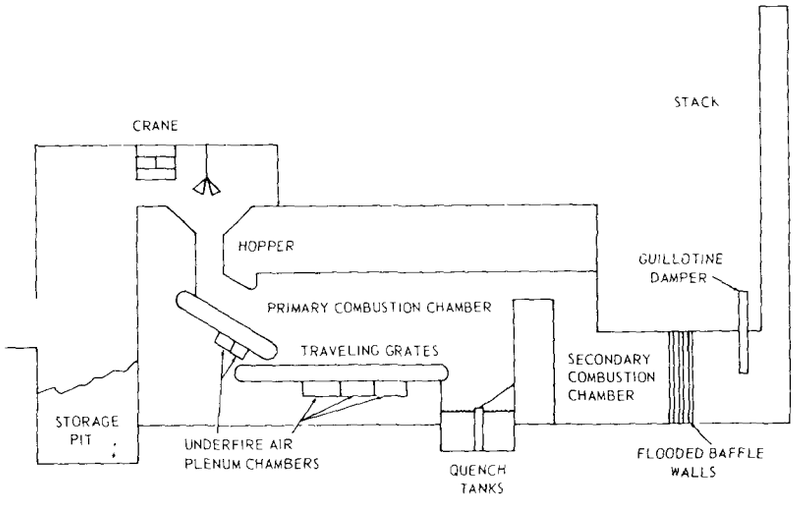


Fig. A-10 Schematic for Incinerator D

contains three sections of rocking grates. The air-pollution-control system is a flooded, baffle-wall water scrubber. Incinerator C, built in 1967, is a pilot-plant conical burner with a design capacity of 1000 lb/h. A centrifugal water scrubber, an afterburner, an electrostatic precipitator, or some combination thereof is used for air-pollution control. Incinerator D was built in 1965 with a design capacity of 500 tons/day. Each furnace contains two sections of traveling grates, and a flooded, baffle-wall water scrubber is used for air-pollution control. Incinerators E and F are rotary kilns built in 1963 with design capacities of 500 and 600 tons/day, respectively. Each furnace contains three sections of reciprocating grates followed by a rotary kiln. Air-pollution control is achieved through a baffle-wall and water-spray system. Incinerator G was built in 1967 with a design capacity of 400 tons/day. Each furnace contains four sections of reciprocating grates. A multitube dry cyclone following a wet-baffle wall is used for air-pollution control.

A more detailed summary of the physical characteristics of each incinerator studied is presented in the Appendix.

Heat Release and Burning Rates

The design burning rate per unit area of grate and the heat release rate per unit volume (Table 2) for each incinerator were calculated by using the design capacity of the plant and waste averaging 5000 Btu/lb. The actual burning and heat-release rates were

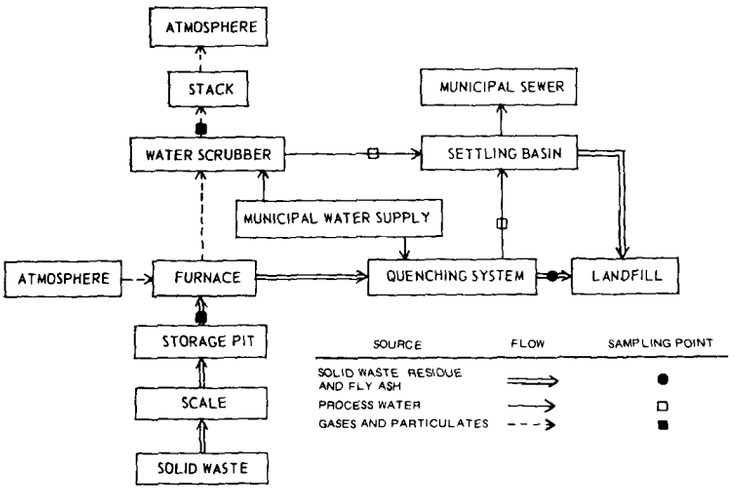


Fig. A-11 Flow Diagram for Incinerator D

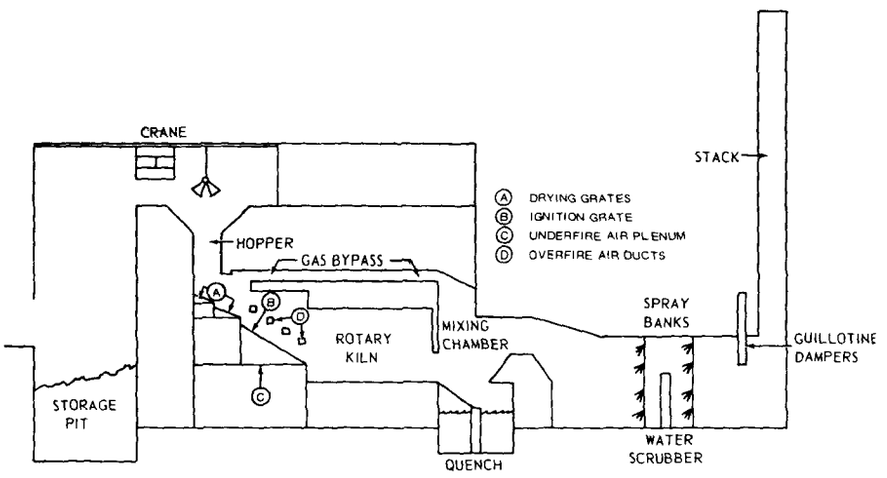


Fig. A-12 Schematic for Incinerators E and F

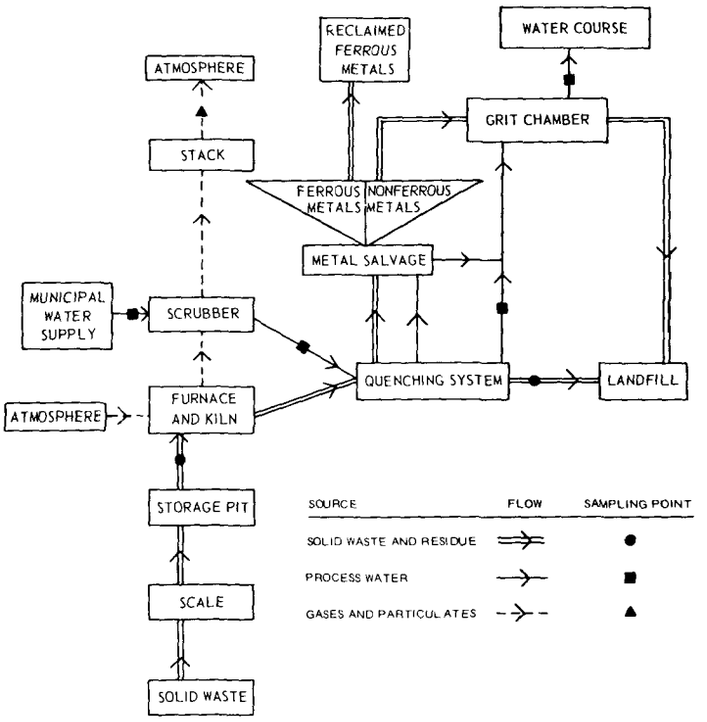


Fig. A-13 Flow Diagram for Incinerator E

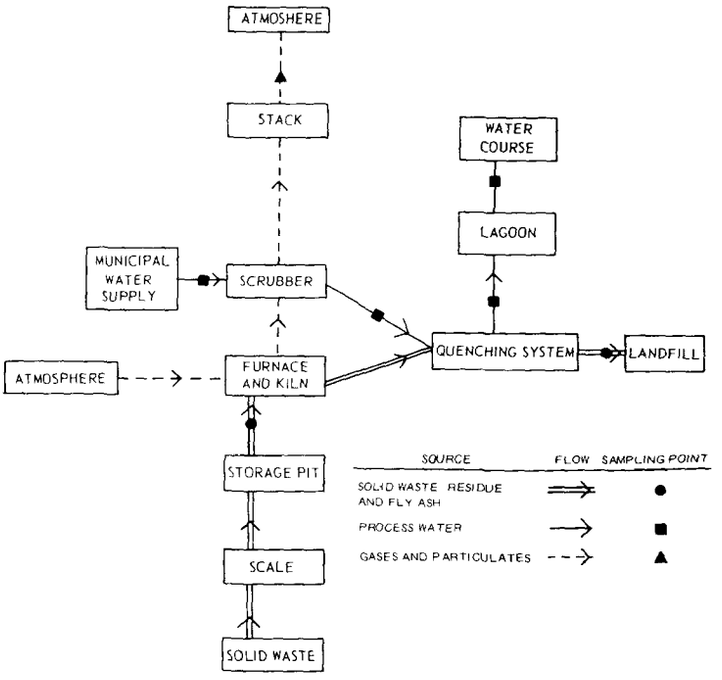


Fig. A-14 Flow Diagram for Incinerator F

calculated from the charging rate of the plant and the heat content of the solid waste as measured during the study. For the conical burner, the area of the base of the burner was used to calculate the grate burning rate. For the rotary kilns, the grate burning rate was calculated with the use of the surface area of a 2-ft bed depth in the kiln.

Solid Waste

Composition

The solid waste (Table 3) received by the incinerators during the studies was composed generally of 79 percent combustibles and 21 percent noncombustibles.

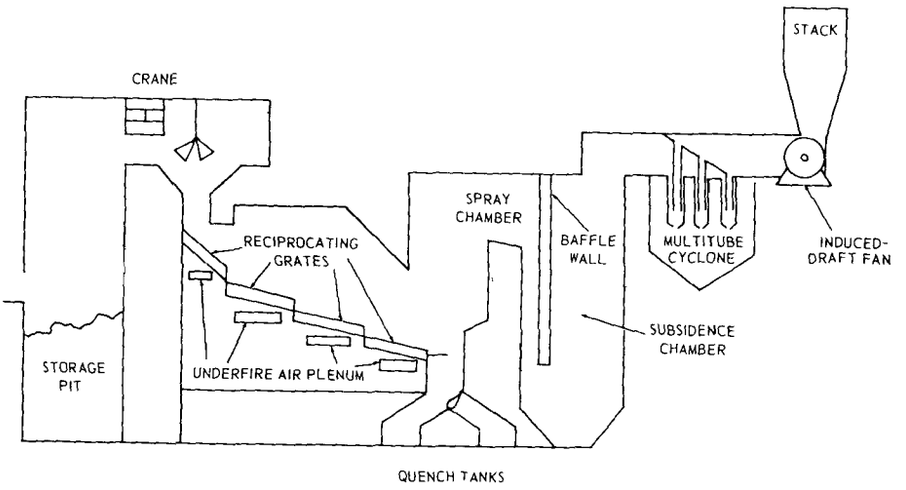


Fig. A-15 Schematic for Incinerator G

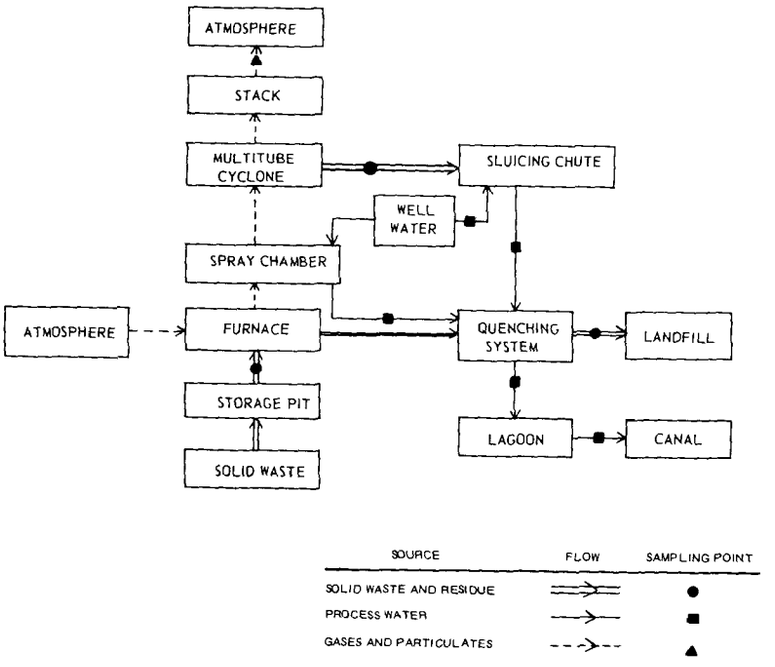


Fig. A-16 Flow Diagram for Incinerator G

Proximate Analyses

The low combustible content of the waste received by Incinerators C and G is reflected in a lower volatile and heat content of the waste (Table 4).

Residue

Composition

The residue composition (Table 5) is expressed on a percent by weight "as-sampled" basis. The fines are defined as the unidentifiable materials passing through a 0.5-in. wire-mesh screen. The unburned combustibles are those visually identifiable

Table 2

Heat-Release and Burning Rates

Incinerator	Capacity (tons/day)		Burning Rate Per Unit Area of Grate (lb/ft²/h)		Rate of Heat Release Per Unit Volume (Btu/ft³/h)			
					Primary Chamber		Total Furnace	
	Design	Actual*	Design	Actual	Design	Actual	Design	Actual
A	300	281	45	42	23,000	19,000	14,300	11,800
B	300	308	52	53	28,600	25,300	13,800	12,300
C	1000†	1444†	3	5	–	–	2,400	2,600
D	500	(‡)	(‡)	(‡)	(‡)	(‡)	(‡)	(‡)
E	500	660	45	59	23,300	31,000	13,900	18,600
F	600	645	47	50	21,900	26,000	14,400	17,000
G	400	482	51	62	23,600	22,000	14,400	13,400

* See discussion of burning rates under the section on the sampling of incoming solid waste.

† lb/h.

‡ Information not available.

Table 3

Solid-Waste Composition (Percent by Weight)

Component	Incinerator						
	A	B	C	D	E	F	G
Combustibles:							
Food waste	7.4	6.1	20.3	8.5	12.2	18.3	11.0
Garden waste	3.4	8.4	11.1	0.5	1.6	0.6	9.8
Paper products	62.5	58.0	30.2	60.4	58.7	60.6	44.9
Plastic, rubber leather	2.8	3.3	3.1	5.4	3.0	2.1	3.5
Textiles	2.4	3.1	5.2	2.4	1.8	1.8	3.2
Wood	2.4	1.4	1.7	5.4	0.4	2.3	3.1
Total	80.9	80.3	71.6	82.6	77.7	85.7	75.5
Noncombustibles:							
Metal	9.0	8.2	6.8	9.0	8.6	8.5	8.1
Glass, ceramics	4.2	8.1	10.5	3.5	10.3	5.4	9.5
Ash, rock, dirt	5.9	3.4	11.1	4.9	3.4	0.4	6.9
Total	19.1	19.7	28.4	17.4	22.3	14.3	24.5

Table 4

Solid-Waste Analyses

Incinerator	Moisture, As Sampled (%)	Heat, As Sampled (Btu/lb)	Ash, Dry, Basis (%)	Volatiles, Dry Basis (%)	Density, As Sampled (lb/yd³)
A	20.0*	4410	34.2	65.8	(†)
B	20.0*	4320	31.8	68.2	(†)
C	26.5	3770	47.1	52.9	(†)
D	20.7	4520	35.6	64.4	(†)
E	20.2	5030	29.9	70.1	200
F	21.0	5530	22.7	77.3	140
G	28.2	3870	42.3	57.7	230

*Assumed.

†No measurement made.

combustible materials that pass through the incinerator without being burned. The unburned combustibles describe the visual appearance of the residue rather than the combustible content of the residue. The volatiles and heat content are more reliable indicators of combustible content. As stated previously, the fines also contain ferrous and nonferrous metals that are not determined during the separation procedure.

Incinerators E and F, rotary kilns, probably produced a higher percentage of fines than the other incinerators (74.5 and 79.4 percent, respectively) because the tumbling action of the kiln reduced the size of glass and rocks. The larger percent produced by Incinerator F, although not great, could be because its kiln is longer than that of Incinerator E, 30 ft compared with 23.

Table 5

Residue Composition
(Percent by Weight)

Component	Incinerator						
	A*	B	C*	D	D	F	G
Fines	44.9	52.5	38.9	36.4	74.5	79.4	52.6
Unburned combustibles	(†)	(†)	1.3	35.8	0.1	0.7	1.1
Metal	23.9	14.6	13.0	14.5	21.4	16.8	20.0
Glass, rock	31.2	32.9	46.8	13.3	4.0	3.1	26.3

* Dry samples.

† Unburned combustibles included with fines.

Table 6

Residue Analyses

Incinerator	Moisture, As Sampled (%)	Heat, Dry Basis (Btu/lb)	Ash, Dry, Basis (%)	Volatiles, Dry Basis (%)	Density, As Sampled (lb/yd^3)
A	15.0*	170	97.4	2.6	(†)
B	24.5	200	98.4	2.0	(†)
C	0.3	180	98.0	2.0	(†)
D‡	–	–	–	–	–
E	21.8	520	97.0	3.0	1490
F	24.8	940	92.7	7.3	1620
G	10.5	70	99.4	0.6	1600

* Assumed.

† No measurement made.

‡ No laboratory analysis performed.

Incinerators C and D, a conical burner and a traveling grate, produced the lowest percentage of fines, 38.9 and 36.4 percent, respectively. The residue from Incinerator C fused into a slag that minimized the quantity of fines.

The residue from Plant D contained 35.8 percent unburned combustibles. The facility was overloaded during the study week because the refractories in one furnace had collapsed. Although the actual burning rate could not be determined because the solid waste was stockpiled during the time and no reliable estimate could be made of the quantities burned, waste was being processed as fast as possible. The obviously overloaded furnace and the lack of agitation on the traveling grate contributed to the high percentage of unburned combustibles.

Proximate Analyses

The proximate analyses (Table 6) of the residue indicate the composition of the residue. The residue from the conical burner, Plant C, was air cooled but not water quenched; thus, the moisture content is quite low. The samples from Plants B, E, F, and G were taken from the drag conveyor. No explanation can be given for the low value at Plant G.

The moisture content, which is an important consideration when determining incinerator efficiencies, can change drastically depending upon where the sample is taken. For composition analysis, the best sampling location is the residue conveyor. This, however, is the poorest sampling location for the moisture determination needed to calculate incinerator efficiencies, since the moisture content of the residue is the highest when leaving the conveyor and the lowest when the residue truck is weighed. For accurate calculation of incinerator efficiency, the moisture content of the residue when it is weighed must be known. Since the residue samples in Studies B, E, F, and G were taken from the residue conveyor, the moisture content of the samples is higher than it would be if the samples had been taken from the residue truck when it was weighed. In the efficiency calculations, however, the moisture contents of the samples as collected were used. This assumption increases the calculated efficiencies. If the moisture content of the residue at the time the residue truck was weighed were 10 percent lower (14.5 instead of 24.5), the weight reduction efficiency would be reduced by about 4 percentage points, the volatile reduction by about 0.2 percentage points, and the reduction in heat content by about 0.4 percentage points.

Fly Ash

Fly-ash samples could be obtained from only four of the plants studied. The variation in the proximate analysis (Table 7) was probably because of different air-pollution-control devices. The electrostatic precipitator (Plant C) collected fly ash with the highest volatile content, multitube cyclone (Plant G) with the lowest, and the water scrubbers midway between that collected by the other units. The difference between the water scrubbers and the cyclone may be explained by the better burnout achieved by Plant G (cyclones) where both the residue and fly ash had low volatile and heat contents. Since the electrostatic precipitator is considered a "high-efficiency" control device (collects smaller particles than less efficient devices) and the water scrubbers and multitube cyclone are considered "low-efficiency" devices, the combustible portion (indicated by the percent volatiles) of the fly ash would probably be smaller in particle size than the noncombustible portion of the fly ash.

Wastewater

The incoming water, scrubber water, quench water, and plant effluent after treatment were sampled to determine their characteristics. The scrubber and quench waters from Incinerator A were not mixed and flowed to separate lagoons. The scrubber and quench waters from Incinerator B were not combined, but both were recycled individually and, after a week, discharged to the city sewers. The process waters from Incinerators D, E, F, and G were combined in the quench tank, treated in a settling basin, grit chamber, or lagoon, and were discharged. In these incinerators, the source labeled quench water (Table 8) is actually a mixture of the scrubber and quench water.

The temperature and pH were determined at the plant site, and the remaining analyses were made after the samples were returned to the laboratory.

From the analysis of the process waters (Table 8), some general conclusions can be made about the characteristics of the water from a given source.

Table 7

Fly-Ash Analyses

Incinerator, Type of Air-Pollution-Control Equipment	Moisture, As Sampled (%)	Heat, Dry Basis (Btu/lb)	Volatiles, Dry Basis (%)	Ash, Dry Basis (%)
A, wetted-column water scrubber	64.9	180	14.0	86.0
B, flooded baffle-wall water scrubber	(*)	1290	13.9	86.1
C-1, centrifugal water scrubber	(*)	(*)	16.4	83.6
C-3, electrostatic precipitator	52.4	3400	27.5	72.5
G, multitube cyclones	0.3	440	4.2	95.8

* No measurement made.

Scrubber Water

Scrubber water was generally acidic. The total solids concentration varied from about 500 to 7000 mg/l with about 80 to 85 percent being dissolved solids. The chloride, hardness, sulfate, and phosphate concentrations of the incoming water were significantly increased after passing through the scrubber.

Quench Water pH

The quench waters from Incinerators A and B were alkaline because the scrubber water was not added to the quench water. Although the spray water used to cool the flue gases and the water used to carry the fly ash to the quench tank in Incinerator G were added to the quench tank, the volumes were not large enough to reduce the pH of the quench water, and it remained alkaline. The scrubber water in Incinerators E and F was acidic, but combining it with the quench water helped raise the pH of the combined waters.

Quench Water Solids

The quench water from each incinerator had a high concentration of total solids. The quench water from Incinerators A, E, and F, however, contained approximately 60 percent suspended solids, whereas the quench water from Incinerators B, D, and G contained approximately 25 percent suspended solids. There is no explanation for this anomaly.

At Incinerator E, a grit chamber achieved a 90 percent reduction in suspended solids concentration;

Table 8

Wastewater Analyses

Incinerator, Sample Source	pH	Temperature (°F)	Suspended Solids (mg/l)	Dissolved Solids (mg/l)	Total Solids (mg/l)	Alkalinity (mg/l $CaCO_3$)	Chlorides (mg/l)	Hardness (mg/l $CaCO_3$)	Sulfates (mg/l)	Phosphates (mg/l)	Conductivity (μmhos/cm)
A, quench water	8.4-11.2	(†)	1860	1280	3140	120	420	460	230	0.5	3000
A, scrubber water	3.8-4.2	(†)	1350	5820	7170	1.0	2300	3430	720	51	7100
B, quench water	11.2-11.5	110	1300	2660	3960	720	680	980	120	38	–
B, scrubber water	4.8-6.5*	165	320	8840	9160	23	3540	2630	1250	13	–
C-1, scrubber water	2.6	(†)	110	540	650	0	270	110	110	4.4	1800
C-1, settling-tank water	2.6	(†)	120	500	620	0	280	110	80	4.1	970
C-2, scrubber water	2.6-3.4	(†)	90	450	540	0	200	150	100	4.1	1000
C-2, settling-tank water	2.4-3.6	(†)	180	480	660	0	230	120	70	6.0	850
C-3, precipitator drain water	3.6-4.0	(†)	1720	7360	9080	0	3200	1890	460	54	6000
C-3, settling-tank water	3.4-4.2	(†)	600	1300	1900	0	470	400	100	24	1600
D, quench water	5.9-7.1	(†)	460	2040	2500	600	360	550	280	21	2020
D, scrubber water	1.8-7.6	(†)	280	1740	2020	80	700	900	220	19	3640
E, tap water	8.4	(†)	0	56	56	100	7	33	1.0	0.1	46
E, quench water	3.9-7.0	120	900	590	1490	240	200	290	25	21	810
E, scrubber water	2.5-3.0	150	90	750	840	0	300	260	28	13	1360
E, final effluent water	4.5-6.9	110	85	570	655	110	200	270	33	4.9	750
F, tap water	5.9	(†)	0	75	75	74	4.0	46	5.0	0.2	46
F, quench water	5.4-7.1	68	760	360	1120	140	98	180	45	14	530
F, scrubber water	3.0-5.0	82	90	520	610	29	180	190	24	8.8	630

Table 8 (Cont'd)

Incinerator, Sample Source	pH	Temperature (°F)	Suspended Solids (mg/l)	Dissolved Solids (mg/l)	Total Solids (mg/l)	Alkalinity (mg/l $CaCO_3$)	Chlorides (mg/l)	Hardness (mg/l ($CaCO_3$)	Sulfates (mg/l)	Phosphates (mg/l)	Conductivity (μmhos/cm)
F, lagoon effluent water	5.8-7.9	65	580	320	900	140	94	180	–	9.3	430
G, well water	7.0-8.4	75	0	950	950	350	420	30	20	0.9	1550
G, spray water	6.6-10.3	104	740	2350	3090	260	1050	400	210	43	3780
G, fly-ash wash water	10.9-12.5	57	3180	890	4070	720	240	340	89	160	1690
G, quench water	9.4-10.9	88	450	1200	1650	470	450	95	53	16	1940
G, lagoon effluent water	9.4-10.3	70	40	1210	1250	310	450	100	70	3.1	1960

*Sample was obtained after soda-ash neutralization.
†No measurement made.

Table 9

Particulate-Emission Data

Incinerator	Particulate Emissions: gr/st ft³ at 12% CO_2	Particulate Emissions: lb/1000 lb at 50% excess Air	Particulate Emissions: lb/h	Particulate Emissions: lb/ton of Waste Charged	CO_2 %	Stack Temp. (°F)	Excess air (%)	Moisture (%)	Gas-Flow Rate (c ft³/min)
A	0.55	1.06	122	10.4	4.6	455	270	16.3	69,800
B	1.12	–	186	14.5	3.5	585	–	16.1	131,000
C-1	0.56	0.75	3.2	4.1	2.8	138	370	18.0	3,890
C-2	0.41	0.46	2.4	3.4	3.3	158	220	25.6	3,990
C-3	0.30	0.52	1.7	2.9	3.3	325	410	15.5	4,460
D	0.46	0.85	173	8.8	5.0	485	260	18.1	120,000
E	0.73	1.19	238	8.6	5.0	305	220	26.6	186,000
F	0.72	1.18	–	12.5	3.9	365	320	16.0	165,000
G	1.35	2.70	386	20.4	3.2	500	500	14.3	130,000

at F and G, lagoons achieved a 24 and 90 percent reduction, respectively. The poor achievement at F (24 percent) was due to the fact that the lagoon was filled with solids. These systems also reduced the alkalinity and phosphate concentrations; the chloride and hardness concentrations remained about the same.

These data indicate the necessity of treating incinerator wastewater before its discharge to a watercourse.

Particulate Emissions

The particulate-emission data (Table 9) are the average of the data collected during each study and reflect the design, operation, and air-pollution-control equipment of the particular plant at the time of the study. All calculations are based upon standard conditions of 29.92 in. mercury and 70°F. Particulate emissions are expressed in the most commonly used units: grains per standard cubic foot (gr/st ft^3) at 12 percent carbon dioxide, lb/1000 lb at 50 percent excess air, lb/h, and lb/ton of waste charged. No correction factor was used to account for any absorption of carbon dioxide that might have occurred in the water scrubbers when the grain loadings were adjusted to 12 percent carbon dioxide.

Comparison with Emission Standards

The particulate emission data, expressed in gr/st ft^3 at 12 percent carbon dioxide, are compared with the emission standards for Los Angeles County Air Pollution Control District, federal installations, and the State of New Jersey (Fig. 2) [6]. The data are also compared with ASME weight concentration standards (Fig. 3) [7]. The particulate-emission level of the revised ASME Model Smoke Ordinance varies since the ordinance allows smaller installations to emit more materials than larger installations. A comparison with New York State and with New York City weight-rate emission standards is illustrated (Fig. 4). These standards also vary with the size of the incinerator. The incinerators studied meet a standard if the bar chart for the incinerator falls below the line depicting the level of the standard. As can be seen from these comparisons, these incinerators with their existing air-pollution-control equipment fail to meet all but the weakest standards. Because the trend in air-pollution control is toward more stringent standards, more efficient air-pollution-control equipment will have to be applied to incinerators if they are to meet air-pollution-control regulations.

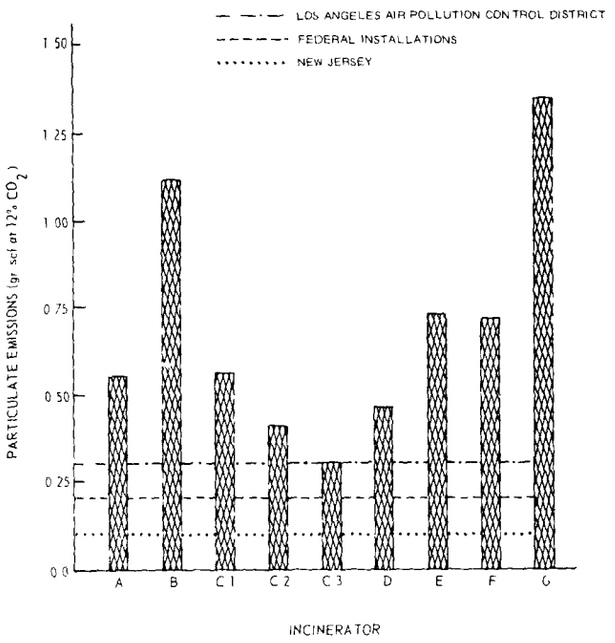


Fig. 2 Particulate-Emission Data Compared with Grain-Loading Emission Standards for Los Angeles County Air Pollution Control District, Federal Installations, and State of New Jersey

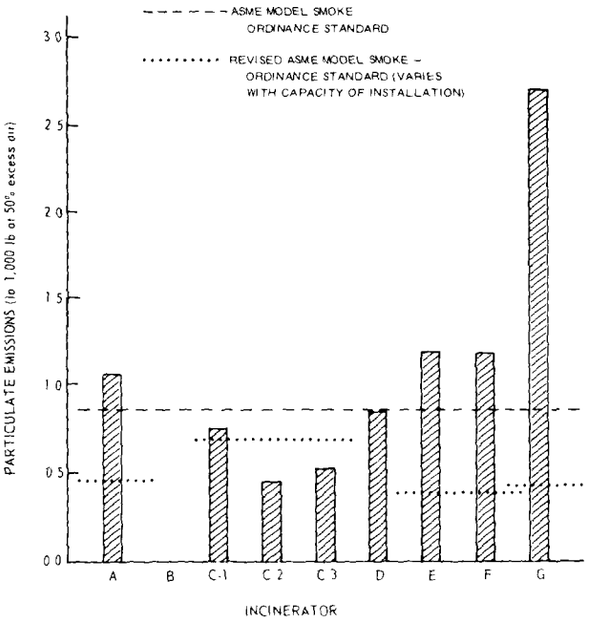


Fig. 3 Particulate-Emission Data Compared with ASME Weight-Concentration Emission Standards

Particulate Catch after the Filter

The recommended NAPCA sampling train and analytical procedures are used in our studies. NAPCA defines particulates as anything except uncombined water that would be a solid or liquid at standard conditions (70°F and 29.92 in. mercury). This definition focuses attention upon the material collected in the sampling train after the filter, which can be a significant portion of the total particulate catch (Table 10). To pass through the filter (MSA Type 1106 HB high-efficiency filter), this material must be submicron or in a gaseous state that condenses to a liquid or solid once it enters the cold region (70 to 100°F) in the impingers. To truly come within this definition of particulates, this material must not be formed by a reaction with other materials that would remain a gas if emitted to the atmosphere. Air-pollution experts disagree whether or not the material collected after the filter should be reported as particulates. Analyses of the material to identify it and its origin are needed to determine whether it should be reported as particulates.

Particulates caught after the filter include (1) residue left after evaporation of the acetone used to rinse the sampling train after the filter and before the impinger that contains the silica gel, (2) residue left after evaporation of the chloroform and ether used to

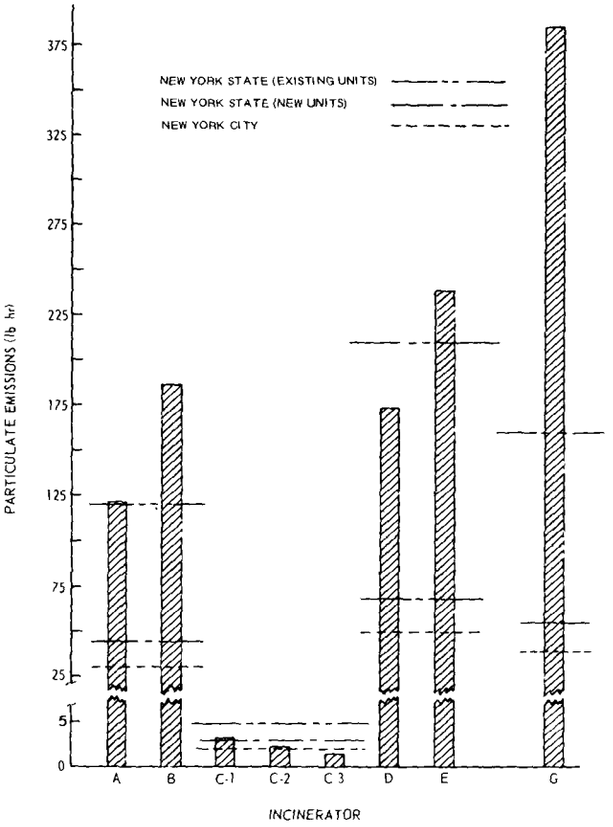


Fig. 4 Particulate-Emission Data Compared with New York State and New York City Weight-Rate Emission Standards

Table 10

Summary of Particulate-Catch Data

Incinerator	Particulate Catch after Filter as Percent of Total Particulates			Impinger-Water Particulates as Percent of Particulate Catch after Filter			Impinger-Water Particulates as Percent of Total Particulate Catch		
	High	Low	Average	High	Low	Average	High	Low	Average
A	23.7	7.7	16.1	93.7	35.8	68.3	16.4	5.5	10.4
B	19.0	0.7	13.6	81.2	69.7	74.1	14.9	4.8	10.6
C*	45.8	12.7	31.0	69.9	26.2	45.5	20.6	6.7	13.6
C-1†	34.5	20.7	28.1	83.3	73.3	81.0	25.2	17.2	22.0
C-2†	54.4	44.3	47.7	80.9	74.4	77.4	44.4	33.0	37.0
C-3†	75.6	70.8	73.3	86.7	45.6	72.0	64.0	34.7	52.9
D	18.7	4.0	11.7	92.8	47.3	78.0	15.2	1.9	9.5
E	35.4	27.6	31.1	93.8	90.7	92.2	34.1	25.7	28.9
F	28.2	16.4	21.1	88.9	77.1	83.1	25.0	13.2	18.0
G	31.6	18.2	26.4	43.3	17.4	31.5	10.6	5.4	8.0
Average	–	–	30.0	–	–	70.3	–	–	21.1

* Sample taken at inlet to air pollution control equipment.

† Sample taken at outlet from air pollution control equipment.

extract organic materials from the impinger water wash, and (3) residue after evaporation of the impinger water wash (Fig. 5).

In these studies, this material averaged 30.0 percent of the total particulate caught. In one study (C-3), however, it amounted to 73.3 percent. The four parts of the study at Incinerator C represent data taken at the inlet to the air-pollution-control systems (C), the outlet of the water scrubber (C_1), the outlet of the water scrubber with the afterburner in operation (C_2), and the outlet of the electrostatic precipitator (C_3). The percent of material caught after the filter increased with collector efficiency, which indicates the amount caught depends on the type of air-pollution-control device. Undoubtedly other factors such as the operation, dust loading, and particle size of the dust may also affect the amount of material, although data are insufficient to prove this contention.

Acetone Wash and Chloroform-Ether Extract Residues

The residues from the acetone wash and from the chloroform-ether extracts averaged 29.7 percent of the material caught after the filter since the residue from the impinger water wash averaged 70.3 percent.

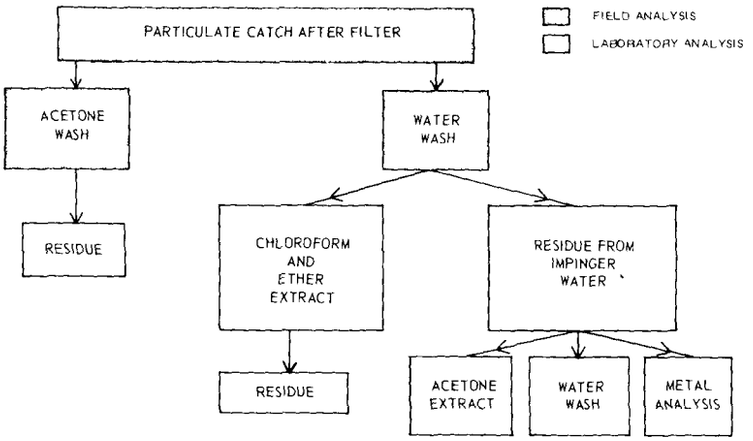


Fig. 5 Analysis of Particulate Catch after Filter

Table 11

Emission Spectrographic Analysis of Impinger-Water Residue for Metals

Element	Quantity (ppm by weight) Sample No. 1	Sample No. 2	Element	Quantity (ppm by weight) Sample No. 1	Sample No. 2
Barium	<0.5	<0.5	Tin	<0.5	<0.5
Manganese	<0.5	<0.5	Copper	2	2
Magnesium	12	13	Silver	<0.5	<0.5
Molybdenum	<0.5	<0.5	Zinc	60	110
Lead	2	1	Cobalt	<0.5	<0.5
Chromium	<0.5	<0.5	Titanium	0.5	0.5
Nickel	<0.5	0.5	Cadmium	<1	<1
Iron	6	6	Vanadium	<0.5	<0.5
Aluminum	35	12	Potassium	0.6	1
Calcium	375	400			

Impinger Water Residues

In an effort to identify residue from the impinger water, two samples from Study G were analyzed spectrographically. The results of this analysis (Table 11) indicate that approximately 0.05 percent of the impinger water residue was metal.

In addition, all eight impinger residue samples from Study F were combined into one sample for wet-chemical analysis for inorganics and instrumental analysis for organics, and 15 impinger residue samples from Study G were combined and analyzed in a similar manner. Approximately 28 and 43 percent, respectively, of these residues were acetone soluble (Table 12). Sulfates were present in approxiamtely 32 and 20 percent, respectively. The acetone extract of both samples showed carbonyl and aromatic bands in the infrared (presumably derived from polynuclear compounds). No hydroxyl or aliphatic bands were noted.

These analyses of the material caught after the filter indicate that perhaps some of it should be reported as particulates and some should not. The organics and metals would probably condense in the atmosphere to form particulates. The chlorides, sulfates, and phosphates may be formed by gases reacting with cations to form particulates while in close contact in the impinger water. If so, they probably would not react if emitted to the atmosphere and would not fall within the category of particulates. Further work is needed on identifying composition of impinger water residues and their origin since this work was primarily screening.

INCINERATOR EFFICIENCY

The efficiencies of the incinerators studied were measured by calculating the reduction in weight, volume, volatiles, and the amount of available heat released (Table 13). The weight reduction is calculated from the dry weights of solid waste, residue, and fly ash. The volatile reduction is calculated from the volatile content of these materials, and the heat released is based upon their heat content. The volume reduction was calculated from the wet densities and weights of solid waste and residue.

Although the amount of solids in the wastewater should be included in efficiency calculations, the quantity of wastewater was not measured and cannot be included. Estimates indicate this effect is small.

For all practical purposes, no real distinction can be made between any of the incinerators studied when efficiencies are based on volatile or volume reduction or heat released. It should be pointed out, however, that the incinerators studied were selected because they were noted for achieving "good burnout". Because the degree of weight reduction is inversely proportional to the amount of noncombustibles in the waste, it is not a good indicator of incinerator efficiencies. Better indicators are the volatile and volume reduction and the amount of available heat released.

Table 12

Analyses of Impinger-Water Residue

Analysis	Incinerator F	Incinerator G
Acetone extract	28.3%	42.9%
Chloride	1.0%	0.3%
Sulfate	31.8%	20.1%
Phosphate	0.2%	0.2%
Hardness	25.4%	4.5%
Iron	strong	percent
pH of water solution	2.8	3.0

Economics

Annual Costs

The actual annual costs for the municipal-sized incinerators (A, B, D, E, F, and G) varied from $171,838 to $675,864 (Table 14) and correspond to unit costs from $4.02 to $6.69 per ton of waste processed. Incinerator C was a pilot plant, and meaningful cost data were not available.

Table 13

Incinerator Efficiency

Incinerator	Weight Reduction (%)	Volatile Reduction (%)	Heat Released (%)	Volume Reduction (%)
A	61	98	98	(*)
B	68	99	99	(*)
C	62	99	99	(*)
D*	–	–	–	–
E	63	98	97	95
F	72	97	96	97
G	53	99	99	94

* Measurements not made.

Table 14

Annual Cost Data

Item	Incinerator A				Incinerator B				Incinerator D			
	Normal Capacity		Design Capacity		Normal Capacity		Design Capacity		Normal Capacity		Design Capacity	
	Actual	Adjusted	Projected	Adjusted	Actual	Adjusted	Projected	Adjusted	Actual	Adjusted	Projected	Adjusted
Operating costs:												
Direct labor	$75,184	$73,703	$112,776	$110,555	$197,500	$185,730	$197,500	$185,730	$193,138	$186,301	$193,138	$186,301
Utilities	17,352	17,352	35,135	34,135	20,000	20,000	25,850	25,850	18,000	18,000	19,301	19,301
Parts and supplies	12,509	12,509	24,608	24,608	32,950	32,950	42,580	42,580	0	0	0	0
Vehicle operations	1,739	1,739	3,421	3,421	7,200	7,200	9,300	9,300	7,670	7,670	8,225	8,225
External repairs	7,346	7,346	14,451	14,451	6,250	6,250	8,080	8,080	22,339	22,339	23,954	23,954
Disposal charges	700	700	1,377	1,377	2,000	2,000	2,580	2,580	32,232	32,232	34,562	34,562
Overhead	11,326	11,326	11,326	11,326	52,800	52,800	52,800	52,800	32,959	32,959	32,959	32,959
Total operating cost	126,156	124,675	202,094	199,873	318,700	306,930	338,690	326,920	306,338	299,501	312,139	305,302
Operating cost/ton	2.95	2.92	2.41	2.38	4.90	4.72	4.03	3.89	2.35	2.29	2.23	2.18
Financing& ownership costs:												
Plant depreciation	23,581	21,651	23,581	21,651	80,149	84,842	80,149	84,842	200,000	142,572	200,000	142,572
Vehicle depreciation	6,042	6,042	6,042	6,042	9,675	9,675	9,675	9,675	0	0	0	0
Interest	16,059	32,477	16,059	32,477	64,558	127,262	64,558	127,262	70,448	213,858	70,448	213,858
Total financing and ownership cost	45,682	60,170	45,682	60,170	154,382	221,779	154,382	221,779	270,448	356,430	270,448	356,430
Financing and ownership cost/ton	1.07	1.41	0.54	0.72	2.38	3.41	1.84	2.64	2.07	2.73	1.93	2.55
Total cost	171,838	184,845	247,776	260,043	472,082	528,709	492,072	548,699	576,786	655,931	582,587	661,732
Total cost/ton	4.02	4.33	2.95	3.10	7.28	8.13	5.87	6.53	4.42	5.02	4.16	4.73

Table 14 (Cont'd)

Item	Incinerator E				Incinerator F				Incinerator G			
	Normal Capacity		Design Capacity		Normal Capacity		Design Capacity		Normal Capacity		Design Capacity	
	Actual	Adjusted	Projected	Adjusted	Actual	Adjusted	Projected	Adjusted	Actual	Adjusted	Projected	Adjusted
Operating costs:												
Direct labor	$202,407	$205,139	$202,407	$205,139	$165,684	$181,391	$165,684	$181,391	$150,949	$145,434	$160,949	$145,434
Utilities	65,260	65,260	90,418	90,418	67,632	67,632	70,500	70,500	31,952	31,952	75,777	75,777
Parts and supplies	57,332	57,332	79,433	79,433	51,540	51,540	53,725	53,725	2,700	2,700	6,403	6,403
Vehicle operations	4,188	4,188	5,802	5,802	9,600	9,600	10,007	10,007	13,968	13,968	33,127	33,127
External repairs	1,999	1,999	2,770	2,770	12,758	12,758	13,299	13,299	808	808	1,916	1,916
Disposal charges	0	0	0	0	10,364	10,364	10,803	10,803	27,720	27,720	65,741	65,741
Overhead	123,577	123,577	123,577	123,577	84,674	84,674	84,674	84,674	21,331	21,331	21,331	21,331
Total operating cost	454,763	457,495	504,407	507,139	402,252	417,959	408,692	424,399	259,428	243,913	365,244	349,729
Operating cost/ton	4.50	4.53	3.60	3.62	2.49	2.59	2.43	2.53	5.49	5.17	3.26	3.12
Financing& ownership costs:												
Plant depreciation	110,726	168,574	110,726	168,574	80,000	121,795	80,000	121,795	101,234	111,722	101,234	111,722
Vehicle depreciation	3,516	3,516	3,516	3,516	0	0	0	0	0	0	0	0
Interest	106,859	252,860	106,859	252,860	75,840	182,693	75,840	182,693	81,494	167,583	81,494	167,583
Total financing and ownership cost	221,101	424,950	221,101	424,950	155,840	304,488	155,840	304,488	182,728	279,305	182,728	279,305
Financing and ownership cost/ton	2.19	4.20	1.58	3.04	0.97	1.89	0.93	1.81	3.87	5.91	1.63	2.50
Total cost	675,864	882,445	725,508	932,089	558,092	722,447	564,532	728,887	442,156	523,218	547,972	629,034
Total cost/ton	6.69	8.73	5.18	6.66	3.46	4.48	3.36	4.34	9.36	11.08	4.89	5.62

The adjusted projected annual cost at design capacity was also determined (Table 14). All incinerators were operated below design capacity on an annual basis because of insufficient waste or equipment downtime; this was not true, however, during the study periods. The projected costs were determined by prorating costs that depend on the quantity of material processed (actual vs. design). The costs that vary with the amount of material processed are utilities, parts and supplies, vehicle operations, external repair charges, and residue disposal charges. With one exception (Incinerator A), labor costs did not increase significantly with the amount of waste processed because all facilities studied were staffed for operation at full capacity. Incinerator A was operating on a two-shift basis, and projection to design capacity required the addition of another shift. To determine the annual design capacity, the daily design capacity was multiplied by 280 operating days. To illustrate this projection, Incinerator A, with a design capacity of 84,000 tons/year (300 tons/day × 280 days), actually processed 42,700 tons of waste. The projected utility costs for processing 84,000 tons was $34,135, an increase from the actual cost, $17,352.

The projected annual cost data were also adjusted to a common reference point so that the data from the various incinerators could be compared (Table 14). The primary items requiring adjustment are labor costs, plant depreciation, and interest. To adjust labor cost to reflect similar wage rates, the actual cost was multiplied by $3.00 and divided by the average hourly labor cost for the facility (which for Incinerator A was $3.06). Thus, the adjusted labor

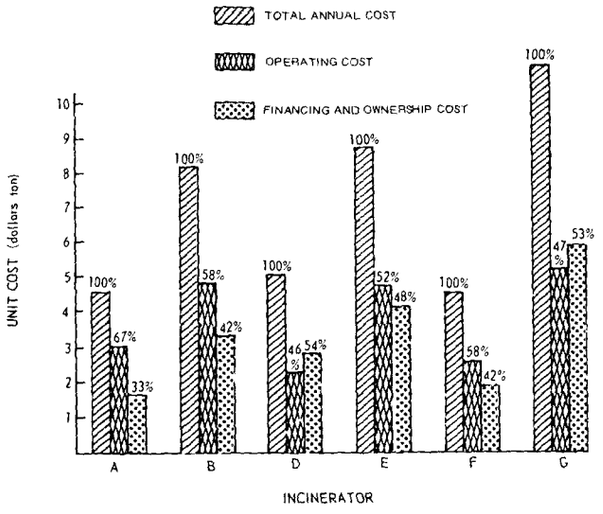


Fig. 6 Total Annual Costs of Incinerators

cost for Incinerator A was $73,703, down from the actual cost of $75,184. To adjust the plant depreciation and interest charges, it was assumed that plant life is 25 years, simple interest charges are 6 percent, and construction started 2 years before the facility began operating. Capital costs were adjusted to the year 1967 with the use of a construction cost index. This construction cost index was developed from three sources [8-10]. Unpublished data developed by the American Society of Civil Engineers and The American Society of Mechanical Engineers show that the capital costs for constructing incinerators are divided between building and equipment in a 60:40 ratio [8]. As a result, 60 percent of a building cost index [9] and 40 percent of an equipment cost index [10] were used to develop the facility cost index:

Year	Index
1967	1.0000
1966	1.0526
1965	1.1036
1964	1.1476
1963	1.1881
1962	1.2326
1961	1.2687

To adjust interest charges, the adjusted capital costs were multiplied by the 6 percent interest charged. For Incinerator A, the adjusted interest charges were $32,477, up from the actual $16,059. To calculate the adjusted plant depreciation, the adjusted capital costs were divided by the assumed 25-year plant life.

Comparison of adjusted annual costs for a per ton of solid waste processed shows that financing and ownership costs (Fig. 6) are a significant portion of the total costs.

Comparison of actual costs with projected costs shows the effect of operating the incinerator at less than design capacity (Fig. 7). Operating an incinerator at less than design capacity, as shown by the data for Incinerator G, can be quite expensive. (Note that the data for Incinerator G were for the first year of operation and that the facility presently operates near design capacity.)

When a new incinerator is designed, facilities for handling future quantities of waste should be carefully considered. If the size of the plant is too large, it is implied that the cost of "idle" equipment may be excessive. These data tend to reinforce the concept of building a facility to dispose of the current amount of solid waste with provisions for adding

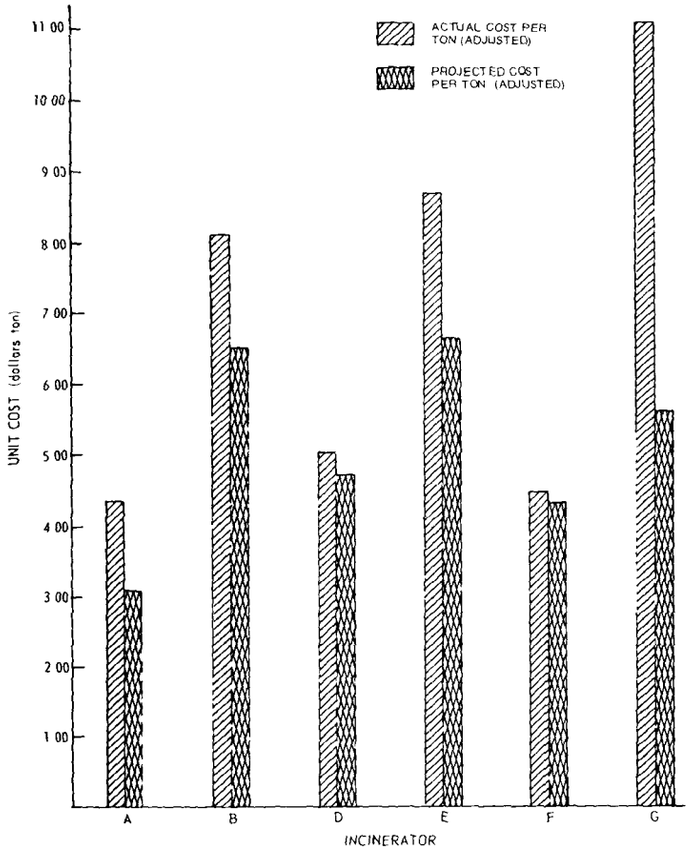


Fig. 7 Projected Costs at Design Capacity and Actual Costs of Incinerators

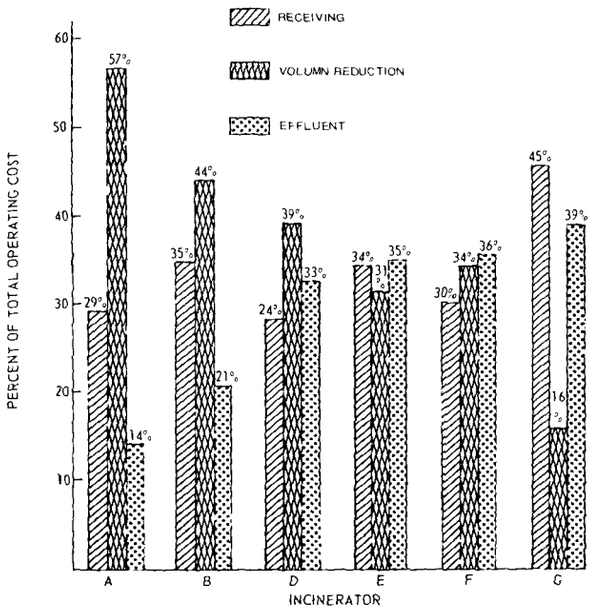


Fig. 9 Percentage Distribution of Operating Costs by Cost Center

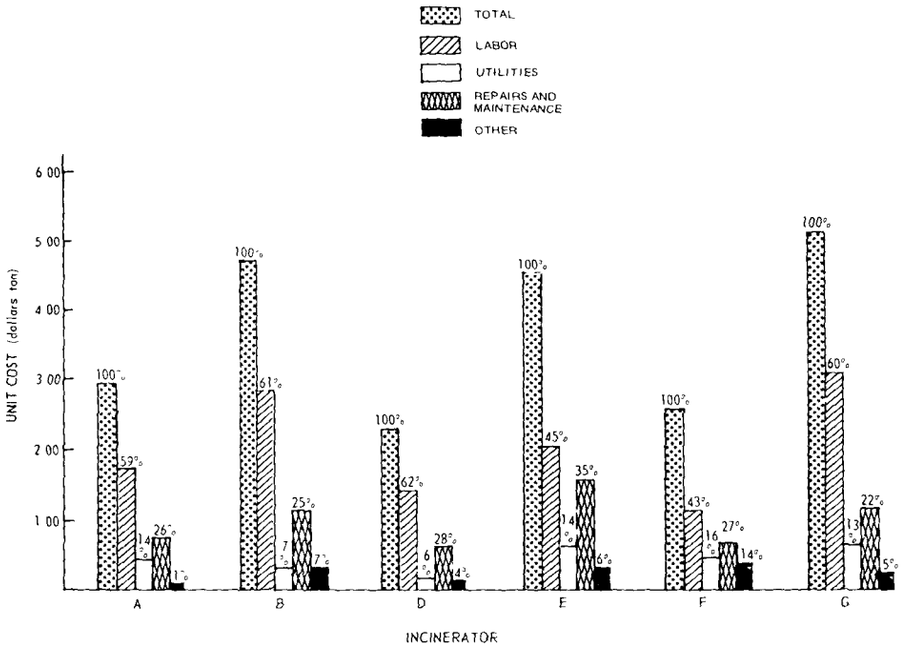


Fig. 8 Operating-Cost Breakdown by Expenditure Type

additional combustion units as required. This is too simple a picture, however; increasing construction and interest costs may override this concept.

Capital Costs

Capital investment in the incinerators studied varied from $1,800 to $8,400 per ton of design capacity (Table 15). Because Incinerator A did not have scales, residue quench tanks, a crane (charging was with a front-end loader), or a storage pit, the capital requirements were obviously less.

Table 15

Analysis of Capital Investment

Incinerator	Actual Cost	Adjusted Cost	Adjusted Cost/Ton
A	$471,659	$541,276	$1804
B	1,848,240	2,121,040	7070
D	3,000,000	3,564,300	7129
E	3,321,779	4,214,341	8429
F	2,400,000	3,044,880	5075
G	2,530,855	2,793,052	6983

To identify the capital costs further, investments in buildings, equipment, and miscellaneous items were analyzed (Table 16). (Note that the incinerators analyzed were very different in construction and design.)

Table 16

Breakdown of Capital Investment

Plant	Adjusted Cost	Percent of Total
Incinerator A:		
Buildings	$191,979	35.5
Equipment	333,977	61.7
Miscellaneous	15,320	2.8
Total	541,276	100.0
Incinerator B:		
Buildings	1,428,119	67.3
Equipment	530,593	25.0
Miscellaneous	162,328	7.7
Total	2,121,040	100.0
Incinerator E:		
Buildings	1,312,506	31.2
Equipment	2,711,198	64.3
Miscellaneous	190,637	4.5
Total	4,214,341	100.0

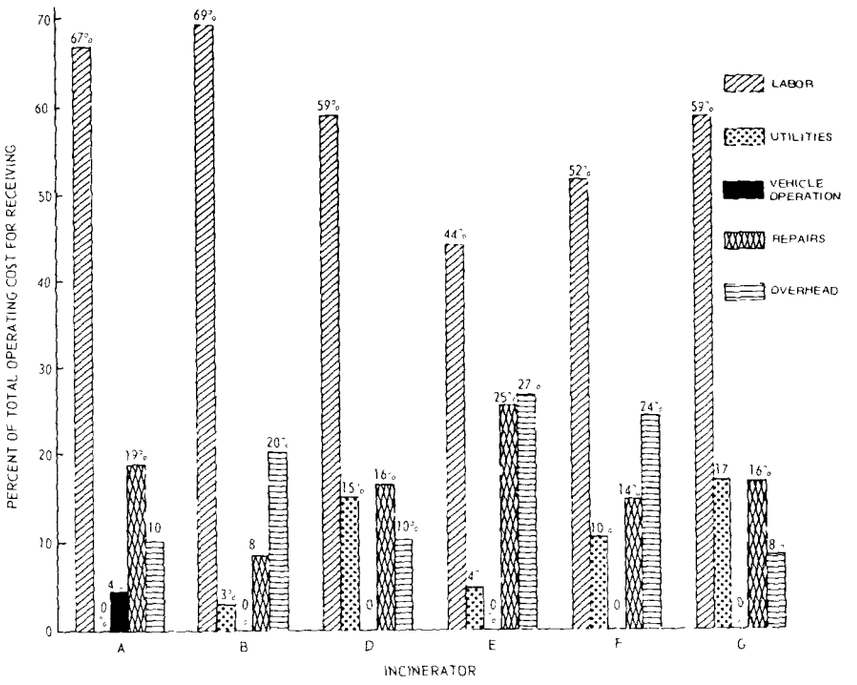


Fig. 10 Receiving Cost Center. Percentage Distribution of Operating Costs by Expenditure Type

Table 17

Repairs and Maintenance Cost Data

Item	Incinerator A		Incinerator B		Incinerator D		Incinerator E		Incinerator F		Incinerator G	
	Actual	Adjusted	Actual	Adjusted	Actual	Adjusted	Actual	Adjusted	Actual	Adjusted	Actual	Adjusted
	Expenditures											
Expenditure type:												
Labor	$10,442	$10,237	$29,625	$27,861	$53,590	$51,695	$61,335	$62,164	$31,679	$34,685	$44,003	$39,762
Parts	12,509	12,509	32,951	32,951	0	0	57,332	57,332	51,540	51,540	2,700	2,700
External charges	7,346	7,346	6,250	6,250	22,339	22,339	1,999	1,999	12,758	12,758	808	808
Overhead	1,574	1,574	7,919	7,919	9,145	9,145	37,447	37,447	16,189	16,189	6,799	6,799
Total	31,871	31,666	76,745	74,981	85,074	83,179	158,113	158,942	112,166	115,172	54,310	54,069
	Allocation											
Cost center:												
Receiving and handling	$6,824	$6,780	$9,112	$8,903	$13,766	$13,460	$39,345	$39,552	$17,960	$18,442	$18,642	$17,187
Volume reduction	21,641	21,502	56,825	55,518	60,109	58,770	85,597	86,045	77,804	79,888	17,834	16,441
Effluent handling & treatment	3,406	3,384	10,808	10,560	11,199	10,949	33,171	33,345	16,402	16,842	17,834	16,441
Total	31,871	31,666	76,745	74,981	85,074	83,179	158,113	158,942	112,166	115,172	54,310	50,069

Table 18

Operating Cost Breakdown by Cost Centers

Cost Center	Incinerator A		Incinerator B		Incinerator D		Incinerator E		Incinerator F		Incinerator G	
	Actual	Adjusted	Actual	Adjusted	Actual	Adjusted	Actual	Adjusted	Actual	Adjusted	Actual	Adjusted
Receiving and handling:												
Direct labor	$25,062	$24,568	$79,000	$74,290	$51,942	$50,103	$67,470	$68,381	$59,294	$64,915	$73,360	$66,288
Utilities	0	0	3,020	3,020	12,600	12,600	6,964	6,964	12,715	12,715	18,720	18,720
Vehicle operating expense	1,564	1,564	0	0	0	0	0	0	0	0	0	0
Repairs and maintenance	6,824	6,824	9,112	9,112	13,766	13,766	39,345	39,345	17,960	17,960	18,642	18,642
Overhead	3,775	3,775	21,119	21,119	8,864	8,864	41,192	41,192	30,302	30,302	9,081	9,081
Total	37,225	36,731	112,251	107,541	87,172	85,333	154,971	155,882	120,271	125,892	119,803	112,731
Volume reduction:												
Direct labor	35,504	34,805	59,250	55,720	48,451	46,736	30,667	31,081	34,226	37,471	14,260	12,885
Utilities	8,597	8,597	7,480	7,480	2,700	2,700	7,724	7,724	8,251	8,251	6,193	6,193
Repairs and maintenance	21,641	21,641	56,826	56,826	60,108	60,108	85,597	85,597	77,804	77,804	17,834	17,834
Overhead	5,348	5,348	15,839	15,839	8,268	8,268	18,725	18,725	17,492	17,492	1,819	1,819
Total	71,090	70,391	139,395	135,865	119,527	117,812	142,713	143,127	137,773	141,018	40,106	38,731
Effluent handling and treatment:												
Direct labor	4,176	4,094	29,625	27,860	39,156	37,770	42,935	43,515	40,485	44,323	29,325	26,498
Utilities	8,755	8,755	9,500	9,500	2,700	2,700	50,572	50,572	46,666	46,666	77,039	7,039
Vehicle operating expense	175	175	7,200	7,200	7,670	7,670	4,188	4,188	9,600	9,600	13,968	13,968
Disposal charges	700	700	2,000	2,000	32,232	32,232	0	0	10,364	10,364	27,720	27,720
Repairs and maintenance	3,406	3,406	10,809	10,809	11,199	11,199	33,171	33,171	16,402	16,402	17,834	17,834
Overhead	629	629	7,920	7,920	6,682	6,682	26,213	26,213	20,691	20,691	3,632	3,632
Total	17,841	17,759	67,054	65,289	99,639	98,253	157,079	157,659	144,208	148,046	99,519	96,691
Total	126,156	124,881	318,700	308,695	306,338	301,398	454,763	456,668	402,252	414,956	259,428	248,153

Operating Costs

The operating costs were analyzed to determine the relationship between labor, utility, and repair and maintenance costs. In all cases, labor costs were highest and utility costs, lowest (Fig. 8). A breakdown of the repair and maintenance costs and allocation to cost centers was made (Table 17).

Analysis of operating costs by cost centers shows no real trend between the three cost centers (Table 18, Fig. 9). Analysis of the operating cost for the receiving cost center shows, however, that

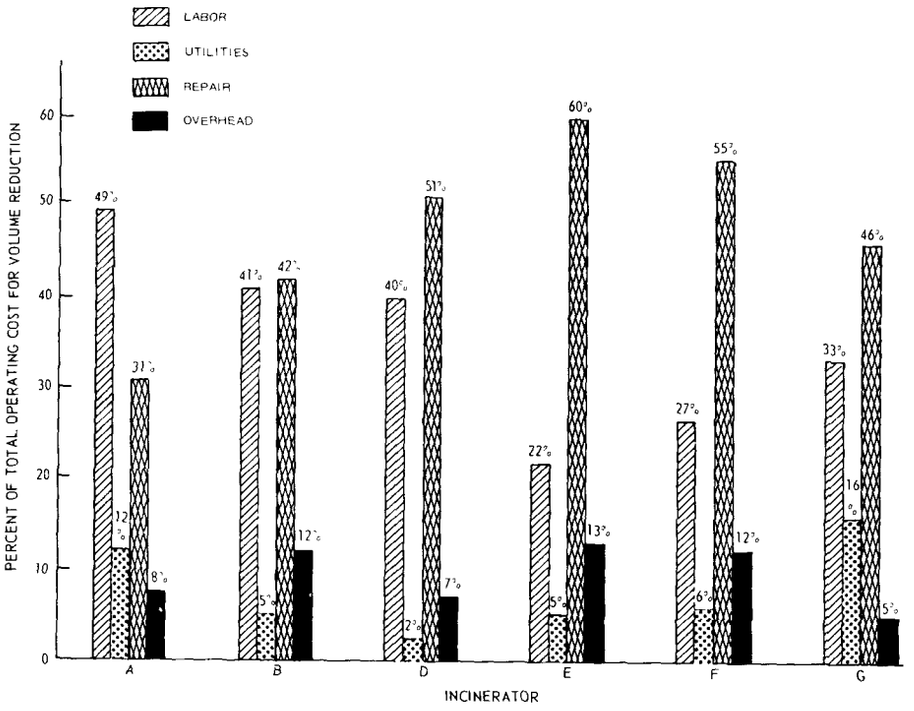


Fig. 11 Volume-Reduction Cost Center: Percentage Distribution of Operating Costs by Expenditure Type

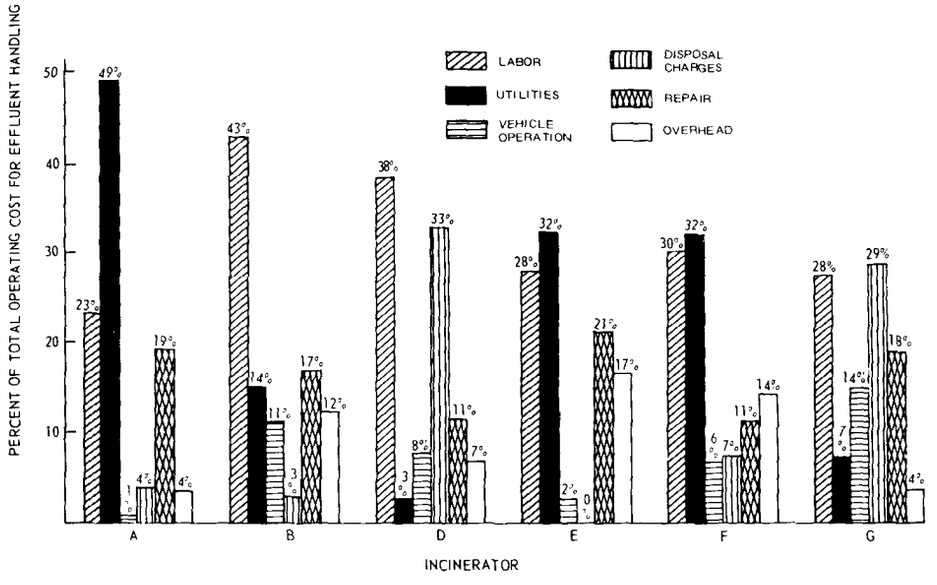


Fig. 12 Effluent-Handling Cost Center: Percentage Distribution of Operating Costs by Expenditure Type

labor costs average 58 percent and far exceeded all other costs (Fig. 10). This would tend to indicate that costs in this center might be reduced by automating the operations. Analysis of operating costs for the volume-reduction cost center shows that labor and repair costs are the major expenditures and average 35 and 47 percent, respectively (Fig. 11). Analysis of operating costs for the effluent handling cost center shows no definite trend between the various items (Fig. 12).

CONCLUSIONS

For disposal of solid waste, these incinerators functioned well; reduction of volume and volatiles and the amount of heat released were greater than 94 percent in all cases and in some cases approached 99 percent.

The proper treatment and disposal of incinerator effluents has generally been neglected at these facilities. Process waters were contaminated, and, although several plants have primary treatment facilities, further treatment is required before discharge to a watercourse. Particulate emissions were in excess of all but the most lenient air-pollution-emission standards. The quality of the effluents could be improved, however, by increasing investment in pollution-control equipment.

Labor costs were the major portion of operating costs at every facility. Capital costs varied widely at these facilities without affecting the quality of the effluents.

ACKNOWLEDGMENTS

The excellent assistance and cooperation extended by the staffs of the seven incinerators, including administrative personnel, contributed to the successful completion of these studies. The analytical support, laboratory assistance, and facilities provided by county and State health departments, sanitation authorities, and universities are greatly appreciated.

The credit for the success of these studies belongs to the study team members. Among others, the authors would like to acknowledge the efforts of J. Giar, A. O'Connor, I. Cohen, J. Hahn, T. Hegdahl, R. Perkins, and J. Bridges, all of the Bureau of Solid Waste Management.

REFERENCES

[1] D. E. Carruth and A. J. Klee, "Analysis of Solid Waste Composition; Statistical Technique to Determine Sample Size," U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio, 1969.

[2] "Standard Methods for the Examination of Water and Wastewater; Including Bottom Sediments and Sludges," American Public Health Association, American Water Works Association, and Water Pollution Control Federation, American Public Health Association, Inc., New York, N.Y., 12th ed., 1965.

[3] "Specifications for Incinerator Testing at Federal Facilities," National Center for Air Pollution Control, U.S. Department of Health, Education, and Welfare, Durham, N. C., October 1967.

[4] E. R. Zausner, "An Accounting System for Incinerator Operations," U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio, 1969.

[5] E. Zausner and R. L. Helms, "Computerized Economic Analysis for Incineration," U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio, (In press).

[6] T. L. Stumph and R. L. Duprey, "Trends in Air Pollution Control Regulations," paper presented at 62nd Annual Meeting, Air Pollution Control Association, New York, June 22-26, 1969.

[7] "Air Pollution Control Standards for Particulate Emissions," National Air Pollution Control Administration, Training Lecture Outline for Elements of Air Quality Management Course; U.S. Department of Health, Education, and Welfare, 1966.

[8] Unpublished data for the years 1940 to 1956, Solid Waste Engineering Section, Committee on Sanitary Engineering Research, ASCE, unpublished data for the years 1953 to 1968, Task Group of design Subcommittee, ASME.

[9] "Indexes for Updating the Costs of General or Special Buildings," *Engineering News Record*, vol. 180, no. 12, March 21, 1968, pp. 84-85.

[10] "General Purpose Machinery and Equipment (Code 11-4) Wholesale Price Index," U.S. Department of Labor, Bureau of Labor Statistics, Washington, D. C., March 1966.

APPENDIX: PHYSICAL DESCRIPTIONS OF INCINERATORS STUDIED

Incinerator A

Year Built – 1966.
Design Capacity (tons/24 h) – 300.
Solid-Waste Storage and Charging System – Dumped on enclosed tipping floor and transported to charging hoppers by a front-end loader; continual feed from hoppers by conveyors.
Furnace Type and Components – Two refractory-lined, multiple-chambered furnaces with inclined, modified reciprocating grate sections followed by stationary grate sections.
Air-Draft System – An 11,000-ft 3/min forced-draft underfire-air fan and a 57,000-ft^3/min induced-draft fan per furnace; no overfire air.
Residue-Handling System – Common chain flight conveyor for both furnaces; partial spray quenching.
Air-Pollution-Control System – Wet scrubber impingement on 42 12-in. diameter wetted columns.
Effluent-Water Systems – Residue-quenching water flows to complete retention lagoons. Fly-ash scrubbing water flows to settling basins and then to complete retention lagoons.
Date Studied – April 1968.
Location – Western United States.

Incinerator B

Year Built – 1966.
Design Capacity (tons/24 h) – 300.
Solid-Waste Storage and Charging System – Enclosed tipping floor; 3,000-yd^3 storage pit; one bridge crane with grapple bucket; two charging hoppers.
Furnace Type and Components – Two refractory-lined, multiple-chambered furnaces with three sections of inclined rocking grates.
Air-Draft System – Two 19,000-ft^3/min forced-draft fans for each furnace and one 200-ft-tall stack for natural draft.
Residue-Handling System – Quench tank with chain flight conveyor; duplicate system available.
Air-Pollution-Control System – Wet scrubber: flooded baffle walls.
Effluent-Water Systems – Fly-ash scrubbing water receives pH adjustment, detention in settling basin, and is discharged weekly to sewerage system. Residue-quench water is detained in settling basin and discharged weekly to sewerage system.
Date Studied – May 1968.
Location – Eastern United States.

Incinerator C

Year Built – 1967.
Design Capacity (tons/24 h) – 5 to 6 (1000 lb/h for 10 to 12 h).
Solid-Waste Storage and Charging System – Pilot plant; no permanent storage; charging by screw conveyor from hopper.
Furnace Type and Components – Conical burner; double metal walls; fixed grates.

Air-Draft System – An 1,800-ft^3/min forced draft underfire-air fan and 3600- (water scrubber) or 5000-ft^3/min (electrostatic precipitator) induced-draft fan.
Residue-Handling System – Manual cleanout after cooling period.
Air-Pollution-Control Systems – Water scrubber: centrifugal type; afterburner and water scrubber; electrostatic precipitator.
Effluent Water Systems – Fly-ash scrubbing water flows to settling basin and final discharge to open watercourse.
Date Studied – July 1968.
Location – Southern United States.

Incinerator D

Year Built – 1965.
Design Capacity (tons/24 h) – 500.
Solid-Waste Storage and Charging System – Open tipping floor; two storage pits; two bridge cranes; two charging hoppers.
Furnace Type and Components – Two refractory-lined, multiple-chambered furnaces with two sections of traveling grates (one inclined and one horizontal).
Air-Draft System – Forced-draft fan and natural draft from 200-ft-tall stack for each furnace.
Residue-Handling System – Quench tank with chain flight conveyor; duplicate system available.
Air-Pollution-Control System – Wet scrubber: flooded baffle walls.
Effluent-Water Systems – All process water flows through a settling basin and then to sewerage system.
Date Studied – October 1968.
Location – Midwestern United States.
Comments – One of two furnaces was out of operation during the week of the study; in an effort to process as much waste as possible, the other furnace was overloaded.

Incinerator E

Year Built – 1963.
Design Capacity (tons/24 h) – 500.
Solid-Waste Storage and Charging System – Open tipping floor; 5150-yd^3 storage pit; two bridge cranes; two charging hoppers.
Furnace Type and Components – Two furnaces with three reciprocating grate sections followed by a rotary kiln.
Air-Draft System – A 25,000-ft^3/min forced-draft, underfire-air fan per furnace and one 200-ft-tall stack for natural draft.
Residue-Handling System – Residue-quench tank with chain flight conveyor; duplicate system available.
Air-Pollution-Control System – Wet scrubber: water sprays and a baffle wall.
Effluent-Water Systems – Fly-ash scrubbing water is also used for residue quenching; it then flows through a grit chamber before discharge to open watercourse.
Date Studied – December 1968.
Location – Southern United States.

Incinerator F

Year Built – 1963.
Design Capacity (tons/24 h) – 600.
Solid-Waste Storage and Charging System – Open tipping floor; 2430-yd^3 storage pit; two bridge cranes; two charging hoppers.
Furnace Type and Components – Two furnaces with three reciprocating grate sections followed by a rotary-kiln section.
Air-Draft System – A 25,000-ft^3/min forced-draft, underfire-air fan per furnace and one 200-ft-tall stack for natural draft.
Residue-Handling System – Residue-quench tank with chain flight conveyor; duplicate system available.
Air Pollution Control System – Wet scrubber: water sprays and a baffle wall.
Effluent Water Systems – Fly-ash scrubbing water is also used for residue quenching: it then flows through a lagoon before discharge to open watercourse.
Date Studied – December 1968.
Location – Southern United States.
Comments – One of the two furnaces was out of operation during the study.

Incinerator G

Year Built – 1967.
Design Capacity (tons/24 h) – 400.
Solid-Waste Storage and Charging System – Open tipping floor; 1750-yd^3 storage pit; one bridge crane; two charging hoppers.
Furnace Type and Components – Two furnaces with four sections of inclined reciprocating grates.

Air-Draft System – A 20,000-ft^3 min forced-draft underfire air, 24,000-ft^3 min forced-draft overfire air, and 120,000-ft^3 min induced-draft fan per furnace.

Residue-Handling System – Residue quench tank with chain flight conveyor; duplicate system available.

Air-Pollution-Control System – Multitube dry cyclones following a wet-baffle wall.

Effluent-Water Systems – All process waters enter residue-quench tank and then go to a lagoon with discharge to a canal.

Date Studied – February 1969.

Location – Southern United States.

An Evaluation of Seven Incinerators

W.C. ACHINGER and L.E. DANIELS

DISCUSSION by David L. Brenchley, Purdue University, Lafayette, Ind.

The authors and their colleagues are to be complimented on their efforts on this rather ambitious project. As indicated by the authors, there is a great need for such operational and cost information.

In conducting their evaluation the authors found and reported their frustrations concerning the need for standardized methods for incinerator testing and evaluation. Unfortunately this project became entangled with the problems of sampling, analysis, and testing methodology. Since standard methods do not exist at this time, I feel the authors should have been more detailed in describing the procedures used.

One of the objectives of this study was to evaluate the potential impact of the incinerator operation on the environment. This has not been adequately achieved! Some process water quality tests are reported in Table 8 but there is no information on quantities of water used. With respect to air pollution, only measurements for particulate matter, carbon monoxide, carbon dioxide and oxygen were reported. Obviously, more measurements should have been taken to properly evaluate the air pollution potential.

The use of the "cost center" approach is most enlightening, as indicated in Tables 14, 17, and 18. However, it should be noted that none of the municipal incinerators tested met the particulate emission standards established by regulative organizations such as Los Angeles and the state of New Jersey. It would be most interesting to know what the total cost per ton would be if these installations were required to meet these air pollution control regulations.

Finally, I wish to emphasize that the cost information presented should not be used as the basis for selecting a particular incinerator design. The variation of waste composition, differing operational characteristics, and the test methodology itself strongly influence the results.

DISCUSSION by P. B. Hall, Director of Public Works, City of Alexandria, Va.

The subject paper "An Evaluation of Seven Incinerators" presents data relating to design, operation and costs which should be carefully considered in future incinerator design. It is impossible, in the time allotted, to fully discuss the paper; too many important factors are contained in it.

I would like to confine my remarks to two particular sections of the paper; the section on Stack Effluents and the section on Costs.

Referring to the Stack Effluent tests, I am not satisfied that the present techniques for sampling will give accurate or even meaningful results. While I do not quarrel with the conclusion that more sophisticated methods of pollution control must be eventually instituted, I feel that the data presented in the paper give an unfair picture of the actual operating results. Until a system of collecting flue gases on a constantly monitored basis is evolved, intermittent stack tests cannot be relied upon. The constantly varying nature of the fuel, climatic conditions occurring during the test and variations in operating procedures to properly burn a non-homogeneous fuel make such intermittent tests indicative only of a particular condition under particular circumstances. The need for a permanently installed fly ash monitoring system must receive priority consideration.

It should also be pointed out that, unless we can get the results of the stack effluent tests as soon as possible after they are made, it is very difficult to correlate them with the operating conditions existing at the time of the tests. Thus we are not able to effectively make operating changes to correct unsatisfactory effluent results. I see no realistic answer at present until a constant monitoring system can be put into daily use.

The cost data presented are interesting but not necessarily conclusive unless all units studied are reporting on the same basis. Budgetary format,

handling of charges for major repairs (are these spread out over the life of the repair or costed entirely at the time of making the repair) and overhead allocations may present a distorted picture. In this connection, the current A.P.W.A. study on "Comparative Public Works Statistics" may point the way toward more meaningful data of this type.

As you have probably surmised, the incinerator which is operated by my City was one of those tested. I would like to express my appreciation to the officials and staff of the Bureau of Solid Waste Management for their efforts to give us a picture of what actually goes on in the incineration process; their cooperation has been excellent, even though, as I remarked, I have doubts as to some of their final results.

DISCUSSION by Fred R. Rehm, Milwaukee County Department of Air Pollution Control, Milwaukee, Wisc.

Mr. Achinger and Mr. Daniels (and their Associates) are to be commended for this fine paper and for the depth of the studies reported about the seven incinerators evaluated.

One thing that bothered me somewhat in studying the paper was the inclusion of the *Pilot Plant* test data on the Conical Burner (Tepee) in their tables right alongside those results derived from the more conventional high burning rate, high heat-release rate, high temperature refractory-lined *going* municipal incinerators. The Tepee burner, of course, is a separate beast unto itself. Therefore, the comparisons made in the various tables in the report must be viewed with considerable care lest erroneous and questionable conclusions be drawn when comparing this rather distinctive *pilot* plant system with the more conventional municipal incinerator.

It was fine that this pilot plant work was done. What I am saying is that perhaps the results might have been better presented as a separate paper to avoid the possible misinterpretations that can, and probably will, be made.

For some time now, I have been calling attention to the rather basic problems created by NAPCA's position with regard to the definition of "Particulate Matter", as opposed to that definition which has been in effect for many years and has been widely accepted by the incinerator industry, the air pollution control equipment manufacturers, many air pollution control people and virtually the vast majority of all interested groups working in this field. As you know, ASME and most of these other groups have defined and measured particulate as a dry, filterable *solid.* NAPCA has expanded this definition to include *liquids* at standard conditions. And, of course, Mr. Achinger and Mr. Daniels clearly point out some of the questions that have been raised as to whether the NAPCA sampling test train really measures and reports particulate matter *consistent with its own definition.* This paper helps a great deal to draw into sharper focus this problem created by the NAPCA proposed definition and its sampling train. In this regard, the paper is a most worthwhile addition and contribution to the field since it is one of the first official Federal government publications which illustrates in depth the basic problem area that has its origin in this rather unique approach and interpretation.

The data, as Mr. Achinger pointed out, clearly show that "particulate" emissions "exceed all but the most lenient air pollution emission standards"; emission standards, which, incidentally, were established based upon the current prevailing definition of particulates, and which were not meant to consider absorbable gases, condensible vapors and their reaction products as particulate matter.

This statement on emissions has particular meaning when viewed alongside another statement made in the Conclusions section of the paper which reads, "For disposal of solid waste, these incinerators *function well*; reduction of volume and volatiles and the amount of heat released were greater than 94 percent in all cases—and in some cases approached 99 percent." In other words, for the job they were designed to do—that is to consume wastes—these incinerator plants operated well.

I believe in the field of incineration, more than in any other field or application, we tend to discredit the whole or total system because the air pollution performance requirement has become "the tail that wags the dog." Having some personal familiarity with some of these plants, I know that they have been a "Godsend" to their communities in meeting the local solid waste disposal crises—and frankly, the air pollution problems created by these plants are rather trivial in comparison to the problem that existed from the on-site open burning or disposal of these same wastes by private citizens, or by ill-equipped small, private disposal firms. So I think we must not, in our haste and impatience to reach the utopian or ultimate solution to our air pollution problems, lose sight of the fact that while room for much improvement still remains, many of these incinerator plants have performed, and continue to perform, a very worthwhile and needed function in their particular communities.

Since there is this great question mark about the "particulate" definition problem and what it really is that the NAPCA sampling train *measures and reports as particulates*, I would like to make the suggestion to Mr. Achinger and Mr. Daniels that they promptly publish or make available for review and scrutinity by ASME and APCA (and other interested and concerned groups), the full and complete test data relating to the air pollution tests of these plants.

In reading over that part of this paper in which I am most interested – the air pollution performance – I had a great number of questions which I felt would have a significant bearing on the air pollution performance of these plants that were not touched on in the paper. This data probably exists in the voluminous files of field data that were taken at these plants and which, of course, the limitations of an ASME paper do *not readily* permit reporting upon. I feel that answers to the following questions would be helpful to an in-depth evaluation of the air pollution test data presented here:

Operating Conditions

1. What were the plant conditions of operation when each emission test was run? By this I mean:

a) What was the charge rate (as best as could be determined) to the furnace during the actual air pollution test run sampling periods?

b) What was the range of furnace and combustion chamber temperatures during the actual sampling periods?

c) What was the physical or apparent condition of the control systems during the period of tests? We all know that maintenance of many such plants leaves much to be desired. And since all of these plants were two to six years old at the time of testing, this could be a significant factor in the test results.

d) What was the draft loss across the collector system during the tests? This might provide an insight as to the effectiveness of the design and/or to the state or condition of the collection system.

Testing

I have always found it difficult to describe a plant's air pollution performance by a single "average" number whether I was describing grain loadings, mass emission rate, excess air levels, volumetric flows, etc., as given in Table 9. I suggest that it would have been most helpful had the authors provided an insight as to the ranges of each of these indicators or parameters measured at each plant – in addition to citing an *"average"* figure as in Table 9 of the report. And, of course, air pollution performance test results are invariably judged by the maximum emission rates rather than the *average emissions*.

I would like, too, to see what emission results were obtained with various rates of operation and with the charging of different characteristic refuse. Table 1 of the paper showed the rather wide range of daily refuse composition at one plant. And, of course, we know that moisture content will vary widely from day to day with local rainfall amounts and seasonally – such as during the grass-clipping, watermelon or corn-on-the-cob seasons.

I feel, too, that it would be helpful to know the number of emission test runs made at each plant, the range of the test results and the charge rate condition associated with the sampling period. Since the NAPCA test procedure itself is under attack in some quarters, it would appear to be helpful to publish in greatest possible detail the data that may help to answer such questions as:

a) What were the sample volume rates and sample volumes used in each test run?

b) Does it appear that reproducible test results were being achieved for what appeared to be approximately the same set of operating conditions? In Table 10, there seems to be a wide range between the high and low fraction of "condensables and absorbables" measured at the same plant – ranging as much as 25 to 1 at one of the plants. Are reasonably reproducible results attained using the low volume NAPCA test procedures and sampling train?

c) No mention is made in the report on the visual appearance (Ringelmann-wise or opacity-wise) of the stack plume. This, too, is a fair indicator of particulate emissions and often is a key to improper operation. This information would be helpful in evaluating the findings.

d) What was the distribution of the catch fractions amongst the five different component groups in the sampling train?

While some of these comments and suggestions may appear to be very critical, they are certainly not offered in that vein. I believe this paper and this study to be a most important one and that a commendable job has been done. If anything, my specific criticisms might be summarized by stating that you have done such a good job that you have really presented "too much" information of interest to too many people to put it all into a single paper. And what I hope my comments are taken to convey is that I, for one, would like to see an in-depth paper pre-

sented showing the full and complete test findings at each of these plants in which additional attention could possibly be given to some of the questions that I have raised.

I might add, too, and this is not meant as a personal criticism but as a suggestion, that hopefully the Federal Government paper release and technical paper communication policy will improve since I note that some of this test work was conducted more than two years ago and is only now being made public.

DISCUSSION by Charles O. Velzy, Charles R. Velzy Associates, White Plains, N.Y.

This paper is perhaps one of the most important contributions to the field to be presented at the Conference, not, however, because it gives us, finally, adequate tools with which to develop economical designs with confidence. Rather, it serves to point up the need to conduct further, even more comprehensive, coordinated studies, after wide agreement on sampling methodology and analysis techniques, as soon as possible with the results released on a timely basis so that incinerator designs can be rapidly optimized.

There seems to be a discrepancy in the information presented in Table 2 with respect to Plants B and G. Even though the actual capacity and the actual burning rate per unit area of grate are higher than the design capacity and rates noted, the actual rate of heat release per unit volume is lower than the design rate of heat release. This does not seem to follow although perhaps the authors have an explanation.

In Table 7, Fly-Ash Analyses, at plants B, C-3, and G, the ratio of Heat, Dry Basis to Volatiles, Dry Basis ranges around one hundred to one while at plant A this ratio is about thirteen to one. Do the authors have an explanation for this difference? Was the composition of the fly-ash at plant A significantly different than that collected at the other plants and, if so, what were these differences and what was the cause?

I would like to emphasize the authors' comments to the effect that, "further work is needed on identifying composition of impinger water residues and their origin". This becomes particularly important when one considers that this material, which we are uncertain about as to quantity, origin, or health hazard, has been lumped in with dry particulates in many jurisdictions for purposes of determining Code compliance. This is one of the few areas that I know of where Code compliance is subject to apparent measurement differences of 300 to 500 percent.

It is interesting to note, in Table 13, that at the three plants where measurements were made, volume reduction ranged from 94 to 97 percent or close to that claimed for "high temperature" incinerators even when weight reduction only ranged from 53 to 72 percent. This, plus inspections of the residue from newer, conservatively designed plants, indicates that so-called "conventional" incinerators are capable of burning refuse to a point where it can be processed for beneficial ultimate disposal.

The results presented in this paper indicate that this method of refuse disposal has potential. However, the results also indicate that before the full potential can be realized, much further investigation and testing effort must be done so as to develop adequate parameters for design and operation.

DISCUSSION by W. M. Harrington, Jr., Whitman, Requardt & Associates, Baltimore, Md.

This paper shows the need for a well designed standard incinerator test procedure which can be used to determine operating efficiency, offer an evaluation of the basic design concepts used in a plant, reward operating efficiency, and allow the determination of the firm operating capacity that a plant can be considered capable of providing. With the present high cost for providing modern, efficient incinerators, it becomes vitally important to develop information which will allow the design engineer to provide the greatest amount of firm capacity at the minimum cost. The only way to develop this information is by extensive testing of existing facilities. The U.S. Public Health Service effort offers a significant beginning in this direction.

I suggest that the next step for the Public Health Service is the development of a standard test program which can be incorporated in construction specifications and which will require all new facilities to be tested as part of the initial start-up procedure in order that the design can be evaluated and the plant operating capacity fixed. If the test procedure were standardized, test ports and other provisions could be incorporated in the initial construction at little additional project costs and the testing job would be made easier. Periodic retesting should be performed throughout the life of the plant to indicate plant maintenance and operating efficiency and allow re-evaluation of plant firm capacity in

order to help prevent the overload operation so prevalent in this country today.

DISCUSSION by Walter R. Niessen, Arthur D. Little, Inc., Cambridge, Mass.

The authors are to be congratulated for the quality work reported in this paper and for the comprehensive yet succinct method of presentation of the data and experimental techniques. It is clear that only through such detailed reporting and analysis of system behavior can the state of incinerator technology be advanced through improved understanding of the processes extant in the incinerator. There are, however, three points that I would like to make regarding studies of the type reported in this paper.

There is no mention made in the paper of the great difficulty in obtaining a representative gas sample. The data of Woodruff *et. al.* [1] suggests great variation in the flue gas composition and temperature throughout the flue gas ducts. It would be expected, therefore, that a meaningful estimate of particulate and gaseous air pollutant emission rates should involve a rather complex integration of gas property values (velocity, composition, temperature, etc.) across the ducts rather than a single probe sample or an average of samples at a single location. While such tests are no doubt costly and difficult to carry out, it would seem that the sizable sampling and analysis team assembled for the tests described in the paper would provide an excellent opportunity for carrying out such a comprehensive sampling program.

I would suggest that a number of tests be made *ahead* of the air pollution control device such that one can begin to build a stronger causal relationship, based on data, to relate incinerator design and operating characteristics with emission rates. Such data would also be of use in evaluating the performance of the scrubbers or other air pollution control devices installed on the units reported upon and units to be tested in the future.

The third area where I would suggest that consideration be given concerns an expansion of the data-gathering activity to provide a comprehensive statement of the operating conditions for the incinerator during the test runs. To a large exient, the tests described in this paper support such a characterization in that the composition of the refuse residue and the flue gas parameters are measured and reported. It would be of great value, however, to have documented, in some detail, such operating variables as the quantity of forced air, divided between undergrate and overgrate air. These air flows should be defined through measurement. I recognize that in many cases the duct work in incinerators does not make such tests easy to perform, but none the less, such data would contribute greatly to our understanding of the interrelationship between aspects of equipment performance and the operating and design features of the unit. Because of the large number of manual adjustments possible in incinerators (grate speed, damper settings, etc.), the design data on fans and other equipment does not provide sufficient information to assess the plant operating characteristics.

References

[1] "Combustion Profile of a Grate-Rotary Kiln Incinerator", P. H. Woodruff and G. P. Larson, Proc. of 1968 Incinerator Conference, pp. 327–36, ASME, New York, 1968.

AUTHORS' CLOSURE

We wish to thank Messrs. Brenchley, Hall, Harrington, Niessen, Rehm, and Velzy for the time they took from their busy schedules to review and evaluate our paper. We believe constructive criticism will increase the rate at which technology advances in the incinerator field.

It was obvious to us after reading these discussions that we did not fully convey the intent of our evaluation program. In undertaking this program, our objectives are to develop reliable sampling methodology and to identify the present capabilities of incineration in this country.

The development of sampling methodology is an evolutionary process. Therefore, we are continually working to overcome the deficiencies the discussants pointed out and other deficiencies as well. More detailed descriptions of the testing procedures used in these studies will be found in a testing manual presently being developed.

Several discussants wanted more information than was presented. As in any paper, the amount of material we could include was restricted. However, upon written request, more detailed information will be made available.

Professor Brenchley wanted to know what effect more efficient pollution control equipment would have on the cost of incineration. We did not evaluate this effect since our objective is to identify the costs as they are and not as they might be. Undoubtedly, though, this equipment would increase the cost of incineration. We agree with Professor Brenchley's statement that cost data should not be used as the

sole criterion for selecting an incinerator design.

Mr. Hall questioned the reliability of test data generated by 1 week of testing. We recognize that a 1-week test is less reliable than a long-term test, but until reliable continuous monitoring equipment becomes available, short-term testing programs must be used.

Mr. Hall also questioned the comparability of the cost data between the incinerators studied. As pointed out in the paper, we adjusted the cost data during analysis for differences in labor costs, interest rates, depreciation rates, time of construction, and actual versus design capacity. To try to avoid error during the collection process, our economists used the same personnel to examine the available cost records and to interview the people who keep the records. Major repair items having a long life, such as replacement of the grate system, were costed out over their life expectancy. The repair and maintenance costs include the yearly cost of major repairs and the routine day-to-day charges. Thus, we believe the cost data are comparable between incinerators.

Mr. Rehm questioned the advisability of including pilot plant (Plant C) data with that from the other municipal installations. We believe the data are useful but should be interpreted with the reservation that this plant is not a typical full-scale conical burner.

Mr. Rehm wanted to know the reason for the extreme variation in the figures for particulate caught after the filter ("condensible"), particularly in relation to Plant B (Table 10). Upon reviewing the raw data used to calculate these values, we discovered an error. The low value should be 6.6 instead of 0.7; thus, the average for Plan B is 14.3 instead of 13.6. Evaluating the ratio of high to low, as suggested by Mr. Rehm, yields an average value for all our studies of 2.3, with a range of 1.1 (C-3) to 4.7 (D). We believe such variation is reasonable when comparing two 1-hour tests for particulate emissions at municipal incinerators.

Mr. Rehm and also Mr. Velzy stressed the importance of identifying the constituents of the "condensible" portion of the particulates. Since, on the average, this condensible material is not greater than 30 percent (Table 10), the urgency of identifying these constituents is not too great. In the case of Plant C-3, however, these materials amounted to 73 percent of the total particulate. Because Plant C-3 uses a "high efficiency" electrostatic precipitator to control particulate air pollution and the other plants use lower efficiency collectors, the obvious conclusion is that as the efficiency for collecting "dry" particulate increases, the percentage of "condensible" particulate leaving the collector increases. Since the trend in air pollution control is toward high efficiency particulate collectors, controlling these condensible materials becomes critical. We, therefore, agree with Messrs. Rehm and Velzy that these materials, which are a form or air pollution, must be identified so they can be efficiently controlled. We are so concerned over the implications of this problem that we conducted some screening tests, as reported in the paper, in an attempt to identify these compounds even though our objectives do not include research-oriented goals.

Mr. Velzy pointed out a possible discrepancy between the design and actual heat release rates (Table 2) for Plants B and G. A discrepancy does not exist. Even though the charging rates in both studies were in excess of the design rate, the low heat content of the incoming waste (Table 4) did not provide enough heat to achieve design heat conditions.

The heat content of the fly ash from Plant B (Table 7) should be 180 Btu/lb instead of 1,290. Thus, the ratio, pointed out by Mr. Velzy, for Plants A and B is about 13:1 and for Plants C-3 and G, about 100:1. The only difference we can see is the fly ash was collected in a water scrubber in Plants A and B and in dry collectors in Plants C-3 and G.

Mr. Velzy commented on the apparent high degree of volume reduction (Table 13) achieved by the plants studied. This high reduction is related directly to the techniques we use to determine sample density of the incoming solid waste. This density is determined by filling a 20-gallon container with uncompacted waste and obtaining the net weight of the waste. This procedure yields lower densities (Table 4) than normally reported in the literature and, thus, results in the high volume reduction. In the absence of any standardized test for the density of solid waste, we believe that any *identified* test, consistently employed, could be used for comparative purposes.

μσ 623